DEVELOPMENT OF SIMPLE AND ECONOMIC FILTRATION METHODS FOR RURAL WATER SUPPLIES

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TO

THE WORLD HEALTH ORGANISATION

TOWARDS THE GOAL OF

SAFE WATER SUPPLY

IN RURAL AREAS

BY

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DECEMBER 1978

CERTIFICATE.

This is to certify that Shri.J.N. Kardile has carried out this work under my supervision and guidance during the period 1973 to 1978. The results presented in this thesis have not been submitted to any other University or Institute for award of any other Degree or Diploma. I find the work comprehensive, complete and fit for evaluation.

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Place : Nagpur.
Date : 7th December 1978.

D E C L A R A T I O N

This work was carried out by me under the supervision and guidance of Dr. A. G. Bhole, Professor in Public Health Engineering, Department of Civil Engineering, Visvesvaraya Regional College of Engineering, Nagpur. The work was carried out during 1973-1974 at Nagpur and further in the Maharashtra Engineering Research Institute at Nasik during the remaining period of 1974-1978. The work presented here-in has not been submitted to any other University or Institute for award of any Degree or Diploma. The papers published on some aspects of this work during 1972-1978, as a part of this study, are enclosed in the Appendix D of this thesis.

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SUMMARY.

1. BACK GROUND.

A mass scale programme of providing drinking water supply facilities in the rural and semi-rural areas is under implementation in India and in most of the developing countries. The United Nation's Water Conference has declared that 1980 to 1990 should be designated as the "International Water Supply and Sanitation Decade" to cover 100% population of the world by community safe water supply and sanitation.

For villages where the assured ground water sources are not available in the near vicinity for safe drinking water supply schemes surface water sources are required to be tapped. Adequate treatment has to be given to such waters irrespective of the size of community to be served. Naturally the capacities of these water treatment plants in the villages will be generally very small. The costs of construction of such small capacity conventional water treatment plants, such as slow sand, rapid sand and pressure filter plants are seen to be disproportionately high. Moreover skilled supervision which is necessary during construction and maintenance of the conventional plants will not be available generally in most of the rural areas. Hence, in many rural water supply schemes water treatment facilities are seen to be deleted partly or completely, even though these are essential for supplying safe drinking water.

There are number of problems in the design, construction and maintenance of the conventional water treatment plants, particularly for the small capacity rural water supply schemes. There is therefore,an urgent need for the development of simple and cheap water treatment facilities for the rural and small capacity water supply schemes. This is one of the basic factors in the improvement of the community health in the rural areas.

2. AIM OF STUDY.

The aim of the present study was to carryout experimental pilot plant as well as prototype plant study, on the various water treatment processes, based on new and unconventional techniques, so as to try to solve the different problems in the development of simple and cheap water treatment methods suitable for the rural and semi-rural areas.

3. ACHIEVEMENTS DUE TO NEW METHODS.

During this study it was possible to develop three simplified and unconventional water treatment plants as constructed, first at Ramtek,second at Varangaon and the third, which is under construction at Chandori village in the Maharashtra State. The designs and actual performances of the pilot and prototype plants are discussed in details in this thesis. In addition to this the experimental pilot plant study for the development of non-mechanical and continuous type flocculation systems as discussed in Chapter 4 is an interesting one and may have a considerable impact on the future developments of unconventional as well as conventional treatment plants.

3.1 Ramtek Treatment Plant :

The Ramtek plant constructed in the year 73 for a capacity of 2.4 mld, is mainly designed for the treatment of average low turbidity water sources from the storage reservoirs, canals and the upland waters. However it can tackle occasional higher turbidity loads even upto 1000 JTU. It has been specially designed to substitute the conventional slow sand filters, which are likely to be choked up even by a single high turbidity load. In the Ramtek plant gravel bed prefilters have been provided in place of the conventional pretreatment works, and simplified dual media high rate filter beds have been adopted in place of the conventional rapid sand filter beds. Only hard backwashing has been adopted for the filter beds, while the prefilters can be cleaned by gravity desludging operation as well as, by backwashing when required. The actual plant performance showed very good results for an observation period of three years. This may perhaps be the first of such simple and cheap small capacity water treatment plant provided for village water supply scheme. The Ramtek plant is a very simple and compact unit due to the unconventional design as explained above, and the actual cost

(Rs. 1,25,000/-) was less than 1/3 of the cost of the conventional treatment plants of the same capacity constructed in the same year.

The crushed coconut shell has been used as a top coarse media over the fine sand in the dual media filter beds at Ramtek for the first time in the world,and the author has received a patent (No. 134979) for its use in India in 1974. The author is of the view that this is one of the best media available in the world at present for the use of high rate filtration. The author is happy to state that the patent rights for the use of this new media have been donated to the Indian Water Works Association.

3.2 Varangaon Treatment Plant :

The Varangaon plant having a capacity of 4.2 mld is constructed during the year 1977, for a regional rural water supply scheme, for supplying water to five villages. The plant is specially designed for the treatment of high turbid water sources. In this unconventional high rate treatment plant, baffle mixiing channel, two units of gravel bed flocculation,two units of tube settling tanks and three units of dual media filter beds have been provided in place of a conventional rapid sand filter plant. The gravel bed non-mechanical type flocculation units and the tube settling tanks are the special features of this plant, which may have been provided for the first time for a rural water supply scheme. PVC square tubes of 50 mm x 50 mm size were specially got fabricated for the first time in India, and tube modules were fabricated of required size to cover all the settling tank area.

The other special feature is the declining type rate controlling arrangement provided at this plant. Due to this arrangement, it is possible to accommodate the pure water pumping machinery in the control room. The alum solution and dosing tanks alongwith a small laboratory are provided in a chemical room over the control room, while the wash water tank has been provided on the top of the chemical room. The actual plant performance showed very satisfactory results for a period of one year. The Varangaon plant is a very compact unit due to the unconventional design as stated above and the actual cost of (Rs. 4,00,000/-) may be less than 50% of the cost of a conventional treatment plant of the same capacity.

3.3 Chandori Treatment Plant :

The Chandori treatment plant is specially designed to treat turbid water sources for the small villages, and the plant is presently (1978) under construction. This new plant includes a pretreator unit which is followed by a dual media filter bed. The high rate pretreator, which is a combination of the gravel bed prefilter of the Ramtek plant and the tube settler of the Varangaon plant, is the special feature of this new plant, designed to treat turbid water sources for the small capacity treatment plants. This is a modified form of the Ramtek plant and has got a special advantage of two stage construction as explained in the thesis.

3.4 Field Applications :

About five such small capacity unconventional treatment plants have been constructed recently and the actual plant performance results for the three plants at, Surya Irrigation Project, Murbad, and Bhagur in the Maharashtra State are also included in Chapter 11 of this thesis. The Surya Project and the Murbad Plants are the modified forms of the Ramtek Plant design, for the adoption for specific water quality conditions, while the Bhagur plant is based on the design of the Varangaon plant with some changes in the surface loadings, as discussed in details in Chaper 11.

Further about twenty plants based on these new designs are under construction at various places. In addition to this, these new techniques have also been proposed for the conversion of the existing bigger capacity plants in the Maharashtra State. Table 11-I showing the places where these new treatment plants have been adopted, alongwith the probable saving due to the adoption of the new techniques, is enclosed in Chapter 11. It can be seen from this Table that the average saving is more than 50% of the cost of the conventional plants of the same capacity and the overall saving may be more than a crore of rupees due to application of these new techniques so far.

4. UTILITY OF THE NEW TECHNIQUES.

Considering the large scale programme during the proposed "International Drinking Water Supply and Sanitation Decade" during 1980 to 1990, the provision of safe drinking water supply facilities will have to be provided on priority basis. The new treatment methods as developed during this study have shown very satisfactory resultes as discussed in details in the thesis. Table 12-I showing the recommended general design criteria based on this study for adoption of such new treatment plants is enclosed in chapter12. It will be seen that the new treatment plants as developed in this study are very simple for construction, and maintenance and are also cheap as compared to the costs of the conventional plants of the same capacities. The author sincerely feels that the new simplified treatment methods as developed in this study may be able to help in solving this great problem of providing safe drinking water supply in the rural and semi-rural areas.

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CONTENTS.

APPENDICES

N.B. : 1) Tables, figures, drawings and photoplates are included within or at the end of respective chapters.

2) Metric units are adopted in this study except in the chapters 2 in which units in the original references are kept as they are.

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CHAPTER I

APPROACH TO THE PROBLEM

1.1 BACK GROUND.

Number of water treatment plants are under design and construction particularly in the developing countries, for the supply of filtered water in the cities and villages. As the conventional water treatment plants are fairly costly in their construction and maintenance,an intensive search is going on, all over the world for the development of cheaper water treatment plants. This includes the use of improved pretreatment methods including the use of coagulant aids and higher rates of filtration through the dual and multimedia filters. In addition to these, extensive automation for the various controls in the treatment plants are under development in the developed countries to reduce the operational cost.

Due to the high cost of construction and maintenance in adopting the conventional water treatment plants, many towns and particularly the villages in the developing countries cannot afford to adopt the same for their water supply schemes. Further even in the conventional treatment methods there are some problems in the efficient performance of the treatment plants which can be observed in the existing conventional treatment plants. However, for want of new techniques and designs to solve these treatment problems, conventional treatment plants are generally seen to be adopted for the city and village water supply schemes.

1.1.1 Task Ahead :

If the present (1975) condition of urban and rural water supply position in India is considered,(29) out of 2921 number of towns 1585 number of towns have been supplied with protected water supply schemes while out of 5,67,100 number of villages 3,91,000 have been found as difficult, while only 39,000 number of villages have so far been provided with some sort of protected water supply schemes. The population of the urban areas is about 110 millions while that of rural areas is about 440 millions. The protected water supply schemes have been provided for about 60% population in urban areas and for about 10% population in rural areas.

The position in the other developing countries may not be different from the above mentioned position in India. The thirtieth World Health Assembly has declared in May 1977, to observe "International Drinking Water Supply and Sanitation Decade during 1980-1090", so as to cover all the population in the world by the safe drinking water supply and sanitation facilities,(30). All the countries in the world have been requested to concentrate all their efforts so as to fulfil these targets in their respective countries. Thus the next decade (1980-1990) will be very important for providing protected water supply for thousands of villages for improvement in the Community health.

Considering this gigantic task before the public health engineers in the world, every effort will have to be made by them to fulfil the same. There are number of problems to be tackled to fulfil this task. The field of water treatment is one of the aspect where there are number of problems, and to develope very simple and cheap water treatment plants for the rural and small community water supply schemes is a very importamt task. This will have to be achieved on urgent basis in order to fulfil this great task before the world.

1.1.2 The Aim of Present Study :

The aim of the present study is to search out the new techniques for the better performances of the various processes in the field of water treatment so as to utilise them in the design of very simple and cheap water treatment plants particularly for the villages and small capacity water supply installations. The principal idea behind the present study is to design on the basis of new techniques small pilot treatment plants for actual observations of their performances and based on these studies, to design a few prototype plants in the field and to study their actual plant scale performances, so as to develope simple and cheap small capacity water treatment plants. Therefore the topic of the present thesis is selected as "Development of simple and economic filtration methods for the rural and small community water supplies".

1.2 IMPORTANT STEPS IN THE HISTORY OF WATER TREATMENT.

If the history of water treatment is considered for the development of the water treatment processes the important steps can be described as below.

1.2.1 Slow Sand Filters :

These filters were first developed in England by about 1830 and were then adopted all over the world. The slow rate of filtration of about 100 to 500 $l/m^2/h$, through the fine sand bed of average effective sand size of 0.3 mm and uniformity coefficient up to 2.5, and its cleaning by scrapping the top layer of sand of 1 to 2 cm. for a limiting head loss of 0.5 m, are its main design features. However there is important limitation for the raw water turbidity to be applied on these filters,which should be normally within 30 units. Coagulation is not recommended before this filter for its proper functioning. The main action of the purification of water through this filter bed is said to be done by the biological activity through the various algal and bacterial colonies in the filter bed. Thus this filter is mainly suitable for treating the clean and low turbidity raw waters which are polluted by dissolved organic matters. These filters are more efficient than high rate filters in removing the bacterial load in the raw waters. This special biological aspect of the treatment is not possible in high rate filters. Hence for treating polluted turbid raw waters, high rate prefilters have been provided at some places before the slow sand filters. If the turbid raw waters are directly applied on the slow sand filters then there is possibility of early clogging of the filter beds and at times even developing anaerobic conditions in the filter beds.

1.2.2 Rapid Sand Filters :

These filters were developed first in America in the beginning of this century and were then spread in the other parts of the world. The main advantage of this filter is that, the filter can treat turbid raw water with the adoption of the pretreatment before the filter bed and with the use of back wash, the filter bed can be brought to its original conditions. The rate of filtration adopted is generally from 5000 to 10000 $l/m^2/h$, depending on the type of pretreatment method and raw water quality for a limiting head loss of 2 to 2.5 metres. This is the most common filter in use in the world including India at preent.

1.2.3 Upflow Filters :

These filters were first developed in the European countries and USSR and then spread in the other parts of the world. These filters with the same back wash arrangements as that of a rapid sand filter have the additional advantage of effective utilisation of the full filter depth due to the upward direction of the flow. When the raw water is fairly clean throughout the year, the upflow filter can be directly adopted, without the necessity of pretreatment, where such filters are known as contact clarifiers. These filters generally require deep beds and are not adopted for the high rate filtration due to the possibility of break-through of the filter-bed due to the boyancy effect when filter bed gets clogged.

1.2.4 Biflow Filter :

A combination of upflow and down flow filter which is known as biflow filter has also been developed in some countries. However these filters have not become common in practice for the various operational difficulties.

1.2.5 Dual and Multimedia Filters :

These filters have come into practice during the decade 1960-1970 in America, England and some other countries. This filter can be adopted directly when the raw water is moderately clean throughout the year, as in the case of upflow filter. However, this filter has got some advantages over the upflow filter as the flow direction is downwards as in a rapid sand filter bed, and the depth of the filter bed is considerably less as compared to the upflow filter. In addition to this, there is no boyancy effect of filter bed as observed in the case of upflow filter bed. These filters can be designed for very high rate of filtration of 10,000 to 15,000 $l/m^2/h$. Thus this filter may be the cheapest as compared to the others and may be a popular filter in the future,provided the suitable quality and cheap filter media are available locally in the required quantities.

1.2.6 Conventional Pretreatment Practice :

For the treatment of raw waters, the conventional pretreatment consisting of chemical mixing flocculation and clarification is necessary to remove the turbidity load before putting the water on the filter beds. The capital as well as the maintenance cost of the conventional pretreatment units are considerably high.

At the same time the conventional pretreatment, with the coagulation and clarification processes is the most delicate process to handle in the whole of the water treatment processes. The various chemical reactions involved are complicated and are yet to be understood completely and are still under active research. The mechanical equipments required in the chemical mixing, flocculation, and clarification processes make this problem still more difficult particularly for the construction and maintenance of the small capacity water treatment plants in the villages, in the developing countries.

1.3 PLANT OBSERVATIONS.

Plant observations on the existing water treatment plants are discussed below.

1.3.1 General :

The author has carried out the on-plant study on the existing slow sand and semi-rapid filters and the pretreatment works for the small capacity water treatment plants constrctued by the Environmental Engineering Organisation in the Maharashtra State in India. Two comprehensive reports (33) (34) were prepared by the author on the basis of these field studies as given below for submission to the Govt. for further consideration regarding the improvements to be carried out in these plants.

Report 1 : The evaluation of the performances of the efficiencies of the slow sand and semi-rapid filters in the Maharashtra State (34).

Report 2 : The report on the evaluation of the efficiency of the serated and hopper bottom rectangular settling tanks (33).

A cyclostyled copy of the report 2, is enclosed in the Appendix D of the present thesis. On the basis of the recommendations made in these reports the Govt. of Maharashtra has already directed the concerned authorities to carryout the necessary improvements as suggested in these reports for the better performances of these plants.

1.3.2 Report 1. The Evaluation of the Performances of the Efficiencies of the slow Sand and Semi-Rapid Filters in the Maharashtra State :

On the basis of the comprehensive report prepared on the on-plant study the author has published a paper (25) "Observations on some semi-rapid and slow sand filters in Maharashtra State", in the Journal of the Indian Water Works Association, Vol.II No.4. (1970). A copy of this paper is enclosed in the Appendix-D which gives the important findings in the Report 1.

From the observations given in the Report 1 and the paper, it can be seen that the most of these plants were not giving the desired performances so as to get the acceptable quality of the effluent to the drinking water standards. There are number of problems in the various stages of mixing, flocculation,settlement and filtration as discussed in details in this report and the paper. On the basis of the plant observations, some improvements were recommended to solve these problems so as to improve the general plant performances.

1.3.3 Report 2. The Report on the Evaluation of the Efficiency of the Serrated and Hopper Bottom Rectangular Settling Tanks :

In this report the on-plant observations mainly on the pretreatment units consisting of the serrated and hopper bottom rectangular settling tanks, which are generally provided in the Maharashtra State, for the small capacity treatment plants, are given.

From the observations given in this report 2, it will be seen that the actual performances of the most of these pretreatment works are not found satisfactory. From this study it is seen that the pretreatment process is the weakest link in the whole treatment process, mainly due to the defective design and construction of units, which includes absence of proper dosing of chemicals, deletion of mixing or flocculation units, defective inlets and outlets, and absence of proper sludge removal arrangements.

From this study it is revealed that the multiple hopper bottom rectangular settling tanks are very efficient in the sludge removal by hydrostatic pressure while the plain and serrated bottom settling tanks are not efficient in sludge removal by hydrostatic pressure and are required to be made empty for the periodic sludge removal from these tanks. On the basis of this study the hopper bottom settling tanks are now adopted as a type design in the Environmental Engineering Organisation of the Maharashtra State.

1.4 APPROACH TO THE PRESENT STUDY.

As per para 15(i) of the ordinance No.92 of the

Nagpur University, for the consideration of degree of Doctor of Philosophy in the Faculty of Engineering and Technology, it is stated that "it must be a piece of research work characterize either by the discovery of new facts or by a fresh approach towards the interpretation of facts or theories".

The theory of water treatment has been advanced mainly from the beginning of this century and particularly during the last fifty years. From these advancements and the literature published during this period it can be seen that this advancement is mainly in the conventional processes of water treatment and particularly for big size plants. Even for small capacity plants the same conventional approach was adopted for the construction of these plants. When the conventional units of mixing, flocculation clarification and filtration are designed for the small capacity plants, the cost of such small units goes disproportionately high due to the structural cost as well as the mechanical units, which may go even from 100% to 400% higher than the unit cost of the bigger plants for the same processes of the treatment. This can be seen from the actual costs of construction for such small capacity plants. Due to the high cost of construction for the small capacity plants, the cost of treatment for small capacity plants in the rural and semi rural areas goes very high and there is a natural tendency either to avoid full or part of treatment works while providing water supply schemes in the rural areas. This does not solve the problem of providing the safe drinking water supply to the rural communities. There is thus urgent need of research in the field of water treatment, specially for the development of simple and cheap small capacity treatment plants.

If the research is oriented in the field of conventional treatment processes which is generally done due to the availability of the technical literature in the field, the result will naturally be on increasing the efficiency of the conventional units for applying higher rates, but it may not come out of the conventional processes as a whole.

The author therefore feels that if the existing small capacity plants and the various problems involved in the design and construction of such plants are studied very critically in the field and from the actual on plant observationa, such a study itself may give some new ideas for the development of simple and cheap treatment methods for the small capacity plants.

The author earnestly feels that as a result of such a critical on-plant study of the existing small capacity plants and the study of the recent technological advances in the field of water treatment, it was possible to develop the new designs for the small capacity treatment plants at Ramtek, Varangaon and Chandori as discussed in this thesis. The original ideas and the new facts which have been developed in the design of the new treatment methods in this thesis are as given below.

(i) The use of gravel bed for flocculation as adopted in all the three new treatment methods developed in this thesis.

(ii) The adoption of P.V.C. tube settling tanks for the Varangaon treatment plant which may have been adopted for the first time in India.

(iii) The development of the pretreator unit for the treatment of turbid water sources as proposed at Chandori treatment plant.

(iv) The use of crushed coconut shell media as a top media in a dual media filter bed over the fine sand media for higher rate of filtration, may be the first use of this media in the world.

(v) The simplification in the design of structures for the small capacity water treatment plants as developed in this thesis.

1.5 QUALITY OF WATER TO BE TREATED.

In the conventional water treatment practice the slow sand filter is generally adopted for very low turbid raw waters containing dissolved organic matters and these filters are generally recommended for the stored water sources.(26) While for turbid raw water sources pretreatment consisting of coagulation flocculation and sedimentation is generally adopted before rapid sand filters(26). In special cases rapid sand filters without pretreatment are provided before slow sand filters so as to remove the suspension load for further treatment of waters on slow sand filters at higher rates. For turbid waters with high organic pollution, complete rapid sand filtration including pretreatment is provided before the treatment of water on slow sand filters. As the only rapid sand filtration is not adequate to treat such waters to the required standards,such type of double filtration though very costly, has to be provided at some places.

Low turbidity waters can also be treated directly without conventional pretreatment through deep bed,upflow or contact bed clarifiers,or through the dual or multi-media filters as explained earlier.

1.6 APPROACH IN THE TREATMENT OF WATER QUALITY.

Even though the quality aspects of raw water for treatment as explained above are available,in practice the conventional treatment plants are generally seen to be provided even though these are considerably costly for construction. Further these techniques do not give cheaper solution to some type of raw waters as explained hereafter.

In the present study raw water qualities are mainly considered in the following three catagories for the design of simple and cheap treatment methods for small capacity treatment works.

i) Raw water of low turbidity and pollution but with occasional increase in turbidity loads.

ii) Raw water with high turbidity load and moderate pollution.

iii) Raw water with high turbidity and high pollution load.

In the present study, first two cases are proposed to be tackled as these are the common cases in practice while the third case is rarely seen and it will need further special treatment of either slow sand filtration or any other after the treatment for the case No. (ii) and hence the third case is not considered in the present study.

1.7 TREATMENT OF LOW TURBIDITY WATER SOURCES.

This is a peculiar case for raw water available at many places in India and in the Maharashtra State. As per present conventional practice slow sand filters can not be adopted in this case as there is occassional increase of turbidity during the rainy season. Therefore full conventional pretreatment followed by rapid sand filters are generally adopted at present. At many places with the policies of particular government organisations either only slow sand filters or conventional pretreatment followed by slow sand filters are also seen to be adopted. But this practice is against the theoretical design aspect of the slow sand filters and after some use, such filters are seen giving trouble for maintenance due to clogging of filter beds. Further the biological activity in such filters is also seen hampered at the top of such slow sand filters during the plant study carried out by the author.

As the only slow sand filters are not suitable for these conditions of the raw water and the conventional rapid sand filters with its pretreatment will be generally costly as explained earlier., a new unconventional complete filtration unit originally designed by the author at Ramtek is proposed to be studied in details in the present study for the treatment of raw water with low turbidity and pollution and with occassional moderate turbidity loads.

1.8 TREATMENT OF HIGH TURBIDITY WATER SOURCES.

As per conventional filtration practice, pretreatment consisting coagulation and settlement followed by rapid sand filtration is generally adopted in this country. This can be said as the popular method of treatment at the present time. Apart from the high cost of construction for such treatment plants, there are a number of problems which are discussed earlier in this chapter.

The author has therefore designed the new unconventional treatment plants at Varangaon and Chandori for the treatment of high turbidity water sources, which are proposed to be studied in details in the present study.

1.9 RAMTEK FILTER.

When the source of water supply is from storage dams or from rivers in rocky catchment areas the turbidity of raw water is generally low through out the year with occasional increase of moderate turbidity during the rainy season. In the present study the author has constructed a new type of unconventional complete filtration unit for Ramtek Water Supply Scheme near Nagpur in India. In this filter a gravel bed upflow type prefilter is provided before a dual media filter unit. The filter is designed for a higher rate of filtration of 7150 $l/m^2/h$. i.e. about one and half times the normal designed rate for a rapid sand filters. For chemical mixing a baffled mixing channel is provided before the water enters the prefilter beds. The detailed design aspects and the experimental results on the pilot plants and the Ramtek filter plant are given in the chapters 6 and 7 respectively.

From the cost comparison with the conventional plants of same capacity which have been actually constructed during the same time, it can be seen that the Ramtek type filtration unit may cost 50% to 25% of the cost of the conventional rapid sand filters.

Some more filters of this type with minor changes in the design are under construction in the Maharashtra State and the on-plant observations on the same have also been given in this thesis in the chapter 11.

1.10 VARANGAON TREATMENT PLANT.

In the present study the author has designed a new type of unconventional high rate simplified treatment plant as proposed for the Regional Rural Water Supply Scheme for five villages near Varangaon, for the treatment of high turbidity water sources. This plant consists, of baffled mixing channel, two units of gravel bed flocculation chambers and tube settling tanks and three units of dual media high rate filter beds. Thus no mechanical equipment is adopted for the chemical mixing, flocculation and sludge removal processes. The detailed design aspects and the experimental results on the pilot plant and the Varangaon treatment plant are given in the chambers 8 and 9 respectively.

From the comparison of the cost of the Varangaon treatment plant of 4.2 mld capacity with the conventional plants as given in the chapter 9, it can be seen that the Varangaon plant is cheaper by more than 50% in cost as compared to the conventional plants of the same capacity constructed during the same period in the Maharashtra State.

Similar type of filter plants, with some minor modifications have also been constructed at a few rural water supply schemes in the Maharashtra State and the plant observations on the Bhagur plant are also included in the chapter 11 of this thesis.

1.11 CHANDORI TREATMENT PLANT.

The design of Chandori treatment plant consists of pretreator unit followed by dual media filter bed. The pretreator unit is a combination of gravel bed prefilter and tube settler as explained in details in the chapter 10.

This may be the cheapest treatment plant for the treatment of turbid water sources for the rural water supply schemes. The plant is under construction and the actual plant performance results are yet to be obtained. However the pilot plant results are included in the chapter 10 of this thesis. This may be a very simple and cheap treatment plant to be recommended for the small rural water supply schemes for the treatment of turbid water sources.

1.12 CONCLUSIONS.

The purpose of the present study is to develope simple and cheap water treatment plants for the small capacity water supply schemes in the rural and semi-rural areas. In order to achieve this purpose comparative study of the pilot plants and the new simplified water treatment plants proposed at Ramtek Varangaon and Chandori was considered necessary.

From the comparative study it can be seen that the purpose of writing this thesis is fulfilled to a great extent and number of such simple and cheap water treatment plants are under construction in the Environmental Engineering Organisation in the Maharashtra State. Further these simplified treatment plants are likely to be adopted not only in this country but also in some other developing countries, where the similar problems are faced.

Thus this thesis may be a useful reference for the construction of such simple and cheap small capacity water treatment plants. Further the thesis will also be useful for the future research in the field of water treatment for the development of simple and cheap treatment plants for the rural and semi-rural areas in the world.

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CHAPTER-2.

LITERATURE REVIEW.

GENERAL APPROACH.

The urgent need for the development of simple and cheap filters for the rural and small capacity water treatment plants has been explained under the para 1.2 and 1.3 of the chapter 1. As stated in the para 1.3 of the chapter-1, on the basis of the actual field observations and the problems faced in the existing small capacity purification plants in the Maharashtra State, the author has developed three unconventional but simple designs for providing cheaper water treatment plants for the rural and semi-rural areas.

As explained in the chapter-1, the design of Ramtek filter includes, baffle mixing channel, gravel bed prefilter and the dual media filter bed for the treatment of low turbid water sources, while the design of Varangaon treatment plant includes baffle mixing channel, gravel bed flocculator, tube settling tank and the dual media filter bed for the treatment of high turbid water sources. While the Chandori treatment plant is based on the design of a totally new type of pretreator followed by a dual media filter bed for the treatment of turbid water sources for small capacity plants. As these are unconventional designs with some new ideas in the field of water treatment it is proposed to take a literature review of the special theoretical aspects which can be compared or utilysed in the development of the new designs proposed in this thesis. This review work is therefore, mainly carried out under the five aspects as given below.

2.1) Mixing and coagulation.

2.2) Flocculation and use of gravel bed for flocculation.

2.3) High rate tube clarification.

2.4) Dual and multi-media filtration and finding suitable cheaper media.

2.5) Simplification in the design and construction for the small capacity plants.

Although the references are given in short, in some cases these are given in more details as the author feels that these are very important in the design and adoption of new techniques in the field of water treatment and will be of great use to the students of this subject. The units in the references are not altered.

2.1 MIXING AND COAGULATION.

General : In practice mechanical as well as baffle mixing is generally adopted for the small capacity water treatment plants. However there can be no simpler and cheaper method than the baffle mixing channel for mixing of chemical dose in the small capacity plants. Important literature references in respect of mixing and coagulation are given below.

2.1.1 Cox (5) in the WHO monograph No.49, on "operation and control of water treatment process" has clearly explained the importance of mixing and flocculation. He states"an under-standing of the coagulation and flocculation processes requires a distinction between successive steps in the process. First a coagulating chemical is applied to the water. In order that the chemical may react uniformly it must be distributed promptly through out the body of water. This requires rapid agitation or mixing of the water at the pilot where the coagulant is added. Second, complex chemical and physicochemical reactions and changes occur, leading to coagulation and the formation of microscopic particles. Third, much more gentle agitation of the water causes the agglomeration of the particles. In other words, the fine particles are flocculated into settleable floc.

In the past, flocculation was termed "mixing" and the whole process was given that name. It is now realised, however, that mixing for the distribution of the coagulant in the water is only the first step in flocculation. Never the less this rapid or flash mixing is necessary. Because otherwise the coagulant would diffuse through quiescent water very slowly and the initial chemical reactions would be restricted to that portion of the water in which the concentrated coagulant happened to be introduced. This would produce localized conditions quite unlike those intended, because of the marked influence of the concentration of chemicals on the resulting type of reactions. On the other hand, if flash mixing were followed by quiescent conditions, the fine precipitate would not be agglomerated into sizable floc in a reasonable period of time. Effective and economical clarification, therefore, requires the completion of coagulation and flocculation before the treated water enters sedimentation basins.

Complex forces are at work in water coagulation and flocculation, which are influenced by the character and quality of the water, the type and dose of coagulant, the water temperature, the period of time and the degree of agitation. These factors which are of chief importance and which are subject to control and supervision, need to be clearly understood to secure effective results".

Regarding the mixing methods Cox further states", rapid mixing to distribute the coagulant throughout the water being treated is frequently called "flash mixing". The rapid agitation may be provided in special basins with capacities equivalent to about one minute of flow, in which small propellers are driven by electric motors. Some times the hydraulic jump, or standing wave, is used for flash mixing, being provided by a channel with sloping and widening sections. The coagulant is added just before the water flows down the channel at high velocity to enter to level portion of the channel, where the energy of rapid flow is suddenly transformed into static head of deep water, turbulence being produced at the wave front of the deeper water. In other instances turbulence is provided by aerators, weirs, or spiral flow tanks, but flow in channels used to conduct the coagulant treated water to flocculation basins is not sufficiently turbulent for flash mixing unless obstructions are placed in the channels below the point where the chemical is applied".

2.1.2 Fair and Geyer (12) states, "The suspended or dissolved chemicals that are to be added to water or waste water must be dispersed uniformly through the water or waste water that is to be treated. The more rapidly this can be done, the less time is wasted in setting the chemicals to work. To this purpose, the chemicals may be introduced (1) in advance of hydraulic structures in which the water is agitated violently but which have some other function to perform as well or (2) into special mixing units. For examples of the first are turbines, pumps, and spray or injection aerators ; examples of the second are heavily baffled basins, or tanks equipped with mechanical stirrers or air diffusers. Exposures of 30 to 60 sec. ae are commonly enough".

2.1.3 In the manual of British water engineering practice (35) it is stated that "whenever the chemicals used in coagulation or precipitation, it is desirable that they should be rapidly and evenly distributed through out the mass of water being treated. This is assisted if the chemicals are added in the form of solutions, although the importance of this is not normally so great where relatively large volumes are being added, as in the case of lime or [redacted] soda are used in a softening plant. It is usual to introduce the chemical at some point of high turbulance in the water. This may be caused by sudden drop in the hydraulic level of water, as over a weir or through an orifice plate, or may be produced by mechanical stirring. The degree of agitation produced is of greater importance than the time over which the mixing continues and, if a special mixing chamber is provided, adequate dispersal of chemicals can be obtained in a period as short as 30 sec. to 1 min. if sufficient power is provided for the purpose".

2.1.4 In the "manual and code of practice on water supply section I-A" (36) by Ministry of Health Govt. of India, detailed description for the mixing is given which is very important for the design purpose. While describing the need, it is stated that" mixing is that phase of coagulation where in the coagulant, usually by violent agitation of the water to be treated is quickly dispersed throughout the water, thereby resulting in the formation of sub-visual floc particles. The necessity for uniform diffusion of the coagulating chemicals is obvious, in as much as the chemical dose is proportioned to the entire flow of the water into the plant, and a uniform reaction between applied chemical and the dissolved mineral constituents of the raw water necessitates **uniform** dispersion, other wise some of the water should be over dosed and some would pass on without direct treatment. The time required for this rapid mixing is relatively short about one minute being adequate where the velocity or turbulenee is sufficient. The velocity of this mix need not be confined within close limits as long as it is high enough to cause considerable turbulence and not continue too long. Any velocity greater than 5 ft/sec. should be sufficient. The higher the velocity the shorter the time should be to avoid damaging the early formed floc".

2.2 FLOCCULATION AND USE OF GRAVEL BED FOR FLOCCULATION.

General : References for flocculation by baffled mixing and mechanical flocculation are available in the literature. Some typical references are given in this thesis to represent the general trends in the designs, their limitations and actual use in the plants.

Flocculation by baffled channels are rarely used due to very long lengths of channels required for ideal flocculation. Only alternative was to have mechanical flocculation. In the small capacity plants in rural areas it is considered desirable to avoid electrically operated mechanical flocculation both from the point of high cost of construction and maintenance and also for the simplicity in the construction and maintenance.

The author has therefore developed the gravel bed for flocculation in all the three new plants at Ramtek, Varangaon and Chandori. There is no reference in the literature on the use of gravel bed as a prefilter unit before dual media filter unit as adopted at Ramtek filter and also as a flocculation unit before a tube settling tank as adopted at Varangaon plant as developed in this work. Further the pretreator at Chandori is a totally new approach with the combination of gravel bed up-flow flocculation-cum-tube clarification in a single chamber. It is,therefore, proposed to find out the literature references on the use of the baffle flocculation and gravel bed flocculation in the process of pretreatment in general.

2.2.1 Regarding the proper design aspects, Cox (5) states "the flocculation basins are of various types,some using patented equipment. Good results have been reported with very simple types consisting of a weir for flash mixing, with provision for subsequent gentle agitation in the channel leading from the weirs to the sedimentation basins. Early basins were fitted with a series of baffles around the ends of which the flowing water was reversed in direction, thus causing more gentle turbulance in the channels formed between the baffles, but more violent agitation at each point of reverse flow. The same effects were secured by arranging the baffles so that the water flowed over and under them alternatively. Such basins are cheap to build, as the baffles may be of ordinary lumber placed in concrete basins. They are only moderately successful,however, because the degree of agitation is determined by the space between the baffles, the total length of the channels so produced and the volume of flow. While the spacing of the baffles may be altered, this is a major operation and usually is restricted to the correction of initially faulty design. Further more, as the degree of agitation decreases with the volume of flow, the water is less effectively flocculated during the period of low flow, and serious loss of head results from turbulence at each point of change in direction together with friction due to the area of the baffles and the bottom of each channel between the baffles in contact with the flowing water. For instance, a basin of this type with an average velocity of 0.3 m/s (1 ft/sc) would require a channel of 18 m (60 ft.) for each minute of flocculation period. Therefore even periods of 5 min. provided by channels 90 m(300 ft) long, would entail serious loss of head,especially at smaller plants where the friction losses are proportionately higher due to a large surface ("wetted perimeter") per unit volume of water. These basins are therefore seldom ~~are~~ large enough to provide the flocculation period of 15-30 min. favoured by modern practice.

Baffled flocculation basins are being superseded by those fitted with mechanical agitators or paddles or using either diffused air or the jet action of the flowing water to secure controlled agitation.

Mechanical agitators or flocculators, consist of revolving paddles with horizontal or vertical shafts, or of paddles suspended from horizontal oscillating beams and moving up and down as the beams are driven by a crank attached to a speed reducing unit, in turn driven by an electric motor. The total area of the paddles usually is 10% to 25% of the area swept by their movement, so that the paddles move at about twice the speed imparted to the water, that is, the paddles move through the water at about one half their average speed of movement, causing eddies to form around the edges of the paddles and thus imparting agitation. The speed reducing units usually provide for variable speed, so that the degree of agitation may be regulated to secure best results. The degree of agitation is thus controlled, independent of the rate of flow of water. The maximum peripherial speed should be about 0.6 m/s (2 ft/s) so as to provide an adequate range of speeds below that value".

Regarding the degree of agitation he states" the experience has shown that flash mixing requires pronounced agitation for a brief period to mix the coagulant and favour the initial chemical reactions associated with coagulation. Subsequent flocculation however, should be aided by controlled agitation represented by velocities of flow or of paddle speed of 0.2-0.6 m/s (0.6-2.0 ft/sec) velocities below 0.1 m/s (0.3 ft/s) permit sedimentation of the floc when it should be in suspension aiding in the absorption of smaller floc, where as velocities over 0.6 m/s (2.0 ft/s) will prevent the growth of readily settling floc. In general, the best results are secured with intermediate degrees of flocculation secured with velocities of about 0.3-0.4 m/s (1.0-1.4 ft/s). Higher velocities are favoured for turbid waters and lower velocities for coloured waters or those of low turbidity".

Regarding detention period he states "flocculation should be continued for periods of 10-30 min. and even longer periods have been used. In general, the longer periods permit lower coagulant doses and the use of a lower degree of agitation to ensure the formation of large floc easily settled. Conversely, when detention time is short, the degree of agitation should be increased. A period of only 5 min. would require agitation at a rate of 0.6 m/s (2.0 ft/s); this extreme, however, is not advocated".

2.2.2 Fair and Geyer (12) states, "In their initial phases, coagulation and precipitation produce, finely divided or colloidal, suspensions. These suspensions are converted into settleable solids by agglomeration. In a quiescent fluid, colloids collide because of their

Brownian movement, and finely divided solids come into contact with one another when more rapidly settling solids over take more slowly settling ones. As a result, flocs of ever increasing size are formed. Floc growth by these means, however is exceedingly slow. It can be hastened by stirring the water. This increases the number of collisions or contacts. The increased opportunity for contact is called flocculation. It may be provided by hydraulic or mechanical means including the injection of air".

Regarding flocculation devices they state "floc growth is encouraged by gentle stirring. This too may be accomplished by hydraulic means such as baffling, by mechanical means such as revolving paddles, or by air diffusion, Detention periods must be adjusted to chemical dosage. They may be as low as 10 min. but 30 to 60 min. are common. The velocity in conduits connecting flocculation chambers with settling tanks should lie between 0.5 fps. and 1.0 fps. They should be large enough to prevent deposition of floc but small enough to prevent its disintegration. Means may be provided for the return of slury or sludge in order to promote floc formation and growth".

2.2.3 In the "manual of British Water Supply Engineering practice" (35) it is stated that "the object of floccula_tion is best achieved by keeping the water in a state of controlled agitation and in contact with material previ-ously precipitated. Due to the large surface area offered by the floc, the supersaturated material rapidly changes from the solution to the solid phase. At the same time the relative movement of the nuclei of solid material, caused by the agitation of the water, increased the probability of collisions occuring between these nuclei and so accelerates the rate of growth into large particles.

The controlled agitation or flocculation should be continued for a period of 5 to 30 min. depending on the type of impurity being removed and the coagulant or precipitant used. The degree of agitation required for the most efficient results will vary, but frequently involves water or paddle velocities between 1/2 and 2 ft/sec (0.1 and 0.6 m/sc). In general, the higher velocities are required where the suspended matter is relatively heavy, as,for example, in a softening plant or where a turbid river water is being treated.

Flocculators may consist of tanks having power operated paddles on horizontal or vertical shafts, in these the direction of water flow is substantially horizontal and parallel or at right angles to the paddle shafts. Flocculator, of this type are generally separated from the settling tanks proper even though they may be installed at one end of the same compartment.

Another type of flocculator is usually associated with vertical-flow settling tanks. In these tanks the central and bottom sections are devoted to the mixing of the incoming water with the chemicals and preformed precipitate to accelerate the reactions and to facilitate flocculation. This is usually followed by the upward flow of the water through a "blanket" of preformed sludge, which still further flocculates the water by causing the smaller particles of floc to collide and join up with larger particles capable of settling against the upward movement of the water.

The agitation necessary to produce flocculation and keep the precipitated sludge in suspension may be provided by paddles or impellers driven by external power or by the velocity of the incoming water. In general power required varies between 1/4 to 2 h.p. per 1000 gpm or from 9 to 72 in. (0.2 to 1.8 m) head loss where hydraulic power is used".

2.2.4 Babbitt and Doland,(1) state" among the factors to be considered in the design and control of mixing and flocculation devices are the time of detention and velocity of the currents. In general, the time of mixing should be as short as possible consistant with satisfactory results. The aim is to secure, as nearly and as quickly possible, a thorough diffusion of the chemical throughout the incoming waters. The duration of the period of flocculation depends on the condition of the raw water, the kind and amount of chemical used, the type of flocculator, and the desired results. It can be determined best by laboratory control and experience with the water in hand.

In general, periods of flocculation used in practice are in the order of 30 to 60 min. when preparing water for coagulation, and slightly longer for lime softening. It is to be appreciated that in general, a good flocculation is to be expected in a shorter time with highly turbid waters than is required for an equal amount of coagulation when the turbidity is low. Horizontal velocities of flow as high as 0.5 to 1.0 fps are recommended in baffled mixing basins and in flocculators without mechanical agitation. Care should be taken to keep the floc in suspension with just enough agitation to prevent breaking it up. This type of motion seems of greater importance than the velocity of flow. A circulatory, twisting, sweeping confusion of the floc, resembling snow swirls, has been found best. It is undesirable to form either a large, feathery, and fragil floc, or a tough, tenacious floc that lacks absorption capacity".

Regarding the design of baffled basins they have stated,"basins through which water flows horizontally,back and forth, past around the end baffles placed 2 to 3 ft. apart, or in which itflows up and down, past under and over baffles about 2 to 3 ft apart, are known as baffled basins. They may serve as combined mixing and coagulation basins, depending on the turbulence of flow. Their use is becoming less general because of the advantages of mechanical mixing and mechanical flocculating basins.

Disadvantages of baffled basins,when compared with mechanical devices, include (1) less flexibility of control (2) greater loss of head which may amount to 1 to 2 ft. in baffled basins and to practically nothing in the mechanical flocculator and (3) greater expense of construction due to baffle walls".

While discussing the advantages and disadvantages of mechanical flocculators they have stated, "mechanical flocculators are displacing other forms of flocculators because they provide numerous gentle contacts between the flocculating particles that are essential to successful floc formation. Such contacts occur in a manner not provided by other methods of flocculation. Amoung the advantages of mechanical flocculators may be included (1) reduction of 10 to 40 percent of the amount of chemical required by a baffled basin.(2) better floc formation with resulting diminution in required coagulating basin capacity. (3) less filter washing (4) cost of installation lower than baffled basins (5) flexibility of operation through control of speed of paddles. (6) good control of currents (7) relatively low head loss or power requirements (8) Case of installation in existing plants and (9) marked improvement in treatment with activated carbon. Among the disadvantages may be included (1) low velocity near paddle shafts (2) dead spaces in corners. (3) need of equipment maintenance and bad short circuiting".

2.2.5 In the "Manual and code of practice on water supply-sec. I-A" (36) detailed description for flocculation is given. Some important aspects are given below.

"Flocculation is the second phase of the process of coagulation and is the means by which the growth of sub-visual floc particles into the larger,rapidly settleable flocs is facilitated. In this promotion of growth, flocculation depends on two factors,collision, which in turn is dependent entirely upon physical action,particularly agitation of the water, and adhesion which is controlled by chemical or electronic forces. It follows that as the floc particles grow in size and density, with the accumulation of silt, they become more and more susceptible to sedimentation when agitation is discontinued.

Thus the object sought is a moderately large dense and heavy floc which will settle readily. This is obtained by continuous stirring. The ideal condition to produce the flocs would be a continuously decreasing turbulence as the floc becomes larger and more fragile. The optimum velocity for coagulation is usually found to be 0.5 to 1 ft. per sec.

Regarding time factor, the floc will settle usually at velocities less than 0.3 ft./sec and will be broken up by velocities greater than 2.5 ft/sec. with the current trend towards long periods of agitation it is now usual to provide for coagulation period from 30 to 60 min. including preliminary flash mixing.

Regarding the types of basins, there are two general types of flocculation basins, first those using the kinetic energy of the water flowing through the plant, and second, those stirred by mechanical devices operated by an external source of power.

The most commonly used method of agitation in basins of the first type, has been by means of baffles. The baffles are so arranged that the sudden changes in direction of flow either vertically or horizontally (or both) set up eddies in the water and a stirring action results.

By far the most satisfactory flocculation is obtained by mechanical stirring devices and these are coming into more general use. Mechanical agitators are of two general types, those revolving on a vertical shaft and those revolving on a horizontal shaft.

Regarding baffled channels, although flocculation by flow through a baffled channel can be expected to effect intimate dispersal of the chemical in the body of the water during its passage through the channel, there is a disadvantage in that the chemically dosed water does not have any detention period as such within a confined flocculating chamber where the flocs could coalesce in the body of the revolving water, agglomerate and gather mass. Velocities in baffle chambers should be kept within a range of 1.0 to 0.3 ft. per sec. and dead pockets should be avoided.

Regarding the advantages and disadvantages of mechanical flocculation, the advantages are flexibility in speeds, constant intensity of agitation regardless of the variations in plant flow, little or no head loss in the plant flow and low power requirements. The disadvantages are points of low velocity in the chamber near the shaft, deposits in corners and at centre of vertical shaft type, maintenance of equipment and bad short circuiting."

2.3 HIGH RATE TUBE CLARIFICATION.

General : The principle of the tube clarification in the pretreatment process is now well accepted and the plant performance data is also available in the literature. However this practice has not yet been adopted in the small capacity plants. The author considers that this is a very economical and simple process in the available clarification methods in the field of pretreatment at present. The author has therefore adopted this process in the design of the new simplified high rate treatment plants at Varangaon and Chandori for the treatment of turbid water sources as discussed in this thesis. Some important references in the design and plant performances for tube clarification are given below.

2.3.1 Hansen and Culp,(14) have given the history of tray settling basins and tube settler basins. They have discussed the theoretical aspects of both these processes. They have carried out wide range of pilot plant experiments on tube length of 2,4 and 8 ft. with diameters of 0.5,1,2, and 4 in. for their study. The flow rates through the tubes were 2,5 and 8 gpm/sft.of ond area of the tubes. Results of various raw water turbidities and settled water turbidities through tube settler show 80 to 90% removal in turbidity. However they have mainly worked on slightly inclined (5 degrees) tubes. The important conclusions of their study are given below.

i) The theoretical benefits of shallow depths sedimentation have been recognized since the turn of the century. Sludge removal and flow distribution problems can be over come in the tube settling process described in the article.

ii) Relatively small diameter (1-4 in) tubes 2-4 ft.

in length provide efficient sedimentation with detention times of 6 min. and less.

iii) Tube length, diameter, and flow rate, the nature of the incoming settlable material and the nature and quantity of the chemicals added affect the performance of the tube settler. Raw water turbidities upto 1000 jackson units were successfully treated in these studies.

iv) A tube settler, mixed media filter combination has successfully treated several types of raw waters. The tube settler provides settled water quality compatible with the filtration capabilities of the mixed-media filter at filter rates in excess of 5 gpm/sqft.

v) Inclining the tubes slightly in the direction of flow permits sludge removal by gravity drainage and eliminates the need for mechanical sludge removal equipment. The tube settler normally provides at least 24 hr. of sludge storage. The tube cleaning cycle can be integrated into the backwash cycle so that no water is lost.

vi) The use of small diameter tube allows proper flow distribution to be readily achieved by maintaining proper tube reservoir inlet and outlet conditions.

vii) In cases where settling is required prior to mixed media filtration, the tube settler, high rate filter combination greatly reduces the space requirements and cost for the water treatment facility. The tube settling process allows the long recognized advantages of shallow depth sedimentation to be applied in a practical manner.

2.3.2. Culp, G.L.et. al. (8) while describing the historical developments in clarification,stated in the paper, that the basic criteria for design of sedimentation facilities used in water or waste treatment plants have undergone little changes in the past 40 years. Basin depth, overflow rates, and detention times for a sedimentation facility designed in 1969 are likely to be essentially the same for a basin of the same type designed many years earlier. This new tool permits the practical application of basic sedimentation theory which, in turn, permits, marked reduction in the size and cost of water or waste water clarification facilities. The experiences, some of which are treated in this paper, gained in applying the new technique in over 50 plants indicate its applicability to existing or new plants of any capacity.

Theoretical Aspects :

Describing the theoretical aspects they have stated that the use of tubes aid in overcoming the unstable hydraulics associated with tray settling basins. Such tubes have a large wetted perimeter relative to the wetted area and provides low Reynolds number. A 2 in. diameter tube 2 ft. long through which water is passed longitudinally at a rate of 4 gpm/sqft of tube entrance area, has a Reynold number of only 20, while providing an equivalent surface overflow rate of 380 gpd. per sqft. The 4 min. detention time of such a tube settling device under these conditions certainly makes the cost and space saving potential apparent.

Basic Tube Clarification System :

The two basic tube settling systems are (1) Essentially horizontal and (2) Steeply inclined. The operation of the essentially horizontal tube settlers is coordinated with that of the filter following the tube [redacted] settler. The tubes essentially fill with sludge before any significant amount escapes. Solids leaving the tubes are retained by the filler. Each time the filter backwashes, the tube settler is completely drained. The tubes are inclined only slightly in the direction of normal flow (5°) to promote the drainage of sludge during the backwash cycle. The rapidly falling water surface scours the sludge deposits from the tubes and carries them to waste. No mechanical sludge removal equipment is required.

(2) In ~~a~~ steeply inclined tubes the settling solids are trapped in a down ward flow system of concentrated solids. The continuous sludge removal achieved in these steeply inclined tubes (greater than 45°) eliminates the need for drainage or backwashing of the tubes for sludge removal. The advantage of the shallow settling depth coupled with that of continuous sludge removal extends the range of application of tube clarifiers to installation with capacities of many millions of gallons per day.
A practical means has been developed to incorporate steeply inclined tubes into a modular form which is economical to build and can be easily supported and installed in a sedimentation basin. By altering the direction of inclination of each row of the channels forming the tube passage ways the module becomes a

self-supporting beam which needs support only at its ends. These modules are normally 10 ft in length by 30 in. in width with a module depth of 21 in. Module with tube cross section of 2 in. by 2 in. are commonly used. The installation of these modules of steeply inclined tubes in an existing clarifier enables the existing structure to provide efficient clarification of flows far in excess of its original designed capacity. Number of operating plant experiences are given in this important paper.

In the conclusive remarks the writers state that the capacity of the existing clarifier can be increased from 2 to 4 times by installing modules of the steeply inclined tubes in the existing clarifier structure. The size of new clarifier facility can be reduced by integrating steeply inclined tubes in the design.

2.3.3. Culp,G.L.et.al. (7) have given the details for the development of tube clarification process and discussed the theoretical aspects. They have given the laboratory and actual plant results in their paper and the paper is very important both for research and field engineers. The paper is based on the similar ideas as discussed in the earlier paper (8). Hence only some other important aspects are given below.

Regarding their laboratory study on the inclination of the tubes, they state, it was noted that tube efficiency showed an increase as the angle of inclination was increased to 35-45 deg. and then began to decrease as the angle of inclination was increased further. Results comparabld to those obtained at 5° inclination, however, were achieved at angles as steep as 60 deg. It appeared that, as the angle of inclination was increased to the point where the settled sludge began to move down the tube bottom, additional floc settled and collided with the smaller, upward moving floc, contributing to the increased efficiency over that achieved at 5 deg. A continuing increase in angle eventually results in the tube acting as an upflow clarifier, however and the advantages of the shallow tube depth are lost, resulting in a decrease in efficiency.

In their experiments in this respect, the tubes were repositioned at angles of 35,40,45, and 60 deg. A slight decrease in efficiency was noted as the angle of inclination approached 60 deg. The self-cleaning action, however, was enhanced as the angle was increased from 45-60 deg. To insure adequate sludge removal from the tubes, an angle of inclination of 60 deg. was used in the subsequent tests of multi-tube units.

Regarding flow rates in their laboratory study a mud slurry was mixed with the incoming (ground) water to provide various levels of raw water turbidity. Alum (40 mg/1) was added as the primary coagulant with the polyelectrolyte additions made in some tests. Tube loadings of 4 to 6 gpm/sqft were investigated (tube entrance area - 9 sqft.) with raw water turbidities of 50 and 250 JTU. In some runs as noted, the flocculation drive motor was turned off to evaluate the tube efficiency without prior mechanical flocculation. At the lower rate of 4 gpm/sqft. the addition of polyelectrolyte did not markedly improve the effluent clarity. When the flow rate was increased to 6 gpm/sqft., however the higher settling velocities imparted by the polyelectrolyte were of significant benefit. When the flocculator was operated, the turbidities were fairly constant through out the run. When the flocculator motor was not operated, however, it was found that the effluent turbidity decreased with time as the solids concentration beneath the tubes increased. This is not surprising as solids contact in and beneath the tubes was the prime source of flocculation in this case. Although it was found that the sludge blanket could be established with the steeply inclined tube settler without subjecting the incoming water to mechanical flocculation, flocculation hastened the development of the blanket. After the sludge blanket was well established the flocculator could be turned off with no noticeable effect on the clarified effluent quality. This observation suggests that by maintaining an upflow of newly coagulated water, settled water turbidities consistent with the capabilities of the mixed media filter under all the conditions.

They have also given field evaluation data, on the plant application for augmenting the existing capacity of 1.5 mgd to 3 mgd at the city of Newport, Oregon in America The tube settler and mixed filter were both operated at 5 gpm/sqft. in these pilot tests. The actual hydraulic loading on the tube area in the plant was 4.3 gpm/sqft.

From the plant scale observations it is stated, as was expected, the outer modules nearest the effluent weir receiving the bulk of the flow and were operating at 6.6 gpm/sq.ft. based upon the entire surface area covered by tubes. Even with this flow distribution, the tubes were performing as efficient sedimentation devices. The tube effluent turbidity increased only slightly as the flow rate increased from 2 gpm/sqft. to 6.6 gpm/sqft. in the module near the weir. The fact that the tube modules operating at 4.3 gpm/sq.ft.(average)were producing better effluent than the clarifier previously did operating at 0.7 gpm/sq.ft. was further confirmed by the fact that the length of filter runs increased from 26 to 60 hr. following the modification of the clarifier.

The installation of the tube modules in an existing clarifier and the conversion of the filter to a mixed media bed provides plant expansion with substantial savings in cost and space. The coupling of tube settlers and mixed media filters allows a reduction in the size and cost of new treatment facilities. This combination provides new design concepts to achieve efficient treatment plant design produce a given quality finished water from a given raw water or waste water.

2.3.4 Gomella (13) presented the General Report No.1, on"Recent developments related to preclarification" before the Tenth International Water Supply Congress (1974). This is one of the very important report which gives the uptodate developments in the field of pretreatment and will be very useful both for research and field engineers.

However only import aspects in lamellar or tube settling basins are given below.

Under conditions of laminar flow, the theory of Hazen is fully justified and experience has confirmed that very high separation performance can be achieved. Lamellar modules are operated for purposes i.e. (i) to extend the total settling area and to obtain a laminar flow.

Under horizontal flow and inclined settling plates, it is stated, to avoid the accumulation of the settled sludges by removing them in a continuous cycle, the settling plates should be inclined, ensuring automatic removal. The optimum slope for hydroxide sludges currently collected in water treatment plants is slightly less than 60°. At a 60° slope, sludges are removed almost continuously and at 52° slope the deposits become loose and scale off at a limited thickness. Settling plates should be inclined parrallel to the direction of the flow in order to maintain the flow horizontally.

A new plant can always be designed very compact and efficient, with such settling basins, but the modification at an existing plant is quite a different problem which must be solved in a reversed way,starting from the settling plates, spaced as near as they can be technologically set (5 to 10 cm) and then working out the flow obtained under laminar conditions.

Lamillar modules with inclined flow : Geometrical requirements when the flow is vertical.

Considering a structure with vertical flow and modules with given geometric dimensions, the maximum gain of performance is obtained with modules made of tubes having a slope lying between 45° and 52°. [redacted]

This technical conclusion is positive but must be moderated for economic reasons.

Under the conclusions of this report it is stated for about 40 years, preclarification procedures were strongly influenced by flocculation methods, but they are at present under examination for major revision.

The general trend now brings together the preclarification process and the final clarification process, in one way or another.

In stead of increasing the velocity of the particles of suspended matter in the direction of a settling surface or collecting area, new methods are generally directed to reducing the travel and statistically increasing the probability of contacts with collecting surfaces.

Inclined modules are easily adopted to existing plants, with an arrangement of inclined flow modules located at the surface of parallelipipedic structures. Clarification efficiency is greatly improved, as well as the capacity.

2.3.5. Culp and Culp (9) state "sedimentation in tubes inclined at angles in excess of 45 deg. does not accumulate but moves down the tube to eventually exit the tubes into the plenum below. A flow pattern is established in which the settling solids are trapped in a downward flowing stream of concentrated solids. The continuous sludge removal achieved in these steeply inclined tubes eliminates the need for drainage or back flushing of the tubes for sludge removal. The advantage of shallow settling depth completed with that of continuous sludge removal extends the range of application of this principle to installations with capacities of many million of gallons per day".

Regarding fabrication of tubes they state,"various manufactures have developed alternative approaches for incorporating steeply inclined tubes into a modular form which is economical to build and can be easily supported and installed in a sedimentation basin. One modular construction is known as Neptune Microfloc in which the material of construction is normally PVC and ABS plastic. Extruded ABS channels are installed at 60 deg. inclination between thin sheets of PVC. By inclining the tube passage ways rather than inclining the entire module, the rectangular module can be readily installed in either rectangular or circular basins. By alternating the direction of inclination of each row of the channels forming the tube passage ways, the module becomes a self supporting beam which needs support only at its ends. The rectangular tubular passage ways are 2 in x 2 in square in cross section and normally are 24 in long.

Regarding general design considerations they state" steeply inclined tubes can be either upflow solids contact clarifiers or horizontal flow basins to improve performance and / or increase capacity of existing clarifiers, of course, they can be also incorporated into the new facilities to reduce their size and cost. Capacities of the existing basins can be usually be increased by 50 to 150 percent with similar or improved effluent quality. The over flow rate at which tubes can be operated is dependent upon the design and type of clarification equipment, character of the water being treated, and the desired effluent quality".

Regarding the design criteria for upflow clarifiers the writers have recommended the overflow rates in the range of 2 to 4 gpm/sqft. for the portion of basin covered by tubes, so as to get the effluent turbidity between 3 to 7 JTU. For horizontal flow basins also the overflow rates are recommended between 2 to 4 gpm/sqft. to get effluent turbidity within 3 to 7 JTU when the raw water turbidity can be in range of 100 to 1000 JTU, However these guide lines are based on the assumption that both the chemical coagulation and flocculation steps have been carried out properly. Also the sludge removal requipment has been assumed adequate.

2.4 DUAL AND MULTI-MEDIA FILTRATION AND FINDING SUITABLE CHEAPER MEDIA.

General :

The principle of dual media filter beds for high rate filtration is now well accepted and references for its design as well as plant performances are now available in the literature. The author has adopted dual media filter beds for all the three new designs proposed for small capacity treatment plants for the reasons as given in their detailed designs in the respective chapters.

However the present literature shows there are no suitable cheap media which can be easily adopted for dual and multi-media filters. Author has therefore carried out experimental research to find out suitable cheap media for dual and multi-media filter beds. During this study it was possible to invent the new media of crushed coconut shell which was used for the first time at Ramtek filter.

It is, therefore, proposed to take the important literature review for the development of dual media filter beds and for the search of new cheaper media for the use in dual and multi-media filter beds.

2.4.1 Huisman (15) in his paper "trends in the design construction and operation of filter plants" has explained the advantages and necessity of adopting dual and multi-media filter beds. This is a very important paper in the field of filtration and the author has undertaken the study of investigating new and cheaper filter media for dual and multi-media filter beds mainly because of the urgent need of research in this respect as expressed in this paper.

Explaining the present difficulties in the rapid sand filtration Huisman states", generally speaking, effluent quality will be better as the filter bed is finer grained, promoting the efficiencies of straining, sedimentation and adsorption. With very fine filter grains 0.4 to 0.6 mm, for instance, the purifying effect is even so high that impurities from the raw water penetrate the filter bed over a short distance only, mostly not more than a few cms. An excellent effluent quality is now assured under all conditions but with the small silt storage capacity the length of filter run would be extremely short if other than fairly clear water was filtered at fairly low rates for instance 3 or 5 m/hour (1.0 or 1.7 Imp.gallon/sq.ft. minutes). The cost of rapid filtration in the mean while is about inversely proportional to the design rate of filtration and indeed an appreciable saving could be obtained by the application of coarser grains, allowing the filtration of a more turbid water at higher rates and still acceptable lengths of filter run. This however, is only possible by a greater **silt** storage capacity, by a deeper penetration of the impurities from the raw water into the filter bed.

The difficulties mentioned above can be lessened by the application of a multi-layered filter bed and decreasing grain sizes in the direction of flow. Most simply this is obtained with an upflow filter, equipped with non uniform filtering material, hydraulically graded by back washing. With this set up with the maximum permissible filter resistance corresponds in theory to the submerged weight of the filtering material and is about equal to the bed thickness when sand is used. With unavoidable variation in pore space and the accompanying danger of local break through of the raw water, the maximum permissible filter resistance is in practice even smaller and consequently fairly low, even when deep beds (2-3 m) are applied. In the Netherlands this problem has been solved by equipping the filters with a grid of steel bars. This grid keeps down the sand, taking up the difference between filter resistance and submerged weight and again prevents a break-through of untreated raw water as many installations constructed for industrial water supplies has already shown.

With regard to the hydraulic classification accompanying back washing, downward filtration from coarse to fine is only possible by composing the filter bed of 2 or more layers of filtering material with different mass densities as for instance coarse anthracite, medium sand and fine garnet with specific gravities of 1.5, 2.6 and 3.9 respectively. The gradual transition of the upflow filter is now replaced by a sudden decrease in grain size, which might result in a rapid clogging at the inter-face. To prevent this phenomenon as much as possible the ratio between the successive grain sizes should be chosen to correspond with the ratio between the successive mass densities, allowing a certain amount of mixing of the two filtering materials during back washing. With the specific gravities mentioned above, grain sizes of 2.0, 1.0 and 0.6 mm could for instance be chosen. The greatest difficulty, however, is the selection of suitable filtering materials, sand offers no difficulty and also garnet gives excellent results but its price is very high. Anthracite is not only fairly expensive, but it is also very difficult to obtain a uniform grade with an adequate wear resistance and a satisfactory length of useful life. Plastic would seem a logical choice, but prices will be in u.s. $ 250 per m^3 range, that is 15 times as expensive as the best quality filter sand. Nowadays artificial anthracite (powdered, baked and broken) is on the market and although practical experience is still scarce, the outlook is permissing".

He further states,"provided that skill supervision is constantly available, coarse to fine filtration offers enormous advantages of high filter rates and the same or better effluent quality and equal or longer filter runs. It also allows the filtration of a more turbid water, widening the choice of raw waters fit for transforming into a good quality drinking water and in many cases it does away with the necessity of pretreatment. Whether upflow filtration and cheap and easy to obtain filtering material, must be preferred to the more stable multi-layered downflow filtration and,the difficulties and expenses of obtaining suitable filtering material is still difficult to say. In any case, the loss in safety factor makes desk top designs impossible and good results are now only possible on the basis of data gathered by running a pilot plant for an extended period of time. The mathematical theory of filtration is fascinating,helps greatly in a better understanding of filtration phenomena,but is (and will long be) insufficient for this purpose",

2.4.2 Conley (4) states"results of laboratory,pilot plant and full scale plant tests with a variety of filter types over a period of 16 years show that filters made of Anthracite and sand together are superior to filters made of either material alone". This is one of the very important papers based on plant observations for a long time and it is very useful for designing either new or conversion of the existing rapid sand filters into dual media filter beds. Some of the important observations in this paper are stated below.

"The plants have been used six main filter types. The comparative value of these filters is determined by their ability to produce high quality water at high filtration rates and with long filter runs. On this basis of judgement, filters made of 6 in of 0.43 mm effective size sand and 24 in of 0.9 mm effective size anthracite are superior to any of the other filter types used.

The large capital savings were made possible by increasing the flow through all plant components. Consequently, flocculation and settling times are short and filtration rates are high. For a long time one plant filter operated successfully at 8 gpm/sq.ft.,with very short flocculation and settling time. Most of the plants are capable of operating at 6-7 gpm/sq.ft. There has been no difficulty in keeping the filters clean. The percentage of backwash water used is usually below 2% of gross output and is often below 1%.

At about the same time a number of the filters were changed to give a medium consisting of 6 in of 0.43 mm sand and 24 in of 0.9 mm anthracite. The anthracite size in the filters was changed by adding coarse material and skimming off the fine materials from the surface of the filter beds. The results have been excellent. The converted filters have a practical capacity of 6-8 gpm/sq.ft. depending on the flocculation and settling time and the size of the filter effluent piping.

One filter was made of 1.3 mm anthracite and 0.43 mm sand. This filter was not good as expected, either in head loss or in water quality.

Properly made anthracite sand filters provide a means for increasing water plant capacity without working any other basic plant changes. Anthracite loss during back wash has been 1-4 in/year depending on the frequency of back wash. Most of the anthracite is lost during the period when air binding is a problem. It is thought that the air floats the anthracite out of the filter during back wash. The loss is not a serious problem either in terms of money or of operating efficiency. The lost material is replaced avery year or two. The annual cost of the anthracite is less than 10% of the annual cost of alum. Some sand is lost through the under drain system for some filters. The under drain system consists of gravel and wheeler bottom".

2.4.3 Camp (3) during the discussion on the above paper has reported following observations.

"The coarse grained anthracite medium has been employed to allow deep penetration of floc and correspondingly long filter runs. The finer grained sand beneath the anthracite is relied on as a polishing agent to remove most of the floc remaining after passage of the water through the coal. In order to take the full advantage of the effectiveness of the finer sand grains just below the coal, the firm has designed its filters to avoid or to minimise mixing sand and coal during back washing. Relatively deep sand beds have been used for avoidance of filter breakthrough which was reported in so many of Conley's experiments.

Anthracite with a specific gravity of 1.4-1.6 and greater angularity than silica sand must have a grain size of 2-3 times that of the sand with specific gravity of 2.6 to be lifted at the same wash rate. If the size ratio at the interface between the sand and the coal is greater than about 3, there will be mixing at the interface during washing. The larger the size ratio the greater will be mixing of the two media".

2.4.4 Diaper and Ives (10) have discussed the theoretical considerations for rapid sand, upflow and multi-media filters and this is one of the very important paper in the field of filtration.

In the introduction of the paper they state "most practical water filters contain sand that is not of uniform size and consequently, the sand stratifies during the backwashing process to form a size graded medium in the filter. There is an inherent disadvantage in size graded filters because they become rapidly clogged at or near, the inlet surface where the medium is finest, with consequent inefficient use of the depth of the filter, some developments in filter design and practice have overcome this disadvantage by using coarse grain anthracite overlying the sand, or upward flow filtration or biflow filtration.

Modern filtration theory, developed principally in the period 1954-1964 has been mainly concerned with filtration of suspensions through unisize granular media. It has identified the irrationality of normal size graded filters, but could not present rational comparisons between upflow and downflow systems, or predict the performance of filters containing more than one filter medium material".

They have discussed the experimental results to compare filtration through size graded media in both upflow and down flow filters. In addition an experimental three media filter has been operated to show the rationale of size grading combined and density stratification to maintain a coarse to fine grain filter, stable in configuration during reverse flow backwashing .

Some of the important observations given in the analysis of their experimental results are given below.

"Comparing upflow with down flow, the efficiency of removal was higher with down flow but because the head loss increased more rapidly, the filter runs were usually longer in the upflow tests. It was also noted that,where as in downflow the efficiency of removal decreased in the lower layers of the filter, the up-flow filter showed an increase in filtration efficiency towards the outlet surface as would be expected from the theory.

These results show that the effect of gravity is important in filtration because the removal efficiency of anthracite is decreased in the upflow tests. Another explanation of the improved performance in downflow could be the higher removal efficiency of anthracite.

These results show that in the absence of the formation of a surface blanket, the composite and sand beds gave similar results. In general, the head loss in the composite bed was less for a corresponding efficiency. The composite bed in down flow appeared to be the best for removal efficiency and head loss combined. This is attributed to better removal characteristics of anthracite and the effect of graded media size on the overall filtration performance.

With upflow filtration in the graded sand filter, cleaning was generally more difficult than with downflow. It was not found possible to clean completely by allowing the water to pass downwards through the filter, even at high rates. This indicates that an important step in liberating the suspended solids from the depth of the bed is the initial fluidization of the layers, which effects a physical break-up of the deposit. Expansion of the bed therefore seems to be essential if solids are deposited in the depth of the media.

In the case of upflow filter, because of the direction of washing was the same as the direction of filtration, the effect of pressure was to push the trapped deposits further into the finer sand, where the arching effect of the clogged media created an impervious barrier. It would appear, from these experiments, that special washing arrangements should be built into an upflow filter. The variation of washing rate if used in practice, might cause difficulties with the supporting gravel media. This requires further investigation.

In the 14-22 composite bed, the effect of the coarse anthracite grading at the top of the bed was to allow penetration of solids in down flow so that removal was more evenly distributed through out the depth of the filter. Consequently back washing had to expand all the layers. The densest medium,garnet was at the base of the filter and when this was completely suspended by upflow, the anthracite layer showed 80% expansion. The problem of bed expansion and height of overflow sills is thus more critical with graded media of different densities than with a sand filter".

The important conclusions of their study are given below which will be very useful for further study and field applications.

1. In general, graded filtration appeared to follow the equations that have developed from the existing theory for filters containing media of one size only.

2. Upflow filtration gave increased length of run to a given head loss arising from the more even distribution of deposit within the filter compared with downflow.

3. Inlet surface deposition for the dicolite suspension was one of the principal differences between upflow and down flow filtration, causing very high head loss in the latter case.

4. The main disadvantages of upflow filtration appeared to be (a) the tendency for the bed to expand because of pressure differences overcoming the weight of the media. (b) the difficulty of backwashing if layers of deposit accumulate in certain depths of the media, and (c) the possibility of deposition in the underdrains that may be difficult to remove.

5. The principle of graded filtration (i.e. passing the flow through successively finer grains), can be applied in down flow, using media graded by density. An experimental three layer filter of anthracite, sand and garnet sand was operated successfully on this basis, giving the expected

5. improved results compared with a normal rapid-sand filter. This three layer filter retained its proper stratification after backwashing on several occasions.

6. The best application of graded filtration appeared to be to high concentrations of suspension and high rates of flow.

7. Further investigations are needed on the extension of the three layer filter to a multi-layer design using a range of different media with suitable densities.

2.4.5 Shull (54) has given the experimental pilot plant and actual plant results after conversion into a multi-~~med~~ media filter bed at the crum creek plant in America. The multi-media filter bed consists of 20 in of coal with an effective size of approximately 0.9 mm was placed over 6 in of sand with an effective size of 0.44 mm. The gravel arrangement was also unconventional. It was based upon the excellent research of the late John R. Baylis at Chicago. The results of nearly a year's operation with the two experimental filters were so encouraging that it was ~~dec~~ decided to rebuild all 22 filters at the pickering creek plant. The renovation programme which began in December 1963 and completed in Feb.1964, consisted essentially of removing all existing sand and gravel from the filters and replacing it with new gravel, sand and anthracite coal as per pilot plant experiments. It also included installation of a polyelectrolyte aid system.

The important conclusions of their study are given below.

1. Improved water quality at normal rates of filtration.

2. Increased rates of filtration, without depreciation of water quality.

3. Need of less alum and certain other chemical.

4. Need for less wash water to back wash the filters.

5. The objective of water treatment include the removal of turbidity, harmful bacteria and other organisms, colour and taste and odour. As the process of filtration is involved either directly or indirectly in each of these, the more efficiently a filter operates, the greater will be the removal of impurities. The multiple bed filter process, if properly applied, is more efficient than conventional filtration, and it should play an increasingly significant role in the quest for quality water.

2.4.6 Rimer (51) in his paper "Filtration through a trimedia filter" gives the following specific conclusions from the pilot plant study the details of which are given in the paper.

1. Garnet exhibited filtration characteristics similar to sand of equivalent gradation under identical flow conditions. (2) the upper fine layers of a conventional single medium filter dominate the filtering capacity of the filter. (3) the pattern of head-loss development in a multilayered filter appear to be essentially linear with depth (i.e. non necessarily in time) while those in the sand bed are nonlinear (4) the trimedia filter resulted in a substantial head loss reduction (approximately 50%) with no concurrent reduction in filtrate quality, when compared with a conventional sand filter of

equivalent size distribution under the same operating conditions (the average net yield of the trimedia filter was therefore approximately 50% greater than the conventional sand filter) (5) multimedia filtration is limited by the selection of media, but material such as garnet or synthetics could serve as additional types of media. (6) the trimedia filter required more wash water at a higher rate to adequately clean the bed. (7) programmed backwashing cycles, which would progressively expand and fluidize the bed, should be used to assure proper backwashing of a complex filter.

2.4.7 Mohanka (39)(40)(41)(42) states the multi-media filtration achieves the rational requirement that the suspension to be filtered passes into the coarsest grains first and through subsequent finer and finer media. In addition the filtration can be in the conventional down-flow direction with reverse flow washing, maintaining a separation between the unfiltered and filtered water at all times. Due to the density gradation the filter is hydraulically stable in configuration even after upwash fluidisation. He has explained the mathematical model developed for multilayer filter bed.

In the pilot filter for his experiments, he has used different media. Regarding selection of media he states "selection of media for multilayer filter was a result of various individual investigations. This includes density, settling velocity and sieve size of various plastic grains, anthracite, crushed flint sand, ordinary sand, garnet, magnetite and alumina. As a result of these investigations the multilayer filter was comprised of extruded granules of polystyrene, anthracite, crushed flint sand, garnet and magnetite".

2.4.8 Ives (19) in his paper "Theory of Filtration" has given the various theoretical aspects consisting attachment and detachment mechanism of particles in the water, mathematical models, clarification process, head loss developments and optimisation of a rapid sand filter with uniform media. In this respect he states", so far, these formal methods of optimum design have only been developed for filters containing uniform media. Although highly desirable, it has not yet been possible to extend the theoretical methods to size graded or multiple layer filters".

At the end of this paper he has discussed the value of the theory which is very important for initiating future research in the field of filtration. He states "filtration theory can not be expected to be completely predictive. The complexity of particle and fluid motions in filter pores the randomness of filter grain packing and the variability of natural water quality prevent predictive calculations. Nor will optimisation studies reveal the most economic design (i.e. the lowest cost per cubic metre filtered), since this is partially dependent upon price structures in each country, which are variable with time.

Filter theory can, however, be useful in the following ways :

1. Theory can indicate what are meaningful observations both in practice and experiment. For example : optimisation studies indicate the importance of continuous monitaring of filtrate turbidity.

2. Theory can indicate reasonable extrapolations of observed data. For example : if head loss is due to deposits within the pores a linear extrapolation with time is reasonable.

3. Theory can indicate what types of experimental models should be useful and those which would give false results. For example : a 30 cm.deep bed of size graded sand is not a good model of a 75 cm. deep bed of similar size graded sand, because there is no simple extrapolation of one to the other.

4. Theory can indicate the usefulness of new or alternative designs. For example : the multiple layer filters and radial flow filters can be shown theoretically to be superior to conventional designs.

5. Theory can suggest a reasonable mathematical model of filtration behaviour. Together with mathematical models of other unit processes of water treatment the relative role of each treatment can be assessed and economic load showing can be planned. For example : should flocculation sedimentation achieve most of the clarification leaving filtration to treat the residuum or should the efficiency of flocculation sedimentation be deliberately reduced to make filtration play a greater part or can either process be dispensed with entirely?"

2.4.9 Robeck,Dostal and Woodward (52) have given following general conclusions based on the pilot plant study for 1.5 year to treat turbid water from the little

Miomi River for suggesting various plant design modifications.

1. A double layered bed of coarse media made of 18 in of coal (e.s. 1.05 mm) on top of 6 in. of sand was able to remove as much or more turbidity, coliform bacteria, on powdered activated carbon as a bed of coal or sand alone. Such a bed also permitted the extention of filter runs.

2. With proper coagulation ahead of the filter, 6 gpm/sqft. filtration rate was as effective in removing all test particulates listed in conclusion 1 as 4 or 2 gpm/sqft. rate.

3. Adequate floc strength was more important in achieving clarity than a certain settleability, when coarse media and high filtration rates were used. This strength was frequently obtained only by addition of 5-20 ppm of activated silica as a coagulant aid or 0.50-0.2 ppm of a synthetic polyelectrolyte as a filter aid.

4. When the water was relatively clear ($<$ 2.5 units), the flocculation and sedimentation steps of conventional treatment design could be omitted if coarse media were placed on top of sand.

5. For this particular river water, the inclusion of flocculation and limited sedimentation permitted longer filter runs and better water during winter and flood conditions.

2.4.10 Laughlin and Durall (32) carried out simultaneous plant scale test of mixed media and rapid sand filters on municipal plant at Greenville, U.S.A. during 1966-67. The mixed media filter bed was composed of coarse coal, medium sand and fine garnet with approximate specific gravities of 1.5, 2.5 and 4.5 respectively. They have carried out comparative study for 2,4 and 6 gpm/sq.ft. on both these filters and gave the following conclusions from their study.

1. Mixed-media beds have longer filter runs to a given head loss.

2. A clearer effluent is produced in mixed beds.

3. The new media can operate at the nominal filter rate of 5 gpm/sqft. and a peak rate of 8 gpm/sqft. In emergencies the filters can produce 10 gpm/sqft.

4. Mixed-media beds require less wash water,

5. Improved control equipment, including a pilot filter for optimizing coagulant dosage, accompanies conversion to mixed media and improves over all plant performance.

6. For a minimal cost, nominal plant capacity can be increased 150 percent and peak capacity 100%.

2.4.11 Culbreath (6) described the experience with multi media filter on williams creek plant. The old rapid sand filters were designed for a filtration rate of 2 gpm/sqft. After conversion of existing filters into multi media filters the rate of filtration was increased to 5 gpm/sqft., while the filter beds were designed for 8 gpm/sqft. rate for possibility of changing to high rate at a later stage.

The multimedia consists of 18 inch carbonaceous media at top and below this finer media of black silica sand 7 inch, pink sand 3 inch and maroon sand 3 inch.

were placed respectively over 12 inch gravel.

2.4.12 Nasikkar, Bhole and Paramshivam (44) have given the following conclusions of their study.

"Dual media filter gives longer filter run for same head loss. Similarly the increase in loss of head is uniform and linear. Dual media filter can handle unsettled waters efficiently as compared to conventional filters. Anthracite being costly and scarce must be suitably replaced by cheap materials. Crushed coconut shell gives good performance. But long range bacteriological study will have to be done before using it on large scale".

2.4.13 R.Paramashivam (45) et.al. state "CPHERI has made an intensive search in the last 2 years to locate sources of good quality anthracite in the country, but with little success".

They have further stated "In view of this it was considered worthwhile to explore the suitability of good quality bituminous coal as substitute for anthracite. Samples of bituminous coals were procured and tested in the laboratory for the following which are of significance in the choice of coal as media for filtration.
i)Density,(ii)Durability,(iii)sphericity,(iv)Acid solubility,(v) Test for leaching of phenols.

The test results indicate that good quality bituminous coals which are available indegenously in large quantities can very well act as substitues for anthracite, though they do not equal anthracite in all respects".

2.4.14 Ray (50) presented the General report No.2 on "Recent advances in methods of filtration" before the Tenth International Water Supply congress (1974), is one of the very important report which gives the uptodate new develop ments in the field of filtration and will be very useful both for research and field engineers. This report gives details on the following topics.

1. Conventional Techniques.
2. Development of existing methods.
3. Improved methods of cleaning.
4. New techniques.

This general Report has been drawn up following a review and analysis of the information supplied in the National Reports from the various countries. Important aspects concerning with multimedia filtration are given below considering the scope of the present study.

Development of existing methods; All the National reports emphasise the increasing interest in the development of dual and multi media filtration techniques and particularly the application of dual media filtration to the expansion of the output existing plant. Dual media filtration began to find favour about ten years ago and represents a most significant development in filtration practise, particularly since it can be applied to existing as well as new plant.

In dual media beds the most commonly used combination is anthracite on top of quartz sand. In Belgium,Holland and Germany hydroanthracite, a German synthetic product, is commonly used. The specific gravity of anthracite varies from 1.4 to 1.7 according to its source, that of quartz sand being 2.65. In Russia such materials as crushed and uncrushed keramsite and scovia, all of similar density to anthracite are being used increasingly, also crushed fused rocks in place of quartz sand.

The main improvement resulting from the use of dual media beds is the reduction in the rate of head loss build up at given filtration rate. Advantage may be taken of this effect to extend filter runs at existing rates or to increase rates while maintaining acceptable run lengths. Nominal overall filtration capacity may be increased by as much as 100% by this technique. The length of filter run using dual media bed may be 1.5 to 3 times that achieved using a conventional bed; alternatively the filtration rate may be increased to 10m/hr. or in a few cases upto as much as 15 m/hr.

Results of experiments carried out by the water Research Association in Britain using 1.25 mm to 2.5 mm anthracite with 0.5 to 1.0 mm sand illustrate the effect of changing the proportions of anthracite and sand in beds (all of 0.76 m total depth) filtering coagulated and settled lowland river water from the Thames. The results indicated considerable advantage of using the two layer system. The results also show, however, that increasing the proportion of anthracite beyond certain levels led to little further head loss advantage. It was established that this was due to increasing stratification of the anthracite as its proportion increased. However the floc passing to the sand layer did not decrease at higher anthracite proportions and since the sand depth was less there was an increasing tendency for breakthrough to occur.

Studies in the U.S.A. have indicated the same trend. A closely graded coal/sand combination showed on higher rate of head loss development and no effect on filtrate quality compared with commercial gradings. Important observations and suggestions are given on the back washing of the dual and multi-media filter beds in this report.

2.4.15 Losnier Jeffery, and Laburn,(31) in their reports under special subject No.4, at the I.W.S.Congress (1974) on the subject "Cost and Treatment" practical experience of increasing the capacity of an existing water treatment plant have given specific examples of the existing plants and as such the reports are very useful for research and field engineers.

2.4.16 Mintz.(38) presented the special subject No.10, on "Modern theory of filtration" presented before the international water supply congress (1966), is one of the very important report in which following topics are discussed in details.

i) Physical nature of the rapid filtration process.

ii) Main mathematical relations.

iii) Practical applications.

iv) Major problems for further development of theory.

At the end of this report following major problems for further development of theory are given.

i) Development of dependable methods for direct control of porous medium geometrical parameters during clogging.

ii) Further and more precise determination of the effect of filtration rate, grain size and uniformity of a hatero-genous medium upon filtration parameters for different conditions of operation.

iii) Further study of the effect of suspension properties on filtration parameters, accumulation and systematisations of data for practical use in design.

iv) Improvement of methods and technique of technolo-gical modelling, using pilot plants and observations on plant filters under different conditions of treating a given water.

v) Determination of filter sizes to be most economic under actual operating conditions.

vi) Development of dependable methods in design of filter beds and optimum filter operation.

vii) Optimisation of the whole water treatment process with the most economic distribution of loads as its various stages.

viii) Study of the effect of grain form and filtering media properties, to serve as basis for selection of more effective media.

ix) Obtaining more precise criteria which determine a change from filtration with no deposit forming a surface mat to filtration through a surface mat.

x) Development of a more general theory of filtra-tion which takes into account the effect of all factors that may act under different conditions in the practical use of rapid filters.

xi) Thorough checking of scientific results by solving practical problems in design and operation of water treatment plants on the basis of a closer working relationship with practising engineers.

2.4.17 Culp and Culp (9) in their book "New Concepts in water purification," have explained the development and the theory of the Mixed-media filter beds, and the important aspects are given below.

Development of coarse-to-fine principle of filtration has taken place in two major steps. The first step was the development of the dual media filter which typically uses 24 in of 1 mm anthracite coal above 6 in of silica sand. Basically this provides a two layer filter in which the coarse upper layer of coal acts as a roughing filter to reduce the load of particulates applied to the sand below. Because of the different specific gravities of the two materials,(coal 1.4 and sand 2.65) the coal of the proper size in relation to the sand remain on top of the sand during backwashing. With applied turbidities of less than about 15 JTU, dual media filters can operate under steady state conditions at 4 to 5 gpm/f^2 (180 to 230 lpm/m^2) with the production of high quality water. Dual media filters can retain more material removed from the water than a sand filter, however they have a low resistance to turbidity breakthrough with changing flow rates. This serious short comings is due to the low total surface area of media particles, which is actually less than that for a conventional sand bed. Coal sand beds in which there is considerable mixing of the two materials near the interface perform better and wash easier than coal sand beds which are designed for more distinct layering.

Ideally the size of the media particles and the pore space both should be uniformly graded from coarse-to-fine in the direction of flow through a filter bed. In a down flow filter, this would require almost an infinite number of materials each having a different specific gravity. However a uniformly tapered void graduation and a uniformly tapered average particle size can be obtained using only three properly graded materials; coal (specific gravity 1.4) sand (specific gravity 2.65), and garnet (specific gravity 4.2) approximately in the proportions of 60,30, and 10 percent respectively.

The particle size range from 1.0 mm down to 0.12 mm from top to bottom of the bed. After backwashing, the three materials are mixed throughly through out the depth of the bed. At each level in the bed are particles of coarse coal, medium sand and fine garnet. The top of the bed is predominantly coal, the middle is predominately sand and the bottom is mostly garnet, but all three are present at all depths. In a properly designed mixed media bed, pore space uniformity decreases from top to bottom, to total number of particles at any level increases from top to bottom of the bed, and the average grain size decreases uniformly from top to bottom. Many persons have the misconception that a mixed media bed is a three layered bed. This is neither the case or the intent.

A three layered bed is not nearly as efficient. Ives has referred to mixed media as "mixed up" media, which is perhaps the phrase which best describes the composition of the filter. Multi media is another less descriptive term, which is sometimes loosely applied either to mixed media or multilayered filters.

Particles of turbidity in the influent to a mixed media filter first pass through a large pores and encounter the coarse media, then reach the smaller pores resulting from the mixing of the finer media with the coarse media when more opportunities, for contact occur. Materials are removed and stored throughout the full depth of the bed in contrast to the same functions in a sand bed which occur only in the top few inches of sand. The vast storage capacity of the mixed media bed greatly increases the length of filter run before terminal head loss is reached. The total surface area of the grains in a mixed media is much greater than for a sand or dual media bed which makes it much more resistant to break through and more tolerant to surges in flow rates. This provides a great factor of safety in filter operation. Despite the greater total surface area of grains in mixed media as compared to sand or dual media filters, the initial (clean filter) head loss in the two types are comparable. At 5 gpm through put the initial head loss in either a 0.50 mm sand or a mixed media bed is about 1-1/2 ft. in each.

Filter rates of 5 gpm/ft^2 are commonly used for design and operation of mixed media beds as compared to 2 gpm/ft^2 for sand filters. At the same time, water quality is improved, which was the original purpose behind the developmemt of the mixed media bed. Along with the development and acceptance of the mixed media filter has come a recognition that the rate of filtration is only one factor (and a relatively unimportant one) affecting filter effluent quality and that chemical dosages for optimum filtration rather than maximum settling as well as other variables are much more important to production of good water.

In the modern concept of water treatment, coagulation and filtration are inseparable, They are actually each very closely related parts of the liquid solids separation process. It is only because most water plants utilize sedimentation for a preliminery gross separation of settleable solids between coagulation and filtration that the crucial direct relationship of coagulation to optimum filterability has been over looked in the past.

Over the period of the last 10 years, the mixed media filter has begun to gradually replace the rapid sand filter as the standard of the industry. In the late 1960 the use of mixed media filters spread to all parts of the world, and there are now hundreds of operating installations as discussed in more detail later. In view of the higher capacity, superior quality of water produced, and greater safety and reliability of the mixed media filter as compared to other types, its current wide spread use is not so surprising as the fact that more than 10 years elapsed after it was completely developed and fully demonstrated before it became so widely recognized and used. But, then, the acceptance of new ideas is excruciatingly slow in the water works field because of the public health considerations which are involved.

One of the key factors in constructing a satisfactory mixed media bed is the careful control of the size distribution of each component medium. Rarely is the size distribution of commercially available materials adequate for construction of a good mixed media filter. The common problem is failure to remove excessive amounts of fine materials. These fines can be removed by placing a medium in the filter, backwashing it, draining the filter and skimming the upper surface. The procedure is repeated uptil field sieve analysis indicate on adequate particle size distribution has been obtained. A second medium is added and the procedure repeated. The third medium is then added and the entire procedure repeated, sometimes,20-30 percent of the materials may have to be skimmed and discarded to achieve the proper particle size distribution.

Regarding dual media filter bed it is stated that as compared to mixed media, the dual media (coal-sand) filter has less resistance to break through because it is made up of coarse particles and has less total surface area of particles. Mixed media is capable of producing lower finished water turbidities than dual media. These differences are greater and become more pronounced when the difficulty of the filtration application increases. In polishing highly pretreated waters, the differences are not great, and some designers continue to use coal sand media. However it is doubtful that any one who has observed the two filter types running side by side on the same water would do so. Typically, coal sand filters consists of a coarse layer of coal about 18 in deep above a fine sand about 8 in. thick. Some mixing of coal and sand at their interface is desirable to avoid excessive accumulation of floc which occurs at this point in beds graded to produce well defined layers of sand and coal. Also such intermixing reduces the void size in the lower coal layer forcing it to remove floc which otherwise might pass through the coal layer.

i) Capping of Sand Filters with Coal:

One very easy and inexpensive expedient to improve rapid sand filter performance is to remove about 6 in. of sand from a bed and replace it with 6 in. of anthracite coal. Commonly 0.5 mm sand is capped with 0.9 mm coal. This produces a layered type bed which has only part of the advantages of a dual media bed that has been designed for some intermixing at the interface, but which is superior in performance to a single media (sand or coal) bed.

ii) Filter Backwashing : During the service cycle of filter operation particulate matter removed from the applied water accumulates on the surface of the grains of fine media and in the pore spaces between grains. With continued operation of a filter the materials removed from the water and stored within the bed reduce the porosity of the bed. This has two effects on filter operation; it increases the head loss through the filter and increases the sheering stress on the accumulated floc.

Eventually the total hydraulic head loss may approach or equal the head necessary to provide the desired flow rate through the filter, or there may be a leakage or breakthrough of floc particles in to the filter effluent. Just prior to either of these potential occurrences, the filter should be removed from service for cleaning.

As mentioned previously, in the old slow sand filters the arrangements of sand particles is fine-to-coarse in the direction of filtration (down)and most of the impurities removed from the water collect on the top surface of the bed and the bed can be cleaned by mechanically scrapping the surface and removing about one half inch of sand and floc. In rapid sand filters, there is somewhat deeper penetration of particulates into the bed because of the coarser media used and the higher flow rates employed. However most of the materials are stored in the top 8 in. of a rapid sand filter bed. In dual media and mixed media beds, floc is stored through out the bed depth to within a few inches of the bottom of the fine media. Rapid sand, dual media, and mixed-media filters are cleaned by hydraulic backwashing (up-flow) with potable water. Thorough cleaning of the bed makes it advisable in case of single media filters and mandatary in the case of dual or mixed media filters to use auxiliary scour or so called "surface wash" devices before or during the back wash cycle,Backwash flow rates of 15 to 20 gpm/sf. should be provided. A 20 to 50 percent expansion of the filter bed is usually adequate to suspend the bottom grains. The optimum rate of wash water application is a direct function of water temperature, as expansion of the bed varies inversely with viscosity of the wash water. The time required for complete washing process varies from 3 to 15 min. Following the washing process water should be filtered to waste until the turbidity drops to an acceptable value. Filter to waste outlets should be through an air gap-to-waste drain which may require from 2-20 min. depending on the pretreatment and type of filter. This practice was discountinued for many years, but modern recording turbidimeters have shown that this operation is valuable in the production of a high quality water. Operating the washed filter at a slow rate at start of a filter run may accomplishing the some purpose.

2.5 SIMPLIFICATION IN THE DESIGN AND CONSTRUCTION OF THE SMALL CAPACITY PLANTS.

General : The author has rarely come across the literature references particularly on the subject of simplification of the design and construction for the small capacity purification plants. This is one of the very important aspect in providing simple and cheap purification plants for rural and semi-rural area, in the developing countries. In the new designs proposed in this thesis the author has tried to make maximum simplicity in the design and construction of these small capacity plants Important references in the available literature are given below.

2.5.1 Varheul (56) presented a paper on "The water supply situation in Developing countries" before the ninth International watèr supply congress (1972). It is one of the very important paper giving the position (1970) of the urban and rural water supply in the various countries and the urgent need for the research and development and co-ordination in the field of community water supply facilities so as to fulfil the targets proposed during the United Nations second Development Decade 1971-1980. Regarding the approach to the design and construction of simple and cheap community water supply schemes followings guide lines are given in the paper.

It is realised that the proper place to study national problems is primarily, within the country itself. For this reason, it is proposed to enlist the assistance of suitable institutions which will collaborate in the programme, will work towards the identification and solution of problems in their respective countries, and by liaison with similar institutions in other countries, both development and developing, make use of experience gained elsewhere to improve their own national water supply conditions. To promote of an increasing use of local materials and skills, the simplification of construction and operation techniques and the adoption of methods which have proved successful are thus the aims.

Immediate application should be one criterian, and concern should much more apply to practical development than to theoretical research. It is absolutely essential that institutions collaborating in these efforts should maintain a close liaison with the Government departments responsible for the construction,operation, and surveillance of water supplies in the country,so that the results of any research and development work may be implemented as appropriate, as early as possible.

In 1970, a WHO International conference on Research and Development in community water supply was held in Dubrovnik, Yugoslavia, the purpose of which was to explore ways in which educational and research organisations can contribute to the practical solutions of water supply problems in their respective countries and in particular to methods of overcoming the twin obstracles of inadequate finances and in sufficient skilled staff; to discuss needs for research and development studies and to plant for the establishment of the international net work of collaborating institutions, linked by the IRC. The ultimate goals of the IRC were reviewed and general tasks were agreed upon. One of the important goal for providing community water supply he states "To develop criterias for the design and operation of community water supply facilities especially in developing countries, and to encourage the maximum use of local materials and skills within such countries"

While impressing the need for development of simple and practical solutions he further states "the collection of information relevant to these activities and studies by the IRC, either alone or with the help of colloborating institutions, will not of itself lead to optimum results. The everyday water supply problems of a country are unusually best known by the local or regional water uner-undertakings. Parctical, simple designs are usually developed on the spot by local workers. Contacts with water undertakings be it indirectly should therefore be maintained".

2.5.2 Richard (53) has presented a paper on "Smaller capacity water purification installations for the supply of water to rural communities and domestic consumers" under special subject No.14 before the Eighth International water supply congress at Vienna (1969). Though the paper is important it mainly deals with the situations in the developed countries as he has recommended the use of automation, remote control including closed circuit television, in the small water supply installation units in rural areas as can be seen from some recommendations given below.

The increase in water consumption, by encouraging communities to group themselves together there by enables greater financial resources to be made available and this permits an increases in automation. Regarding the objects of automation of plant, he states "let us make clear right from the start that this automation will not be confined merely to the treatment plant, but should also be extended to the pumping installation and the distribution system.

Automation should allow better supervision of treatment stations. It should also be so designed that the staff need make only quick maintenance check at intervals to be established according to the size of the plant. This is an essential aim, but it should not be considered as a cure for all ills. Further more, the study of the automated system should clearly establish the economic feasibility of what it is required to do, the more advanced the automation one requires, the more this involves the installation of delicate and expensive apparatus which is liable to go wrong easily and needs maintenance that is more costly both in material and in labour.

The problem of remote control is complementary to that of automation, and is at the same time closely linked with it. It is possible to have either remote indication or remote control. Remote indication is simply the transmission of a figure : water level, pH, resistivity etc. Remote control enables an order to be sent over a distance.

Let us also mention a new technique which has not yet been adopted to water treatment plants because it is very expensive and delicate. This is closed circuit television; in the extensive systems which are to be found in rural areas, this would allow visual inspection of certain apparatus for example one might check "at sight" the operation of dosing pumps, filter washing etc. one should not be afraid of making greater investments in order to achieve this aim and allow a flexible and entirely safe operation.

2.5.3 Kardile (22)(23)(24)(25)(26)(27)(28) the author in all these papers has explained the need for the design of simple and cheap structures for providing small capacity water treatment plants and made important suggestions for the design and construction of such plants. These important suggestion include simple baffles or staggered pipes for mixing channel on the side wall of filter unit, gravel bed prefilter unit as adopted in the Ramtek filter, in which flocculation and settlement processes are combined together, while in the Varangaon plant gravel bed flocculation unit is provided before tube settling tank and dual media high rate filtration units have been provid provided for these filters. In the Chandori plant the pretreator is a totally new design in which the gravel bed flocculater-cum-tube settler is provided in one unit for high rate clarification of turbid water sources. All the beds are open to sky except control room in which control chamber and chlorination are provided. All the structures are masonry, designed as gravity walls with RCC work only for roof slab over control room, and over wash water masonry tank. Only hard washing is adopted, while, under drain, wash water gutters and piping are of simple type. All these and other points are discussed in details in the respective chapters of this thesis, where design for the simplified treatment plants at Ramtek, Varangaon and Chandori are given.

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CHAPTER 3

PROBLEMS IN THE DESIGN OF SIMPLE AND CHEAP SMALL CAPACITY WATER TREATMENT PLANTS

3.1 INTRODUCTION.

As already stated in the Chapter 1, either slow sand or conventional rapid sand or pressure filters are adopted for the small capacity plants in the rural areas in this country. The quality of the raw water is not generally taken into consideration for providing a suitable type of treatment. The capital costs of these treatment plants are considerably high as discussed elsewhere in this thesis. Even after providing these conventional treatment plants, in the rural areas, number of such plants are not seen working satisfactorily. The actual on plant observations carried out by the author on such small capacity plants show the various problems in the construction and maintenance of these small capacity plants. These observations show an urgent need for the development of simple and cheap water treatment methods for the rural areas, so as to solve the various problems faced in the design and construction of these plants.

It is,therefore, proposed to discuss in this chapter the problems in the design and construction of the conventional treatment plants for the rural areas, so as to find out new techniques for the design of simple and cheap small capacity treatment plants.

3.2 PROBLEMS IN ADOPTING SLOW SAND FILTERS.

The slow sand filters are generally adopted for the small capacity plants in the rural areas of this country whenever the turbidity of the raw water source is generally low throughout the year. When the raw water turbidity during the rainy season is between 50 to 500 units, a coagulation and settling tank is generally adopted before the slow sand filters. The problems in adopting slow sand filters in such conditions are discussed below.

3.2.1 General Recommendations in the Literature :

The slow sand filter is not recommended in the technical literature whenever the raw water turbidity is higher than 30 units, as the slow sand filter is basically proposed not for the removal of the suspension matter, but for the treatment of the dissolved organic matter in the raw water.

3.2.2 Effect of Coagulation before Slow Sand Filtration :

By adopting chemical coagulation and sedimentation as pretreatment before slow sand filter, the filter bed gets clogged up through out the sand bed due to the fine floc which is generally not expected in the raw water to be treated through a slow sand filter. Due to the clogging of bed the normal washing practice of scrapping of 1 to 2 cm of the top layer and replacing the same by fresh sand is not adequate and the full filter bed needs removal and washing of the sand media. If this is not done, the filter runs become shorter and shorter and the filter does not serve the purpose and the quality of filtrate also gets deteriorated. In this respect the author has given a detailed report on the actual plant observations in his paper (23) and the comprehensive report on the study of the existing slow sand and semi-rapid filters in the Maharashtra State (34). All the three slow sand filters which were studied in this report were found to be in the deteriorated conditions and giving unacceptable quality of filtrate. One of these filter was found in unaerobic conditions and giving bad smell and taste of the effluent. All these three filters are provided with coagulation and settlement as pretreatment. Even though the sources are storage reservoirs, for all these three cases, the turbidity during rainy season and summer season is quite high and some times goes even upto 2000 to 3000 JTU. So the pretreatment works, though not provided originally,had to be constructed at a latter stage to reduce the turbidity before taking water on the slow sand filter beds.

3.2.3 Necessity of Aerobic Condition in the Bed :

The slow sand filter bed has to be maintained in an aerobic condition and due to slow rate of filtration the oxygen is continuously provided in the filter bed for the various aerobic activities in the filter bed. In this respect the relevent extract from the paper (55)'comparison of slow and rapid filters' is given below for ready reference as it is of fundamental importance in the treatment by a slow sand filter.

"The speed of slow sand filters is merely a consequence of their natural function,it is not caused by a hidden falt in their construction. First too much increased velocity tends to drive through the sand the algae that would otherwise form loose aggregates that lodge in the spaces between the upper most grain and so produces oxygen in the presence of light, and secondly it reduces the period of retention in the filter,the specific germs do not have sufficient time to destroy efficiently the more complex organic matter. The filter may become too rapidly clogged and the lower layers may for this reason become deficient in oxygen and hence be working under anaerobic conditions which gives a most undesirable filtrate.

These filters cannot cope with too much turbidity certainly not with inorganic turbidity. The cellulose thread of the chlorophyceas and the silica bodies of the diatoms being smaller than the finest filter sand, this algae skin is very rapidly clogged. Further more the cloudy water in the filter, this diminishes photosynthesis. The brighter the water the greater is production of oxygen by the algae. According to our experience the filters function best when the turbidity of water at their inlet is less than 2 ppm SiO_2".

3.2.4. Effect of Intermittent Operations :

It can be seen from the above explanation that the slow sand filtration is a continuous process and oxygen from the water is vital for keeping up the filtration process efficiently. However, in the small capacity plants which are generally provided for rural schemes, the plants are designed for 16 hours working in the ultimate stage and about 8 hours working in the immediate stage. Thus the filter will be working intermittently in such conditions and it may be deficient in oxygen donation from the water as it remains in stagnant conditions for a long time. In such conditions the specific microorganisms in the bed will not be able to work in the desired way as mentioned above. Thus the effluent quality will not be to the required standard and in many cases the filter bed may go in unaerobic conditions when the raw water turbidity is high as explained above. However, this important aspect is not being considered by the various authorities,while providing slow sand filters in the rural areas.

The author is of the view that all such slow sand filters provided with intermittent working with or without the pretreatment, with coagulation and settlement, will not give the satisfactory quality of the filtered water and such filters will be the sources of permanent nuisance in supplying potable water to the rural population.

3.2.5 Cost Aspects :

When the pretreatment is provided with some type of alum mixing and settlement, the cost of such purification plants may go even more than the cost of a conventional rapid sand filter considering the increase in the construction cost in the past few years. Further the maintenance cost including chemical dosing and frequent cleaning of the filter beds may also go generally higher than that of a rapid sand filter as per actual experiences on such plants.

3.2.6 Need for the New Approach :

In most of the cases slow sand filters are provided for rural schemes because the construction is simple and there is also some simplicity in the operation of the valves. When the slow sand filters are being constructed on mass scale for rural water supply schemes, in such conditions as discussed above,there is immediate need for reconsideration for this situation, when the technological advances in the water treatment field are very promising to provide simple and cheap small capacity treatment plants.

It is for this reason that the author has tried to design the simplest possible and cheap water treatment plants based on the new techniques and some new ideas for providing small capacity treatment plants for the rural areas.

3.3 PROBLEMS IN ADOPTING CONVENTIONAL RAPID SAND FILTERS.

The capital cost of the conventional treatment plant consisting of mixing,flocculation,settling tank and rapid sand filter for such small capacity plants is generally very high. This is particularly so because the cost of mechanical equipments for mixing and flocculation and structural cost for small works including R.C.C.roof over filter beds goes very high. All these problems are discussed below in details.

3.3.1 Mixing and Flocculation :

It is desirable to delete the mechanical equipment in such small capacity plants. In the present conventional process there is no suitable and cheap process for flocculation without mechanical equipment. For this reason in many small capacity treatment plants flocculator is generally not provided. And even if it is provided the mechanical equipment is not properly maintained, with the result it is generally not found in working order. Thus the capital as well as maintenance cost for such mechanically operated units are high and hence the overall cost of the plant goes very high.

3.3.2 Rectangular Settling Tanks :

Rectangular settling tanks are suitable for small capacity plants and generally these are provided in the rural units. However, if proper mixing and flocculation is not provided before settling tanks, the efficiency of clarification is reduced to a considerable extent when the turbidity of the raw water is high. Further sludge removal arrangement is one of the important factor in the design and operation of these tanks. Generally plain, slightly sloping and serrated bottom rectangular settling tanks are seen to be provided. In this respect the Environmental Engineering Organisation of the Maharashtra State has developed multiple hopper bottom settling tanks, which have been provided at many water works in the Maharashtra State. The author has an opportunity to carry out on-plant study on the serrated and hopper bottom rectangular settling tanks in the Maharashtra State, and a comprehensive report (33) has been submitted to the State Govt. A copy of this report is enclosed in the Appendix-D for the ready reference. It has been found from this on-plant study that the hopper bottom rectangular settling tanks are far superior as compared to the serrated bottom or plain bottom settling tanks in the effective sludge removal and clarification.

3.3.3 Sludge Blanket Type Vertical Flow Tanks :

In many small capacity water treatment plants these tanks have been recently provided. The main advantage claimed, is the separate mixing and flocculation is not necessary in such tanks and higher surface over flow rates can be adopted as compared to the rectangular settling tanks. However these are continuous flow type tanks as the sludge blanket has to be maintained at a certain level by sludge withdrawal arrangement. As the rural water supply schemes are generally designed for 16 hours pumping in the ultimate stage, the plants are basically of intermittent nature and hence creation of sludge blanket every day is not an easy job at such rural schemes, as per actual experiences on such plants. The author during the on-plant study, of such plants has observed such difficulty and effluent turbidity is generally high during the rainy season when the raw water turbidity is high. The author is therefore, of the view that these sludge blanket type settling tanks are not suitable for small capacity plants based on intermittent working.

3.3.4 Rapid Sand Filters :

The conventional rapid sand filters with the automatic rate controlling arrangements and washing system with air and wash water and with R.C.C. roof structures become very costly. There is a great need for simplification of such filters and the author has therefore proposed suitable methods in his paper (26) on "Simplified rapid sand filters for rural areas". Such simplified methods are adopted for the new plants developed in this thesis.

3.3.5 Pressure Filters :

There is a growing tendency to provide pressure filters for small capacity water supply schemes. Even though these are easy and quick to install at site and cheaper than the conventional rapid sand filter beds, these are closed shells and difficult to repair and maintain properly at rural level. For want of direct observations, back wash is not generally given satisfactorily and many times the media is seen mixed up with the gravel layers, for want of proper pressure control during back washing. Corrosion is also one of the important factor, and life of the steel shells is generally short. It is, therefore, normally recommended for small industrial water requirements. It is, therefore, not generally suitable for the small capacity plants except in the conditions when, one pumping stage can be saved by adopting a pressure filter directly in the line of pumping main. Further these can be adopted for low turbidity sources only, as there are no suitable and cheap pressure pretreatment units yet available in the market.

3.4 APPROACH TO THE NEW DESIGNS.

Considering all the problems in providing the slow sand and the conventional rapid sand filters for the small capacity plants as discussed above, it can be seen that there is a great and urgent need for the development of simple and cheap small capacity treatment plants for the rural areas. In order to solve most of the present problems and difficulties in providing small capacity plants, the author has developed three new designs for providing simple and cheap small capacity treatment plants in the present study.

3.4.1 Ramtek Filter :

For the treatment of low turbidity water sources a new design of Ramtek filter is developed in this study which includes baffle mixing channel, gravel bed prefilter and a dual media filter bed. This is a type of complete treatment unit without any mechanical equipment. The structure is also very simple and the cost of this plant was Rs. 1,25,000/- in the year 1973, which was about 1/4 of the cost of a conventional rapid sand filter plant for the same capacity. The plant is working very satisfactorily for the last five years. The detailed design and plant observations are discussed in the chapter 7 of this thesis.

3.4.2 Varangaon Treatment Plant :

For the treatment of high turbidity water sources and with moderate pollution, the new water treatment plant at Varangaon has been developed in this study. This new treatment plant, includes baffle mixing channel, two units of gravel bed flocculators and tube settling tanks and three units of dual media filter beds. This is a high rate simplified treatment plant without any mechanical equipment. The structure is also simple and cost of this plant was Rs. 4,00,000/- in the year 1976-77, which was about 50% of the cost of the conventional rapid sand filter plant for the same capacity. The plant is working satisfactorily and the detailed design and the plant observations are discussed in the chapter 9 of this thesis.

3.4.3 Chandori Treatment Plant :

For the treatment of moderate turbid water sources the Chandori treatment plant is specially developed for small villages. The plant consists of one unit of pretreator which is a combination of gravel bed flocculator and tube settler, and is followed by a dual media filter bed. Both the units have been designed for the surface loading of 4,500 $l/m^2/h$. The Chandori treatment plant may be the cheapest plant, which may be recommended for any small rural water supply scheme for the treatment of turbid water sources. The detailed design and pilot plant observations are discussed in the chapter 10 of this thesis.

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CHAPTER-4.

STUDY FOR THE DEVELOPMENT OF NON-MECHANICAL FLOCCULATION PROCESSES.

4.1 APPROACH TO THE STUDY.

The importance of the flocculation in the field of water treatment is given from the various references from the literature under the chapter 2. It can be seen from the various literature references that there is no suitable non-mechanical flocculation process in the present pretreatment methods. Cox (5) in the WHO monograph No.49, has thoroughly discussed the various design aspects of the different methods of flocculation. It can be seen from this discussion that a baffle channel flocculation, though basically a non-mechanical unit, is not a practical solution for the design of a cheap and efficient flocculation unit for the small capacity water treatment plants. Therefore mechanical flocculation units are seen to be adopted in practice in the conventional water treatment plants.

To avoid the mechanical flocculation units in many small capacity water treatment plants, flocculation units are seen to be deleted. In such small capacity plants, at least in India, only the baffle mixing channel is generally provided to work as mixing-cum-flocculation unit, which is not a correct approach. In such plants, when the flocculation unit is not provided, the alum dose required is considerably more and as the floc formed is not of good and consolidated size, the efficiency of the settling tank is low in the removal of turbidity. This is particularly observed during the worst period in the rainy season. Due to the higher load of turbidity on filters, during such periods, the filter runs become considerably short and many times the effluent turbidity goes beyond the acceptable limit from such plants. Thus there is an urgent need for developing non-mechanical and simplified flocculation units for small capacity water treatment plants.

The author has therefore, introduced the gravel bed flocculation units for the Ramtek, Varangaon and Chandori water treatment plants, perhaps for the first time in the field of water treatment. Considering the basic importance of the flocculation process, a separate chapter is included in the present thesis for the pilot plant study on the different types of non-mechanical flocculation units. Thus it is proposed to compare the various flocculation processes so as to study the special merits as well as limitations for adopting the non-mechanical flocculation units. It is also necessary to find out the design criterias for adopting such simple flocculation units in the small capacity water treatment plants.

4.2 DESIGN OF PILOT PLANTS.

In this chapter it is proposed to discuss the pilot plant observations as well as comparative performances of the different flocculation units. The author has designed five types of pilot flocculation units for this study and for comparison purpose the study on the mechanical pilot flocculation unit was also done as discussed in this chapter. The pilot plant study was conducted on the below mentioned flocculation units

i) Gravel bed flocculation units.

ii) PVC tubes surface contact flocculation unit.

iii) PVC tube flocculation unit.

iv) LDP Film flocculation units.

v) Mechanical flocculation unit.

Fig.4-III to 4-VII enclosed in this chapter show the details of some of the above mentioned pilot flocculation units. The various dimensions adopted in these pilot plants are given in these figures. The details of the design of each pilot plant are given latter before conducting experimental observations on each unit.

4.2.1 Design of common Aspects for the Pilot Plant Study :

The comparative performance study was carried out on the various pilot flocculation units for the below mentioned common aspects.

i) Raw water supply of constant turbidity of 100 JTU: Raw water from the Gangapur left bank canal was brought by a jeep-trailor at the laboratory. The raw water turbidity was then adjusted to 100 JTU by mixing with clean tap water as the raw water turbidity was generally more than 100 JTU during this period. Occassionally when the raw water turbidity was less, some bottom fine silt of the canal, was mixed in the constant turbidity supply tank of 1000 lit. capacity so as to get turbidity of 100 JTU throughout these pilot plant experiments conducted in the present study. The constant turbidity (100 JTU) raw water was then pumped by means of a small electrical pumping set

(1/20 H.P.) to a small balancing tank of 30 litres capacity as and when required by operating the pumping set. A water level indicating glass tube was attached to the balancing tank to know the water level.

ii) Constant raw water flow arrangement : In order to get constant raw water flow (100 JTU) from the balancing tank to the pilot plant flocculation units,a constant flow arrangement was made as shown in the Fig.4-I. In this arrangement a constant level chamber of 10 x 10 x 20 cm. size was made of perpex sheet with one 12 mm dia. outlet connection with a gate valve to adjust required flow for the experiment. One over flow outlet was kept to maintain constant level in this chamber just near the inlet 12 mm dia connection. One 12 mm dia gate valve was attached to the outlet connection of the balancing tank from where the raw water was taken through a plastic tube in the constant level tank. Raw water flow from the balancing tank was adjusted in such a way, so as to maintain a constant water level in the constant level chamber by allowing a small quantity to tricle from the overflow outlet.

iii) Chemical mixing chamber : A chemical mixing chamber of size 10 x 10 x 20 cm size was made of perpex sheet with one inlet connection at 15 cm from the bottom and one outlet connection at the bottom on the opposite side. The inlet connection was connected with the outlet connection of the constant level chamber as explained above. At the outlet connection of the mixing chamber one pinch-cock was attached to adjust . the required constant

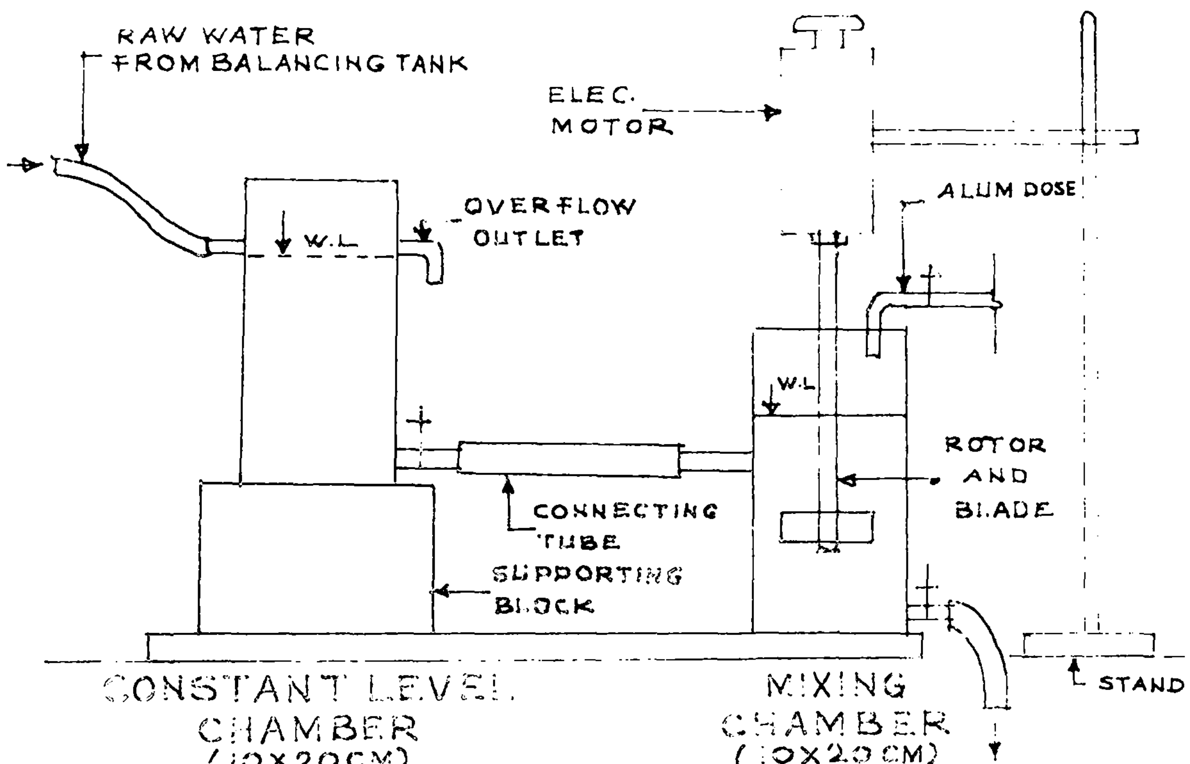


FIG. 4 I

CONSTANT FLOW ARRANGEMENT

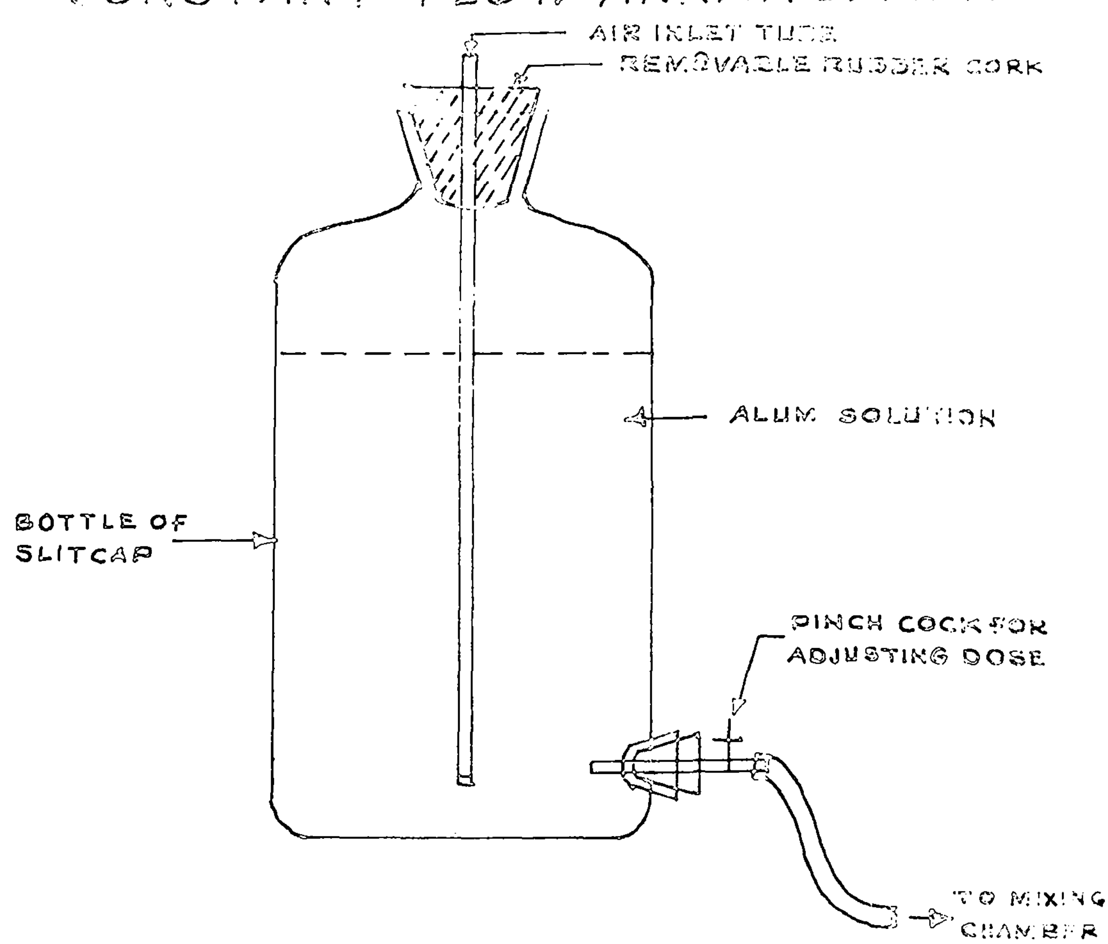


FIG. 4-II

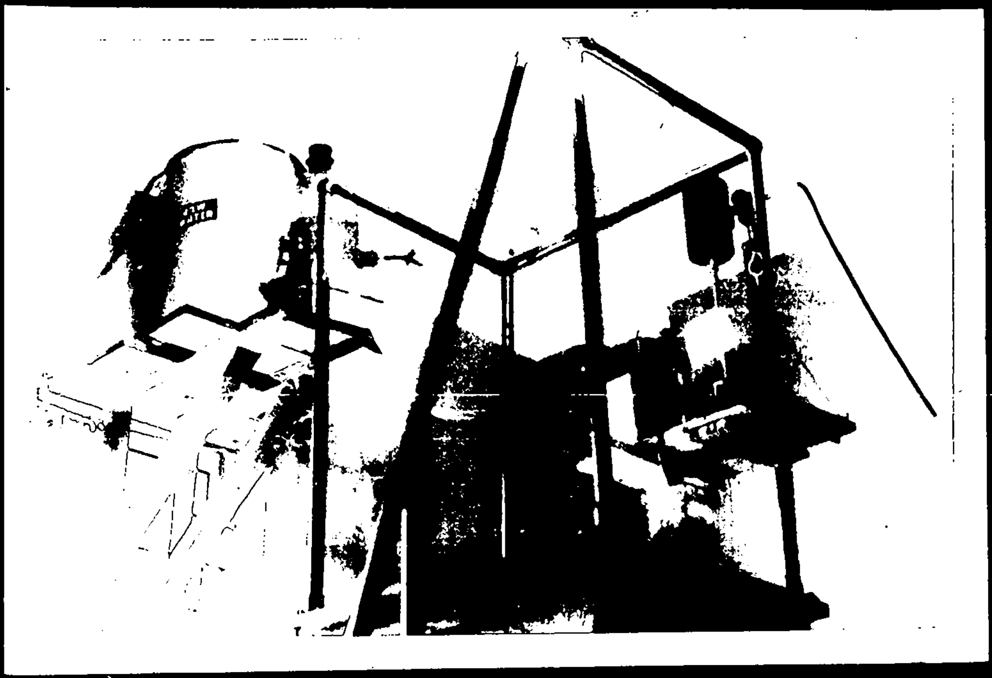
CONSTANT DOSING ARRANGEMENT

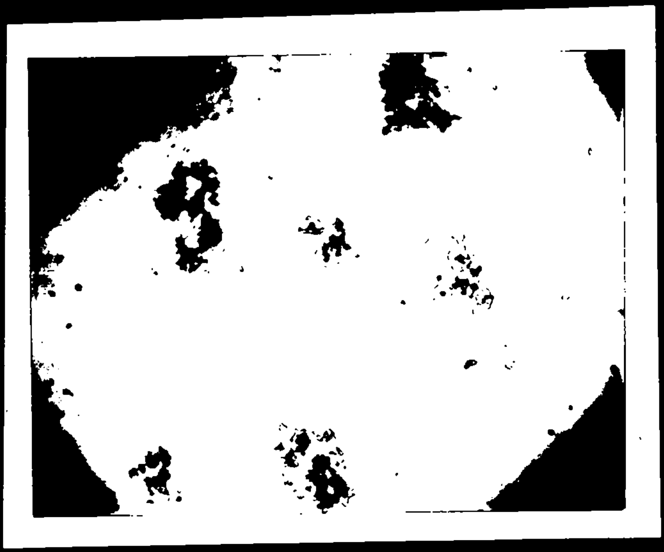
flow for the further pilot plant study. The detention period in the mixing chamber was adjusted to about one min. by adjusting the top water level and constant flow through the constant level chamber. One electrically operated mixing unit was fixed by the side of the mixing chamber. The mixing rod with a blade of 25 x 50 mm was fixed to the rotor so as get mixing speed of about 100 rpm. in the mixing chamber.

Purpose of adopting mechanical mixer : In all the simplified treatment plants developed in this thesis, the baffle mixing channel was adopted before the raw water was introduced in the treatment plant, as explained in the respective chapters. However, it was difficult to [redacted] provide such a pilot baffle mixing channel in the pilot plant study in the laboratory. In order to simplify the mixing arrangements and to give uniform mixing effect, the mixing chamber with an electrically operated mixing unit was adopted in all the pilot plant studies as explained above.

iv) Constant dosing arrangement for alum solution : To give constant alum solution dose in the mixing chamber, a constant dosing arrangement bottle of 5 lit. capacity was prepared as per details shown in the Fig.4-II. It will be seen that one glass tube was fixed in the rubber cork in the top opening of the bottle and extending upto the bottom to admit the required air to allow constant flow from the outlet glass tube fixed in the bottom opening. A pinch-cock was fixed on the outlet plastic tubing to adjust the required alum solution dose in the mixing

PHOTOPLATE 4-I





TOP
View of the constant flow arrangements for raw water,and alum dosing and mixing arrangements.

MIDDLE & BOTTOM
View of the enlarged sizes of the floc particals from the sludge blanket zone below the tube settler in the pilot plant study after gravel bed flocculator.

chamber. Alum solution was prepared in the plastic bucket of 10 lit. capacity by adding 15 grams of alum (0.15%) and the solution was poured in the constant dosing bottle whenever required, by removing the top rubber cork.

For adjusting a required alum dose for the standared raw water of 100 JTU the alum dose was fixed on the laboratory flocculator model as and when required. After fixing the optimum alum dose, by above mentioned standard method, the required alum dose was adjusted in the pilot plant experiments as conducted during the present study. Average alum dose of about 55 ppm was given for the standard raw water turbidity of 100 JTU during these experiments.

v) Flow rate for the pilot flocculator study : During all the pilot flocculator experiments a constant flow rate of 1600 ml. per min. was adjusted to get comparative results. This particular flow rate of 1600 ml/min. was adjusted to give surface loading of 10,000 $l/m^2/hr$ for the gravel bed flocculator adopted for the Varangaon pilot treatment plant, as shown in the hydraulic design calculations in the chapter-8. The same rate of flow was adjusted for all the other pilot flocculator studies as discussed in this chapter.

The author has carried out number of experiments with different surface loading rates, for the gravel bed pilot flocculator study, and has fixed this optimum rate, for the Varangaon treatment plant. The results for the other flow rates are not given in this chapter to limit the scope of the present study and to simplify the comparative study on different flocculation pilot units.

However the results for some other specific flow rates, lower than the above mentioned loading are discussed, during a few experiments. The results for lower loading rates than 10,000 $l/m^2/hr$ will generally give better results as the loading is reduced.

vi) Tube settler pilot unit : A tube settler pilot unit as shown in the Fig.4-III, is adopted after all the different flocculation units, during this study so as to give uniform clarification conditions for comparison of flocculation efficiencies of the different pilot flocculation units.

The surface loading on the tube opening area was adopted as 6850 $l/m^2/hr$ and the detention time in the tube settler unit as 23 min. as shown in the hydraulic design claculations in the chapter-8.

The author has purposely adopted the pilot tube settler unit after all the pilot flocculation units,as he feels that the tube settler tanks are likely to be adopted in the future in the place of the rectangular settling tanks and the hopper bottom verticle flow sludge blanket type tanks,for the small capacity water treatment plants. This aspect is discussed in details in the chapters 9 and 10.

4.3 PROCEDURE FOR EXPERIMENTAL STUDY.

Same procedure was followed for this experimental study to compare the efficiencies of the different pilot flocculation units. As explained earlier, each pilot plant was installed in the laboratory as per details given in the respective figures. The main components of each pilot plant were (i) Chemical mixing (ii) particular flocculation unit and (iii) the tube settler unit. The details of the chemical mixing and tube settler units have already been explained earlier, while the details for each pilot flocculator unit are given later in the next para.

4.3.1 Procedure for Operation :

Before running the pilot plant, all the units were first filled with the tap water. The raw water after adjusting the desired flow of 1600 ml/min and adjusting the required alum dose in the mixing chamber, was introdueced at the top of the flocculation unit. The flow in the flocculator was in the downward direction. The flocculated water from the bottom of the flocculator was then introduced through the bottom of the tube settling tank and about 15 cms. above the top of the hopper. The settled water from the top of the tube settling tank was then taken to the waste through a plastic tubing. The rate of flow was also checked intermittently at the out let and in a measuring cylinder. The pilot plant was operated for seven hours during the laboratory working. After stopping the plant operation after seven hours, the sludge in the flocculation unit and the tube settler unit was drained out on the next day before starting the plant. The removed sludge, was then measured and the sludge volume was noted as explained in the next para.

The pilot plant after removing the sludge was cleaned by tap water and then filled with the tap water and was kept ready for the second set of experiment when necessary. After completion of experiments on one pilot plant,the flocculator unit was removed and the pilot plant was installed for the next experiments after introducing the required flocculation unit.

4.3.2 Important Observations on the Pilot Plant Study:

i) Turbidity measurement : The turbidity of the settled water samples was measured after every hour with an Aplab turbidi meter. As the raw water turbidity was adjusted to 100 JTU,only settled water turbidity was measured.

ii) Sludge removed from the flocculation and tube settling tank : The sludge removed from the flocculator and tube settling tank was removed on the next day, carefully from the bottom sludge outlets. Care was taken to see no sludge was remained in any of these units by giving adequate washing to these units and collecting the washed water separately. The washed water from each unit was then allowed to settle in the buckets for about two hours. The clear supernent water was then taken out by syphon action, care being taken to keep about five cm. thick clear water above the settled sludge, so that no sludge was lost during syphoning. The remaining sludge and water in the buckets was then mixed properly and poured in the measuring cylinders of 1000 ml. capacity. This sludge was then allowed to settle for one hour in the measuring cylinders and the total volume of sludge was then recorded in cubic centimeters.

It was tried to measure the sludge on the weight basis but it was found that volumetric measurement was more suitable for comparing the sludge volumes in the different units of the pilot plant study.

The author has not read any such reference of measurement of sludge volumes in the various processes of the treatment units. Further such observations may not be possible on the prototype plants for various practical difficulties. He has therefore, carried out the actual sludge removal study in all the pilot plant experiments carried out during the present study. This may be one of the important parameters in the comparison of the efficiencies of the different processes involved in the water treatment.

iii) Head loss in the flocculation units : It was observed that there was some head loss in the gravel bed flocculator units. In all other flocculation units there was practically no head loss. However the head loss in the gravel bed flocculators was between 2 to 3 cm and hence this was not recorded for comparison.

iv) Bacteriological observations : Samples of raw and settled water were collected just at the end of the seven hours in the sterilised bottles, and bacteriological analysis was carried out in all the pilot plant studies to find out coliform removal efficiencies by adopting different flocculation units.

v) Cleaning of flocculation units : In order to find out the sludge volumes and to clean the flocculation units sludge was removed by draining the units. Further the units were cleaned by gravity desludging and occasionally by giving back wash to some of the pilot plant units as discussed latter.

4.4 EXPERIMENTAL STUDY.

The experimental study was conducted to find out comparative efficiencies of the different flocculation units as mentioned below -

i) Gravel bed flocculation units.

ii) PVC tubes external surface contact flocculation units.

iii) PVC tube double surface contact flocculation units.

iv) LDP sheet flocculation units.

v) Mechanical flocculation units.

The present study was carried out for the flow of 1·600 ml/min. and the principal parameters for the comparison of the efficiencies of the different flocculation units are as below.

i) Surface loading.

ii) Volumetric loading.

iii) Detention period.

iv) Turbidity removal.

v) Sludge removal.

vi) Bacteria removal.

The design of each type of flocculator and the experimental observations on the same are discussed hereafter in this chapter.

4.4.1 Gravel Bed Flocculation Units :

a) Back ground : In all the three simplified treatment plants developed in the present thesis, the author has adopted gravel bed for the basic flocculation process. In the Ramtek plant the gravel bed is adopted in the prefilter unit, where the flow in the gravel bed is in the upward direction and the design and the pilot plant observations are given in the chapter 6, while the actual plant observations are given in the chapter 7 of this thesis. In the Chandori treatment plant the gravel bed is adopted in the pretreator where the flow is in the upward direction and the design and the pilot plant observations are given in the chapter 10 of this thesis. In both these new treatment processes the flow in the gravel bed is in the upward direction so as to utilise the portion of above the gravel bed for settlement action. A separate settling tank is not adopted in both these processes to simplify the design aspects as already discussed in details in the chapters 6,7, and 10 of this thesis.

In the Varangaon treatment plant the author has adopted .. the gravel bed as a separate flocculation unit before the tube settling tank, and the pilot plant and the actual plant observations are discussed in the chapters 8 and 9 of this thesis. The author has not therefore, carried out separate pilot plant studies for gravel bed flocculation process in this chapter.

b) Pilot plant observations : Details of the gravel bed pilot plant units are given in the chapters 6,8, and 10 of this thesis. The author has given below the results of the pilot plant observations for the pretreatment process,from the chapters 6,8, and 10 for the comparative study with the other pilot flocculation units. Table 4-I gives the results of the pilot plant study on Ramtek, Chandori and Varangaon type pilot plants.

TABLE 4-I

Results of the Ramtek, Chandori and Varangaon Pilot Plant Study.

Parameters.	Average results of pilot plant study.		
	Ramtek	Chandori.	Varangaon.
i) Raw water flow in ml/min	1060	1455	1600
ii) Surface loading on gravel bed in $l/m^2/hr$.	7150	4500	10000
iii) Volumetric loading on gravel bed in $l/m^3/hr$.	4600	6430	4700
iv) Detention period in gravel bed in min.	6	5	5
v) Raw water turbidity (JTU)	100	100	100
vi) Settled water average turbidity range	20 to 25	25	12 to 17
vii) Sludge removal from gravel bed in ml.	1300	1453	1323
viii) Sludge removed from tube settler in ml.	-	-	1740
ix) Sludge removed by filter in ml.	756	690	530
x) Bacteria removal in pretreatment in percentage	70.47	87.50	74.00

4.4.2 PVC Tubes external surface contact flocculation Units :

a) The details of the pilot plant unit are shown in the figure 4-III. In this pilot plant 2 cm. dia PVC tubes were placed in horizontal positions in the flocculation unit as shown in the figure 4-III, so as to give required surface loading on the outer surface area of these tubes. These tubes were placed in staggered

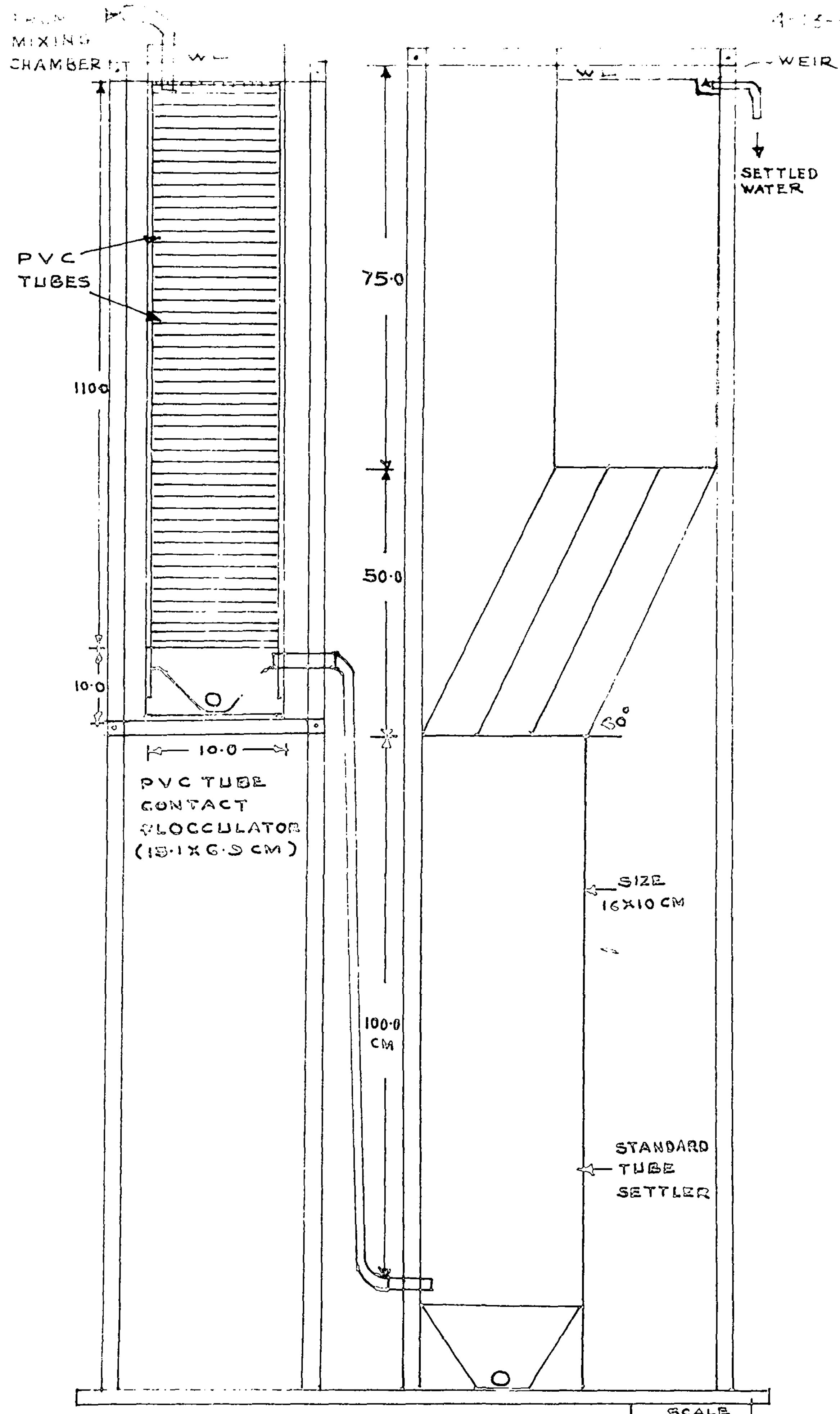


FIG. 4-III
PVC TUBES EXTERNAL SURFACE CONTACT FLOCCULATOR

positions in alternate layers with a clear spacing of about one cm. between the layers to give effective surface contact for flocculation, when the raw water was passed from top to bottom in the downward direction. The flocculated water from the bottom of the unit was introduced in the bottom of the standard tube settler unit as already explained earlier.

b) Hydraulic design of the flocculation unit :

i) Size of unit = 13.1 cm x 6.9 cm.

ii) Depth of water = 110 cm.

iii) Volume of unit = 10,000 ml.

iv) Number of PVC tubes used = 113

v) Outside dia of tubes = 2 cm

vi) Outside surface area of tubes = 9230 sq.cm.

vii) Internal surface area of sides of the unit = 2 x 13.1 x 110 = 2880.

$$+ \frac{50}{100} \times 2 \times 6.9 \times 110 = \frac{760}{3640}$$

total

viii) Total surface area of contact = 1.2870 sq.m.

ix) Volume of tubes = 4650 ml.

x) Net volume of water deducting tube volume= 5350 ml.

xi) Surface loading of the flocculator for 1600 ml/min.

$$\frac{1600 \times 100 \times 100 \times 60}{13.1 \times 6.9 \times 1000} = 10600 \ l/m^2/hr.$$

xii) Surface loading of tube surface area for 1600 ml/min.

$$\frac{1600}{1.287} \times \frac{60}{1000} = 75 \quad l/m^2/hr.$$

xiii) Detention period $= \frac{5350}{1600} = 3.35$ min.

c) Pilot plant observations : Table 4-II-a shows observations on the two flow rates of 1600 and 800 ml/min on the pilot plant. Table 4-II-b gives the comparative results for the general parameters of the study.

TABLE 4-II-a

Pilot plant observations with PVC tube external surface contact flocculator.

Hours of run.	Settled water turbidity for flow water of 1600 ml/min.	Settled water turbidity for flow rate of 800 ml/min.
0	-	-
1	50	50
2	40	30
3	40	30
4	40	20
5	40	20
6	30	20
7	25	20

TABLE 4-II-b

Comparative pilot plant observations.

	Parameters.	Flow rate 1600 ml/min.	Flow rate 800 ml/min.
i)	Surface loading flocculator in $l/m^2/hr$.	10600	5300
ii)	Surface loading on PVC tube in $l/m^2/hr$.	75	37.5
iii)	Detention period in min.	3.35	6.7
iv)	Raw water turbidity in JTU	100	100
v)	Settled water turbidity range in JTU.	25 to 40	20 to 30
vi)	Sludge removed from flocculator in ml.	250	270
vii)	MPN in raw water	930	24000
viii)	Sludge removed from the tube settler in ml.	410	270

	Parameters.	Flow rate 1600 ml/min.	Flow rate 800 ml/min.
ix)	MPN of settled water	930	2100
x)	Bacteria removal in pretreatment.	Nil	91 %

d) Other general observations : The head loss was practically nil. The settled water turbidity showed improvement after there was sludge formation on the top of the tube surfaces as observed from the side transperent surface.

4.4.3 PVC Tube Double Surface Contact Flocculation Units :

a) Pilot plant details : The details of the pilot plant unit are shown in the figure 4-IV. In this pilot plant 2 cm dia PVC tubes of 30 cm length were placed in vertical positions in four rows of 9 tubes and with clear spacing of 20 cm in between the rows as shown in the figure 4-IV. The tubes were placed in such way that there was about one cm clear space all around each tube. Thus in this pilot plant study both the surfaces of the tubes were in contact with the flowing water. Four rows of tubes were fabricated to bring water in to contact after each layer to accelerate flocculation action by increasing the contacts of the flocs. The flocculated water from the bottom was introduced into the bottom of the standard tube settler.

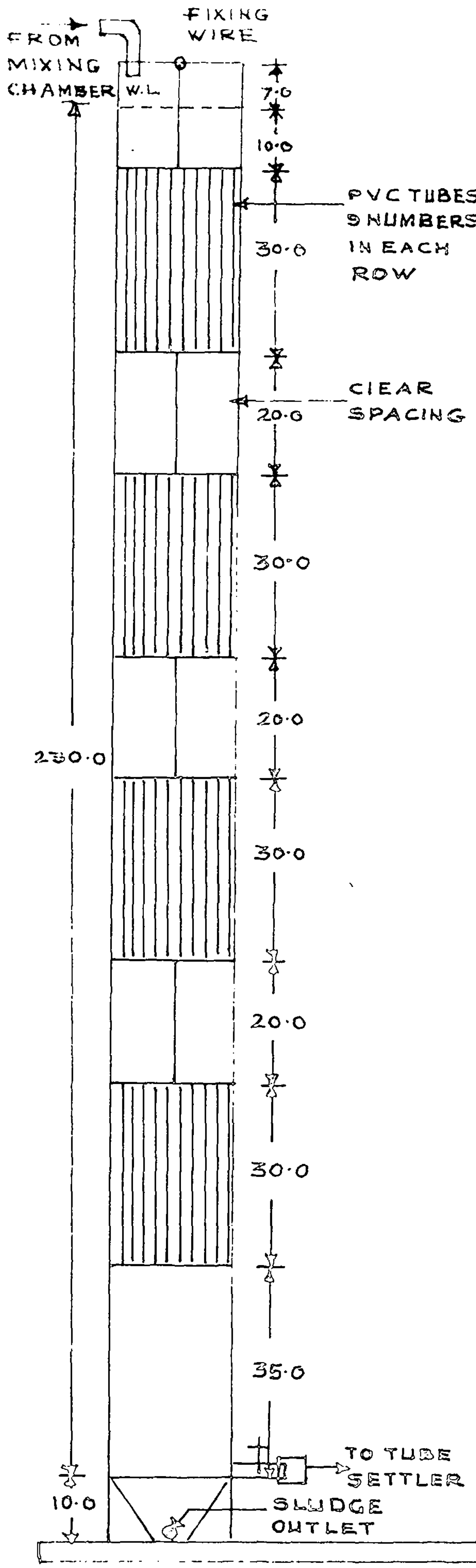


FIG. 4 - IV
PVC TUBE DOUBLE SURFACE
CONTACT FLOCCULATOR

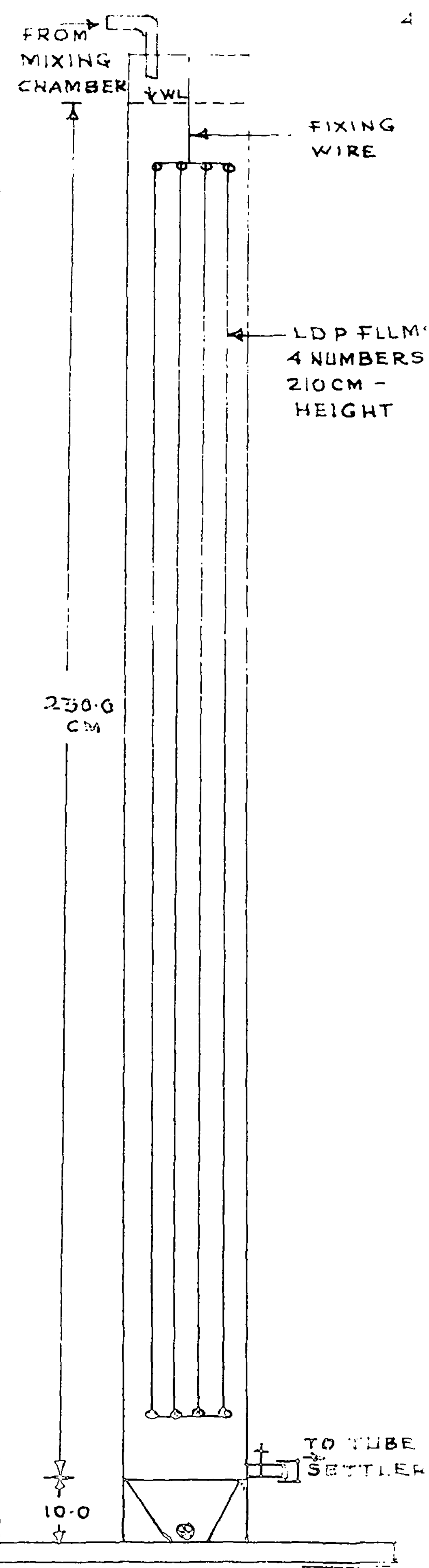


FIG. 4 - V
L.D.P. FILM
FLOCCULATOR

b) Hydraulic design of the flocculation unit.

i) Size of unit = 9.5 cm x 10 cm

ii) Surface area = 95 sq.cm.

iii) Depth of water = 230 cm.

iv) Volume of bed = 21850 ml.

v) Average dia of the tubes = 1.8 cm.

vi) Thickness of tubes = 1 mm

vii) Number of PVC tubes 9 x 4 = 36

viii) Length of tubes = 30 cm .

ix) Surface area of tubes $= 36 \times 2 \times 30 \times \pi \times d$

$$= 36 \times 2 \times 30 \times \pi \times 1.8$$

$$= 12250 \text{ cm}^2.$$

x) Surface loading on the flocculator = 10000 $l/m^2/hr$ for 1600 ml/min.

xi) Surface loading of tube surface area for 1600 ml/min. $= \frac{1600}{1.2250} \times \frac{60}{1000}$

$$= 78.5 \ l/m2/hr$$

say 80 $l/m^2/hr$.

xii) Detention period in min (neglecting tube material volume) $= \frac{21850}{1600} = 13.65$

say 13 min.

c) Pilot plant observations : Table 4-III-a shows observations on the two flow rates of 1600 and 800 ml/min. on the pilot plant, Table 4-III-b gives the comparative results for the general parameters of the study.

TABLE 4-III-a

Pilot plant observations with PVE tube double surface contact flocculator.

Hours of run.	Settled water 1600 ml/min.	Turbidity 800 ml/min.
0	-	-
1	20	20
2	20	20
3	20	20
4	20	20
5	20	18
6	18	16
7	18	15

TABLE 4-III-b

Comparative pilot plant observations.

	Parameters.	Flow rate 1600 ml/min.	Flow rate 800 ml/min
1.	Surface loading on flocculator in l/m2/hr	10,000	5000
2.	Surface loading on PVC tubes in $l/m^2/hr$	80	40
3.	Detention period in min.	13	26
4.	Raw water turbidity in JTU	100	100
5.	Settled water turbidity range	20	18
6.	Sludge removed from the flocculator in ml.	150	240
7.	Sludge removed from the tube settler in ml.	1260	850
8.	MPN of raw water	15000	110000
9.	MPN of settled water	4600	2400
10.	Bacteria. removed in pretreatment	70 %	97 %

d) Other general observations : There was no appreciable improvement when the loading was reduced by 50% on the flocculator.

4.4.4 LDP Film Flocculation Unit :

a) Pilot plant details : The details of the pilot plant unit are shown in the figure 4-V. In this pilot plant four low Density Polyethylene films of 210 cm length were placed in verticel position with clear spacing of about two cm between the films as shown in the figure 4-V. Thus in this pilot plant study both the surfaces of the films and the sides of the bed were in contact with the flowing water in the downward direction. Flocculated water from the bottom was introduced in to the bottom of the standard tube settler unit. Two sets of the observations were carried out, one with vertical film model and the other with slant films at four places.

b) Hydraulic design of the flocculation unit.

i) Size of the unit = 9.5 cm x 10 cm.

ii) Surface area of unit = 95 $cm.^2$

iii) Depth of the water = 230 cm.

iv) Volume of water = 21850 ml
(neglecting sheet volume)

v) Number of LDP films (sheets) = 4

vi) size of films = 10 cm x 210 cm.

vii) Surface area of sides of the films. = 4 x 2 x 10 x 210
= 16800 cm^2.

viii) Surface area of sides of the bed. = 4 x 9.5 x 210
= 7980 cm^2.

ix) Total surface area of contact = 24780 cm^2.

x) Surface loading on the flocculator for 1600 ml/min. $= \frac{1600 \times 100 \times 100 \times 60}{95 \times 1000}$

say 10,000 $l/m^2/hr$.

xi) Surface loading on the LDP films surface area for 1600 ml/min. $= \frac{96}{2.478}$

$= 38.75 \ l/m^2/hr$

xii) Detention period in min $= \frac{21850}{1600}$

$=$ 13.65 min.

$=$ say 13 min.

c) Pilot plant observations : Table 4-IV-a shows two sets of observations with the LDP films in vertical positions and the other in the slant positions at four places by suitable modifications. The purpose of study in slant position films was to see the improvement in the flocculation with this modification. Table 4-IV-b gives the comparative results for the general parameters of the study.

TABLE-4-IV-a

Pilot plant observations with LDP films flocculator.

Hours of run.	Settled water turbidity with vertical sheets.	Settled water turbidity with slant sheets.
0	-	-
1	30	30
2	30	30
3	30	25
4	20	25
5	20	25
6	20	20
7	20	20

TABLE 4-IV-b

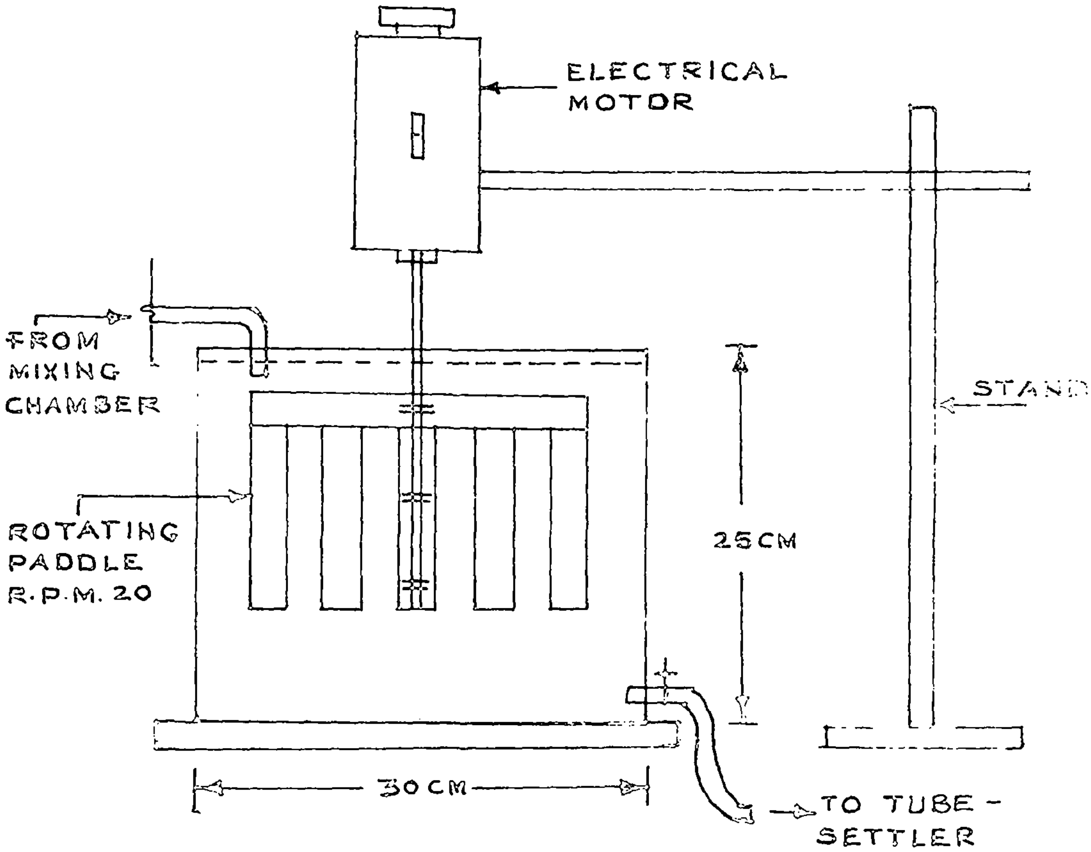
Comparative pilot plant observations.

Parameters.	Pilot plant with vertical sheets.	Pilot plant with slant sheets.
1. Surface loading on flocculator in $l/m^2/hr$.	10000	10000
2. Surface loading on LDP films in $l/m^2/hr$.	38.75	38.75
3. Detention period in min.	13	13
4. Raw water turbidity in JTU	100	100
5. Settled water turbidity range.	20 to 30	20 to 30
6. Sludge removed from the flocculator in ml.	210	350
7. Sludge removed from the tube settler in ml.	975	950
8. MPN of raw water	11000	24000
9. MPN of settled water	280	2400
10. Bacteria removal in pretreatment.	97 %	90 %

d) Other general observations : There was no marked improvement by placing the LDP films in slant position. This may be due to the short circulation of the flow from the outside space. Further, angle given to the sheets was about 10° within the available size, which might have been on the lower side.

4.4.5 Mechanical Flocculation Unit :

a) Pilot plant details : The details of the pilot plant unit are shown in the figure 4-VI. In this pilot plant one mechanical flocculation unit was provided before the tube settler unit. The purpose of this pilot plant observations was to compare the results



FLOCCULATION CHAMBER
(SIZE 30 x 30 x 25 CM)

FIG. 4-VI

MECHANICAL FLOCCULATION UNIT

with the other types of flocculators studied for the similar loading conditions.

b) Hydraulic design of the flocculation unit.

i) Size of unit = 30 x 30 x 25 cm.

ii) Water depth = 23 cm.

iii) Volume of water = 20700 ml

iv) Surface loading for 96 lit/hr. $= \frac{96 \times 100 \times 100}{30 \times 30}$

$= 1070\ l/m^2/hr.$

v) Detention period for 1600 ml/min. $= \frac{20700}{1600} = 12.93$ min.

= say 13 min.

vi) Surface area of paddles = 75 cm^2.

vii) Percentage of paddle area with cross sectional area of unit. = 10 %

viii) Speed of paddle = 17 to 20 rpm.

c) Pilot plant observations : Tables 4-V-a and 4-V-b showing the results on the pilot plant with mechanical flocculation unit are given below.

TABLE 4-V-a

Pilot plant obserfations with mechanical flocculator.

Hours of run.	Settled water turbidity for flow rate of 1600 cc/min.
0	-
1	15
2	15
3	10
4	10
5	10
6	10
7	10

TABLE 4-V-b

Pilot plant observations.

Parameters.	Observations for flow rate of 1600 ml/min.
1. Surface loading in $l/m^2/hr$.	1070
2. Detention period in min	13
3. Raw water turbidity in JTU.	100
4. Settled water turbidity range	10 to 15
5. Sludge removed from the flocculator.	Negligible.
6. Sludge removed from the tube settler in ml.	2050
7. MPN of raw water	2900
8. MPN of settled water	150
9. Bacteria removed in pretreatment	95 %

d) Other general observations : Results were superior to the results of all the other pilot flocculation units.

4.4.6 Pilot plant Study without Flocculation Unit :

a) Purpose : After conducting the pilot plant studies with different pilot plant flocculation units the author carried out the pilot plant observations without flocculation unit. Thus in this pilot plant study raw water from the mixing chamber was directly introduced through the bottom of the standard tube settler unit. The purpose of this study was to compare the results of the pretreatment with different pilot flocculation units and without flocculation unit.

b) Pilot plant observations : Table 4-VI-a and 4-VI-b, showing the results of the pilot plant study with only mechanical mixing followed by tube settler are given below.

TABLE 4-VI-a

Pilot plant observations without flocculation unit.

Hours of run.	Settled water turbidity for flow of 1500 ml/unit.
0	-
1	50
2	60
3	70
4	50
5	50
6	50
7	30

TABLE 4-VI-b

Pilot plant observations without flocculation unit.

	Parameters.	Observations for flow rate 1600 ml/min.
1.	Detention period in mechanical mixing chamber.	One min.
2.	Raw water turbidity in JTU.	100
3.	Settled water turbidity range	50 to 70
4.	Sludge removed from the tube settler in c.c.	760
5.	MPN of raw water	11000
6.	MPN of settled water	2400
7.	Bacteria removed in pretreatment	78 %.

d) General other observations : Settled water turbidity started showing improvement after 6 hours. This may be due to the formation of some floc blanket below the tube settler zone as it was observed. This improvement in the slight turbidity removal may be due to the action of tube settler zone, which also creates some flocculation action.

4.5 DISCUSSION ON THE PILOT PLANT FLOCCULATION STUDIES.

a) Background :

As discussed earlier in details there was great need in the development of non mechanical type, simple flocculation units and the gravel bed flocculation units have been specially developed to replace the mechanical flocculation units particularly for the small capacity water treatment plants. The plant scale results at Ramtek, Varangaon and other places as discussed in chapter No.7,9,10 and 11 show that gravel bed units can replace the mechanical flocculation units for small capacity plants.

b) Limitations of the gravel bed flocculation units :

Even though the gravel bed flocculation units can replace the mechanical flocculation units, there are some limitations in the adoption of the gravel bed flocculation units. The basic limitation,is,that the gravel bed flocculation is not a continuously operated unit as there is accumulation of sludge in the bed, and hence it has to be cleaned by routine gravity deflushing and occasional backwashing of the bed as discussed earlier. Due to this limitation the unit has to be cleaned periodically as in the case of a filter unit. Further some settled or filtered water has to be used for cleaning the gravel bed flocculation unit. In the case of Ramtek and Chandori plants,there is adequate settled water storage capacity on the top of the gravel bed, which can be utilised for deflushing and cleaning the gravel beds. However, in the case of Varangaon treatment plant, the raw water storage on the top of the gravel bed is not adequate to clean the bed. Therefore during high turbidity load, the deflushing operation has to be done by refilling the bed for 2 to 3 times as required or by giving a backwash to the bed. However by adopting this cleaning procedure there is no difficulty in cleaning the bed.

c) Development of non-mechanical and continuously operated simple flocculators :

After developing the gravel bed flocculation units at Varangaon and considering the above mentioned limitations in its adoption, the author felt the need for the development of non-mechanical and continuously operated simple flocculation units for adoption in the small as well as medium capacity water treatment plants.

In fact, after studying in details the new processes of flocculation, clarification and filtration, at the end of this study, the author found the urgent need for the development of non-mechanical and continuously operated simplified flocculation units. With the background of the on-plant study of the gravel bed flocculation units, the author developed some new ideas for the design of such non-mechanical and continuous type flocculation processes. Even though these new ideas were developed practically at the end of the present study, the author proposes to discuss these along with the pilot plant study on the same in this chapter. The pilot plant studies as discussed in this chapter have **not** been carried out in great details as the aim was to find out the possibility of developing such non-mechanical and continuous type flocculation units.

d) Pilot plant study on different flocculation processes :

The author has therefore, carried out the pilot plant studies on the below mentioned flocculation processes in this chapter, so as to compare the performances and limitations in all these flocculation processes.

i) Gravel bed flocculation units.

ii) PVC tubes external surface contact flocculation unit.

iii) PVC tubes double surface contact flocculation unit.

iv) LDP film flocculation unit.

v) Mechanical flocculation unit.

The observations on the pilot plant study as given earlier in this chapter are discussed below

4.5.1 Gravel Bed Flocculation Unit :

The observations on the pilot plant study on the gravel bed flocculation units are discussed in details in the chapters 6,8, and 10 of this thesis. It is now proposed to compare the pilot plant observations on the gravel bed flocculation units as adopted in the three pretreatment processes in Ramtek,Chandori and Varangaon plants.

i) Ramtek and Chandori treatment processes : The comparative pilot plant observations on the above mentioned two processes are given in the Table4-I. In the Ramtek and Chandori treatment processes the gravel bed flocculation is a part of the pretreatment units provided in both these plants. The direction of flow is in the upward direction so as to utilize the upper portion on the gravel beds for settlement action. Separate settling tank is not provided in both these units. Thus the gravel beds are not adopted as independent flocculation units as in the case of Varangaon treatment plant. There are some limitations in providing gravel bed in the pretreatment units at Ramtek and Chandori which are fully discussed in the chapters 6,7, and 10.

ii) Varangaon treatment process : The gravel bed unit in the Varangaon plant is provided as a separate flocculation unit before a tube settler unit. From the comparative observations as shown in the Table 4-I, it can be seen that the performance of the pretreatment unit in Varangaon plant even for high surface loading is found superior. For the treatment of highly turbid water sources the pretreatment process consisting of gravel bed flocculation unit followed by tube settler unit is found to be more stable and simple and hence it can be recommended for the treatment of turbid water sources. The comparative study is therefore discussed of gravel bed flocculation unit of Varangaon plant along with the pilot plant observations of the other flocculation processes in this chapter.

iii) General comparative observations : In order to compare the different flocculation efficiencies, a pilot plant study without a flocculation unit has been carried out for a baseline data, as given in the Table 4-VI-b. Further the observations on the conventional type of mechanical pilot flocculation plant are given in the Table 4-V-b, to compare the results of these flocculation processes. From the general observations on the Varangaon pilot plant as given in the Table 4-I, it can be seen that the gravel bed flocculation unit has given just comparable observations with that of mechanical flocculation unit. The author has therefore adopted the gravel bed flocculation unit in place of the mechanical flocculation unit to simplify the new treatment plant at Varangaon, for the treatment of turbid water sources. The author has then proposed similar designs for a number of small capacity water treatment plants in the Maharashtra State as discussed in the chapter 11.

4.5.2 PVC Tube External Surface Contact Flocculation Unit :

i) From the general pilot plant observations as given in the Table 4-II-b, it is seen that the results are comparatively of lower level, in turbidity removal. However for lower loading rate and particularly for the surface loading of about 40 $l/m^2/hr$ and detention period of 6 to 10 min this flocculator may show similar efficiency to those of mechanical and gravel bed flocculation units as discussed above.

ii) Prototype applications : Even though the PVC tubes of 2 cm dia were adopted in this pilot plant study, in a prototype plant it may be desirable to use RCC or asbestos cement pipes in alternate layers and in the crosswise directions, one layer of pipes over the other with desired clear spacings between the pipes. As the surface of cement pipes is not as smooth as PVC tubes, the rough surface may give better surface contact for the formation of flocs. In such a flocculation bed pipes may not require side supports, as the pipe layers will rest one over other. At the bottom however perforated supporting bed will be necessary. Further the bed will have hoppper bottom as provided for Varangaon gravel bed flocculator. This tube flocculator will not need washing of the bed as in the case of the gravel bed flocculator. With the approximate design factors of 10 min. effective detention period and the surface loading of about 40 to 50 $l/m^2/hr$ of pipes external surface the settled water turbidity after tube settler unit may be within 20 JTU.

4.5.3 PVC Tube Double Surface Contact Flocculation Unit :

i) From the general pilot plant observations as given in the Table 4-III-b, it is seen that the settled water turbidity is within 20 JTU for both the loading rates. Thus the flocculation action is considerably better than the PVC tube external surface contact flocculation, even though the contact surface area is about some (12250 cm^2). Thus the PVC tube double surface contact flocculation with surface loading of 80 $l/m^2/hr$ and the detention period of about 13 minutes may give the settled water turbidity below 20 JTU, and which fairly compare with the results of the mechanical and gravel bed flocculation units as discussed earlier.

ii) Prototype applications : Even though the PVC tubes of 1.8 cm dia were adopted in the pilot plant study, in a prototype plant it may be desirable to adopt PVC tubes of 63 to 100 mm dia. to be provided suitably in the flocculation beds. This tube flocculator will not need cleaning like gravel bed, however at the bottom, hopper may be necessary with sludge removal arrangements.

The action in the tube flocculation may be increased if the tubes will be provided in slant positions with 30° to 40° angle. Further modules of PVC tubes similar to that in the tube settler can also be adopted, which will cost more than the PVC tube double surface contact flocculator as discussed above. The velocity through the bed may be one of the criteria for effective flocculation action.

4.5.4 LDP Film Contact Flocculation Unit :

i) From the general pilot plant observations as given in the Table 4-IV-b, it is seen that the results are just comparable with the results of the gravel bed flocculation unit for the same loading rate. As compared to the mechanical flocculation unit the results are of little lower efficiency as seen from the settled water turbidity removal. The author has therefore, carried out second set of experiment with the films in the slant positions at four places by making suitable modifications. The approximate angle of slant films to the vertical was 10°. With this arrangements it was presumed that the flocculation action may be accelerated, on the basis of the experience on the tube settler. However the pilot plant results did not show any appreciable improvement as compared to the results of the vertical film flocculation. The author feels that the reasons for this lower efficiency than the expected one of the slant film flocculation, may be due to the short circulation of some raw water from the sides of the films due to imperfect modifications.

The author is therefore of the opinion that the slant film flocculation with angle between 20° to 30° with the vertical may give equal efficiency with that of a mechanical flocculation for the same detention period.

ii) Prototype applications : The author predicts that if the detention period is kept between 15 to 20 minutes and the film area is provided for a surface loading of 40 to 50 $l/m^2/hr$ and the films are provided with about 30° angle with the vertical, the flocculation unit may give similar results to that of a mechanical flocculation unit, when it will be followed by a tube settler unit. Thus it may be possible to adopt a non-mechanical and continuous type of flocculation unit, not only in the simplified treatment plants, but also in the conventional treatment plants. The author feels that the LDP films may be a suitable cheap material for such film flocculation unit, however the life of the LDP sheets may have to be found out from the prototype studies. The fixing of films in the required slant positions in the flocculation unit may be a simple job.

4.6 GENERAL COMPARISON.

The observations on the mechanical flocculation unit with the detention period of 13 minutes, showed the superior results in the turbidity removal as compared to the results of the other non mechanical type pilot plants as discussed earlier in this chapter. The purpose of carrying out the comparative study with the mechanical flocculation unit was to search out if the non-mechanical flocculation units can be developed of equal or of little lower efficiency which can be utilised in the simplified treatment plants.

The main reason for carrying out this search, is to reduce the capital as well as maintenance cost of a flocculation unit for the small capacity plants. With the adoption of non-mechanical flocculation units as discussed earlier, the author feels that the capital cost may be equal or little less to that of a mechanical flocculation unit, but the maintenance cost may be practically nil , except the gravel bed flocculation unit, as there will be no power consumption, and the maintenance and repairs of the mechanical paddels etc, which is a must in the case of a mechanical flocculation unit. Further there will be considerable simplicity in the design and construction of the non-mechanical type flocculation units, and such flocculators can be constructed even at village level.

Apart from the maintenance cost of power, it has been experienced from the study of the existing small capacity plants that the proper maintenance of such units is difficult at the village level and at many places the author has seen that the mechanical flocculators are out of order for long times, for want of easy facility of repairs. At such situations the performance of the pretreatment is suffered considerably and there is additional load on the filter beds, with the results of poor effluent quality of filtered water and dissatisfaction of the consumers. Even when there is power failure or shut-off for short periods, which is a normal case at many rural places, in the developing countries, the plant performance is likely to be severely affected as explained above.

The author is therefore of the openion that the non-mechanical type of flocculation units, particularly the gravel bed flocculation unit and the PVC tube double surface contact flocculation units and the LDP film contact flocculation units as discussed in this chapter, may be equally efficient as that of a mechanical flocculation unit and may replace the mechanical flocculation units in the small capacity treatment plants. The operation of such non-mechanical flocculation units is considerably simpler than that of a mechanical flocculation unit. The non-mechanical and the continuous type flocculation units, as mentioned above may also be adopted in the bigger capacity continuously operated simplified as well as conventional water treatment plants. However further on plant research may be necessary for fixing the design criterias for such new flocculation units.

4.7 PROTOTYPE APPLICATIONS.

As the author has developed the idea of gravel bed flocculation units at the beginning of this study, he has adopted the gravel bed flocculation units in all the three simplified treatment plants developed in this thesis. The new ideas on the non-mechanical and continuous type flocculation units were developed practically at the end of this study. The author therefore could not put these new ideas in the prototype plants, so as to include the actual plant scale results in this thesis.

However the author has proposed a few designs for simplified treatment plants units with the non-mechanical and continuous type of flocculation units for a few rural water supply schemes near the Nasik City. Further the author has proposed a non-mechanical and continuous flow flocculation units based on the principal of tapered flocculation for the augmentation of the Nasik Road Water Works capacity from the existing 9 mld to 27 mld capacity. In this augmentation proposals it is proposed to convert the existing mild steel circular settling tanks in to the non-mechanical flocculation units followed by tube settler tanks, while the existing three rapid sand filters are proposed to be converted into the dual media filter beds. The work is in progress.

All the above mentioned new works are situated near about the Maharashtra Engineering Research Institute, at Nasik where the author is working at present and the plant scale results on these plants are likely to be available within one year.

The author is of the opinion that after the successful plant scale results, as stated above, these non-mechanical and continuous type flocculation units may be adopted on the mass-scale particularly for the small capacity water treatment plants.

4.8 GENERAL CONCLUSIONS.

i) The gravel bed flocculation units can be equally efficient to the mechanical flocculation units, when the tube settler is followed for clarification of water.

ii) It may be possible to adopt non-mechanical and continuous type flocculation units, viz. the PVC tube double surface contact flocculation unit and the LDP film contact flocculation units, for the design of the simplified as well as conventional water treatment plants.

iii) The three non-mechanical type flocculation units as mentioned above, may be cheaper in capital as well as maintenance cost as compared to the mechanical flocculatinn unit, as such these can replace the mechanical flocculation units for the small capacity water treatment plants.

iv) The plant performance with a mechanical flocculation unit, is likely to be severely affected either when the unit is under repairs, or when there is power shut-off for some time.

v) The plant performance of the small capacity water treatment plants, where non-mechanical type of flocculation units are adopted will give uniform, performance due to non-dependence on power supply.

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CHAPTER 5

SEARCH FOR THE NEW FILTER MEDIA.

5.1 NEED FOR SEARCH FOR THE NEW FILTER MEDIA.

The principle of dual and multimedia filters for high rate filtration is now well accepted and references for its design as well as plant performances are now available in the literature. Huisman (15) has explained the advantages of adopting dual and multimedia filter beds. Regarding the availability and selection of suitable media he states "the greatest difficulty however, is the selection of suitable filtering materials, sand offers no difficulty and also garnet gives excellent results, but its price is very high. Anthracite is not only fairly expensive, but it is also very difficult to obtain a uniform grade with an adequate weir resistance and a satisfactory length of useful life. Plastic would seem a logical choice but prices will be in U.S. $ 250/- per m^3 range, that is 15 times as expensive as the best quality filter sand. Now a days artificial anthracite (powdered, baked and broken) is on the market and although practical experience is still scarce, the outlook is promising" .

He further states, "provided that skilled supervision is constantly available, coarse to fine filtration offers enormous advantages of higher filter rates and the same or better effluent quantity and equal or longer filter runs. It also allows the filtration of a more turbid water, widening the choice of raw waters fit for transforming into a good quality drinking water and in many cases it does away with the necessity of pretreatment. Whether upflow filtration and cheap and easy to obtain filtering material must be preferred to the more stable multilayered down flow filtration and the difficulties and expenses of obtaining suitable filtering material is still difficult to say. In any case the loss in safety factor makes desk top designs impossible, and good results are now only possible on the basis of data gathered by running a pilot plant for an extended period of time".

Ives in his two papers "Theory of filtration" and "Problems in Filtration" has also discussed the various aspects of dual and multimedia filter beds and the problems in the selection of the suitable media. In the second paper he has given the criteria for the selection of the suitable media for different filter beds.

The author has undertaken the study for finding the new and cheaper filter media for dual and multimedia filter beds mainly because of the urgent need of research as expressed by Huisman and Ives in their papers as discussed above.

The author is happy to state that he had taken this study since 1971 and could successfully develop a new filter media of crushed coconut shell, which he has used for the first time in the Ramtek filter bed and then at Varangaon filter beds as explained in the chapters 7 and 9 of this thesis.

5.2 EXPERIMENTS WITH NEW FILTER MEDIA.

In the study of finding new filter media the author has studied the below mentioned materials for developing new filter media.

i) Crushed coconut shell.

ii) Bituminous coals from five different coliaries.

iii) Fused concrete.

iv) Fused bricks.

Laboratory studies were conducted to find out the suitability of these media for dual and multimedia filtration. Pilot plant experiments were also conducted with some selected media for single, two layer and three layer filter beds for different rates of filtration, and the results of these experiments are included in this chapter. The above mentioned materials have been particularly selected for the comparative study as these materials may be available in the required quantities and may be reasonably cheap for filtration purpose in this country. The PVC granular material of the required size may be one of the suitable material, but its cost is simply exhorbitant and hence such materials were not included in the study.

5.3 TESTS FOR MEDIA SELECTION.

Following important tests were conducted as discussed by Ives (20) in his paper "Problems in Filtration". The results of these tests are given in the Table 5-I.

i) Microscopic test : Under low power (about 20 to 40 times) the media was examined by transmitted and reflected light. Qualitative assessment of shape, roughness, durability, staining was made. Though the microscopic examination is not definitive, it gives some useful observations.

ii) Solubility test : Loss in weight of material was measured in 20% Hcl after immersion for 24 hours. This is one of the important tests for selecting the media.

iii) Durability test : Extended backwashing for 100 hours was carried out to find out the loss of weight. It is presumed that the durability assessed by this test is equivalent of 2 years of working of the media. This shows the resistance to attrition and may be a very important test for selection of the media.

iv) Density test : This was found out by standard density bottle. However because of the micropores the media was thoroughly soaked for 20 hours before carrying out the test. This is a very important test in selecting the media for different filters.

v) Water absorption : Percentage of water absorbed in the dry media was found out by weight basis. For this the media was kept soaked in water for 24 hours and extra water over surface was removed by putting in a filter paper. The ratio of the water absorbed over the dry weight of media gives the water absorption.

vi) Settlement : A uniform sieved size of 1 and 1.5 mm fractions were allowed to settle grain by grain through one metre deep column of water. The settling velocity of upper layer in multiple layer beds should be lower than that of a layer below and this can be ascertained by this test.

vii) Sphericity test : How angular grain is can not be readily defined from geometric measurements so that it has meaning from a hydraulic point of view. For rounded sand it is about 0.85 and for anthracite it is about 0.7. This test was not conducted as this may be not so important for the selection of the media.

viii) Percentage utilisation of the material : This is one of the important test from the point of its economical use for adopting in the dual and multimedia filtration. All the materials were crushed thorough disintegrator with two moving hammers at about 3000 rpm. for comparative study. After crushing all the materials, it was sieved through 2.0 mm and 0.85 mm opening brass sieves. The top coarser media, the next media between 2.0 to 0.85 size and the finer material were collected separately and weights were found out. The percentage availability was found out from the ratio of weight of media size 2.0 to 0.85 and total weight of material passing from 2 mm size sieve. The top coarser material can be again crushed and utilised in the same procedure. The results are shown in the Table 5-II.

TABLE 5-I

Laboratory tests on the different coarse media under study between sieve sizes 2 to 00.85 mm

Media No.	Particulars of media	Specific gravity.	Solubility in 20% HCL by percentage.	Water absorption by %	Settlement rate in water in sec/m	Durability by loss in weight after 100 hr. back wash test in %.
1	Bituminous coal	1.435	2.28	46.6	16.33	2.50
2	-do-	1.38	1.65	49.0	17.28	2.45
3	-do-	1.44	1.99	49.6	15.75	2.10
4	-do-	1.42	3.05	46.8	18.95	2.15
5.	-do-	1.406	1.88	41.6	16.55	2.00
6	Crushed coconut shell.	1.428	0.69	71.0	15.90	2.55
7	Fused concrete	1.765	56.17	94.0	12.65	46.5
8	Fused Brick	2.385	3.13	29.0	6.95	1.50

TABLE 5-II

Percentage utility of different material for coarse media of size 2.0 to 0.85 mm

Media No.	Particulars of media.	Effective size in mm.	Uniformity co-efficient.	Total weight crushed in kg.	Wt. of material retained on 2 mm sieve. (A)	Wt. of material between sieves 2 mm & 0.85 mm openings. (B)	Wt. of material passing from 0.85 mm sieve. (C)	Weight of B+C	% utilisation of the material $\left(\frac{B}{B+C}\right)100$
1.	Bituminous coal.	0.68	1.54	32.35	1.06	5.80	25.49	31.29	18.52
2.	- do -	0.80	1.50	19.08	0.93	3.81	14.34	18.15	21.00
3.	- do -	0.80	1.40	23.14	0.63	3.02	19.49	22.51	13.40
4.	- do -	0.80	1.42	28.44	2.02	5.13	21.29	26.42	19.40
5.	- do -	0.82	1.40	16.83	0.58	2.44	13.81	16.25	15.00
6.	Crushed coconut shell.	0.90	1.39	16.15	6.19	4.83	5.13	9.96	48.50
7.	Fused concrete.	0.45	1.78	12.65	0.19	1.21	11.25	12.46	9.72
8.	Fused Brick	0.63	1.56	37.26	0.97	5.51	30.78	36.29	15.20

5.4 SELECTION OF THE SUITABLE MEDIA FOR DUAL AND MIXED MEDIA FILTER BEDS.

5.4.1 General Comparison :

From the results given in the Tables 5-I and 5-II it can be seen that the bituminous coals and the crushed coconut shell material have near about similar qualities while the fused concrete and fused brick material have considerably different qualities. The fused concrete material even though has got specific gravity of 1.765, its solubility is 56.17% and hence this material is out of consideration for use for filtration purpose.

The fused brick material has got high specific gravity of 2.385 with high settlement rate which is just near to sand, and hence this material is also not suitable for use as a coarse media in a dual media filter bed. However as the solubility is within permissible limit of 5% and it is lighter than the sand media, it may be useful for adoption in a mixed media filter bed. The author has therefore, carried out some pilot plant studies by using this material in the mixed media filter bed comprising coconut shell, fused brick and sand media, as discussed later in this chapter under mixed media study.

Thus the main comparison is between the bituminous coals and the crushed coconut shell media for adoption in a dual media filter bed.

5.4.2 Comparison between Bituminous Coals and Crushed Coconut Shell as Coarse Filter Media :

i) It can be seen that the specific gravity of the bituminous coals vary between 1.38 to 1.44, while for coconut shell the specific gravity is 1.428. However from the solubility test it is seen that the solubility varies between 1.88 to 3.05, whereas the solubility of the coconut shell is only 0.69, which is one of the important test for the comparison. The settlement tests also show that the results are more or less in the same range.

ii) The water absorption test is generally not considered for comparison. However the test shows that the water absorption in the bituminous coals is in the range of 41 to 49% whereas for coconut shell it is 71%. It is difficult to explain the reasons for this discripancy, even though the specific gravity is about same. The reason for this wide gap may be that the coconut shell material readily absorbs the water in the fine porous structure of the material, while the coal structure is not a uniformly porous as that of coconut shell and further there may be some water repellent action by the chemical constituents of the coal. Due to this effect some fine pores in the coals may not be filled up with water and thus during back wash there is a tendency to overflow above the gutters for this material particularly when air bubbles accompany during backwashing.

iii) The microscopic tests for the coals and coconut shell and fused brick materials in dry condition give the following information.

a) Bituminous coals :

Shape : Longtudinal, rounded, triangular piece

Colour : dark black.

Internal structure with reflected light : slightly transparent, irregular shape cells are present, crystaline irregular shape, solid surface contact with angle.

b) Crushed coconut shell.

Shape : Rectangular, triangular shape,particles.

Colour : Brownish and yellowish colour in dry condition, but turns to dark brown and blackish when soaked with water.

Internal structure with reflected light : slightly transparent, longitudinal cells present in layers, solid surface contact with angle.

c) Fused brick.

Shape : Longitudinal, and rounded particals.

Colour : Redish, black colour.

Internal structure, slightly transparent,cellular type structure with vacuum.

5.4.3 Percentage Utility Test :

The percentage utility tests as given in the Table 5-II are of great interest. This test is generally not carried out in the standard procedure for selection of the media. However the author feels that this is the most important single test for the selection of the coarse media for dual and multi-media filter beds. The author has adopted the "Disintegrator machine with 10 H.P. motor" for crushing of all these materials for the preparation of the required size media,between sieve openings 2 and 0.85 mm. Two hammers are rotated at the speed of about 3000 rpm above the mild steel screen with 4 mm openings, placed in the half round bottom position. The crushed material was collected from the bottom of the screen and was sieved to get required size media.

From the results given in the Table 5-II it can be seen that the utility of crushed coconut shell media (between 2 to 0.85 mm) is about 50% where as all other media show the utility below 20%. The author has not conducted the Mohs Hardness test, which may perhaps be taken for knowing the toughness of the material to resist the wear and tear action during the back wash of the material. This test may indirectly show the life of the material for the use in the filter bed. The anthracite media may not show much difference in this test from that of bituminous coals. Thus the crushed coconut shell media may be far superior in this important test as compared to the coals and anthracite media being utilised at present in this field.

This test is further directly related to the cost of the media as the percentage utility of the crushed coconut shell media is about 2 1/2 times higher than the coal media.

5.4.4 Use of Crushed coconut Shell Media in the Present Study :

From the above discussions it can be seen that the crushed coconut shell media is superior in almost all respects to the coal media. The author has adopted therefore the crushed coconut shell media in all the simplified treatment units in which dual media filter beds have been adopted as discussed in the chapters 7,9, and 10. Results of the pilot plant performances as well as actual plant performances by the use of crushed coconut shell media are discussed in details in the respective chapters in this thesis.

The crushed coconut shell media was adopted for the first time, in the dual media filter beds in the Ramtek treatment plant in the year 1973. The media in the Ramtek filter bed was then periodically examined, which showed no deterioration or any other bad effects, after the use of the media or about six years. It is felt that this media may have a life for more than ten to fifteen years. However the actual plant performances will now show the results in this respect.

5.4.5 Additional Advantages with the Use of Crushed Coconut Shell Media :

i) Uniform quality : One of the very important point with the coconut shell media is its uniform quality. In this respect the specific gravity of any coconut shell is in the range of 1.35 to 1.45 in wet condition, while in the case of bituminous coals and anthracites there is considerable variation of quality, mainly due to the variation in the specific gravity of the materials. Thus there is no problem of selection of the coconut shell materials as in the cases of coals and anthracite - materials.

ii) Cost of the coarse crushed coconut shell media : The fine crushed material below 1 mm size which is not useful for the dual media filter bed can be useful, as filler material in the plastic and bacalite materials for manufacturing various articles for use. The market rate of this fine filler material is actually more than the coarsesize material required for the dual media filter bed. Thus the cost of the coarse media is actually reduced due to this use as there is no waste of crushed material. The present market price (1978) for coarse media of size between 1 to 2 mm was quoted as Rs. 800/- per m^3. There is possibility of reduction of this rate if the market demand is increased for this media as there will be more competition. Further the cost of crushing and sieving can also be reduced by developing suitable capacity mechanical equipments. Thus the cost of the media may be about 3 times the cost of the fine sand and may be cheaper than any other coarse media of equivalent quality for the use in the dual media filter bed. Further the fine media of coconut shell with effective size of 0.5 mm and u.c. below 1.5 may have some more advantages as compared to the fine sand media in a rapid sand filter as discussed latter in this chapter. The author therefore feels that the crushed coconut shell media is likely to be a popular media for the use in dual and multimedia filter beds in the near future.

5.4.6 Coconut Plant its Availability and Uses :

The coconut plants are cultivated in most of the tropical countries. If the total cultivation in the world is considered then Philipines grows 26% which is the highest, while the Indonesia grows 19% and the India 18%. The total area under cultivation is about 1.1 m hectors and the present annual production is about 6000 million nuts. The industry provides employment to over 10 million people.

Among the cultivated plants of the world, the coconut is the most versatile. It grows upto a height of 25 metres and lives up to 100 years. Its solid trunk is 30 to 40 cm in dia and is marked by ring like leaf scars. Its botanical name is cocus Nucofera and it belong to Palmac family and covers under the group of flowering plants monocotyledons. It is known as nasikera in Sanskrit, nariyal in Hindi, tenkaro in Talgu and thenguin in Malayalam.

The productivity is measured in terms of yield per hector and non-bearing plants are also included in this computation. In India, Kerala State grows 90% of the country's total production of coconuts, and during the past ten years, the area under the crop has increased by 100%. In Tamilnadu State, the crop is regularly irrigated while in Kerala it is mostly rainfed. The density of planting is yet another factor. There are about 225 plants per hector in Kerala. There is no known tree which gives as continuous a return as the coconut. After every 30 to 40 days the grower can harvest a bunch. Every year the farmer is assured of 80-100 nuts per tree worth of Rs. 100/-. Large scale cultivation of the crops gives an annual income of about Rs. 5000/- per hector, under the rainfed conditions. The average yield per hector in Kerala is about 5000 nuts lower than the all India average of 5,344. The yield in the Tamilnadu and Karnataka State are 8,785 and 5,408 respectively.

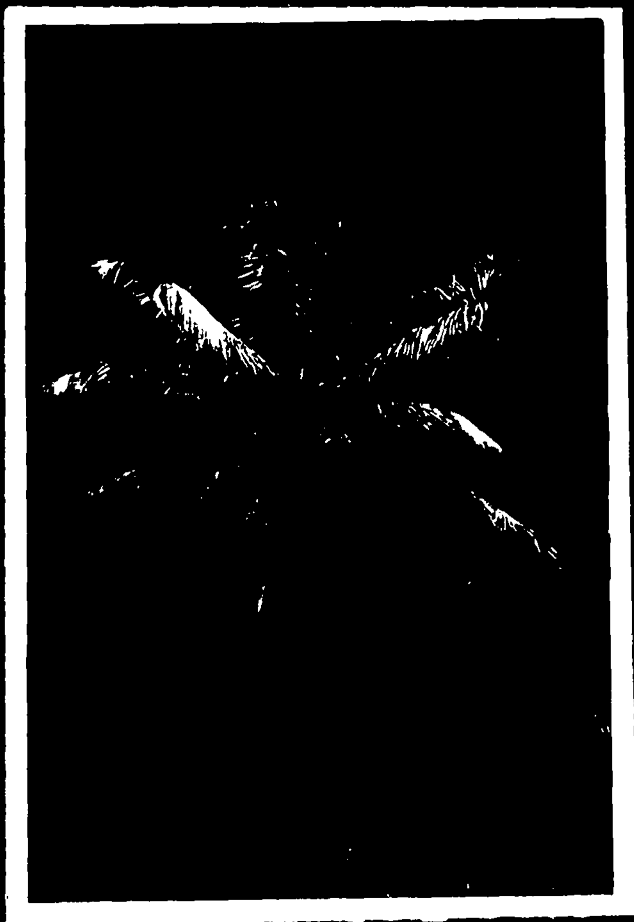
The coconut ranks first among the oil yielding crops of the world, follwed by ground nuts, cotton, sesame and oil palm. More than half the total world production of nuts goes in supporting a great bulk of humanity at the subsistance level. The reminder is processed in-to oil, oil cake, charcoal and coir. Each one of these is put to further use in a wide range of manufactured products for human or animal consumption and the manufacture of the industrial products, Kerala is believed to derive its name from Kera meaning the coconut. The State is deservedly known as the land of coconuts. Most of its scenic beauty owes to its palm fringed lagoons.

Every part of the coconut palm is put to some use. The trunk of a matured tree is used to build houses and the fronds are matted to thatch roofs. The juice extracted from the inflorascences is converted into Jaggery, Sugar, Vinegar and Sweet or fermented toddy. The Coir is produced from the outer husk of the coconut and it is one of the foreign exchange item. The shell is hard and can take up high polish and it lends itself to variety of handicrafts. However the shell is mainly used as fuel, which is indirectly a waste.

With the proposed use of crushed coconut shell as a coarse media for the dual and multimedia filter beds as developed in this thesis the author feels that the only waste material part of the coconut shell will now be utilized as a valuable filter media for high rate filtration and thus the present utility of coconut will still be increased.

Thus the coconut palm is rightly called the "Kalparriksha" the tree of heaven or the wish-tree. The coconut is indispensible to most Hindu ceremonies.

PHOTOPLATE 5-I



COCONUT TREE
The mother plant of the coconut shell media.

Coconuts are given to guests as an auspicious present. They are broken in thousands before the immages of Ganapati and other gods as a part of worship. But the author feels that the use of coconut shell media for filteration may be the most valuable gift of the nature to the mankind.

5.5 PILOT PLANT STUDY.

In this chapter it is also proposed to discuss the pilot plant observations as well as comparative performances of the different pilot filter units. This pilot plant study has been conducted mainly on the below mentioned three important techniques in the filtration.

i) Single media filtration.

ii) Dual media filtration.

iii) Mixed media filtration.

For the study of these techniques two pilot filter units approximately of the same dimentions were fabricated and the figure 5-I showing the details of the pilot plant set up is enclosed at the end of this chapter. The approach for the pilot plant study and the experimental observations on each of these filtration techniques are discussed latter in this chapter.

5.5.1 Design of Common aspects for the Pilot plant Study :

The comparative performance study was carried out on the various pilot filtration units for the below mentioned common aspects.

i) Raw water supply of constant turbidity of 20 JTU : The raw water turbidity was adjusted to 20 JTU ~~by mixing with fine silt at the canal bed in the tap~~

by mixing with fine silt at the canal bed in the tap water supply as required. The constant turbidity (20 JTU) water was then pumped to a small balancing tank of 30 litre capacity as and when required by operating the pump.

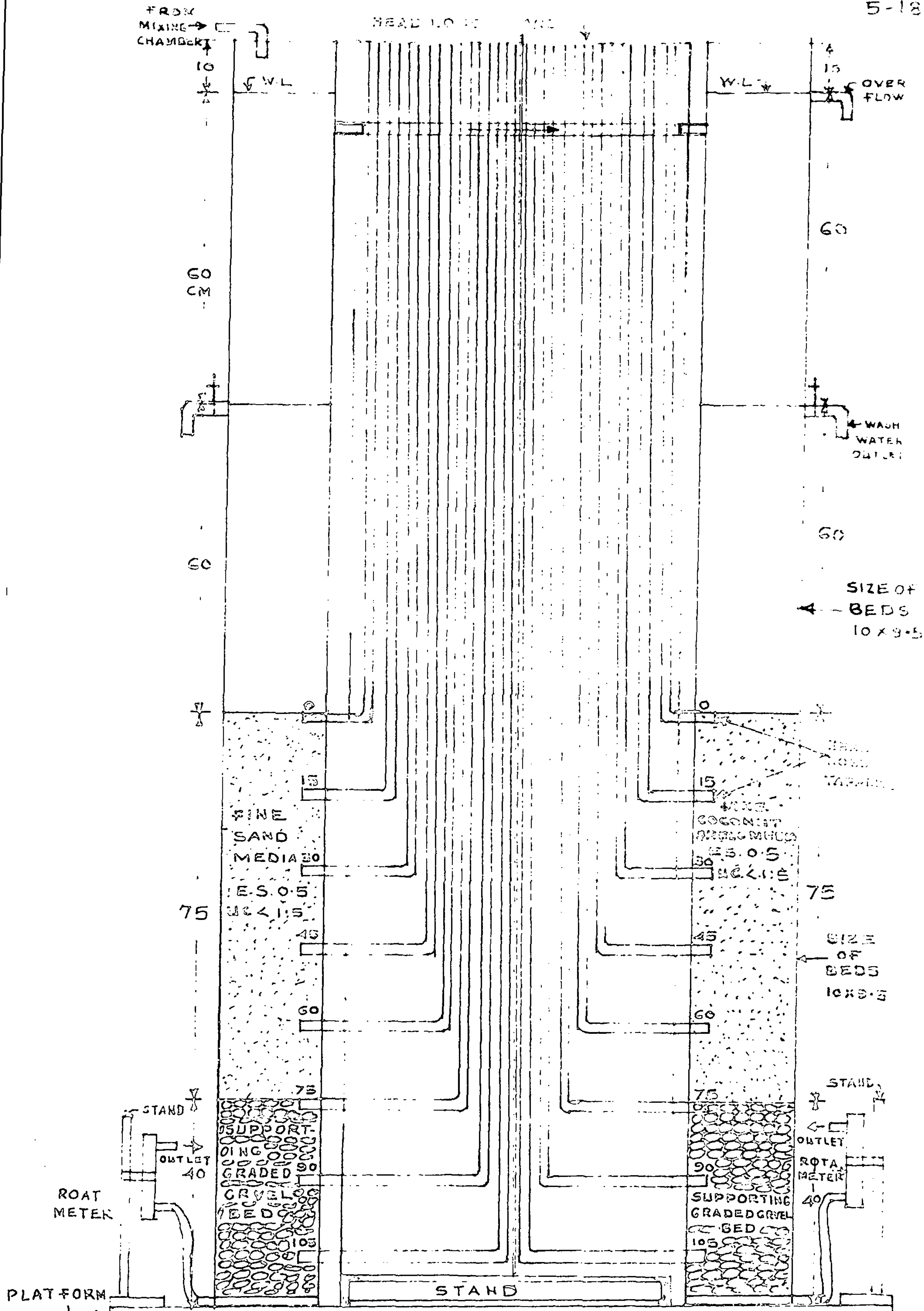
ii) Constant raw water flow arrangement : The arrangements were kept same as explained in the chapter 4.

iii) Chemical mixing and dosing arrangements : These were also kept same as explained in the chapter 4.

iv) Flow rates for the pilot plant study : The pilot plant study was conducted for three filtration rates viz. (a) 5000 $l/m^2/hr$ (b) 7500 $l/m^2/hr$ (c) 10000 $l/m^2/hr$. The corresponding three flow rates were adjusted per minute for each pilot plant study.

The two pilot units were connected just below the top water level in the filter units as shown in the figure 5-I, one over flow outlet was kept for the first unit just above the interconnections to keep the constant top water level, by allowing the raw water to trickle from the overflow outlet.

At the outlet end of the pilot filter units, rotameters were connected to adjust the required flow rates from the filter units. To measure the headlosses at various depths in the filter units, transparent plastic tubings were connected to the perforated probes inserted at the various depths in the pilot filter units.



FILTER BED NO.1. FIG. 5-I FILTER BED NO 2.

PILOT PLANT MODEL FOR SINGLE MEDIA FILTER BEDS

SCALE
VER = 1:10 CM.
HOR = 1:5 CM.

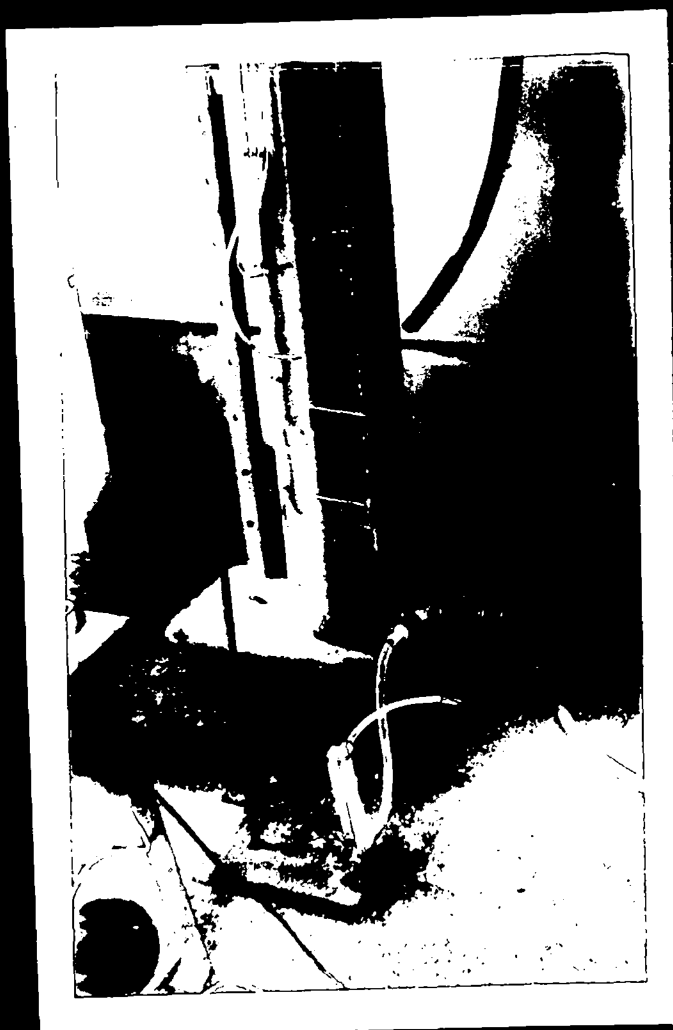
v) Pretreatment before filtration study : To simplify the study on the pilot filter units pretreatment with only chemical mixing was adopted before filtration. A constant alum dose of about 10 ppm was given to the raw water with the adjusted turbidity of 20 JTU during all these filtration experiments. Flocculation and settlement were not provided before filtration in these studies.

5.5.2 Procedure for Experimental Study :

Same procedure was followed for the experimental study to compare the efficiencies of the different pilot filter units. Before running pilot plants both the units were first filled with the tap water. The raw water after adjusting the required combined flow for the pilot filter units, and adjusting the required alum dose in the mixing chamber was introduced at the top of the two pilot plants through inter connections. The flow rate through each pilot filter unit was then adjusted to the required filtration rate for the pilot study. The rate of flow was also checked intermittently at the outlet ends of the pilot filter units. As the raw water was allowed to trickle from the over flow outlet, raw water flow in the mixing chamber was adjusted accordingly.

The pilot units were operated for seven hours during the laboratory working. After stopping the filter units, the sludge in the filter beds was taken out separately by backwashing each unit with the tap water. The filter units were backwashed till the clean water was seen through the wash water drain outlet. After completion of backwash the filter beds were filled with tap water up to

PHOTOPLATE 5-II



The outlet arrangements of the dual media pilot filter bed, with a rotameter to control the rate of flow and side head loss tappings to measure the head losses at various depths.

the top water level and the units were ready for the next experiments.

5.5.3 Important Observations on the Pilot Plant Study :

i) Turbidity removal : As the raw water turbidity was adjusted to 20 JTU, filtered water turbidity was measured after every hour during these studies.

ii) Head loss in the filter units : Head losses were measured at various depths in the single, dual and mixed-media filter beds, through the 3 mm dia perforated aluminium probes fixed at different depths through the sides. The perforated probes were inserted about 3 cm in the bed. The probes were provided with fine perforations of about 0.25 mm dia. so as not to allow the fine media in the probes during back washing and filtration. Further brass mesh pieces were introduced at the outlet ends of the probes to prevent the draining out of any finer media. Plastic transparent tubings were connected to these probes, to show head losses at various depths as shown in the figure 5-I.

iii) Sludge removed from the filter beds : Sludge from each filter unit was collected separately during the back-wash given on the next day. The back wash was given till the clear water was seen from the wash water outlet. The washed water from each unit was then allowed to settle in the buckets for about two hours. The clear supernent water was then taken out by syphon action, care being taken to keep about five cm thick clear water above the settled sludge. The remaining sludge and water in the buckets was then mixed properly and poured in the measuring cylinders of 1000 ml capacity. The mixture was then allowed to settle for one hour in the measuring cylinders and the total volume of the settled sludge was recorded in cc or ml.

iv) Bacteriological observations : Samples of raw and filtered water were collected at the outlets of the filter units at the end of the seven hours, in the sterilised bottles. The bacteriological tests were conducted for these samples to findout the bacteria removal efficiencies in the different filter units.

5.6 EXPERIMENTAL STUDY ON THE SINGLE MEDIA FILTER BED.

The comparative study was conducted to find out pilot plant performances of the single, dual media and mixed media filter units, so as to suggest suitable media and filter units for small capacity water treatment plants.

The details of the pilot filter units are given in the figure 5-I. The pilot plant experiments were conducted for three filtration rates of 5000,7500 and 10000 $l/m^2/hr$. Two single media pilot filter units with fine sand, and crushed coconut shell media were prepared for this study. Uniform size of each media after sieving through 0.4 and 1.2 mm sieves was used for each single media filter bed. The media depth of 75 cm was adopted for each filter unit. Water depth of 120 cm was kept on the filter beds. Supporting graded gravel bed was used below the single media. The effective size and the uniformity coefficient of the media are as given below.

	Type of media.	Depth	E.S.	U.C.	Porosity(%)
i)	Fine sand.	75 cm	0.5	1.50	35.70
ii)	Crushed coconut shell.	75 cm	0.6	1.45	38.60

The results of the pilot plant study are given in the Tables 5-III to 5-VI

5.7 EXPERIMENTAL STUDY ON THE DUAL MEDIA FILTER BEDS.

Two pilot dual media filter units were prepared for this study. In one unit fine sand and crushed coconut shell media were used while in the other unit fine sand and crushed coal were used. Pilot plant experiments were conducted for three filter rates of 5000,7500 and 10,000 $l/m^2/hr$. The depths of the media and the effective sizes and uniformity coefficients of the media are given below.

	Type of media.	Depth	Effective size in mm	Uniformity coefficient
i)	Fine sand for both units.	59 cm.	0.5	1.5
ii)	Crushed coconut shell.	45 cm.	0.9	1.39
iii)	Crushed coal.	45 cm.	0.9	1.42

The results of the pilot plant study are given in the tables 5-VII to 5-X.

TABLE 5-III

Pilot plant observations on the single media filter bed with fine sand media

Filter Bed-I

Filter run 1 : Rate of filtration : 5000 $l/m^2/hr$.

Hours of Run.	Head losses in the single media filter bed in cm. 15	30	45	60	75	Filtered water Turbidity.
0	4.0	8.0	13.0	17.0	20.0	-
1	5.5	9.0	14.0	18.0	21.0	0.8
2	6.5	10.5	15.0	19.0	22.0	0.7
3	7.5	12.0	16.5	20.5	23.5	0.5
4	8.0	13.5	17.0	21.5	25.0	0.4
5	15.0	20.5	24.0	29.5	32.5	0.4
6	28.0	33.5	37.0	41.0	44.0	0.4
7	40.0	45.0	50.0	53.0	57.0	0.2

Filter run 2 : Rate of Filtration : 7500 $l/m^2/hr$.

0	6.0	12.0	17.0	22.0	25.0	-
1	8.0	14.0	20.0	28.0	30.0	0.8
2	11.0	18.0	23.0	32.0	35.0	0.6
3	18.0	25.0	32.0	37.0	42.0	0.5
4	26.0	35.0	40.0	45.0	50.0	0.4
5	30.0	40.0	45.0	50.0	55.0	0.3
6	40.0	50.0	54.0	60.0	65.0	0.3
7	50.0	60.0	65.0	70.0	75.0	0.3

Filter Run 3 : Rate of Filtration : 10,000 $l/m^2/hr$.

0	9.0	17.0	25.0	33.0	39.0	-
1	12.0	20.0	28.0	37.0	44.0	0.8
2	19.0	27.0	36.0	44.0	50.0	0.6
3	35.0	44.0	52.0	60.0	65.0	0.4
4	68.0	74.0	83.0	90.0	94.0	0.3
5	86.0	94.0	100.0	105.0	100.0	0.3
6	108.0	114.0	120.0	125.0	128.0	0.3
7	115.0	137.0	142.0	146.0	150.0	0.3

TABLE 5-IV

Pilot plant observations on the single media filter bed with fine crushed coconut shell.media

Filter Bed - II

Filter Run 1 : Rate of filtration : 5000 $l/m^2/hr$.

Hours of Run.	Head loss in the filter bed in cm.					Filtered water Turbidity.
	15	30	45	60	75	
0	2.0	3.0	5.0	6.0	8.0	-
1	3.0	4.0	6.0	7.0	9.0	0.5
2	4.0	5.0	7.0	8.0	10.0	0.5
3	5.0	6.0	8.0	9.0	11.0	0.5
4	6.0	7.0	9.0	10.0	12.0	0.4
5	10.0	11.0	12.0	14.0	16.0	0.4
6	15.0	16.0	17.0	18.0	20.0	0.3
7	20.0	21.0	23.0	24.0	25.0	0.2

Filter run 2 : Rate of filtration 7500 $l/m^2/hr$.

0	3.0	5.0	7.0	8.0	10.0	-
1	4.0	6.0	8.0	10.0	12.0	0.6
2	5.0	8.0	10.0	12.0	14.0	0.5
3	8.0	11.0	13.0	16.0	18.0	0.4
4	12.0	15.0	16.0	19.0	22.0	0.4
5	13.0	18.0	20.0	22.0	25.0	0.3
6	16.0	21.0	24.0	26.0	28.0	0.3
7	22.0	25.0	28.0	30.0	32.0	0.3

Filter run 3 : Rate of filtration : 10,000 $l/m^2/hr$.

0	4.0	8.0	11.0	14.0	17.0	0.8
2	7.0	10.0	13.0	16.0	19.0	0.6
2	9.0	13.0	16.0	19.0	21.0	0.4
3	12.0	16.0	20.0	22.0	24.0	0.4
4	17.0	21.0	25.0	27.0	30.0	0.4
5	20.0	24.0	28.0	30.0	33.0	0.4
6	25.0	29.0	32.0	35.0	38.0	0.3
7	28.0	32.0	35.0	38.0	41.0	0.3

TABLE 5-V

Sludge removal in the pilot filters.

Filter Run No.	Volume of sludge removed in ml. Filter No.1	Filter No.2	Rate of filtration in $l/m^2/hr.$	Hours of filter run.
1	285	200	5000	7
2	380	350	7500	7
3	420	380	10000	7

TABLE 5-VI

Bacteriological observations (MPN)

Filter Run.	Bacteriological observations.			% Removal of coliform.	
	Raw water.	Filter bed. No.1	Filter bed. No.2	Filter bed No.1	Filter bed bed. No.2
1	2.4×10^4	4600	2400	80.00	90.00
2	2.4×10^4	4300	930	82.00	96.00
3	1.1×10^4	4600	2400	58.20	78.20

Other Observations : During the pilot plant study it was specially observed that the head loss development in the sand media bed was considerably more as compared to the coconut shell media of the same size for the same rate of filtration. The filter run of the sand media bed was just for the limiting conditions as the effluent quantity started showing reduced discharge even with full outlet valve in opened condition after 6 hours of working.

TABLE 5-VII

Pilot plant observations on the dual media filter bed with crushed coconut shell as coarse media.

Filter Bed I

Filter run 1 : Rate of filtration 5000 $l/m^2/hr$.

Hrours of Run.	Head losses in the dual media filter bed in cm. 15	30	45	60	75	105	Filtered water Turbidity.
0	0.5	1.0	1.5	4.0	7.5	12.0	-
1	0.5	1.0	1.5	4.5	8.0	13.0	0.6
2	1.0	1.5	2.0	5.0	8.5	13.5	0.6
3	1.0	1.5	2.5	5.0	9.0	14.0	0.5
4	1.5	2.0	3.0	6.0	9.5	14.5	0.5
5	1.5	2.5	3.5	7.0	10.0	15.0	0.4
6	2.0	3.0	4.0	8.0	11.0	17.0	0.4
7	2.5	3.5	4.5	9.0	13.0	19.0	0.4

Filter run 2 : Rate of filtration 7500 $l/m^2/hr$.

Hrours of Run.	15	30	45	60	75	105	Filtered water Turbidity.
0	0.5	1.0	1.5	4.5	8.0	12.5	-
1	0.5	1.0	2.0	5.0	8.5	13.5	0.8
2	1.0	1.5	2.5	5.5	9.0	14.0	0.6
3	1.5	2.5	3.0	7.0	10.0	15.0	0.5
4	2.0	2.5	3.5	8.0	11.0	16.0	0.5
5	2.0	3.0	4.0	9.0	12.0	18.0	0.4
6	2.5	3.5	4.5	9.5	13.0	20.0	0.4
7	3.0	4.0	5.0	10.0	14.0	22.0	0.4

Filter run 3 : Rate of filtration 10000 $l/m^2/hr$.

Hrours of Run.	15	30	45	60	75	105	Filtered water Turbidity.
0	1.0	2.0	4.0	10.0	18.0	28.0	-
1	2.0	3.5	5.0	13.5	20.0	31.0	0.8
2	3.0	5.0	6.0	16.0	22.0	33.0	0.6
3	3.5	6.0	7.0	17.0	23.0	35.0	0.5
4	4.0	7.0	8.0	18.0	24.0	36.0	0.4
5	4.5	7.5	9.0	18.5	25.0	37.0	0.4
6	5.0	8.0	10.0	19.0	26.0	38.0	0.4
7	6.0	9.0	11.0	20.0	27.0	40.0	0.4

TABLE 5-VIII

Pilot plant observations on the dual media filter bed with crushed Bituminous coal as coarse media.

Filter Bed II.

Hours of Run.	Head losses in the dual media filter bed in cm						Filtered water Turbidity.
	15	30	45	60	75	105	
Filter run 1 : Rate of filtration 5000 l/m²/hr.							
0	1.0	1.5	2.5	7.0	10.0	14.0	-
1	1.0	2.0	3.0	7.5	10.5	14.5	0.8
2	1.5	2.5	3.5	8.0	10.5	15.0	0.6
3	1.5	2.5	4.0	8.5	11.5	15.5	0.5
4	2.0	3.0	4.5	9.0	12.0	16.0	0.5
5	2.5	3.5	5.0	9.5	12.5	16.5	0.4
6	3.0	4.5	7.0	9.5	13.0	18.0	0.4
7	3.5	6.0	10.0	13.0	15.0	21.0	0.4
Filter run 2 : Rate of filtration 7500 l/m²/hr.							
0	1.0	1.5	3.5	7.5	11.0	15.0	-
1	1.0	2.0	4.0	8.0	11.5	16.0	0.8
2	1.5	3.0	4.5	8.5	12.0	17.0	0.8
3	1.5	4.0	5.0	9.0	15.0	18.0	0.6
4	2.0	4.5	6.0	10.0	16.0	19.0	0.5
5	3.0	5.0	7.0	12.0	17.0	21.0	0.5
6	3.5	6.0	9.0	13.0	18.0	23.0	0.5
7	4.0	7.0	11.0	15.0	19.0	25.0	0.4
Filter run 3 : Rate of filtration 10,000 l/m²/hr.							
0	2.0	4.0	5.0	12.0	16.0	29.0	-
1	3.5	6.0	8.0	17.0	23.0	33.0	0.8
2	6.0	9.0	12.0	22.0	30.0	40.0	0.8
3	7.0	15.0	14.0	24.0	32.0	42.0	0.6
4	8.0	12.0	15.0	24.0	33.0	43.0	0.6
5	9.0	14.0	16.0	27.0	34.0	44.0	0.5
6	10.0	15.0	18.0	29.0	36.0	46.0	0.4
7	13.0	17.0	21.0	32.0	38.0	49.0	0.4

TABLE 5-IX

Sludge removal in the pilot filters.

Filter Run No.	Volume of sludge removal in ml.		Rate of filtration in lit/sqm/hr.	Hours of filter run.
	Filter No.1	Filter No.2		
1	255	280	5,000	Seven
2	300	325	7,500	Seven
3	380	400	10,000	Seven

TABLE 5-X

Bacteriological observations (MPN)

Filter Run No.	Bacteriological observations.			% Removal of coliform.	
	Raw Water	Filter No.1	Filter No.2	Filter No.1	Filter No.2
1	1.1×10^4	230	92	97.90	99.20
2	2.4×10^4	1500	11,000	93.75	54.20
3	1.5×10^5	930	2,400	99.40	98.40

Other Observations : The development of the head loss in the dual media filter bed No,1 with the crushed coconut shell media was considerably lower than the filter bed No.2 where crushed coal was used.

5.8 EXPERIMENTAL STUDY ON THE MIXED MEDIA FILTER BED.

One pilot mixed media filter unit was prepared for this study. In this unit fine sand, fused brick and crushed coconut shell media were adopted. The pilot experiments were conducted for three filter rates of 5000,7500 and 10,000 $l/m^2/hr$. The depths of the media and the effective sizes and the uniformity coefficients of the media are given below.

Media used.	Depth in cm.	Effective size in mm	Uniformity co-effici-ent.
1) Fine sand	30	0.45	1.3
2) Crushed fused brick.	30	1.00	1.2
3) Crushed coconut shell.	40	1.3	1.15

5.8.1 Design of the Mixed Media Unit :

In the dual media filter units it was observed that there was no intermixing of the two media and after back washing, two media were clearly visible with a distinct line of interface between the two media.

In an ideal mixed media filter bed the filter media are designed in such a way that there is effective intermixing of the media so that there is no separation of media and the combined media is such that there is uniform increase of the media size,with finest material at the bottom and coarsest material at the top. This aspect is fully discussed in details by Culp and Culp(9).

Even though it is very difficult to achieve the ideal conditions of a mixed media bed for want of the availability of proper media, it may be possible to achieve partially effective mixed media beds by selecting suitable media of different sizes and different specific gravities for designing such mixed media filter units. The author has therefore, designed the experimental mixed media filter unit with sizes of media as stated above.

The results of the pilot plant study are given in the Tables 5-XI to 5-XIII.

TABLE 5-XI

Pilot plant observations on the mixed media filter bed.

Filter run 1 : Rate of filtration 5000 $l/m^2/hr$

Hours of Run	Head losses in the filter bed in cm. 15	45	60	75	90	105	Filtered water Turbidity.
0	1.0	3.0	8.0	11.0	13.0	15.0	-
1	1.5	4.0	9.0	12.0	15.0	17.0	0.5
2	2.0	5.0	10.0	14.0	17.0	20.0	0.4
3	3.0	7.0	12.0	16.0	20.0	22.0	0.3
4	4.0	9.0	13.0	18.0	22.0	24.0	0.3
5	5.0	10.0	14.0	20.0	23.0	26.0	0.3
6	6.0	12.0	16.0	22.0	25.0	28.0	0.2
7	7.0	13.0	18.0	23.0	27.0	30.0	0.2

Filter run 2 : Rate of filtration 7500 $l/m^2/hr.$

0	1.0	3.0	10.0	15.0	20.0	22.0	-
1	2.0	5.0	11.0	16.0	22.0	24.0	0.7
2	3.0	7.0	12.0	17.0	24.0	26.0	0.5
3	4.0	8.0	14.0	19.0	25.0	28.0	0.5
4	5.5	10.0	16.0	21.0	27.0	30.0	0.4
5	7.0	12.0	18.0	23.0	30.0	33.0	0.3
6	9.0	14.0	20.0	25.0	33.0	35.0	0.3
7	10.0	16.0	22.0	27.0	34.0	38.0	0.3

Filter run 3 : Rate of filtration 10,000 $l/m^2/hr.$

0	1.5	5.0	13.0	20.0	27.0	28.0	-
2	2.0	6.0	15.0	22.0	28.0	30.0	0.7
2	3.0	7.0	17.0	24.0	29.0	32.0	0.7
3	4.0	8.0	19.0	25.0	30.0	34.0	0.7
4	6.0	9.0	20.0	27.0	32.0	36.0	0.5
5	8.0	10.0	21.0	28.0	33.0	38.0	0.5
6	10.0	12.0	22.0	30.0	35.0	40.0	0.5
7	11.0	15.0	24.0	32.0	38.0	42.0	0.5

TABLE 5-XII

Sludge removal in the pilot filter.

Filter Run No.	Volum of sludge removal in ml.	Rate of filtration in lit/sqm/hr.	Hours of filter run.
1	300	5,000	7
2	350	7,500	7
3	390	10,000	7

TABLE 5-XIII

Bacteriological observations (MPN)

Filter Run No.	Bacteriological Observations		% Removal of coliform during filtration.
	Raw water.	Filtered water.	
1	2.4×10^4	240	99.0
2	2.4×10^4	2,400	90.0
3	4.6×10^4	3,900	99.50

Other Observations : During the back washing of the mixed media filter bed it was observed that the lower two media of the fused brick and the fine sand were completely mixed up in each other as the difference in the specific gravities (2.40 and 2.65) was not adequate for their proper placements. However the crushed coconut shell media was found at the top with clear interface line above the other two mixed up media.

5.9 DISCUSSION ON THE PILOT PLANT FILTRATION STUDY.

5.9.1 General Comparison :

i) Turbidity Removal : From the pilot plant observations given in the earlier paras for the single, dual and mixed-media filter beds for seven hours of filter runs, it is seen that for the same rate of filtration the single media showed better results than the dual and mixed-media filter units. While the mixed-media bed showed comparatively better results than the dual media filter beds.

In the beginning of the filter run single media bed will show better turbidity removal due to the fine media of e.s. 0.5 and u.c. 1.5 with 75 cm depth than the dual and mixed-media beds as the latter two have coarser media depths above the fine sand media. However this is only true for the particular media sises and depths adopted in the pilot filter units. By adopting finer sizes of the coarse media in the dual and mixed-media beds, the turbidity removal may be done equal or even better than a single media bed, as given in the various references in the chapter 2.

ii) Head loss developments : From the head loss observations it is seen that the dual media filter beds show the lowest head loss developments in both the media as compared to the single and the mixed-media beds, for the same rates of filtration and in similar conditions.

Theoretically the mixed media bed should have shown the lowest head loss among the three, however as explained in the above observations, the lower two media were totally mixed up being the low difference in the specific gravities and as such the actual head loss was more than the dual media beds. In case of single media filter beds, as predicted the head losses were more than the dual media filter beds. However, it was rather surprising to note that the head loss developed in the coconut shell single media bed was about 50% to 35% of the head loss developed in the single sand media bed. The probable reasons for these unusual observations are discussed latter in this chapter.

Figures 5-II to 5-IV showing the head loss developed in the three typies of pilot filter units are enclosed. From the Fig. 5-II it can be seen that the head loss development in the fine crushed coconut shell media was surprisingly less than the head loss development in the find sand media in similar conditions. Fig. 5-III shows the head loss developments in the dual media filter unit with crushed coconut shell over sand is some what lower than the head loss developments in the dual media filter unit with bituminous ccoal over fine sand in the similar conditions. Fig. 5-IV shows the head loss developments in the mixed-media pilot filter unit which are practically straight lines parallel to each other.

iii) Sludge Removal : From the sludge volumes collected from the washed water after seven hours of operation, when the raw water turbidity was adjusted to 20 JTU, it is seen that the sludge volumes are fairly comparable. Theoretically the sludge volumes should have been near about same for each rate of filtration, considering the raw and filtered water turbidities. However the actual sludge volume show some variations viz : for the rate of filtration of 5000 $l/m^2/hr$ the range of sludge volumes was between 250 to 300 ml, while for the rate of filtration of 7500 $l/m^2/hr$, it was 300 to 350 ml and for the rate of filtration of 10,000 $l/m^2/hr$, the range was 350 to 400 ml. It is difficult to give theoretical reasons for this variation in sludge volumes. However this may be due to some variations in the artificial raw water turbidity of 20 JTU as prepared for all these experiments. As the canal silt was used to prepare the artificial raw water turbidity of 20 JTU, it was not as effective as the natural raw water turbidity and there was necessity for stirring the turbidity suspensions intermittently. Thus this variation in sludge removal is understandable.

The study of sludge volumes was made to give some indications of suspension removal efficiency and this basic method can be perfected by trying different types of measured suspension loads and maintaining the constant raw water turbidity.

However from the present sludge removal observations it can be noted that the mixed-media bed showed the higher sludge removal than the other two, while the single media beds showed somewhat more sludge removal than the dual media bed. This may be due to more percentage of finer grains in the mixed media and single media filter beds which is but natural.

One of the interesting observations to note in this comparative study is that, in both the single and dual media filter units, the filter units, in which crushed coconut shell media was used, showed lower sludge volumes than the other similar units in which sand and sand plus coal were used in the single and dual media units. This special observation may have a direct relation with the lower head loss developed in the filter units in which crushed coconut shell media was used, as discussed in the earlier para. Thus the crushed coconut shell media may have some special advantages as compared to the sand and coal media, in the single as well as dual media filter beds. This aspect is further discussed in the para 5.9.2.

iv) Bacteriological Observations : From the bacteriological observation it can be seen than bacteria removal efficiency of all the filter beds is within the range of 90 to 99 % and is seen fairly satisfactory. However disinfection has to be done before the supply of water to the consumers as per accepted practice.

One of the important observation to be noted in the bacteriological results of the single and dual media filter units is that the filter units in which crushed coconut shell media was used showed better bacteria removal in both the units. This aspect is further discussed latter in this chapter.

5.9.2 Special Observations :

In addition to the above mentioned general observations some special observations were made in the study of single, dual and mixed-media filter beds which are discussed below.

i) Single media filter units : From the pilot plant observations on the fine sand and fine coconut shell media filter units it can be seen that even though the size and depth of these filter units were same and they were run for the identical conditions; the coconut shell media unit showed number of advantages over the sand media unit. As already discussed in the above para when the turbidity removal is about same for seven hours of run, in both the filter units, the head loss developed is about 1/2 to 1/3 of the head loss developed in the sand filter unit. Further the sludge volume was on lower side, while the bacterial removal is on higher side.

The most important advantages among these may be the lower head loss development in the coconut shell unit for the similar other conditions as compared to the sand media unit as can be seen from the Fig. 5-II. It is rather surprising to see that the head loss development in the coconut shell media unit for the filtration rate of 10,000 $l/m^2/hr$ is practically same after seven hours of run as compared to the head losses (4.0 cm) in the dual and mixed-media filter units. Theoretically the head losses should have been in the decreasing range in single, dual and mixed-media filter units, and after continuous operation of these filter units, the same may be proved. However the fact that the head loss in the coconut shell media unit is about 1/3 of that in the sand media unit for filter run No.3 is certainly a point of further investigation.

The reason for this important observation may be the more pore space in the coconut shell media for the same size as compared to the sand media. The author feels that this is the significant advantage of the crushed coconut shell media. One of the probable reason for this special advantage of the coconut shell media may be the range of natural specific gravity of this material which falls in between 1.35 to 1.45. With this range of specific gravity of this material, when the media is prepared to ~~of~~ a specific size, this media itself forms a mixed-up-media, with some fine particles of higher specific gravity at the bottom and same coarser particles of lower specific gravity at the upper or at various depths according to the individual specific gravities of particles within the range. Thus the hydraulic gradation which is distinctly marked in a sand media filter bed, was not observed in the fine as well as coarser crushed coconut shell media in a single or dual media filter units. This may be the most probable reason for having more pore space for the same size media as compared to the sand media. It is felt that even in the case of bituminous coal and anthracite media as the specific gravity of a particular material from a local spot is the same, these media may also behave similar to a sand media in hydraulic gradation and thus the coconut shell media may have this special advantage over all other natural media in use.

With the above mentioned natural advantage of the crushed coconut shell media it will be very desirable to adopt single media crushed coconut shell than a sand media bed in place of a conventional rapid sand filter unit. The additional advantages of such a coconut shell single media filter unit will be the lower percentage of wash water quantity and requirement of lower head for wash water for such a filter unit. It will be further desirable to design such a single size dual media filter unit with 15 cm of fine sand and 60 cm of crushed coconut shell media of the same size in place of a single media so as to avoid the possibility of any breakthrough and advantage of polishing material at the bottom as in a dual media filter bed. Such a single size, dual media filter unit may be cheaper than a dual media filter bed as the fine material below one mm size of coconut shell (or anthracite) can be utilised for such filter bed, as this fine material is otherwise a waste. Further the existing rapid sand filter unit can be replaced by such a single size dual media filter bed, in the same bed, to give higher filtration rate with better quality of the effluent.

ii) Dual media filter units : From the observations of the dual media filter unit, one with crushed coconut shell over the fine sand and the other with crushed bituminous coal over the fine sand, the performances are of the same nature. Even in these dual media units, the filter unit with crushed coconut shell media over fine sand showed lower head loss developments, for the same rates of filtration as compared to the other as can be seen from the Fig. 5-III. Further the volume of sludge removed is less while the bacterial removal is more in th the filter unit with crushed coconut shell media over san sand as compared to the other unit. Thus as already discussed in the earlier para there is some natural advantage of the crushed coconut shell media over the crushed coal media as a coarser media in the dual media filter unit.

In all the three new treatment plants developed in this study the author has adopted the dual media filter units, with the coarser crushed coconut shell media over the fine sand to bring in to practice the special advantages of the crushed coconut shell media in the dual media high rate filter beds.

iii) Mixed-media filter units : The mixed-media pilot plant filter unit in the present study was a purely experimental exercise, as a suitable media of specific gravity of about 2.0 was not available to introduce in between the top crushed coconut shell and bottom fine sand media. The fused brick media with specific gravity 2.38 was therefore adopted as a central media in the experimental mixed-media unit. As expected the lower two media, being of similar specific gravities, were seen completely mixed-up, and thus loosing advantage of the ideal mixed-media filter unit.

It is therefore, one of the important field of future research to find out and to bring in to practice the coarser media of specific gravities in between 1.9 to 2.1 so as to design an ideal mixed media filter bed by introducing such a media in between the coarser coconut shell (sp.gr. 1.4) at the top and fine sand media (sp. gr. 2.65) at the bottom.

5.10 CONCLUSIONS.

i) The crushed coconut shell media has shown superior qualities as compared to the crushed bituminous coal media for use as a coarse media in a dual and mixed-media filter units for high rate filtration.

ii) The crushed coconut shell media as adopted for the first time in the dual media filter beds at Ramtek plant (1973) showed very satisfactory results and without any sign of deterioration of this mew media for period of more than five years of its use.

iii) The crushed coconut shell media can be advantageously used in a single media filter in place of fine sand in a rapid gravity filter bed.

iv) There is urgent need for a search for new filter-media having specific gravities between 1.9 to 2.1 for the use in mixed-media filter beds for high rate and better quality water filtration.

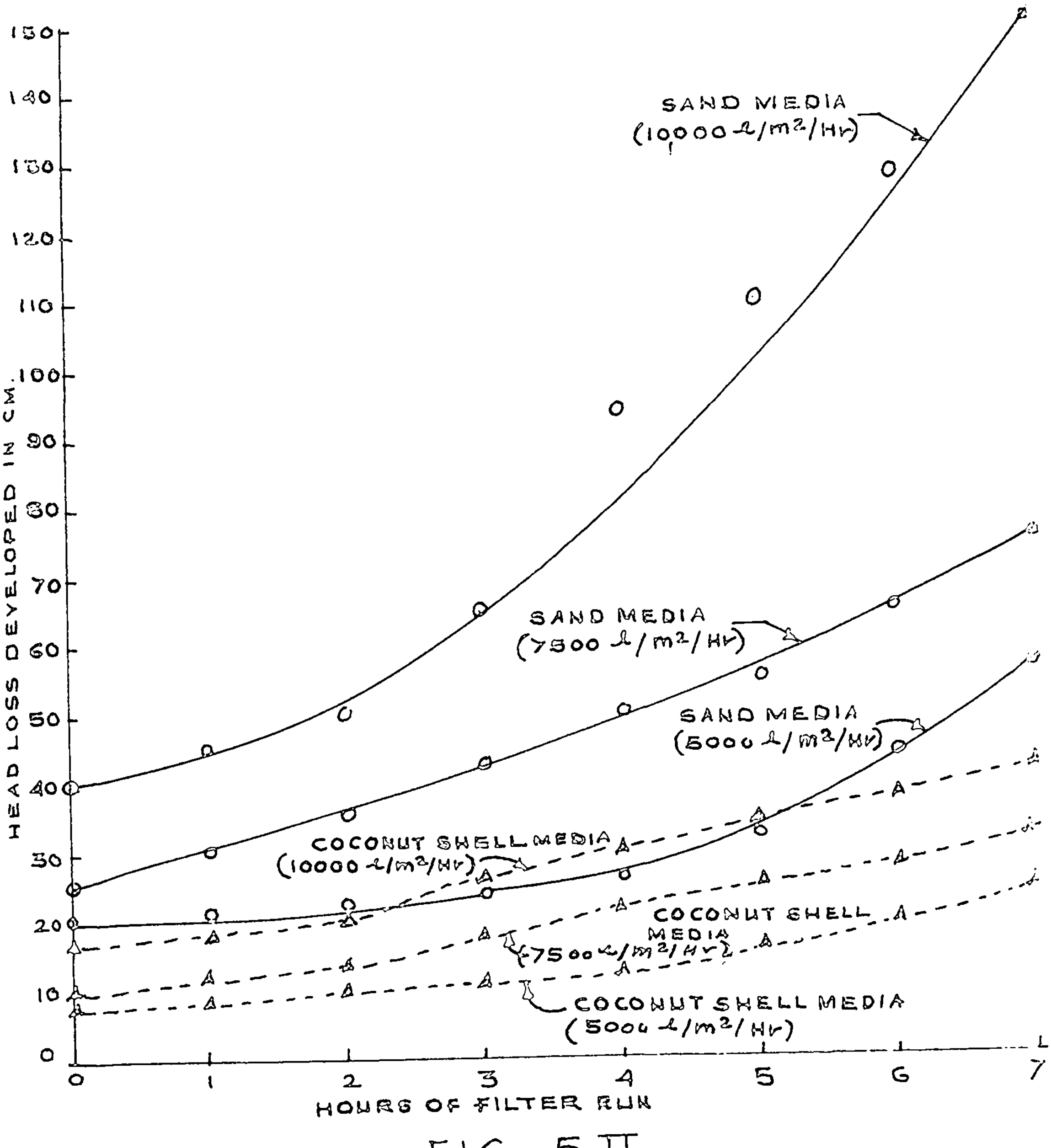
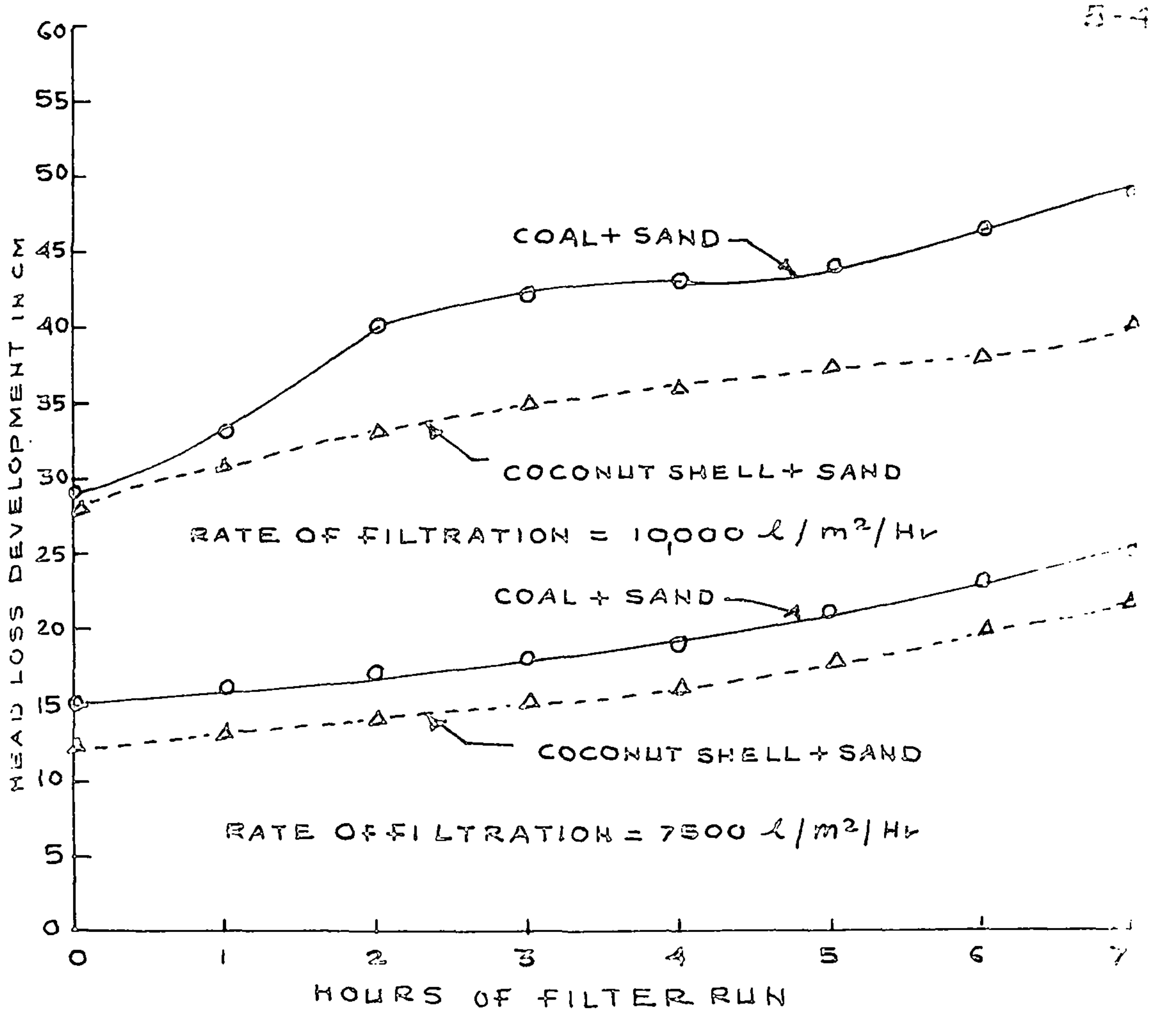


FIG. 5-II

HEAD LOSS DEVELOPMENT IN SINGLE MEDIA PILOT FILTER UNITS



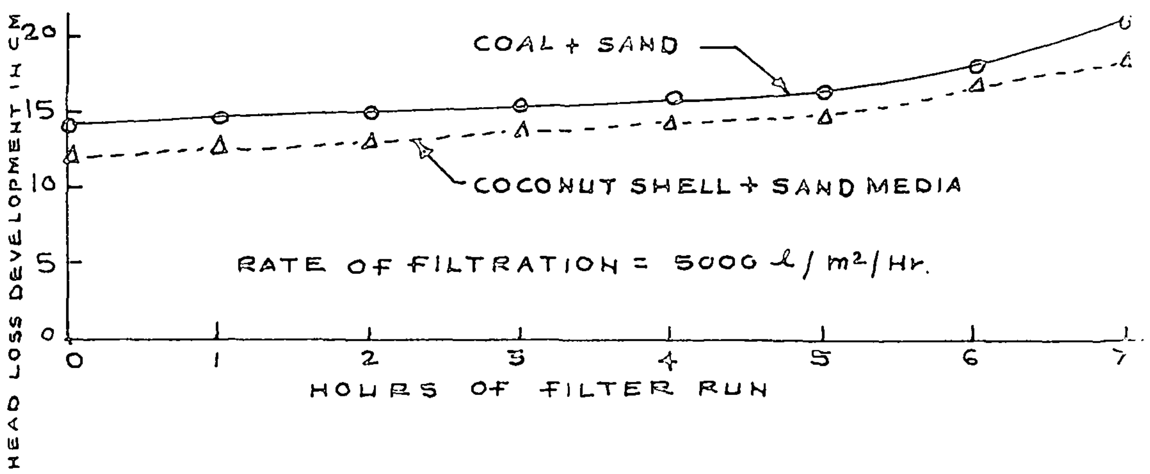


FIG. 5-III

HEAD LOSS DEVELOPMENT IN DUAL MEDIA FILTER UNITS

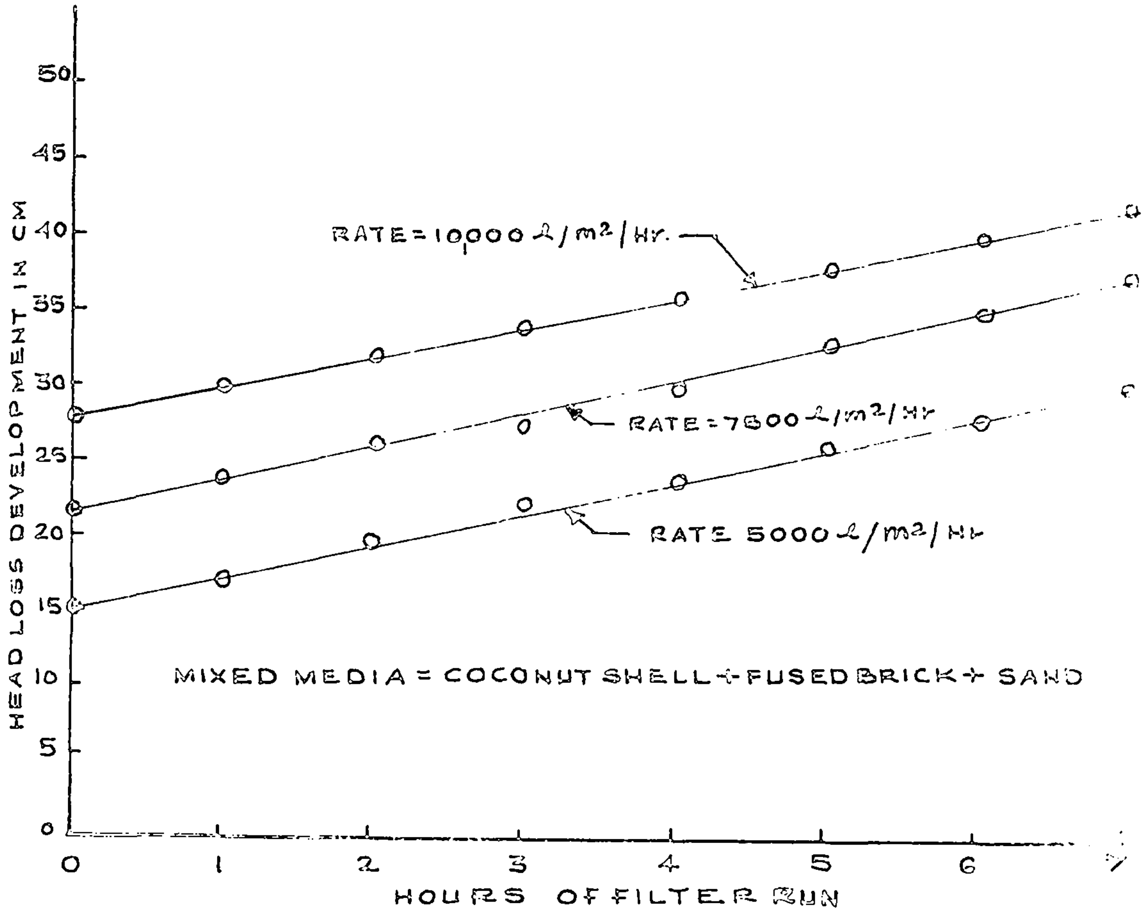


FIG. 5-IV

HEAD LOSS DEVELOPMENT IN A MIXED MEDIA PILOT FILTER UNIT

CHAPTER 6

PILOT PLANT STUDY FOR THE RAMTEK TYPE TREATMENT PLANT.

6.1 INTRODUCTION.

The pilot plant studies for the different flocculators followed by tube settling tank for different conditions have been carried out under the chapter 4 of this thesis. Similarly the pilot plant studies on the dual and the multi-media filter beds for different conditions have been carried out, as explained under the chapter 5 of this thesis.

It is now proposed to carry out the pilot plant study for the same loading conditions as adopted for the design of the Ramtek treatment plant as discussed in the chapter 7 of this thesis. In addition to this it is also proposed to carry out the pilot plant study for the Murbad type treatment plant, which is a modified form of Ramtek plant, designed for the treatment of moderate turbid water sources.

The pilot plant as shown in the figure 6-I was fabricated in the laboratory to study the various aspects of the design adopted for Ramtek treatment plant while the figure 6-II shows the pilot plant fabricated for the study of the Murbad treatment plant. The designs of both the pilot plants and their experimental observations are discussed in this chapter.

6.2 DESIGN OF THE RAMTEK TYPE PILOT PLANT.

The detailed sizes of the Ramtek type pilot plant are shown in the figure 6-I. The main components

6-1-a

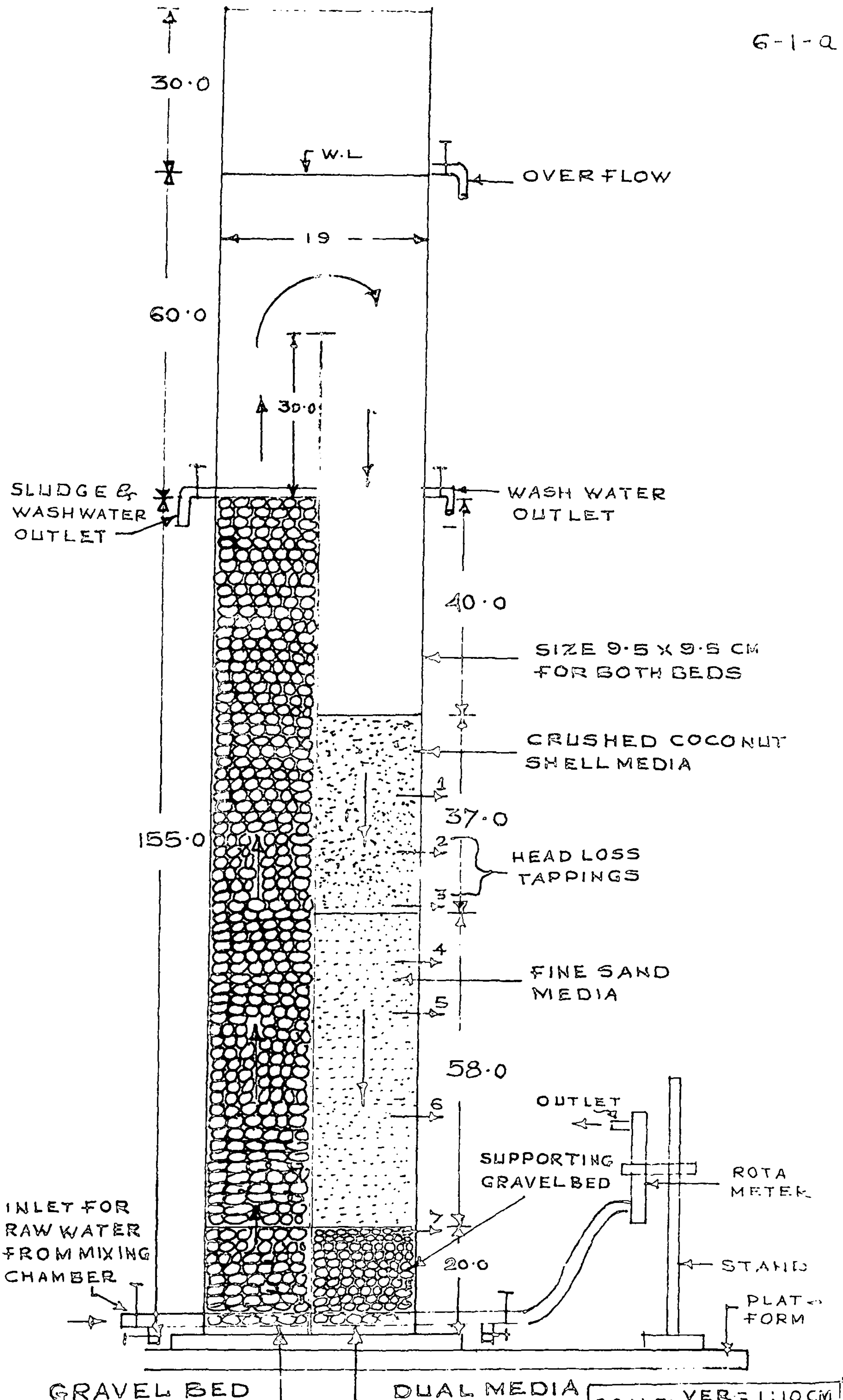


FIG. 6.1
PILOT PLANT MODEL OF RAMTEK TREATMENT PLANT

are gravel bed prefilter followed by the dual media filter bed. The hydraulic design calculations of the pilot plant are given in the para 6.2.6 of this chapter. The depths of the units are adopted nearly to the actual depths adopted for the Ramtek plant so as to get the comparable results of these plants. Perpex sheet pilot plant unit was fabricated in the laboratory so as to observe the actual floc formation, cleaning of the gravel bed prefilter unit, including the floc and sludge removal from the top of the gravel bed, and the performance of the dual media filter bed for the treatment of low turbidity raw water sources.

The inlets and outlets of 12 mm dia. G.I.Pipes and fittings were provided with brass gate valves to adjust the required flows through the pilot plant. For adjusting the required flow, a contant flow arrangement was made as explained in the chapter 4. The alum dosing and mixing arrangements were also provided as explained in the chapter 4. At the outlet end of the dual media filter bed a rotameter was provided to control the rate of flow through the plant. At the top and bottom of the gravel bed prefilter. Sludge outlets were provided with gate valves to drain the sludge by hydrostatic pressure after desired period. A central wall of 30 cm height was provided above the top of gravel bed to represent the gutter level for allowing the settled water to flow on the dual media filter bed. One 25 mm dia washout valve was provided at 60 cm above the top of the dual media filter bed for taking out the wash water to drain.

6.2.1 Pilot Plant Operation :

Before running the pilot plant both the units were first filled with the tap water. The raw water for all these experiments was brought from the Gangapur left bank canal by a trolley fitted to a jeep. The raw water turbidity was adjusted first to 100 JTU in a separate storage tank by mixing with the tap water. This raw water was then pumped to the plant through the constant flow arrangement as explained in the chapter 4. The raw water after mixing with the alum dose was introduced through the bottom of the gravel bed prefilter unit. Thus the flow in the gravel bed is in the upward direction. Water from the top of the gravel bed prefilter was flowing on the top of the dual media filter bed. The rate of filtration through the dual media filter bed was controlled at the outlet and by the gate valve with the help of the rotameter connected after the gate valve by a plastic tubing.

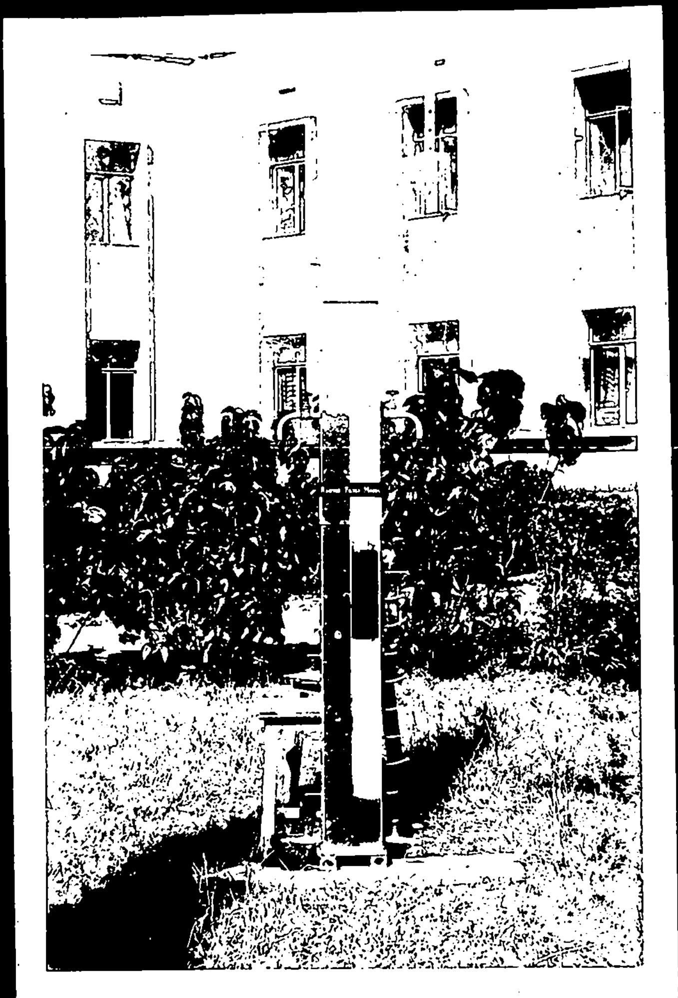
6.2.2 Head Loss Measurements :

The head loss in the gravel bed prefilter can be noted from the difference in the water levels in the pilot plant and the inlet tubing connected with the mixing chamber. However, the head loss in the gravel bed was between 2 to 3 cm through-out these runs and hence it was not recorded. The head losses at various depths in the dual media filter bed were observed from the difference of water levels against the top water level in the bed through the plastic tubings as explained in the chapter 5.

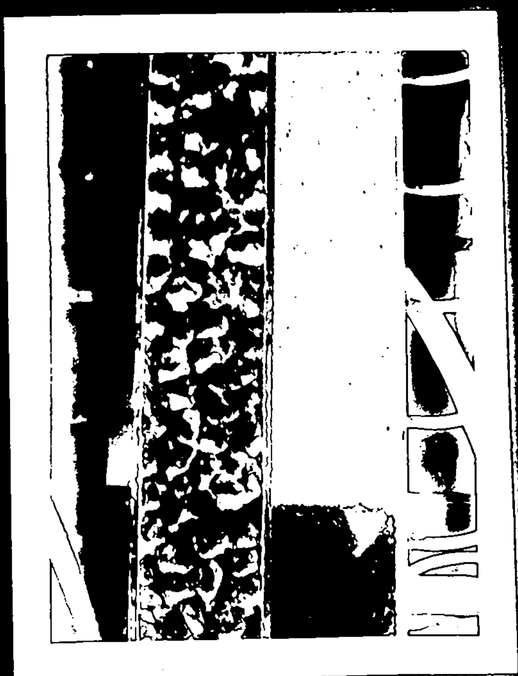
6.2.3 Turbidity Measurements :

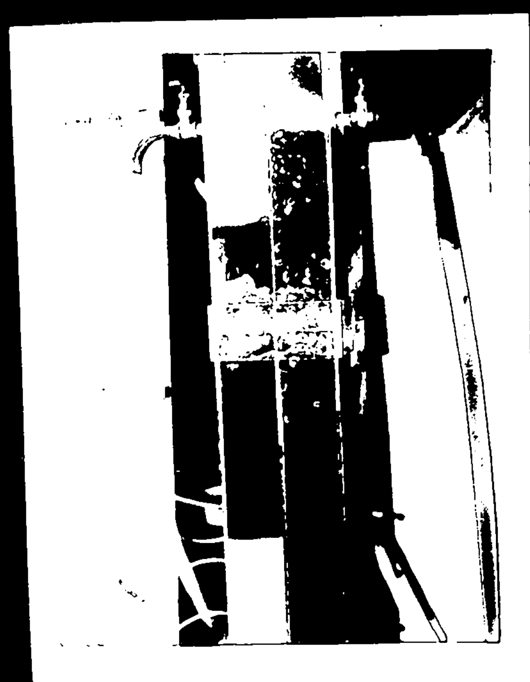
The turbidities of raw, settled and filtered water

PHOTOPLATE 6-I



Experimental pilot plant of the Ramtek type treatment plant showing the gravel bed pre-filter and the dual media filter bed.





LEFT : The gravel bed pre-filter with sludge blanket before cleaning.

RIGHT : The gravel bed after cleaning and the dual media bed under backwash operation.

samples were measured after every hour with an Aplab turbidimeter. Both head loss and turbidity measurements were conducted after every hour.

6.2.4 Cleaning of the Gravel bed Prefilter and Measurement of Sludge Volume :

At the end of each run the inlet valve was closed. The sludge settled at the top of the gravel bed was taken out from the special outlet provided at the top of the gravel bed till clean water was observed from the outlet. Then the sludge outlet valve at the top was closed and the sludge outlet valve at the bottom was opened to drain the sludge accumulated in the gravel bed by gravity flushing out action. To remove all the accumulated sludge the gravel bed was drained twice by filling the bed again from the tap water. In addition to this, back wash was given at the end of day's work to remove all the remaining sludge. It was observed that most of the sludge in the gravel bed was removed by the two sludge draining operations and there was negligible sludge to be removed by back wash. The sludge accumulated in the gravel bed during each run was measured with the glass measuring cylinders, as explained in the chapter 4.

6.2.5 Cleaning of the Dual Media Filter Bed and Measurement of the Sludge Volume :

For cleaning the dual media filter unit, after closing the outlet valve, the back wash valve was opened so as to give about 30% expansion of the filter media. The washing and the sludge measurement process was adopted as explained in the chapter 5 of this thesis.

6.2.6 Hydraulic Design of the Ramtek Type Pilot Plant :

a) Gravel bed prefilter : one unit.

i) Size of bed = 9.5 x 9.5 = 90.0 cm^2

ii) Depth of gravels = 155 cm

iii) Water depth at the top = 90 cm

iv) Total volume of gravel bed = 13,950 ml

v) Actual volume of water up to the top of the gravel bed = 6,000 ml

vi) Actual volume of gravels = 7,950 ml (in wet conditions)

vii) Porosity = 43 %

viii) Number of gravels in the bed = 8,460

ix) Mean dia of the gravels = 1.47 cm

x) Surface area of the gravels = 5.43 m^2 assuming sperical shape.

xi) Loading on the gravel bed = 7,150 $l/m^2/hr$

xii) Flow rate on the bed = $\frac{7,150 \times 90}{100 \times 100}$

= 64.35 lit/hr
or 1,060 ml per min.

xiii) Volumetric loading on the gravel bed. = $\frac{64.35 \times 100}{13,950}$

= 4,600 $l/m^3/hr$

xiv) Detention period in the gravel bed. = $\frac{6000 \times 60}{64.35 \times 1000}$

= 6.0 min.

b) Dual media filter bed : one unit.

i) Size of bed = 9.5 x 9.5 = 90.00 cm^2

ii) Flow rate on the bed = 64.34 lit/hr. (same as above)

iii) Surface loading on the bed = 7,150 $l/m^2/hr$.

iv) Depth of coconut shell media = 37 cm.

v)

v) Average size of coconut shell media = 1 to 2 mm

vi) Effective size of the media = 0.95 mm

vii) Uniformity coefficient of the media = 1.45

viii) Depth of fine sand media = 58 cm.

ix) Effective size of sand = 0.5 mm

x) Uniformity coefficient = 1.5

xi) Depth of supporting gravel bed = 20 cm

xii) Underdrain arrangement = perforated nozzle of PVC type.

xiii) Inlet and outlet pipes = 12 mm dia G.I. pipes.

xiv) Control valves = Brass gate valves.

xv) Water depth over the bed = 100 cm.

xvi) Head loss measuring arrangements = Through 3 mm dia perforated probes from the top of the media at 15,35,45,55,75 and 95 cm.

6.3 EXPERIMENTAL OBSERVATION :

The purpose of this pilot plant study was to find out the actual performance of such pilot plant for the same loading rate adopted for the Ramtek treatment plant and to compare the performances of both the plants. In addition to this the removal of the sludge volume and the proportion of the sludge volume removed at various stages was also studied on the pilot plant as such a study was not possible on the Ramtek treatment plant.

Following important observations were conducted for seven hours of daily working according to the facilities available in the laboratory.

6.3.1 Observations with the Normal Gravel Size :

In the prefilter of Ramtek plant, gravel sizes of 50 mm to 10 mm are used from bottom to the top in gradations. In the pilot plant first same gravel sizes were used.

However, the results of the settled water turbidity on the filter bed was more than 40 JTU for most of the period. Number of observations were carried out, however only two sets of observations are given in the Table 6-I for information. This effect was mainly due to the direct flow of water through the spaces between the side smooth perpex sheet and gravels whereas the flow through the gravels was negligible. This was clearly seen from the flow of the floc particles in the bed. This may be due to the less frictional resistance to the flow of water from the side spaces than through the gravels. This is one of the very important limitation of the pilot plant study. That is why this effect was not observed in the Ramtek plant even for the higher turbid raw water. Some times this may give wrong conclusions from the pilot plant studies. In the actual prototype plant the flow is distributed uniformaly as discussed latter in the chapter 7. In order to remove this difficulty the uniform size of gravels of average dia 1.47 were used as given in the hydraulic design calculations in the para 6.2.6 for the below mentioned observations.

TABLE 6-I

Pilot plant observations on Râmtek type treatment plant, with gravel size between 30 to 10 mm

Filter Run 1

Hours of Run.	Head losses in the dual media filter bed at various depths (cm)						Turbidities.	
	15	35	45	55	75	95	Settled.	Filtered.
0	1.0	1.5	4.0	6.0	8.0	11.0	50	0.6
1	2.0	2.5	5.0	7.0	9.0	13.0	50	0.6
2	3.0	3.5	6.0	8.0	11.0	14.0	50	0.5
3	3.5	5.0	6.0	9.0	13.0	15.0	35	0.5
4	5.0	7.0	7.0	10.0	14.0	15.5	35	0.6
5	5.0	7.5	10.0	12.0	15.0	16.0	35	0.6
6	5.0	8.0	11.0	12.5	15.5	18.0	40	0.5
7	5.0	8.0	12.0	14.0	18.0	20.0	40	0.4

Filter Run 2

0	0.5	1.0	2.0	4.0	7.0	11.0	50	0.5
1	1.0	2.0	4.0	5.0	8.0	12.0	40	0.5
2	2.0	3.0	6.0	8.0	11.0	14.0	32	0.5
3	2.0	4.5	7.0	9.5	13.0	17.0	35	0.4
4	3.5	6.0	10.0	13.0	17.0	20.0	40	0.4
5	5.0	7.0	11.0	14.0	18.0	21.0	40	0.3
6	5.0	8.0	13.5	16.0	20.0	24.0	37	0.3
7	7.0	11.0	16.0	20.0	25.0	29.0	40	0.3

6.3.2 Pilot Plant Observations with Average Gravel Size 1.47 cm:

Table 6-II showing the observations taken for three sets of tests conducted for daily seven hours operation on the pilot plant are given below. Table 6-III showing the removal of the turbidity loads at different stages of the treatment plant is also given. Other observations carried out during these tests are also

shown in these tables. Number of filter runs were studied however the observations of three average runs are given in the table 6-II.

6.3.3 Sludge Removed at Every Stage :

The sludge in the pretreator and the tube settler units was removed by gravity desludging operation and the sludge in the wash water was collected carefully and measured in the measuring cylinders in the same procedure as given in the chapter 4. The sludge in the dual media filter bed was also collected from the back wash water collected in the buckets and was measured .Table 6-IV shows the actual sludge collected from the two units along with the percentage removal of the same.

6.3.4 Bacteriological Observations :

The bacteriological observations of the raw settled and filtered water samples were carried out at the end of day's work. The results of the same are given in the Table 6-V.

TABLE 6-II

Pilot plant observations on Ramtek type treatment plant with average gravel size of 1.47 cm

Filter Run 1

Hours of run.	Head losses in the dual media filter bed at various depths (cm)						Turbidities	
	15	35	45	55	75	95	Settled.	Filtered.
0	1.0	2.5	4.5	6.0	10.0	13.0	-	-
1	2.0	3.0	5.5	7.0	10.5	14.0	18	0.5
2	3.0	4.5	6.0	8.5	12.5	15.0	19	0.4
3	3.5	5.5	8.0	10.0	14.0	17.0	18	0.4
4	4.0	6.0	9.0	11.0	15.0	19.0	20	0.4
5	4.5	6.5	11.0	13.0	17.0	21.0	22	0.4
6	5.0	8.5	13.0	15.0	19.0	22.5	23	0.4
7	5.5	9.0	13.5	15.5	20.0	23.5	25	0.4

Filter Run 2

0	0.5	2.0	3.0	4.5	7.5	10.0	-	-
1	1.0	2.5	3.5	5.0	8.0	11.0	30	0.8
2	1.5	2.5	4.0	5.5	8.5	12.0	30	0.5
3	2.0	3.0	5.5	7.5	10.5	13.5	30	0.5
4	3.0	5.0	6.5	9.0	11.5	15.0	25	0.4
5	4.0	6.0	10.0	12.5	16.0	19.0	20	0.4
6	4.5	6.5	11.0	13.0	17.0	20.0	20	0.4
7	5.0	7.0	11.5	13.5	18.0	21.0	20	0.4

Filter Run 3

0	0.5	2.0	3.5	6.0	11.0	14.0	-	-
1	1.0	2.5	4.0	7.0	12.0	16.0	20	0.5
2	1.5	3.0	5.5	10.0	14.0	19.5	20	0.5
3	1.5	4.5	7.0	11.0	16.5	21.0	19	0.4
4	2.0	5.5	8.0	12.5	17.5	22.0	18	0.4
5	2.5	6.5	10.0	14.0	20.6	26.0	18	0.4
6	3.0	8.0	11.0	15.5	21.0	27.0	18	0.4
7	4.0	9.0	12.0	17.5	23.5	29.0	18	0.4

TABLE 6-III

Turbidity removal

Filter run No.	Pretreatment.			Filtration.	
	Raw water JTU	Settled water JTU	% removal	Filtered water JTU	% Removal
1	100	20.7	79.3	0.41	20.29
2	100	25.0	75.0	0.50	24.50
3	100	21.3	78.7	0.50	20.80

Average turbidity removal :

1. During pretreatment : 77.66 %
2. During filtration : 21.86 %

TABLE 6-IV

Sludge removed in the pilot plant study.

Filter Run No.	Volume of sludge removed in ml.					% of sludge removal.	
	Pre-filter,			Filter bed.	Total volume	Pretreator bed.	Filter bed.
	From top	From bottom	Total				
1	100	1120	1220	690	1910	63.87	36.13
2	150	1180	1330	720	2050	64.87	35.13
3	210	1140	1350	860	2210	61.10	38.90
Average.	153	1146	1300	756	2057	63.28	36.72

TABLE 6-V

Bacteriological observations (MPN)

Filter Run No.	Bacteriological observations.			% removal of coliform by	
	Raw water	Settled water.	Filtered water.	Pretreatment.	Filtered.
1	1.5×10^3	110	0	92.66	7.34
2	9.3×10^2	230	36	75.27	20.86
3	4.6×10^4	2.4×10^4	750	43.48	54.89

Average reduction in coliform by :

1. Pretreatment : 70.47 %
2. Filtration : 27.70 %

6.4 DISCUSSION ON THE OBSERVATIONS ON THE RAMTEK TYPE PILOT PLANT STUDY.

6.4.1 Head Loss Observations :

i) Gravel bed prefilter : The head loss in the gravel bed prefilter was observed from 2 to 3 cm through out the runs and hence these are not included in the observations. At the end of day's run the gravel bed prefilter was drained for gravity flushing out action when all the sludge was seen to be completely removed. To collect all the sludge the gravel bed prefilter was drained twice after refilling with water. At the end, backwash was given to see if there is any remaining sludge, however it was observed there was practically no sludge remained after carrying out two gravity draining operations.

Normally one operation of draining at the end of day's run may be adequate in a prototype plant, when a full back wash can be given once a week, so as to have effective cleaning of the gravel bed prefilter. Such procedure has been already followed at the Ramtek and other treatment plants and was found to be effective.

ii) Dual media filter bed : From the headloss observations at various depths in the dual media filter bed it can be seen that the head loss in the crushed coconut shell media was between 30 to 40 % of the total head loss developed. It can also be seen that there is marked increase in the head loss between 35 to 45 cm depth, whihh is the top layer of the fine sand below the coconut shell media. The head losses in the sand depths at 55,75, and 95 cms also show the steep rise in the development of head loss.

6.4.2 Turbidity Observations :

i) Pretreatment : From the turbidity observations it is seen that the settled water turbidity was generally below 30 JTU. During the beginning of the plant the turbidity was slightly more and the reason for this may be the time required for the creation of the floc blanket in the gravel bed prefilter. This was clearly visible from the sides of the transparent model. The flexible sludge blanket thus created in between the voids of the gravels accelerates the flocculation process in the bed as there is continuous remixing of the floc particles along with the water flow in the upward direction. Thus the micro-floc particles created in the mixing channel, go on increasing progressively due to the increased contacts and remixing action in the bed and when the floc particles come out at the top of the gravel bed there is sudden drop in the velocity of flow of water due to the increased cross section area and there is a tendency for settling of the heavier floc particles. Thus a sludge blanket is created at the top of the bed and this blanket further accelerates the flocculation action by creating more surface contacts. The depth of the sludge blanket thus formed at the top of the gravel bed is required to be controlled by draining portion of the sludge through the sludge draining out let pipe provided just at the top of the gravel bed. There is further drop in the velocity at the gutter level which further accelerates the settlement action for the floc particles. The settled water thus flows above the gutter level to the dual media filter bed. The comparative observations in the removal of turbidity load are given in the Table 6-III. From this Table it is seen that the turbidity load removed during the pretreatment was about 78% while that during the filtration was about 22%.

The Ramtek filter is mainly designed for the treatment of low turbidity raw waters and turbidity of 100 to 500 units may come only for short periods during the beginning of the rainy season. Thus the removal of such turbidity load has been found to be very satisfactory by the simple gravel bed prefilter provided in the Ramtek treatment plant design. The results of the prefilter at Ramtek plant in the removal of the turbidity is far superior to the pilot plant results as given above due to the limitations in the pilot plant design and this aspect is fully discussed in the chapter 7.

ii) Filtration : When the settled water turbidity was in the range of 20 to 30 units, the filtered water turbidity was below one JTU. Here also the turbidity removal efficiency was increased after a period of two to three hours and the reasons for this are discussed in details in the chapter 5. The main reason for providing the dual media filter bed after the gravel bed prefilter is to share more load by the filter bed as the pre-treatment provided in this system is some what of lower efficiency purposely, to make the design as simple as possible. This aspect is fully discussed in the chapters 3 and 7 of this thesis.

6.4.3 Sludge Removal :

The sludge from the gravel bed prefilter and the dual media filter units was collected separately as discussed in details in the chapters 4 and 5 of this thesis. The sludge from the top of the gravel bed was removed separately at the end of each run so as to observe the percentage of sludge removed in the pretreatment. Further this sludge is generally removed during the running of the plant, when the turbidity of the raw water is on the higher side.

The sludge removed from the prefilter and filter units is shown in the Table 6-IV. From the results given in this table it is seen that the average percentage of sludge removed from the gravel bed prefilter was about 63% while the sludge from the dual media filter bed was about 37%. Further the sludge removed from the top of the gravel bed was about 10% of the sludge removed from the prefilter,while it is about 6% of the total sludge removed from the plant.

This shows that the sludge removed during the simple pretreatment process of gravel bed prefilter as provided in the Ramtek treatment process is quite satisfactory. From the comparative observations of turbidity removal as given in the Table 6-III, it is seen that the turbidity removal and sludge removal observations from the pretreatment and filtration are fairly comparable.

6.4.4 Bacteriological Observations :

From the bacteriological observations as given in the Table 6-V, it is seen that the average reduction in the coliform count in the pretreatment was about 70% while the same during the filtration was about 28%. This fairly compares with the actual plant scale performance of the Ramtek plant as discussed in the chapter 7 of this thesis.

6.5 DESIGN OF THE MURBAD TYPE PILOT PLANT.

6.5.1 Aim of Study :

After the completion of the Ramtek plant and observing its actual performance the author considered to modify some minor design aspects of the Ramtek plant so as to make it adoptable for the treatment of the moderate turbid water sources. During the observations of the performance of the Ramtek plant it was noticed that a portion of the fine floc from the gravel bed prefilter was passing to the top of the dual media filter bed. During higher raw water turbidity this may increase the load on the dual media filter bed.

In order to improve upon this aspect the author has designed the Murbad treatment plant. The changes proposed in the Murbad design includes creation of two separate chambers up to the top and to collect the settled water from the top of the prefilter through A.C. perforated collecting pipes and to introduce the settled water through these pipes in the side gutter of the dual media filter bed. In carrying out this change it was proposed to provide the side slopes for the walls from the inside of the prefilter bed, at 60° angle above the gutter level. The purpose was to reduce the velocity of approach towards the collecting pipes for giving better settlement effect. However at Murbad plant this modification was not adopted and vertical side walls are provided. The actual plant performance results of the Murbad plant are discussed in details in the chapter 11 of this thesis. In this chapter the performance of the Murbad type pilot treatment plant is studied so as to compare the same with the performance of the Ramtek type pilot plant, already discussed earlier.

6.5.2 Hydraulic Design of the Murbad Type Pilot Plant :

a) Gravel bed prefilter = One unit separate from the dual media filter unit.

i) Size of bed = 9.5 x 10.0 = 95.00 cm^2

ii) Depth of gravels = 170 cm

iii) Depth of water over the bed = 60 cm

iv) Total volume of gravel bed = 16,150 ml

v) Actual vol. of water upto the top of gravel bed. = 6300 ml

vi) Actual volume of gravels = 9850 ml (in wet condition)

vii) Porosity = 39% say 40%

viii) Number of gravels in the bed = 10,500

ix) . Mean dia of gravels = 1.47 cm.

x) Loading on the gravel bed = 7,150 $l/m^2/hr$ (as on Ramtek treatment plant)

xi) Flow rate on the bed = $\frac{7,150 \times 95}{100 \times 100}$

$= 67.90$ lit/hr.

$= 1,130$ ml/Min.

xii) Volumetric loading on the gravel bed. $= \frac{67.90 \times 10^6}{16,150}$

$= 4200$ $l/m^3/hr$.

xiii) Detention period in the gravel bed. $= \frac{6300 \times 60}{67.90}$

$= 5.5$ min.

b) Dual media filter bed : one unit separate.

i) Size of bed = 9.5 x 10.0 = 95 cm^2

ii) Flow rate on the bed = 67.90 lit/hr. (same as above)

iii) Surface loading on the bed = 7150 $l/m^2/hr$

iv) Depth of coconut shell media = 37 cm

v) Average size of the coconut shell media. = 1 to 2 mm

vi) Depth of fine sand media = 58 cm .

vii) Effective size of sand = 0.5 mm

viii) Uniformity coefficient = 1.5

ix) Depth of supporting gravels = 20 cm

x) Water depth over the bed = 120 cm.

6.6 EXPERIMENTAL OBSERVATIONS.

Even though the Murbad treatment plant is designed for the loading of 3500 $l/m^2/hr$ the pilot plant for the Murbad type treatment plant was tested for the same loading as fOr Ramtek plant for 7150 $l/m^2/hr$, so as

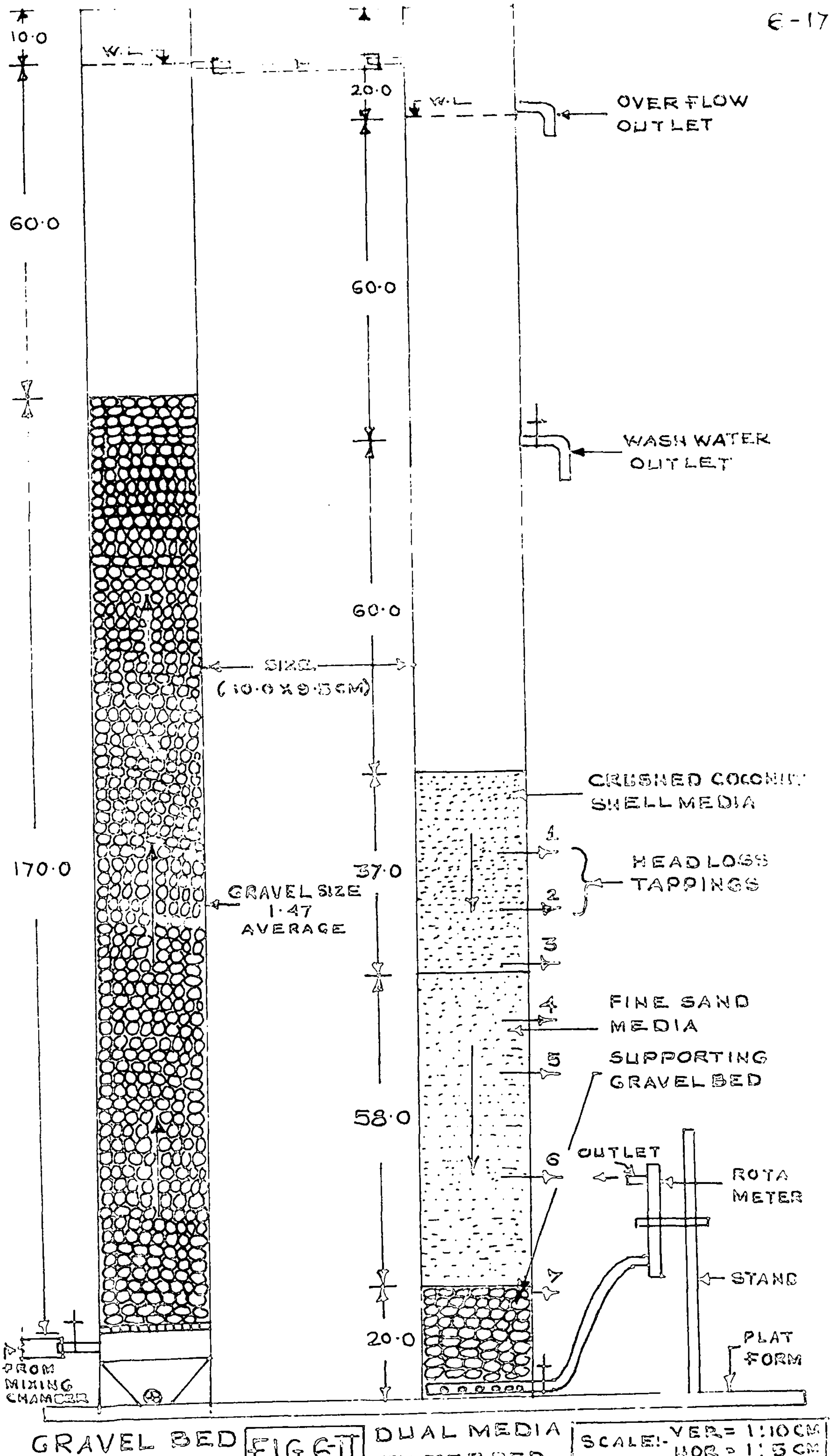


FIG. 6II

PILOT PLANT FOR MURBAD TYPE TREATMENT PLANT to compare the results of these two pilot plants.

The procedure for the pilot plant study and the observations, were the same as adopted for the Ramtek type pilot plant study as discussed earlier in this chapter.

6.6.1 Head Loss and Turbidity Observations :

Table 6-VI showing the observations carried out for the three sets of tests conducted for daily seven hours operation on the pilot plant are given below. Table 6-VII showing the removal of the turbidity load at different stages of the treatment plant is also given.

6.6.2 Sludge Removal at Every Stage :

The sludge load removed from the prefilter and the dual media filter units is given in the Table 6-VIII.

6.6.3 Bacteriological Observations :

The bacteriological observations of the raw settled and filtered water samples were carried out at the end of day's work. The results are given in the Table 6-IX.

TABLE 6-VI

Pilot plant observations on the Murbad type treatment plant.

Filter Run 1.

Hours of Run.	Head losses in the dual media filter bed at various depths (cm) 15	35	45	55	75	95	Turbidities. Settled.	Filtered.
0	0.0	1.0	3.0	4.0	6.0	9.0	-	-
1	0.5	1.5	3.5	4.0	7.0	10.0	40	0.5
2	1.0	2.0	4.0	4.5	8.0	11.0	20	0.5
3	1.5	2.5	4.5	6.0	9.0	12.0	20	0.5
4	2.0	3.5	5.0	7.0	10.0	13.0	20	0.5
5	3.0	4.5	7.0	8.5	12.0	15.0	20	0.4
6	4.0	5.0	7.5	9.5	13.0	16.0	20	0.4
7	4.5	6.5	9.0	11.0	14.5	17.5	20	0.4

Filter Run 2

Hours of Run.	15	35	45	55	75	95	Settled.	Filtered.
0	0.0	1.5	3.0	4.5	7.5	11.0	-	-
1	1.0	2.0	3.5	5.0	8.5	11.5	25	0.5
2	1.5	2.5	4.0	5.5	9.0	12.0	30	0.5
3	2.0	3.5	4.5	6.0	9.5	12.5	25	0.4
4	2.5	4.0	6.0	8.0	11.0	13.5	25	0.4
5	3.5	5.5	7.5	9.5	12.5	16.0	20	0.4
6	4.0	6.0	8.0	10.0	13.0	17.0	40	0.5
7	4.5	6.5	9.0	11.0	16.0	19.0	70	0.6

Filter Run 3

Hours of Run.	15	35	45	55	75	95	Settled.	Filtered.
0	0.0	1.0	2.0	3.0	7.0	9.0	-	-
1	0.5	2.0	3.5	5.0	8.0	10.0	40	0.5
2	1.5	3.0	4.5	6.5	10.5	13.0	35	0.5
3	2.5	4.0	6.0	7.0	11.5	14.0	40	0.4
4	3.5	5.0	7.5	9.0	12.5	15.5	40	0.4
5	4.0	6.0	8.0	10.0	14.5	17.0	35	0.5
6	4.5	6.5	10.0	11.5	15.5	18.5	35	0.5
7	5.0	7.0	10.5	12.5	16.0	17.0	35	0.5

TABLE 6-VII

Turbidity removal.

Filter Run No.	Pretreatment. Raw water JTU	Settled water JTU	% Removal.	Filtration. Filtered water JTU	% Removal
1	100	22.85	77.15	0.46	22.39
2	100	33.60	66.40	0.50	33.10
3	100	37.14	62.86	0.50	36.64

Average turbidity removal :

1. During pretreatment : 68.80 %
2. During filtration : 30.71 %

TABLE 6-VIII

Sludge Removal in the pilot plant study.

Filter Run No.	Volume of sludge removed in ml. From bottom of gravel bed.	Filter bed.	Total volume.	% of sludge removal. Prefilter bed.	Filter bed.
1	1850	465	2315	79.90	20.10
2	1710	950	2660	64.28	35.72
3	1430	820	2250	63.55	36.45
Average	1663	745	2408	69.24	30.76

TABLE 6-IX

Bacteriological observations (MPN)

Filter Run No.	Bacteriological observations.			% removal of coliform by	
	Raw water	Settled water.	Filtered water.	Pretreatment.	Filtration.
1	4.6×10^3	230	0	95.00	5.00
2	1.5×10^2	73	0	51.34	48.66
3	2.4×10^4	2400	0	90.00	10.00

Average reduction in coliform by :

1. Pretreatment : 78.78 %
2. Filtration : 21.22 %

6.7 DISCUSSION ON THE OBSERVATIONS ON THE MURBAD TYPE PILOT PLANT STUDY.

6.7.1 Gravel Bed Prefilter :

The turbidity observations of the settled water show the average removal of 69% and the normal settled water turbidity was in the range of 20 to 35 JTU. As compared with the results of the Ramtek pilot plant, the turbidity removal of Ramtek pilot plant was better than that of the Murbad pilot plant, The reason for this may be the more reduction in the upward velocity at the gutter level in the Ramtek plant as both the units are combined, with surface areas of both the units available at the gutter level. While in the case of Murbad pilot plant two units were separate and only area of prefilter is available at the outlet level at the top. Hence the upward velocity is more than that in the Ramtek plant and hence the turbidity removal in Murbad Pilot plant was on the lower side.

It is for this reason that the author proposes to provide slant side walls at about 60° angle so as to increase the surface area progressively as the water flows towards the perforated collecting pipes. Such a treatment plant has been constructed for the water supply to the colony of the Kandla Port Trust, near Jamnagar in the Gujrat State, The author feels that the actual turbidity removal of such a plant with slant side walls may be considerably improved even for moderate turbid raw water sources. However it is proposed to design such plants generally for the surface loading of 5000 $l/m^2/hr$ and only where the raw water turbidity is very low as at Ramtek, the loading may be adopted upto 7000 $l/m^2/hr$.

Regarding the sludge removal from the prefilter, the Murbad type pilot plant showed about 70% sludge removal, as against 63% in the case of the Ramtek type pilot plant. The increase in the sludge removal in the Murbad type plant may be due to the increased volume of the gravel bed and more storage capacity for sludge as compared to the Ramtek type pilot plant. For the same volume of gravels, the results may be similar to that of the turbidity removal as discussed above. Arrangement for the sludge removal from the top of the actual gravel bed of the Murbad plant is not made and hence in the pilot plant also it was not made.

6.7.2 Dual Media Filter Bed :

The dual media filter bed is similar in both the Murbad and Ramtek type pilot plants, and hence the turbidity removal in the dual media filter bed is equally efficient. The effluent turbidity was generally within 0.5 JTU. However as the sludge storage capacity was more in the prefilter of the Murbad type pilot plant the sludge removal was about 30% which is somewhat lower than that in the case of the Ramtek pilot plant where the sludge removal was about 37%. In both the Murbad and Ramtek type treatment plants even though the dual media filter bed is not a necessity, it is recommended to improve the general plant performance as discussed in details in the chapters 5 and 7 of this thesis.

6.7.3 Bacteriological Observations :

From the bacteriological observations as given in the Table, 6-VIII, it is seen that the average reduction in the coliform count in the prefilter was about 79% while the same during the filtration was about 21%. The coliform removal in the prefilter in Murbad pilot plant was somewhat better as compared to the same in the prefilter of the Ramtek pilot plant. This may be due to the more volume of gravel bed in the Murbad pilot plant as discussed above.

6.8 GENERAL CONCLUSIONS.

i) From the study on the Ramtek type pilot plant, it is observed that such a complete treatment unit may be a possible solution for adopting the design for the small capacity water treatment plants for the treatment of low turbidity water sources.

ii) The gravel bed prefilter may be a possible solution to replace the conventional pretreatment process for the treatment of low turbidity raw water sources for small capacity plants.

iii) The dual media filter bed is not a necessity in such units after gravel bed prefilter, however it is recommended for economy in the wash water use and general improvement in the treatment process. It will be specially useful to absorb the occasional loads of turbidities in the raw water.

iv) There is limitation in the use of the size of gravels in the pilot plant studies, as there is short circulation of water flow from the sides of the pilot plant. The smaller size gravels of about 10 to 15 mm dia. may give comparable results.

v) The study of the Murbad type pilot plant with separate chambers did not show special advantage over the combined units in the Ramtek plant. However with slant side walls to provide increasing surface area in the settling zone at the top of the prefilter, it may be possible to treat moderately turbid water sources by adopting surface loadings from 5000 to 7000 $l/m^2/hr$.

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CHAPTER 7

DESIGN AND EXPERIMENTAL OBSERVATIONS OF THE RAMTEK TREATMENT PLANT.

7.1 INTRODUCTION.

Ramtek is situated about 50 km from the Nagpur city on the National Highway 6 and is a famous prilgrim centre. The temples on the Ramgiri hillock near Ramtek are visited by more than a lakh of pilgrims during each fair season. Recently 'Kalidas Smark' has been constructed on this hillock, which is also an additional attraction for the visitors.

The present population of the Ramtek town is about 13,000 souls and the water supply scheme has been designed for 20,000 souls at the rate of 112 lit/head/day. The capacity of the filter plant is 2.4 mld (0.53 mgd) with the hourly pumping rate of 1,00,000 lit/hr. The source of the water supply is the Ramsagar irrigation tank near Ramtek.

Raw water for the water supply scheme is drawn from the main canal at about 500 m. down stream of the earthen dam and is then pumped to the hillock near Ambala village about three km. away, where the treatment works and ground service reservoir are situated. Filtered water is supplied by gravity from this reservoir to the Ramtek town.

The Ramtek water supply scheme was undertaken as a State Government Scheme which was estimated to the cost of Rs. 20,71,370/- gross. The original scheme was comprised of construction of a rectangular settling tank raw water pump house,pressure filters, pure water pump house, pumping main, ground service reservoir and distribution system. The tendered cost for the construction of the rectangular settling tank in the year 1971, was seen to be 75% higher than the estimated cost of Rs. 1,12,840/-. Considering the cost of pressure filters the total cost of the treatment plant would have gone above Rs. 4.0 lakhs. The cost of construction of a conventional treatment plants of 2.40 mld (0.53 mgd) capacity during the year 1972-73 in the Vidarbha region of the Maharashtra State was between 4.5 and 5.0 lakhs rupees.

Considering the lake water quality of average low turbidity nature, the author has submitted an alternative design of an unconventional high rate simplified treatment plant consisting of two units of gravel bed prefilters and two units of dual media filter beds, estimated to the cost of Rs. 1,25,000/-. Table 7-I showing the tendered costs received for the conventional treatment plants for the small capacity treatment plants in the year 1971-72 in the Vidarbha region along with the actual cost of construction of Ramtek filter is enclosed at the end for ready reference. From this table it can be seen that the cost of Ramtek filter was about 1/4 of the cost of a conventional treatment plant of the same capacity.

The then Chief Engineer (Public Health) and Joint Secretary to the Govt. of Maharashtra, has approved this new design and the author constructed the Ramtek plant within a period of six months in the year 1972-73 and the plant was put into commission from the March 1973. The details of the design and preliminary observations and further one year observations on the Ramtek filter are given in the papers (27)(28) presented by the author before the annual conventions of the Indian Water Works Association in the years 1974 and 1976 respectively. Copies of these papers are enclosed in the Appendix-D.

7.2 QUALITY OF THE RAW WATER SOURCE.

The Ramsagar irrigation tank is the source of the water supply scheme and the raw water is pumped from the canal just down stream of the dam to the treatment site. A few results of chemical analysis of the raw lake water samples are given in the Table 7-II, while the Bacteriological analysis results are given in the Table 7-III to get the general idea of the changes in the quality.

From this data it will be seen that the quality of the raw water source at Ramtek represents the category I, viz. : raw water of low turbidity and low pollution, as discussed earlier in the chapter 1 of this thesis. The Ramtek filter is mainly designed to treat this type of raw water sources.

7.3 THE DESIGN OF THE RAMTEK TREATMENT PLANT.

Following units are provided in the design of the Ramtek treatment plant.

i) Mixing Channel.

ii) Gravel bed prefilter units.

iii) Dual media filter units.

iv) Disinfection arrangements.

The details of the various dimensions for the Ramtek filter are shown in the drawing K-1 enclosed at the end of this chapter. The detailed design calculations are given in the Table 7-IV. The important design aspects of the main units are discussed below.

7.4 MIXING CHANNEL.

The simple way to provide assured mixing for such small capacity plants is by the baffled mixing channel. Various references for its design are given in the chapter 2.

The baffled mixing channel is provided on the two side walls of the treatment plant. The channel side walls of 23 cm thickness are provided for 0.5 m height. The baffles of Shababad stone tiles are fixed in these side walls at one metre centre to centre in the staggered way to accelerate the mixing of the chemical dose.

The length of the channel is about 16.0 m while the clear width from the inside is 0.64 m. The bed slope of 20 cm is given in three steps in the bottom concrete of this channel. This bed slope is important and the drop in the channel of minimum 15 cm to 30 cm is desirable to give proper mixing in the channel and to avoid flooding at the inlet end due to the head loss in the channel. The detention period in the mixing channel is about one minute. The alum solution and dosing tanks are provided on the top of the side wall of the filter unit at the inlet and side, as shown in the drawing.

7.5 GRAVEL BED PREFILTER UNITS.

7.5.1 Design Aspects :

The plant is devided by the central wall in-to two compartments. Each compartment has one gravel bed prefilter unit and one dual media filter unit. Both the prefilter units are of the same size and details for one unit are given below.

The length and width of each gravel bed is 3.5 m x 2.0 m, with the depth of 2.0 m upto the top of the wash water gutter level. At the bottom of the bed, central M.S. manifold of 300 x 200 mm. size and perforated laterals of 50 mm G.I.pipes are provided at 20 cm centres on both the sides of the manifold. The perforations of 6 mm dia holes are provided at 50 mm centre to centre at 90° angle in the staggered positions at the bottom sides of the laterals. The manifold and laterals were fabricated outside and were then fixed in the bottom of the beds. Manifold is fixed in the bottom concrete in such a way that only 10 cm portionwas kept over the bed, in which side laterals were fixed by welding collers to the manifold.

7.5.2 Gravel Size and Depth :

The gravels of rounded shape and of 50 mm to 10 mm size were provided for 1.70 m depth over the bed and keeping 0.30 m clear space at the top for floc collection and withdrawal. It was difficult to get the gravels of uniform size and hence all the gravels were sorted into four sizes and were then provided as shown in the drawing K-1.

7.5.3 Floc Draining Arrangements :

At the top of the gravel bed, sludge draining perforated pipe assembly is provided. One 75 mm dia pipe with side perforated laterals of 50 mm dia and with 10 mm dia perforations were provided at 50 mm centres on the both sides at the centre for draining out the sludge collected at the top by hydrostatic pressure. The outlet valve for the sludge draining arrangement is provided in the control room of the filter. The filter operator can operate this valve periodically by visually observing the colour of the flow of the sludge through the same. This has to be operated mainly in the rainy season when the turbidity is high and so the sludge collection is also high at the top of the gravel bed.

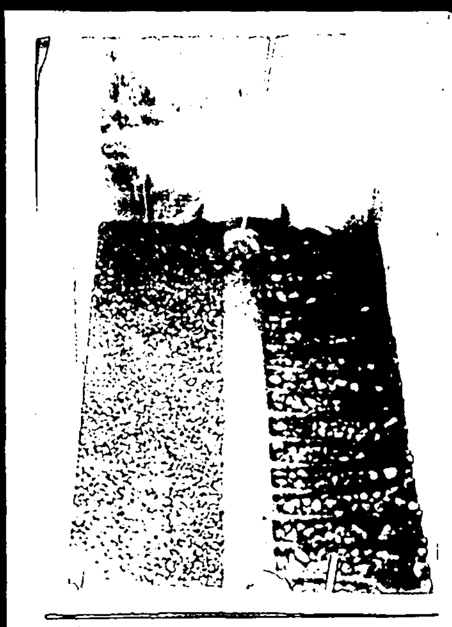
7.5.4 The Direction of Flow :

The direction of flow in the gravel bed is upward and the settled water from the top is taken on the dual media filter bed. Wash water gutters are provided 30 cm above the gravel bed top, on all the four sides.

7.5.5 Cleaning :

The cleaning of the gravel bed is possible by introducing back wash flow as given to a rapid sand filter bed. Cleaning is also possible by gravity flushing out action of the gravel bed with the water stored on the top of the filter beds, through the under drain system. This can be done by opening the outlet valve and taking the wash water to the waste with the arrangements provided for the same. However for periodic effective cleaning, back wash arrangement is provided.

PHOTOPLATE 7-I



TOP

View of the Ramtek treatment plant, with wash water tank at the left from the top of the hillock.

MIDDLE

Bottom view of the dual media filter bed showing under drainage system and supporting gravel bed under filling operation.

BOTTOM

Crushed coconut shell media from bags is being placed in the dual media filter bed.

7.5.6 Theory Behind the Gravel Bed Prefilter :

The prefilter bed in this unit has been provided in place of the conventional flocculation and settling tank. The graded gravel bed acts as an accelerated flocculation unit in which there is ideal condition for continuous remixing of the water in the upward direction. When the raw water after mixing of the alum dose in the baffled mixing channel, is introduced at the bottom of the gravel bed, through the under drain system, the fine microfloc in the water is continuously mixed around the numerous passages around the rounded gravels provided in this bed. The surface area provided by these gravels accelerates the flocculation action in these conditions. The velocity through these numerous passages may be two to three times the flow through velocity of 7 m/ hr. just at the top of the gravel bed. In this condition most of the floc particles when reached to the surface of the bed drop down, when there is sudden drop in the velocity. Further at the gutter level there is further sudden drop in velocity to about 3 m/ hr, and there is further drop down of the remaining floc in the water flowing in the upward direction. Thus most of the floc settles down on the gravel bed and only the fine floc particles are carried further on the dual media filter bed.

In order to absorb somewhat higher floc load, as compared to a clarified water through a convention pre-treatment works, the filter unit provided here is of the dual media type with a layer of coarse media of crushed coconut shell at the top of the fine sand media.

The normal rapid sand filter may get clogged up in a short time with such a type of settled water and it is for this reason the dual media filter bed is provided after the gravel bed prefilter unit.

The author considers that the idea of gravel bed prefilter as adopted in the Ramtek plant may be a new concept in the field of filtration. Due to this new concept only, it was possiblo to design such a "Complete filtration plant" at Ramtek. However further research on this new process is necessary so as to evaluate its most economical use in the field of filtration.

7.6 DUAL MEDIA FILTER BEDS.

7.6.1 Design Aspects :

As explained in the earlier para there are two units of dual media filter beds in the two compartments of this treatment plant. The settled water from the pre-filter bed is introduced from the top on this bed and the direction of floc is downward as in a rapid sand filter bed.

The leggth and width of each bed is 3.5 m x 2.0 m, with the depth of 2.0 m upto the wash water gutter level. The size is the same as provided for the gravel bed pre-filter units. At the bottom of the bed the under drain arrangements are provided in the same way as described in details under the earlier para for prefilter bed design.

7.6.2 Filter Media :

The filter media consists of crushed coconut shell coarse media of 35 cm depth over the fine sand media of 55 cm depth. This media is supported at the bottom by a graded gravel bed of 50 cm thickness over the under drainage system at the bottom. The effective size and the uniformity coefficient of the crushed coconut shell media are 1.45 mm and 1.47 respectively, while for the fine sand media, the valves are 0.45 mm and 1.5 respectively.

The area of each bed is 7.0 sq.m. and the rate of flow during filtration is 7,150 $l/m^2/hr$ for the hourly pumping rate of 1,00,000 lit/hr and the plant capacity of 2.4 mld. The other design details are shown in the Table 7-IV.

7.6.3 Washing of Filter Beds :

The washing arrangement is provided by a high velocity hard back wash. Desired expansion of both the media is achieved between 30% to 50% during the back washing. The filter bed gets clean effectively during this back wash within about 6 to 7 minutes time. This can be seen from the initial head loss observations, when the filter bed is again put into operation. A masonry wash water tank of 50,000 lit. capacity is provided near the filter plant for this purpose. The back wash is givan when either the head loss is reached to its limiting value of 2.0 metres or there is break-through and the turbidity of the effluent is seen above one unit.

7.6.4 Rate Control.

The rate of flow through the filter bed is controlled by a manually operated sluice valve and the operator can control the rate by watching the flow over a 'V' notch in a separate chamber provided in the control room as shown in the drawing K-1. There is arrangement for adjusting any flow from any of the two beds by adjusting the outlet control valves. All the piping is of cast iron of dia 225 and 250 mm as per availability at the time of construction. The filtered water is disinfected with a dose of liquid chlorine in the outlet control chamber and then the water is stored in the ground service reservoir just by the side of the control room, from where it is supplied to the town. As the automatic rate controlling arrangements are very costly for such small capacity plants, these have not been provided.

7.6.5 Head Loss Measuring Arrangements :

The head loss measuring arrangements are provided by plastic tubing showing water levels in the filter bed and before the outlet control valve. In addition to these, perforated pipe probes are provided at various depths in the filter media as shown in the figure 7-I for observing the head losses at various depths in the filter media. All these observation tubes are fixed on the outside wall of the filter bed in the control room.

7.6.6 The Theory behind the Dual Media Filter Bed :

The theoretical aspects in the design of dual and multi-media filter beds are now well accepted and important theoretical aspects are discussed in the chapter 2, from the various references from the literature.

The principal advantage in the dual and multi-media filter beds with the use of coarse size media at the top of fine sand media, is the increase in the sludge storage capacity in the filter bed itself and there by distributing the head loss uniformly in the filter bed. Due to this advantage either the length of the filter run can be considerably increased or the rate of flow through the filter bed can be increased.

However the new approach in adopting the dual media filter bed after the gravel bed prefilter unit at the Ramtek plant, is to share more load in the total filtration process as compared to the conventional rapid sand filter. In the Ramtek filter the gravel bed prefilter is somewhat lower in efficiency in the removal of suspension load as compared to a conventional pretreatment, and there may be some more load of floc on the filter bed. However this lower efficiency in the removal of turbidity is compensated by providing a more stable dual media filter bed so as to make good the total filtration process, by sharing more load by the dual media filter bed.

In this respect Ives (19) in his paper on " "Theory of filtration " has explained the various theoretical aspects of the dual and multi-media filters. At the end of his paper he has given in the value of theory, the possible application of various theories for the future research in the field of filtration. Under the item 5, of this para he has stated that together with mathematical models of other unit processes of water treatment the relative role of each treatment can be assessed and economic load showing can be planned. As an example of his statement he says "should flocculation sedimentation achieve most of the clarification leaving filtration to treat the residuum, or should the efficiency of flocculation sedimentation be deliberately reduced to make filtration play a greater part, or can either process be dispensed with entirely".

7.7 DISINFECTION ARRANGEMENTS.

Liquid chlorine dosing equipment manufactured by M/s Aqua Pura Co. Poona, has been provided. This is simple for operation and it is provided in the control room just near the control chamber. Alternative arrangement of bleaching powder solution and dosing arrangement can be provided as a stand by measure when either the liquid chlorine is not available or the dosing arrangement is out of order.

7.8 COST OF THE RAMTEK PLANT.

Actual cost of construction of the Ramtek treatment plant was Rs. 1,25,000/- which was constructed in the year 1972-73. These works include following main items.

		Rs.
i)	Construction of filtration plant as per drawing K-1.	90,000/-
ii)	Construction of masonry wash water tank of 50,000 lit. capacity.	20,000/-
iii)	Providing duplicate sets of wash water pumping sets.	10,000/-
iv)	Aqua-pura chlorination equipment.	5,000/-
	Net Total Rs.	1,25,000/-

7.9 APPROACH TO THE EXPERIMENTAL STUDY ON THE RAMTEK TREATMENT PLANT.

The purpose of the on-plant experimental study on the Ramtek treatment plant was to find out the actual performance of such a new filter unit for the treatment of low turbidity raw water sources. Further it was also necessary to find out the actual difficulties faced in the maintenance of such an unconventional treatment plant so as to improve it further.

With the above mentioned purpose all the possible observations at the filtration rates for 9650 $l/m^2/hr$ and 7150 $l/m^2/hr$, were carried out on the dual media filter bed 1, which are given in this chapter. For want of proper control for the diversion of flows in the prefilter units the prefilter units were operated only for the rate of 7150 $l/m^2/hr$. The remaining flow after diverting the required flow from the filter bed 1, was directed through the dual media filter bed 2.

To get representative results, the desired filtration rates were continued for a long period and the observations for the same were conducted for one year for each rate of filtration as given in this chapter.

These, observations include, headloss, turbidity bacteria removal, wash water use, the general performanced of the prefilter units and the dual media filter units with special reference to the new filter media of crushed coconut shell, which was adopted in the dual media filter bed for the first time in the world.

7.10 OBSERVATIONS ON THE RAMTEK PLANT.

The filter bed 1 was first run for a filtration rate of 9650 $l/m^2/hr$ for one year period. This filter bed was then run for the designed rate of 7150 $l/m^2/hr$ for one year and plant observations for both these rates are given in this chapter.

7.10.1 Unexpected Conditions Due to Severe Drought of 1972 and Plant Observations :

Due to the unprecedented drought in the Maharashtra State during the year 1972, the new filters had to be tried under abnormal conditions of the raw water quality. The Ramsagar tank, the source of water supply, was almost dry in the month of May 1973. The dead water in the tank, below the canal outlet level was required to be pumped into the canal and then further pumped to the treatment plant. The tank water some times showed green colour due to profuse algal growth and due to this unusual condition the filter was run at a lower rate of 2000 $l/m^2/hr$. Both pre and post chlorination was adopted, and safe drinking water was supplied to the town.

As it was not possible to pump tank water by the end of May 1973, a well was dug on the down stream side of the tank as a scarcity measure and highly turbid water (of 500 to 2000 JTU) obtained during the well sinking operation was pumped to the treatment plant. With the filtration rate of 4500 $l/m^2/hr$ it was possible to obtain effluent of acceptable quality, with turbidity less than one unit. This was continued till the end of July 1973 when the tank got replenishment due to rains. Tank water was pumped to the plant from the beginning of the August 1973. The raw water was highly turbid (500 to 1000 JTU) at the commencement. The turbidity was reduced below 500 JTU from September 1973. All these observations are explained in details in the author's paper (27) copy of which is enclosed in the Appendix-D. There after when the filter beds were tried for higher rate of filtration of 9650 $l/m^2/hr$, the effluent showed higher effluent turbidity above one unit in a short time. On carrying out further investigations about the actual sand media size, it was revealed that the screening of the sand media was not done properly and course sand media of e.s. 0.5 mm and uniformity coefficient of about 2.5 was actually placed by the contractor. Both the media were taken out and screened properly and the required size of media was replaced properly only in the filter bed 1.

7.10.2 Precautions during Relaying the Media :

During relaying of the media the depth of fine sand was kept as 55 cm with e.s. as 0.45 and uniformity coefficient as 1.40. The crushed coconut shell media was placed for 35 cm thickness, having effective size 1.44 mm and u.c. as 1.47, over the sand.

Before placing the crushed coconut shell media, care was taken to give 5 to 6 back washings to only fine sand bed and to remove the very fine sand particles by scrapping the top of bed. This was done to avoid mixing of very fine sand grains with the upper coconut shell media as discussed in the Chapter 2. The mixing of fine sand in coconut shell media was also observed while taking out the original media for replacing the same after proper screening.

Other precaution which was taken before commencing the dual media filter was to soak the crushed coconut shell media for 24 hours in the filter bed and then to give 5 to 6 back washes to the bed so as to remove all the fines and colour of the water due to the coconut shell media. Heavy dose of chlorine was also given for a week so as to treat any bacterial growth remained in the coconut shell media. With these precautions there was no trouble of taste,colour or bacterial growth in the filtered water.

7.10.3 Trial Observation :

Trial observations were taken on the modified filter bed 1, and it was seen that the filter can easily take desired higher load of 9650 $l/m^2/hr$ and hence the filter bed 1 was operated to the higher rate of filtration of 9650 $l/m^2/hr$ from 1/5/1974 continuously for taking one year observations on the same. The remaining flow was diverted from the filter bed 2, which was not modified and not corrected as explained in the earlier para. The filter bed 1 was then run for the designed rate of filtration of 7150 $l/m^2/hr$ continuously and all these observations are given in this chapter.

7.10.4 Observations for the Filtration Rate of 9650 $l/m^2/hr$ for One Year :

In this study the filter bed 1 was run for a filtration rate of 9650 $l/m^2/hr$ and the actual plant observations are given in the Table 7-V for the period 25/5/1974 to 30/5/1975. During this study it was not possible to change the rate of flow through the prefilter beds and hence rate of flow through the prefilter was kept as 7150 $l/m^2/hr$.

i) Observations of Head Losses at Various Depths :

Arrangements for measuring the head losses at various depths in the filter media were made by introducing perforated probes in the filter media as shown in the Fig. 7-I. These probes were made of perforated 12 mm dia G.I. pipe and wrapped by a fine brass mesh of size smaller than 0.3 mm so as to avoid choking by sand particles. These probes were introduced 30 cm in-side the bed at various depths. These probes were washed by flushing out the water inside the bed for cleaning of any floc accumulated in the brass mesh.

Typical observations for one filter run for head losses at various depths are shown in the Table 7-VI.

The Fig. 7-II shows the development of total head loss in the filter bed 1 for two typical runs. The Fig. 7-III shows the development of head losses in the filter bed 1 at various depths. The Fig. 7-IV shows the development of head loss in the two filter media in the dual media filter bed 1.

ii) Observations for Intermittent Operations :

All these observations were collected not for full and continuous filter runs, but these were collected for the intermittent runs as per the actual demand of the water supply for the town. The main reason for such observations was all such small capacity plants are designed for the ultimate working of 16 hours and are operated between 8 to 16 hours daily as per actual requirements. It was therefore decided to conduct the actual plant scale observations in such normal intermittent operation conditions. As the demand of the Ramtek town was between 5 to 10 lakhs litres per day, there would have been a very large waste of filtered water even if the filter bed was to run continuously for a few experimental runs. This can be seen from the table 7-V as the average filter run was found to be 88 hours while the maximum runs were for 200 hours in the day to day intermittent operation.

iii) Bacteriological Observations :

Bacteriological observations for raw, settled filtered and chlorinated water samples are given in the Table 7-III.

7.10.5 Observations for the Filtration Rate of 7150 $l/m^2/hr$

In this study the filter bed 1 was operated for the designed filtration rate of 7150 $l/m^2/hr$ continuously from 22/4/1976 onwards. The actual plant observations are given in the Table 7-VII for the period 22/4/1976 to 1/5/1977. Both the gravel bed prefilters and dual media filter beds were run for the same designed rate of 7150 $l/m^2/hr$ during this study.

The same precedure was adopted as explained in the para 7.10.4 for running the prefilter and filter beds and recording the plant observations.

i) Observations of Head losses at Various Depths :

As already explained in the para 7.10.4 the headloss observations at various depths in the filter media were collected and these are given in the Table 7-VIII. The Fig. 7-V shows the developments of total head loss in the filter bed 1 for two typical runs. The Fig. 7-VI shows the development of head losses in the filter bed at various depths. The Fig. 7-VII shows the development of head loss in the two filter media in the dual media filter bed 1.

7.11 PERFORMANCE OF THE GRAVEL BED PREFILTER.

As per design conditions the total flow was equally diverted through both the prefilter beds the loading being 7150 $l/m^2/hr$. As there was negligible head loss through the prefilters, observations for head losses were not recorded. The important observations on the performance of the gravel bed are discussed below.

7.11.1 Turbidity Removal :

From the turbidity removal from the Table 7-V, it is seen that the turbidity after the treatment through prefilter generally reduced to below 25 units. The working of the prefilter is simpler than a sludge blanket process. However as the filters were run for a short period from 4 to 6 hours a day as per actual demand of water to the town, the floc formed in the gravel bed was disturbed due to the frequent closings of the filter beds. The result of this was that some increased floc was noticed in the settled water at the beginning of each run. To avoid this trouble, the prefilter bed was desludged for 2 to 3 min, after every run to remove the sludge formed in the bed. This was found necessary particularly when the raw water turbidity was more than 50 to 100 units, as during low turbidity period this trouble was not seen.

7.11.2 Sludge Draining from the Top of the Prefilter Beds :

This is an important operation in the prefilter units. The sludge at the top was generally drained out through the special perforated pipes provided at the top of the prefilter bed. The sludge collected on the gravel bed can be observed visually and can be drained out periodically with the hydrostatic pressure within 3 to 4 min. by opening drain valve in the control room. The sludge draining was generally required when raw water turbidity was above 30 units and when the alum dose was given in required quantity.

7.11.3 Cleaning of Prefilter :

This is also the other important operation of the prefilter for its proper functioning. The prefilter beds were generally cleaned at the end of the day's operation by gravity desludging process by hydrostatic pressure with the water available on the bed. The back wash arrangements were provided for the prefilter beds similar to the dual media filter beds, however the back wash to the prefilter beds was given occasionally to varify the thorough cleaning of the prefilter beds. Normally the gravity desludging operation was found adequate to remove the sludge collected in the gravel bed through the under drainage system. The full back wash can be given once in a month during low turbidity period and once in a week when the turbidity is high, to ensure clean bed.

7.11.4 Floc Passing on the Dual Media Filter Beds :

It was observed that some floc was passing from the prefilter bed to the top of the dual media filter beds. However due to this effect there was no appreciable increase in the head loss in the filter bed as can be seen from the head loss observations given in the Table 7-V. The floc settledat the top of bed may be forming a layer of thick blanket at the top of the filter bed and it is felt that this blanket may be increasing the period of the filter runs, as this may be absorbing portion of floc without increasing the head loss in the bed.

However to reduce the floc passing on the dual media filter beds, the side walls of the prefilter beds can be provided slanting at 60° angle from inside. The battered side walls will increase the surface area progressively up to the water level, thereby reducing the approach velocity as the water will flow in the collecting gutters or perforated pipes at the top water level. This may improve the actual performance of these prefilter beds.

7.11.5 Comparison of the Performances of the Pilot Plant and Actual Plant Prefilter Beds :

From the actual comparison of the performances of the pilot plant prefilter unit for the similar conditions, it was observed that the performance of the prefilter unit of the Ramtek plant was considerably superior to that of the pilot plant. Due to this effect the overall plant performance of the Ramtek plant was found superior to the performance of the pilot plant unit. The results of the pilot plant study are given in the chapter 6, from where it can be seen that turbidity after gravel bed unit was considerably high as compared to the turbidity after prefilter at the Ramtek plant. The probable reasons for this difference in the performances are discussed below.

a) In the pilot plant the surface area at gutter level was 100% more than that of the prefilter bed area. While in the Ramtek filter the surface area at the gutter level is 260% more as compared to the surface area of the gravel bed. Due to this effect there may be some better performance of the prefilter unit in the removal of floc particals in the Ramtek plant as the reduction of velocity at gutter level is much more than that in the pilot plant.

b) The other important reason may be the ratio of the perimeter of the bed to the dia of the gravels. For the pilot plant the ratio was $\frac{40}{1.5} = 26.5$, while for the Ramtek plant the ratio was $\frac{11 \times 100}{2} = 550$. Thus the ratio for Ramtek plant is about 20 times more than that of the pilot plant and this may be important factor for giving better performance of the prototype gravel bed prefilter at Ramtek.

c) Similarly the ratio of the area of the prefilter bed to the average dia of the gravel can be seen. The ratio for the pilot plant was $\frac{100}{1.5} = 66.70$ where as for the Ramtek plant, it was $\frac{3.5 \times 2 \times 100 \times 100}{2} = 35000$.

This may also be an important factor for giving better efficiency of the prototype gravel bed prefilter.

Due to the above reasons the flow through the sides may be considerably more due to least resistance in the pilot plant as compared to the prototype plant and therefore the flocculation action is more effective in the prototype gravel bed prefilter.

7.11.6 The Headloss in the Prefilter Bed :

The head loss in the prefilter bed at Ramtek was found to be negligible which was between 3 to 5 cm and there was little increase in head loss, when the plant was run continuously for 6 to 8 hours. Hence its observations were not kept in this study.

7.11.7 Bacteriological Observations :

From the bacteriological results it is seen that there is considerable reduction in the bacterial load in the prefilter as shown in the Table 7-III. Thus the gravel bed is a very simple process to give satisfactory pretreatment before filtration. The author has therefore proposed to name it as "pre-filter". As compared to the conventional pretreatment unit this gravel bed prefilter is a cheaper and simple process which can be adopted for small capacity treatment plants in the rural and semi-rural areas for the treatment of raw water with moderate turbidity upto 500 JTU and occasional load of 1000 JTU. Further on-plant study on this process may reveal more information on the design criteria of its loading capacity, depth, size of gravel, washing etc. and any limitations of the plant capacity in its adoption.

7.12 PERFORMANCE OF THE DUAL MEDIA FILTER BEDS.

As compared to the use of gravel bed prefilter, the adoption of a dual media filter bed is an accepted process. What is specially done in this dual media filter bed is the use of crushed coconut shell as a coarse media over fine sand, which may have been adopted for the first time in the field of filtration. The important observations on the performance of the dual media filter beds are discussed below.

7.12.1 Observations on the Dual Media Filter Bed 1 for Filtration Rate of 9150 $l/m^2/hr$:

a) Length of filter runs.

As seen from the Table 7-V, there were 10 numbers of filter runs during the observation period of one year. The maximum length of run was 200 hours for two numbers of runs, while the average run was for 88 hours. Out of 10 filter runs, two runs were closed earlier for demonstrating working operation to the visitors. The increase in the length of runs of the filter bed was mainly due to the dual media filter bed and the average low turbidity of raw water. Even with the unconventional and rough (lower efficiency) pretreatment provided for this filter units, the increase in the average filter runs is certainly a point for further research.

b) Head loss observations.

From the head loss observations (Table 7-V) it will be seen that the head loss development in the filter bed was more when the raw water turbidities were on higher side, while with low turbidities the rate of development of head loss was considerably low. Head loss observations in the filter media at various depths were made through the perforated probes provided in the filter bed 1. One such typical observation during the study for one filter run is shown in the Table 7-VI, while Fig. 7-II to 7-IV, show the head loss developments in the filter bed in the different conditions. The Fig. 7-II shows the head loss development in the filter bed against the hours of run. The graph shows the uniform increase in the total head loss in the dual media filter bed. The Fig. 7-III shows the head loss development at various depths in the filter bed. The curves show the peculiar development of head loss in the coconut shell and sand media. The Fig. 7-IV shows the typical head loss developments in the crushed coconut shell and the fine sand media. All these graphs show the uniform development of head loss throughout the dual media filter bed, and this may be the main reason for the increase in the length of the filter runs.

c) Turbidity observations.

Table 7-V shows the turbidity removal efficiency of the dual media filter bed, even for the higher rate of filtration. The turbidity of the filtered water was maintained below one unit through out all these filter runs. It was also observed that with the development of the head loss the turbidity was also steadily increasing and for the maximum allowable head loss the turbidity was also just below one unit. This shows that the filter bed performance was in the optimum condition.

d) Back wash observations.

The filter beds were washed only by hard washing. As shown in the Table 7-V, the consumption of the wash water was only 0.85 % of the total filtered water from the filter bed 1. The expansion of the filter media during the back washing operation was generally observed between 30 to 50% of the total bed thickness and the filter bed was found to be effectively cleaned as seen from the observations of the initial head losses after washing, as given in this Table 7-V. The expansion of the fluidised media in the filter bed was measured by an expansion stick, one metre length to which small cups were fixed at 10,20,30,40 and 50 cm.

e) Performance of the crushed coconut shell media.

The crushed coconut shell media was used for the first time for high rate dual media filter beds at Ramtek and the general performance of the media was found very satisfactory from the results given in the Tables 7-V, 7-VI and 7-VIII. There is no sign of deterioration of this media after its use in the dual media filter bed for a period of five years at Ramtek filter. The other aspects of quality and comparison with other media are also discussed in the chapter 5 of this thesis.

7.12.2 Observations on the Dual Media Filter Bed 1 for the Filtration Rate of 7150 $l/m^2/hr$:

The details of observations for the higher rate of filtration are given in the above para. Hence only additional important observations are given below when the filter was run for the filtration rate of 7150 $l/m^2/hr$.

a) Length of filter runs.

As sëen from the observations given in the Table 7-VII, there were 12 Nos. of filter runs during the observation period of one year. The maximum length of filter run was 200 hours while the average filter run was for 140 hours. The increase in the average filter run from 88 to 140 hours was mainly due to the lower rate of filtration for the second series of observations.

b) Head loss observations.

The general head loss observations are given in the Table 7-VII. The head loss development in the filter media at various depths as observed through the perforated probes in the filter bed 1 are shown in the Table 7-VIII for a typical filter run from 6/7/1976 to 13/8/1976. Fig.7- V to 7-VII show the head loss developments in the filter bed 1 in the different conditions. All these graphs show the uniform development of head loss through out the dual media filter bed as already discussed in the para 7.12.1.

c) Turbidity observations.

Table 7-VII shows the turbidity removal efficiency of the dual media filter bed. It was also observed that with the development of the head loss the turbidity was also steadily increasing and for the maximum head loss the turbidity was also just at one unit. This also shows that the filter bed performance was in the optimum condition even for larger filter runs of the filter bed.

d) Back wash observations.

As shown in the Table 7-VII, the consumption of the wash water was only 0.7% of the total filtered water from the filter bed 1. The hard back wash as given to the filter bed 1 was found quite satisfactory as can be seen from the initial head losses after washing in the Table 7-VII.

7.13 MAINTENANCE OBSERVATIONS ON RAMTEK PLANT.

From the plant scale observations as discussed in this chapter it is seen that the Ramtek filter is giving very satisfactory performance. Due to the simplicity in the day to day operation particularly in alum dosing, filter rate control, back washing and disinfection arrangement, one operator with one Chowkidar-cum-labour can maintain the filter plant efficiently as can be seen from the performance. The operator is of S.S.C. standard level and was trained at site for chemical dosing and filter rate control and washing operations. He maintains the register for day-to-day observations at the filter plant. Further he can measure turbidity of raw, settled and filtered water and collects and sends the water samples regularly for chemical and bacteriological analysis. He also runs the electrically operated pumps for filling the back wash tank when required. Due to all these simplified arrangements provided at the Ramtek plant the maintenance of the plant is trouble free, efficient and considerably cheaper as compared to a maintenance of a conventional plant of the same capacity.

7.14 GENERAL CONCLUSIONS.

i) From the actual pilot and plant studies at the new treatment plant at Ramtek it is observed that such a simplified treatment plant may be a possible solution for the development of simple and cheap treatment plants for rural areas and small communities in the developing countries.

ii) Gravel bed prefilter may be a promising process to replace the conventional pretreatment units when dealing with the raw water of low turbidities.

iii) For rural and small capacity water supply schemes, when the raw water turbidities are generally low, with the occasional increase in turbidity upto 500 units during rainy season, slow sand filters without pre-treatment may not be suitable for adoption. The conventional treatment plants consisting of mechanical mixing, flocculation, settling tank and rapid sand filter may be generally very costly for such small capacity treatment plants. In such situation, Ramtek plant may be a proper solution for providing very cheap and simple treatment facility for the small capacity plants.

iv) Crushed coconut shell media has shown very satisfactory results in the dual media filter units at Ramtek, without showing any sign of deterioration of the media for a period of five years in the filter beds at Ramtek.

v) The capital costs of such small capacity plants, may be in the range of 25% to 50% of the actual costs of the conventional treatment plants for the same capacity.

vi) Further research in the design of gravel bed prefilters is considered necessary so as to adopt such simplified treatment plants for higher raw water turbidities.

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TABLE 7-I

A comparative statement showing the accepted tendered costs for the conventional treatment work in the Nagpur P.H. Circle against the cost of construction of simplified filter at Ramtek.

(Period : 1971 to 1973)

Sr. No.	Name of scheme and year of construction.	Main components of the treatment plants.	Capacity of plants.	Tendered costs.
1	2	3	4 mld	Rs. 5
		CONVENTIONAL TREATMENT PLANT.		
1.	Saoner Water Supply Scheme. (1971)	Vertical flow hopper bottom settling tank, rapid sand filter, chemical house, sump, drainage arrangements (without wash water tank and pumps)	1.90	2,49,400/-
2.	Murtizapur Water Supply Scheme. (1973)	Aeration fountain, mixing channel, two vertical flow settling tanks, two filter units, chemical house, sump, pump house. (Without wash water tank and pumps)	2.50	4,91,000/-
3.	Pandharkawads Water Supply Scheme. (1971)	Aeration fountain, baffle mixing channel, vertical flow settling tank, pressure filter (back wash from existing E.S.R. near T.W.) pure water pumping machinery.	1.68	2,90,650/-
4.	Mohapa Water Supply Scheme. (1973)	Aeration fountain, baffle mixing channel, vertical flow settling tank, pressure filter, wash water tank. (Pure water sump already exists.)	1.09	2,14,570/-

1	2	3	4	5
5.	Balapur Water Supply Scheme. (1975)	Aeration fountain, baffle mixing channel, hopper bottom settling tank, filter, sump and pump house, (without wash water tank and pumps).	3.5	3,83,400/-
6.	Washim Water Supply Scheme. (1975)	Aeration fountain, flash mixer, hopper bottom settling tank, filters, sump, pump house, (without wash water tank and pumps).	5.75	7,95,000/-
7.	Desaiganj Water Supply Scheme. (1973)	Aeration fountain, flash mixer, clari-flocculator, filter (without wash water tank and pumps).	2.16	3,98,500/-
		UNCONVENTIONAL TREATMENT PLANT.		
8.	Ramtek Water Supply Scheme. (1972)	Aeration fountain, mixing channel, two units of gravel bed prefilters and open bed simplified filters, chloronome, including masonary wash water tank, wash water pumps etc. complete.	2.40	1,25,000/-

TABLE 7-II

Results of the chemical analysis of the raw water samples at Ramtek

Description of Tests (in mg/lit.)	21/4/73	12/6/73	21/12/73	22/3/74	1/10/76.
1. pH.	7.9	7.2	7.8	8.4	8.0
2. Total solids	165.0	200.0	125.00	120.0	160.0
3. Iron	Nil	Nil	Nil	Nil	Nil
4. Chlorides	54.0	28.0	14.0	20.0	10.0
5. Nitrites.	Nil	Trace.	Nil	Nil	Nil
6. Nitrates	6.3	1.2	2.4	4.5	--
7. Total Hardness	72.0	120.0	80.0	68.0	54.0
8. Perm.Hardness	13.0	16.0	15.0	20.0	Nil

NOTE :- These tests were conducted at the Govt. Public Health Laboratory, at Nagpur.

TABLE 7-III.

Bacteriological results of raw settled and filtered water samples at Ramtek

Period : 22.5.74 to 24.1.77.

Date of collection of sample.	MPN of raw water	MPN of settled water	MPN of filtered water	MPN of Tap water	% Removal only from dual media filter.
22/5/74	+ 180	180	50	0	72.0
1/6/74	+ 180	90	30	0	66.5
17/7/74	+ 180	30	20	0	33.0
17/8/74	+ 180	35	17	0	51.0
13/9/74	+ 180	90	30	0	66.5
11/10/74	+ 180	40	25	0	37.5
5/11/74	+ 180	90	20	0	78.0
3/12/74	+ 180	35	20	0	43.0
2/1/75	+ 180	40	14	0	65.0
5/2/75	+ 180	30	20	0	33.0
2/4/75	+ 180	35	17	0	51.0
9/6/75	+ 180	30	20	0	33.0
7/7/75	+ 180	20	11	0	45.0
6/8/75	+ 180	40	18	0	55.0
30/9/75	+ 1800	278	172	0	37.0
18/10/75	+ 1800	225	110	0	51.0
22/12/75	110	32	14	0	56.3
11/2/76	141	109	63	0	42.0
11/3/76	221	130	13	0	85.0
13/4/76	+ 1800	900	17	0	98.0
18/5/76	300	170	25	0	85.5
31/8/76	+ 1800	278	79	0	69.0
21/9/76	900	141	63	0	55.5
15/10/76	278	33	14	0	57.7
22/12/76	+ 1800	141	0	0	100.0
24/1/77	900	221	0	0	100.0

Notes : 1) Average reduction in MPN in filtration only = 50 %

2) + sign shows MPN count more than 180 or 1800

3) Rate of filtration : i) 9650 $l/m^2/hr$ upto 22.4.76

ii) 7150 $l/m^2/hr$ from 22.4.76.

TABLE 7-IV

Hydraulic Design calculations for the Ramtek treatment plant.

Design for flow = 1,00,000 lit/hr.

Flow through each unit = 50,000 lit/hr.

1. Mixing channel :- Provided on the two side walls of the filter unit as shown in the Drawing K-1

Length = 16.00 m   Width = 0.64 m.

Approximate detention = One min. from float test.

Bed slope = 20 cm in 16 m , Approx. 1 in 80

Spacing of baffles provided = 16 Nos. at 1 m centres in staggered positions.

2. Gravel bed prefilter = 2 units.

Size of each unit = length : 3.5 m

Width : 2.0 m

Depth : 2.0 m upto gutter le level.

Depth of gravels : 1.70 m

Size of gravels :	50 to 40 mm :	60 cm
	40 to 30 mm :	40 cm
	30 to 20 mm :	40 cm
	20 to 10 mm :	30 cm

Surface area : 7.00 m^2

Surface loading = 7150 $l/m^2/hr$.

Average porosity = 50%

Approx. detention in gravel bed = 7 min.

Velocity of flow at surface of bed = 7.15 m/hr.

Surface area at gugger level = 25.15 m^2

Velocity at the gutter level = 1.98 m/hr.

3. Dual media filter beds = 2 units.

i) Size of each unit : Length = 3.5 m

width = 2.0 m

depth = 2.0 m upto gutter level.

Surface area = 7.00 m^2

Rate of filtration = 7150 $l/m^2/hr$.

Velocity through bed = 7.15 m/hr.

ii) Details of media =

Depth of coconut shell media = 35 cm

Effective size of coconut shell media = 1.45 mm

Uniformity co-efficient of shell media = 1.47

Depth of fine sand below shell = 55 cm

Effective size of fine sand = 0.45 mm

Uniformity co-efficient of fine sand = 1.5

Depth of supporting gravel bed below sand = 50 cm

iii) Under drain details :

M.S. Manifold size = 300 mm x 200 mm

Number of laterals = 34 Nos. (17 on each side)

Diameter of laterals = 50 mm G.I. pipes

Perforations for lateral = 5 mm Ø at 50 mm c/c, in staggered positions.

Total perforation area = 2.38 cm^2

Ratio of perforation of filter area = 0.0034.

-oOo-

TABLE 7-V

Observations on the Ramtek Filter Bed No.1 Period : 25.5.1974 to 30.5.1975. Rate of filtration : 9650 $l/m^2/hr$.

Filter Run No.	Date of Starting and washing	Starting				20 Hours				40 Hours				60 Hours.				80 Hours				120 Hours				200 Hours			
		HL	RT	ST	FT	HL	RT	ST	FT	HL	RT	ST	FT	HL	RT	ST	FT	HL	RT	ST	FT	HL	RT	ST	FT	HL	RT	ST	FT
1.	25.5.74	28	1.5	0.8	0.5	45	1.5	0.8	0.5	63	1.5	0.8	0.5	76	1.5	0.8	0.6	92	1.5	0.7	0.7	138	1.5	1.0	0.7	170	100	20	1.2
2.	6.8.74	20	112	20	0.7	20	130	20	0.7	Filter washed.				for visitors.															
3.	8.8.74	20	140	24	0.7	125	35	15	0.7	135	100	20	0.8	washed after 30 hrs.															
4.	20.8.74	20	80	15	0.5	95	40	10	0.5	168	30	9	0.7	210	10	8.0	0.9												
5.	18.9.74	20	10	8	0.5	65	10	8	0.5	115	40	10	0.6	160	30	7.	0.7	220	180	20	1.0								
6.	28.10.74	35	500	25	0.7	100	450	35	0.7	190	200	18	0.7	227	45	5	0.8	Filter washed after 50 hrs.											
7.	26.11.74	15	45	5.0	0.5	100	20	2	0.5	195	15	3	0.6	Filtere washed for visitors.															
8.	17.12.74	20	15	2	0.5	120	13	2	0.6	192	30	3	0.6	228	25	3	0.7												
9.	23.1.75	35	25	3	0.5	70	25	5	0.5	105	15	2	0.5	130	15	2	0.5	148	20	2.0	0.5	195	15	2.0	0.7				
10.	1.4.75	20	15	2	0.5	41	15	2	0.5	59	15	2	0.5	78	5	2	0.5	96	6	2	0.5	154	15	2.0	0.5	198	10	2	0.6

DATA

1. Head losses are given in cms.
2. Turbidities are given in J.T.U.
3. Area of filter bed No.1 = 7.0 sq.m.
4. Total flow through filter bed No.1 =67500 lit/Hr.
5. Daily filter run = Between 1 to 6 hours.
6. Notations : given in the above table.

   i) Head loss = HL
   ii) Raw water turbidity = RT
   iii) Settled turbidity = ST
   iv) Filtered water turbidity = FT

OBSERVATIONS

1. Total water filtered through bed No.1 = 59.4 mld.
2. Total wash water used = 10 x 50,000 = 5,00,000.
3. Percentage of wash water = 0.85 %
4. Total number of wash during the year = 10
5. Total filter run during the year = 880 hours.
6. Average hours of filter run during the year = 88.

TABLE 7-VI.

Typical results for head losses in the Ramtek filter bed No.I

For rate of filtration : 9650 $l/m^2/hr$.

Date	Hours of filter run.	Head losses in filter media at different depths (cm).				
		18	36	54	72	At outlet.
25/5/74	5	5	8	15	20	28
30/5/74	20	15	22	29	35	45
5/6/74	40	28	39	46	54	63
12/6/74	60	38	50	63	70	76
20/6/74	80	48	58	77	86	92
25/6/74	100	57	69	93	102	110
2/7/74	120	69	88	103	130	138
9/7/74	140	71	94	125	142	149
17/7/74	160	73	99	131	150	161
27/7/74	180	76	104	136	158	168
5/8/74	200	83	108	138	160	170

TABLE 7-VII

Observations on the Ramtek Filter Bed No. I   Period : 22.4.1976 to 1.5.1977 ; Rate of filtration : 7150 $l/m^2/hr.$

Filter Run No.	Date of starting and washing	Starting HL	Starting RT	Starting ST	Starting FT	20 Hours HL	20 Hours RT	20 Hours ST	20 Hours FT	40 Hours. HL	40 Hours. RT	40 Hours. ST	40 Hours. FT	60 Hours HL	60 Hours RT	60 Hours ST	60 Hours FT	80 Hours HL	80 Hours RT	80 Hours ST	80 Hours FT	120 Hours HL	120 Hours RT	120 Hours ST	120 Hours FT
1	22.4.76	15	2.	1.5	0.3	30	2	1.5	0.3	55	2	1.5	0.3	72	2	1.5	0.3	93	2	1.5	0.3	130	2	1.5	0.4
2.	31.5.76	8	5	2.0	0.3	24	30	2.5	0.3	50	20	2.0	0.4	80	16	2.0	0.4	116	16	2.0	0.4	170	16	2.0	0.6
3.	6.7.76	10	16	2.0	0.4	26	16	2.0	0.4	48	14	2.0	0.4	70	14	2.0	0.4	90	15	2.0	0.5	143	16	2.0	0.5
4.	14.8.76	9	30	2.5	0.3	30	35	2.5	0.3	58	40	3.0	0.4	85	40	3.0	0.5	120	150	5.0	0.6	182	40	3.0	0.6
5.	15.9.76	15	40	3.0	0.3	43	40	2.5	0.3	75	20	2.0	0.4	102	20	2.0	0.5	134	10	2.0	0.6	200	10	2.0	0.7
6.	13.10.76	12	8	2.0	0.3	36	8	2.0	0.4	70	8	2.0	0.4	100	7	2.0	0.4	128	6	2.0	0.4	200	15	2.0	0.7
7.	10.11.76	15	50	5.0	0.4	40	14	4.0	0.4	71	20	2.0	0.4	103	15	2.0	0.5	142	10	2.0	0.5	202	10	1.5	0.8
8.	10.12.76	15	10	1.5	0.3	40	9	1.5	0.3	70	9	1.5	0.4	97	100	5.0	0.5	129	10	1.5	0.5	186	9	1.5	0.7
9.	10.1.77	15	9	1.5	0.4	40	9	1.5	0.4	75	8	1.5	0.4	108	10	1.5	0.5	145	10	1.5	0.5	205	10	1.5	0.7
10.	10.2.77	15	10	1.5	0.3	43	10	1.5	0.3	78	10	1.5	0.4	104	10	1.5	0.5	133	15	1.5	0.5	200	30	3.0	0.7
11.	12.3.77	15	30	3.0	0.3	34	25	3.0	0.3	70	25	2.5	0.4	92	22	2.0	0.4	122	23	2.5	0.5	175	20	2.0	0.6
12.	5.4.77	20	20	2.0	0.3	45	20	2.0	0.3	72	20	2.0	0.4	98	20	2.0	0.4	128	20	2.0	0.5	185	20	2.0	0.6

No.	Date	HL	RT	ST	FT	160 Hours HL	160 Hours RT	160 Hours ST	160 Hours FT	200 Hours. HL	200 Hours. RT	200 Hours. ST	200 Hours. FT	
1.	22.4.76	15	2	1.5	0.3	170	25	1.5	0.5	210	5	2.0	0.6	
2.	31.5.76	8	5	2.0	0.3	212	16	2.0	0.7	230	16	2.0	0.7	(Washed water after 180 Hrs.)
3.	6.7.76	10	16	2.0	0.4	185	25	2.5	0.6	205	30	2.5	0.7	(Washed water after 177 Hrs.)
4.	14.8.76	9	30	2.5	0.3	200	40	3.0	0.7					(Washed water after 132 Hrs.)
5.	15.9.76	15	40	3.0	0.3									Washed after a 120 Hrs.
6.	13.10.76	12	8	2.0	0.3									Washed after 126 Hours.
7.	10.11.76	15	50	5.0	0.4									Washed after 125 Hours.
8.	10.12.76	15	10	1.5	0.3	205	9	1.5	0.7					(Washed after 132 Hours)
9.	10.1.77	15	9	1.5	0.4									Washed after 112 Hours.
10.	10.2.77	15	10	1.5	0.3									Washed after 125 Hours.
11.	12.3.77	15	30	3.0	0.3	194	20	2.0	0.7					(Washed after 135 Hours)
12.	5.4.77	20	20	2.0	0.3	203	20	2.0	0.7					(Washed after 135 Hours)

DATA

1. Head losses are given in cm
2. Turbidities are given in JTU
3. Area of filter bed No.1 = 7.0 sq.m.
4. Total flow throw the filter bed No.1 = 50000 lit/hr.
5. Daily filter run = Between 4 to 8 hours.
6) Notations given in the above table :
   - i) Head loss = HL
   - ii) Raw water turbidity = RT
   - iii) Settled water turbidity = ST
   - iv) Filtered water turbidity = FT

OBSERVATIONS

1. Total water filter through bed No.1 = 85,00 mld.
2. Total wash rate used = 12x50,000 = 6,00,000 lit.
3. Percentage of wash water used = 0.7 %
4. Total number of washing during the year = 12
5. Total filter run during the year = 1567 hours.
6. Average hours of filter run during the year = 140

TABLE 7-VIII

Typical results for head losses in the Ramtek filter bed I.

Rate of Filtration : 7150 $l/m^2/hr$:

Date	Hours of filter run.	Head losses in filter media at different depths (cm)				
		18	36	54	72	At outlet.
6.7.76.	0	0	0	1	2	4
6.7.76.	5	2	3	4	5	9
7.7.76.	10	3	6	7	8	14
9.7.76.	20	4	11	13	17	25
11.7.76.	30	10	18	23	28	37
13.7.76.	40	16	26	31	38	48
15.7.76.	50	21	32	38	49	59
17.7.76.	60	25	39	47	60	69
19.7.76.	70	30	45	55	69	80
21.7.76.	80	36	53	63	79	90
23.7.76.	90	41	60	73	89	101
25.7.76.	100	47	67	89	100	111
27.7.76.	110	53	75	93	111	123
29.7.76.	120	68	82	101	122	134
1.8.76.	130	81	88	109	132	144
3.8.76.	140	86	94	118	143	159
6.8.76.	150	93	104	130	158	170
8.8.76.	160	98	112	138	168	180
11.8.76.	170	105	122	149	182	194
13.8.76.	180	110	129	158	193	205

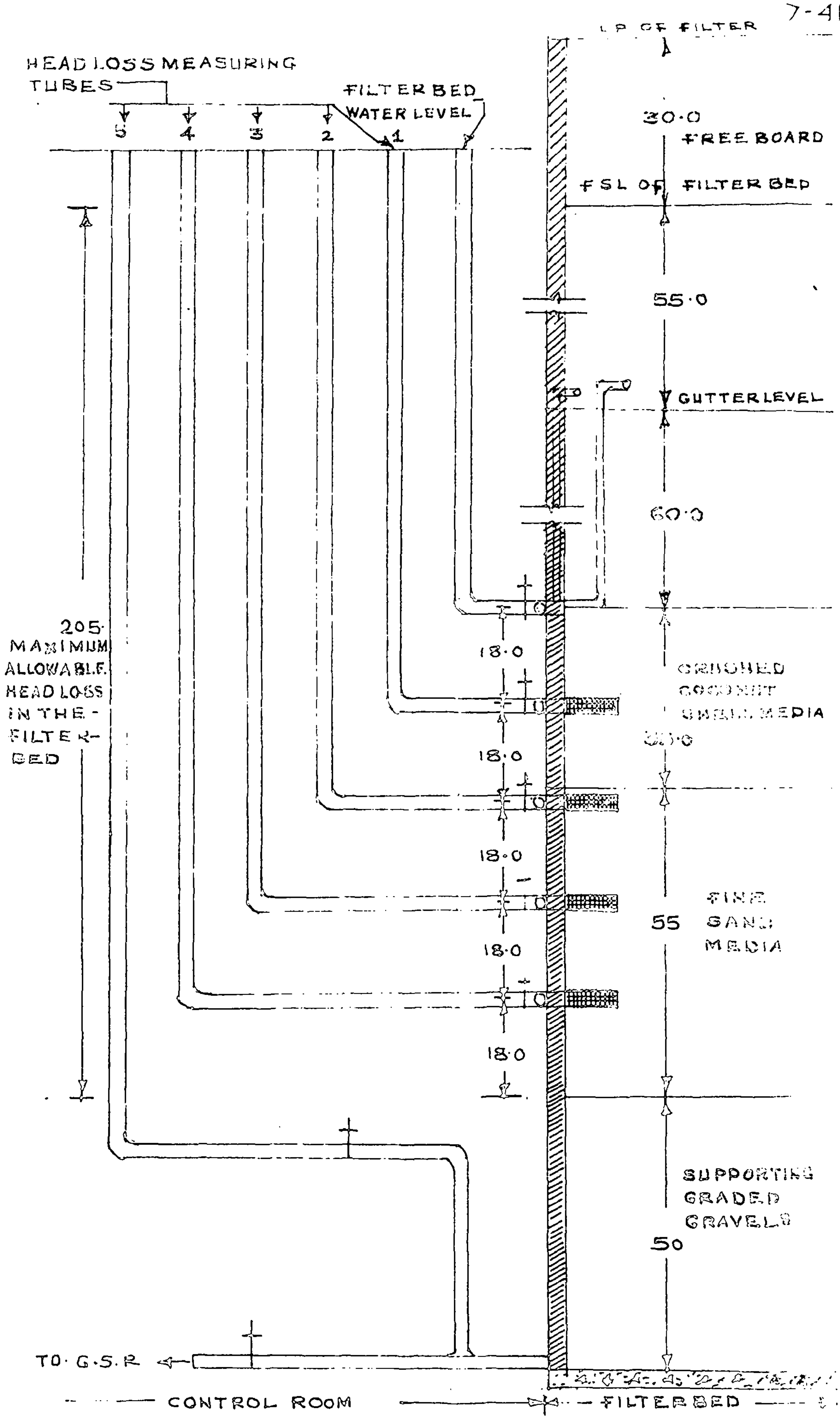


FIG. 7-I

DETAILS OF HEAD LOSS MEASURING POINTS

SCALE:- 1:10 CM

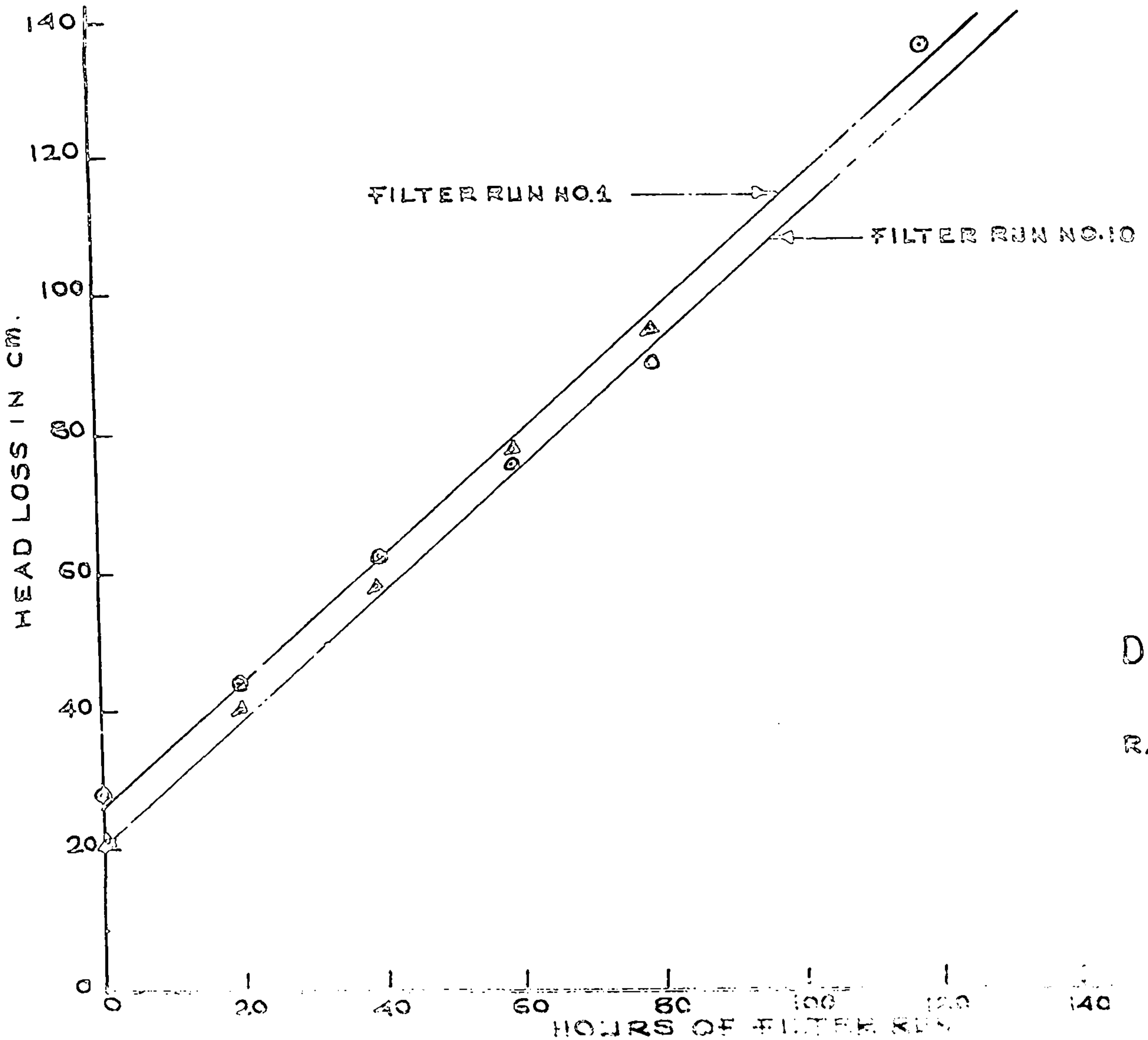


FIG. 7-II

DEVELOPMENT OF TOTAL HEAD LOSS IN THE FILTER BED

RATE OF FILTRATION - 9650 $\ell/m^2/Hr$.

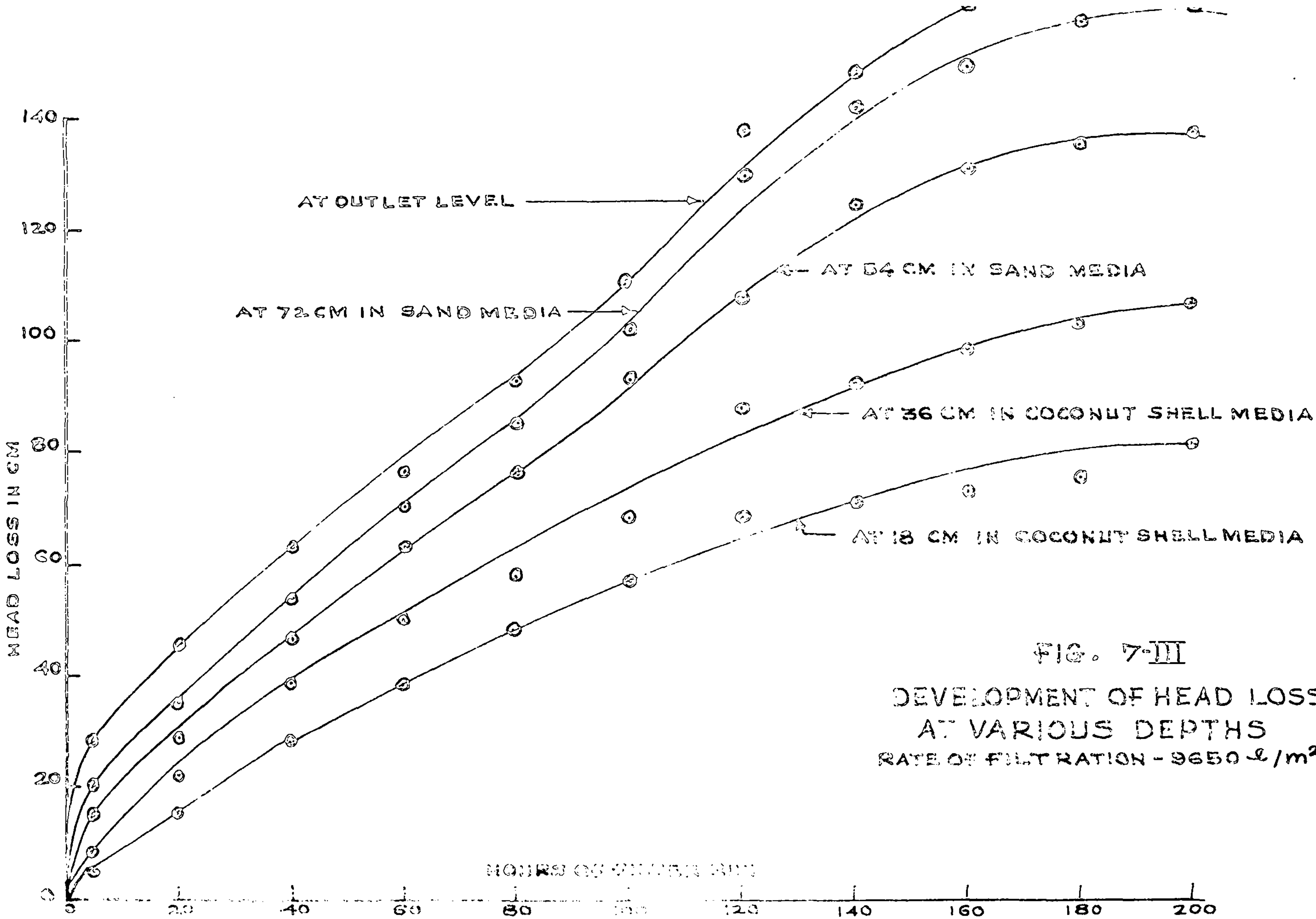


FIG. 7-III

DEVELOPMENT OF HEAD LOSS
AT VARIOUS DEPTHS

RATE OF FILTRATION - 9650 ℓ/m^2/HR.

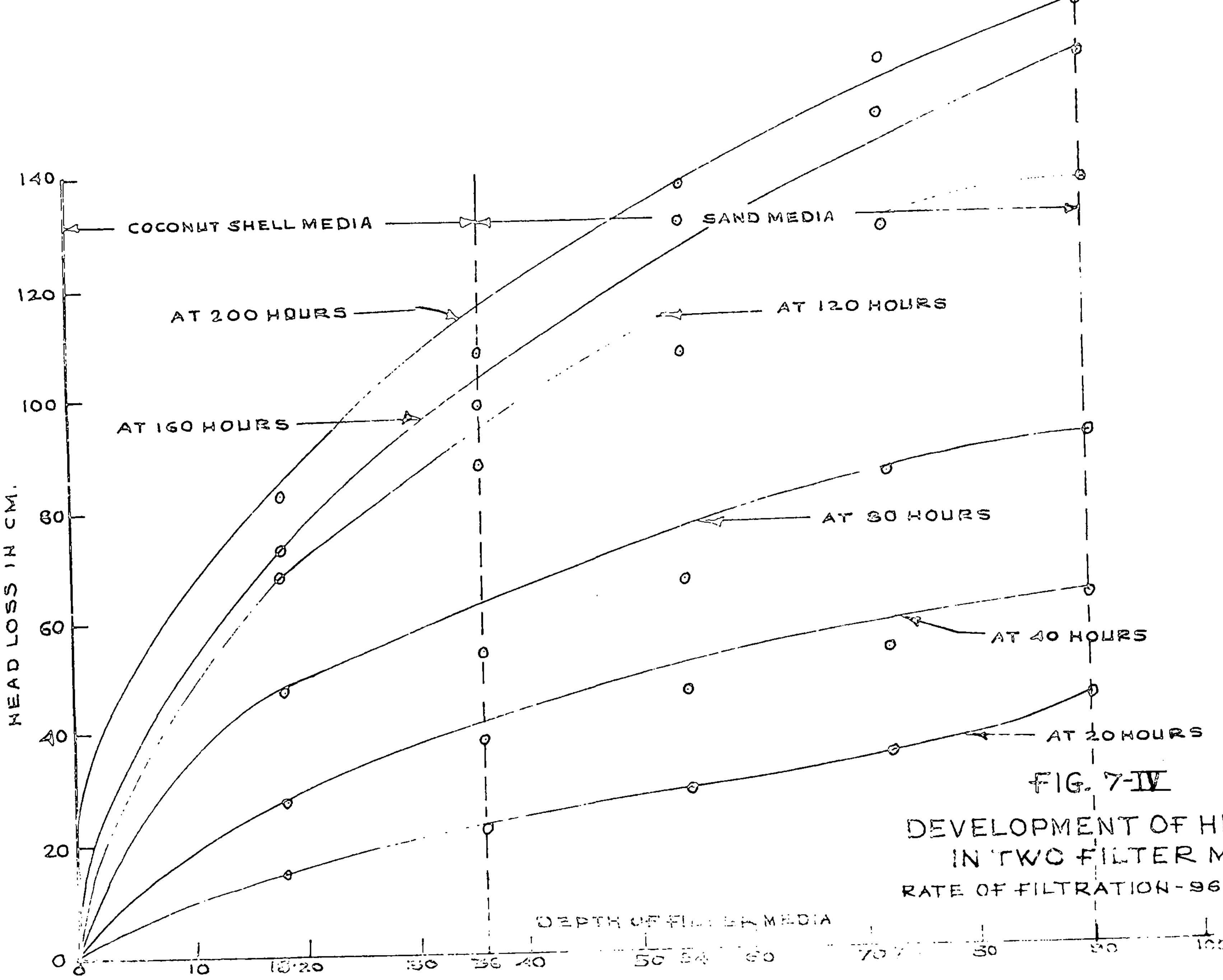


FIG. 7-IV

DEVELOPMENT OF HEAD LOSS IN TWO FILTER MEDIA

RATE OF FILTRATION - 9650 ℓ/m^2/Hr.

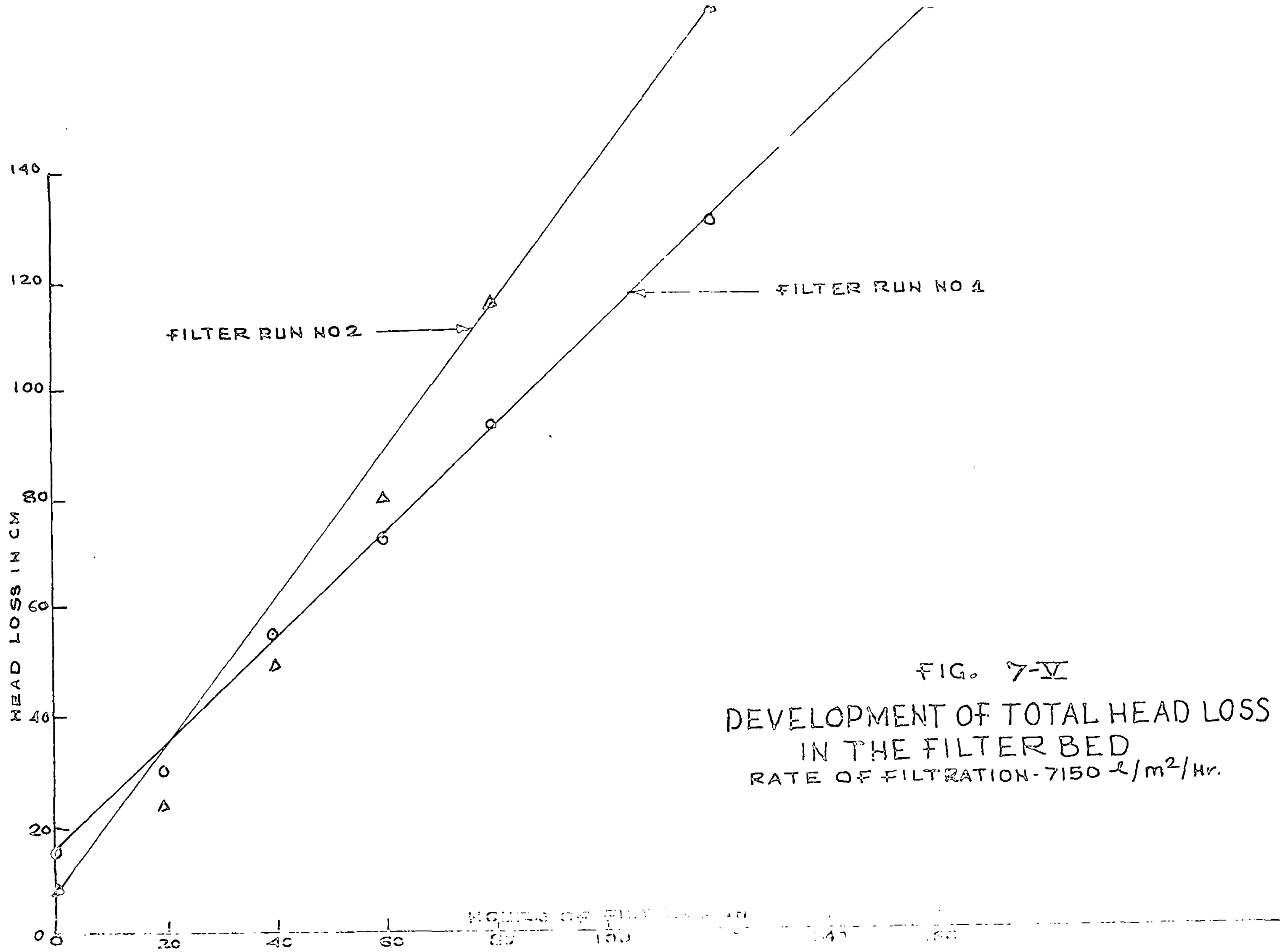


FIG. 7-V

DEVELOPMENT OF TOTAL HEAD LOSS IN THE FILTER BED

RATE OF FILTRATION - 7150 $\ell/m^2/Hr.$

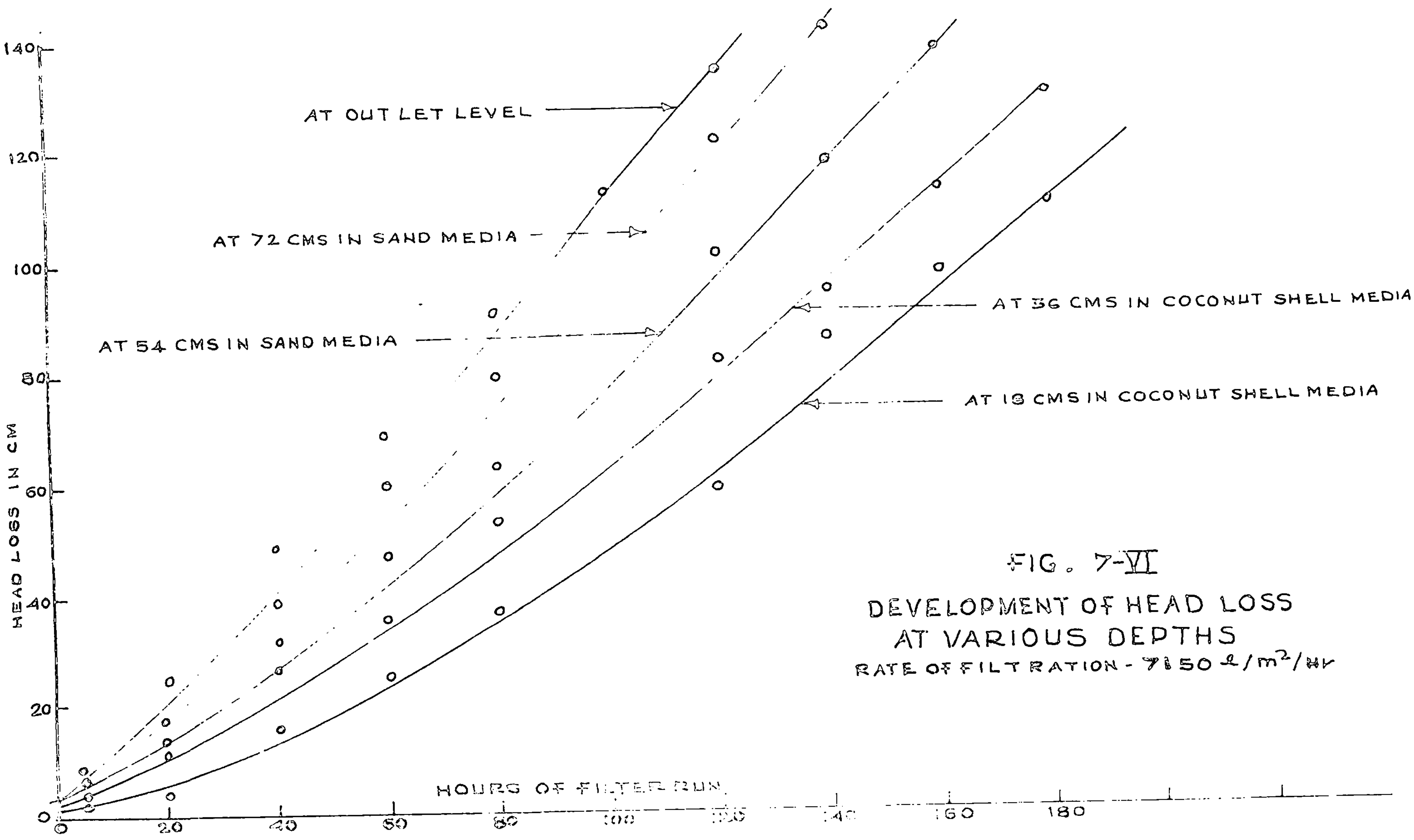


FIG. 7-VI
DEVELOPMENT OF HEAD LOSS
AT VARIOUS DEPTHS
RATE OF FILTRATION - 7150 $\ell/m^2/hr$

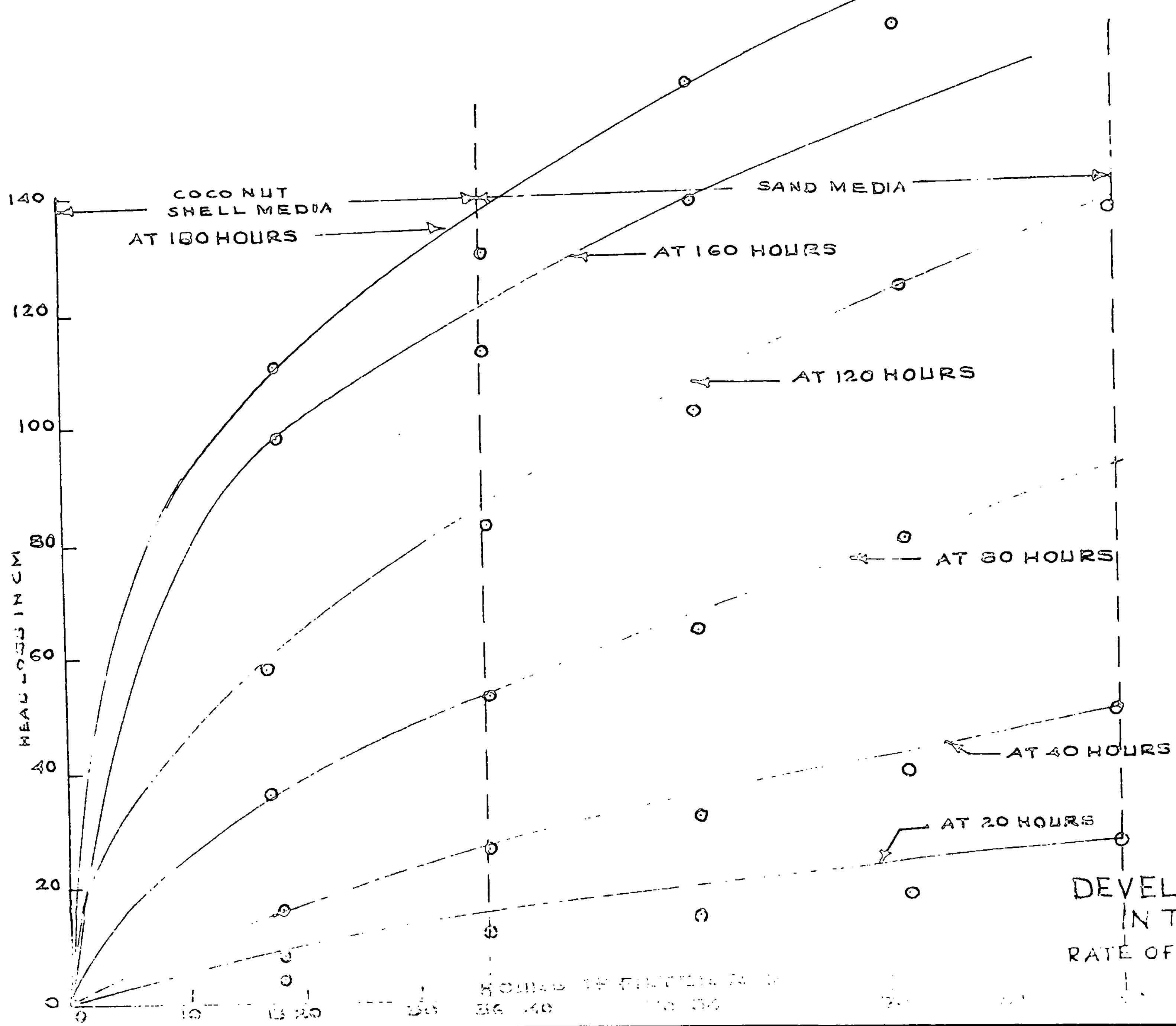


FIG. 7-VII

DEVELOPMENT OF HEAD LOSS IN TWO FILTER MEDIA

RATE OF FILTRATION 7150 ℓ/m^2/hr

CHAPTER 8.

PILOT PLANT STUDY FOR THE VARANGAON TYPE TREATMENT PLANT.

8.1 INTRODUCTION.

The pilot plant studies for the gravel bed floccu-lators followed by tube settling tanks, for different conditions have been carried out as explained in chapter 4 of this thesis. Similarly the pilot plant studies on the dual and the multi-media filter beds for different conditions have been carried out as explained in chapter 5, of this thesis.

It is now proposed to carry out the pilot plant study for the same loading conditions as adopted for the design of the Varangaon treatment plant as discussed in chapter 9 of this thesis.

The pilot plant as shown in the figure 8-I was fabricated in the laboratory to study the various aspects of the design adopted for the Varangaon treatment plant and the design of the pilot plant and the experimental observations on the same are discussed in this chapter.

8.2 DESIGN OF THE PILOT PLANT.

The detailed sizes of the pilot plant are shown in the figure 8-I. The main components are gravel bed flocculator, tube settling tank with six number of square PVC tubes of 50 mm x 50 mm internal size followed by the dual media filter bed. The hydraulic design calculations of the pilot plant are given in the para 8.2.6 of this chapter. It will be seen that the depth of these units

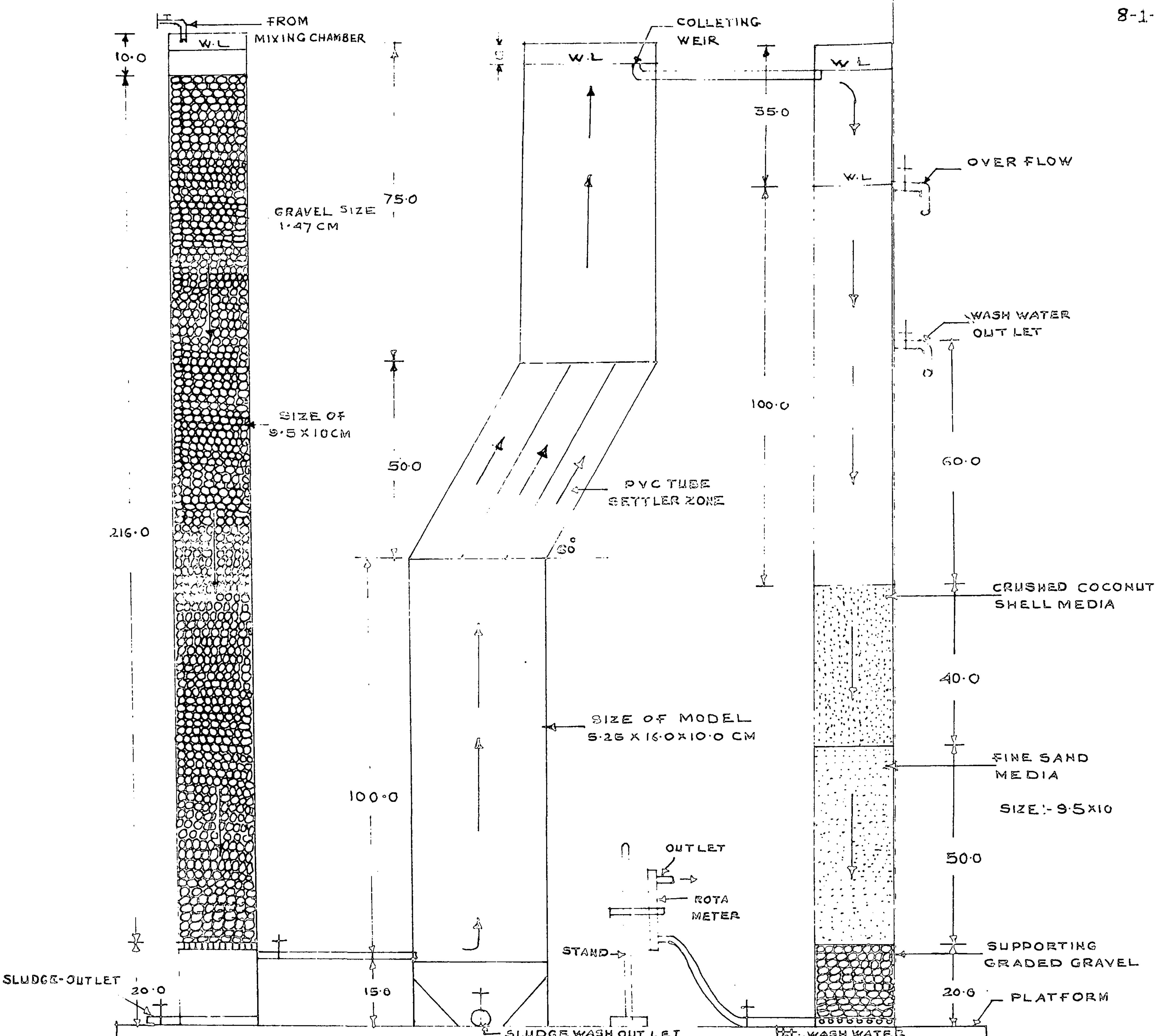
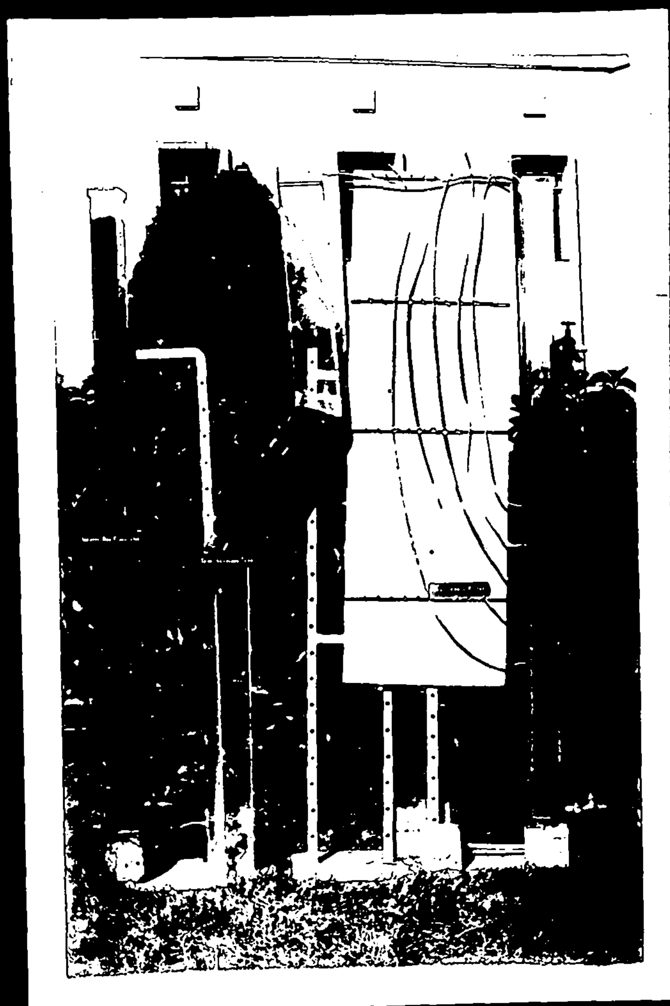


FIG. 8-I

PILOT PLANT MODEL OF VARANGACN TREATMENT PLANT are adopted nearly to the actual depths of the Varangaon treatment plant so as to get the comparable results of these plants. Perpex sheet pilot plant units were fabricated in the laboratory so as to observe the actual floc formation, cleaning of the gravel bed unit, sludge blanket action in the tube settling tank, the removal of settled sludge and the performance of the dual media filter bed for the treatment of clarified water after the high rate pretreatment by gravel bed flocculator and tube settling tank.

The inlets and the outlets of 12 mm dia G.I. pipes and fittings were provided with brass gate valves to adjust the required flows through the pilot plant. The constant flow arrangement and the alum dosing and mixing arrangements were provided as explained in the chapter 4. At the outlet end of the dual media filter bed a rotameter was fixed to control the rate of flow. At the bottom of the gravel bed flocculator and the tube settling tank sludge outlets were provided to drain out the sludge by hydrostatic pressure after desired period. At the top of the dual media filter bed one inlet connection was provided to introduce settled water from the tube settling tank. One 25 mm dia wash out valve was provided at 60 cm above the top of the dual media filter bed for taking out the wash water to drain. Figure 8-I showing the pilot plant and other details is enclosed in this chapter.

PHOTOPLATE 8-I



Pilot plant for the Varangaon type treatment plant showing gravel bed flocculator, tube settler and dual media filter bed with headloss measuring arrangement.

8.2.1 Pilot Plant Operation :

Before running the pilot plant all the units were first filled with the tap water. The required raw water flow to the pilot plant of 100 JTU was adjusted through a constant volume tank to the mixing chamber, along with the alum dose as explained in the chapter 4.

The raw water after mixing with the alum dose was introduced at the top of the gravel bed flocculator unit. The flow in the gravel bed flocculator was in the downward direction and the water from the bottom of the gravel bed flocculator was introduced at the bottom of the tube settling tank at about 15 cm above the top of the hopper. The settled water from the top of the tube settling tank was then introduced on the top of the dual media filter bed. The rate of filtration from the dual media filter bed was controlled at the outlet end by the gate valve with the help of a rotameter, connected by a plastic tubing.

8.2.2 Head Loss Measurements :

The head loss in the gravel bed flocculator was noted from the difference in water levels on the top of gravel bed flocculator and the tube settling tank. The head losses at various depths in the dual media filter bed were observed from the difference of water levels against the top water level in the bed through the plastic tubing as explained in the chapter 5.

8.2.3 Turbidity Measurements :

The turbidities of raw, settled and filtered water samples were measured after every hour with an Aplab turbidimeter. Both head loss and turbidity measu-

measurements were conducted after every hour.

8.2.4 Cleaning of the Gravel Bed Flocculator Unit and Tube Settling Tank and Measurement of Sludge Volume :

For cleaning of the gravel bed flocculator the outlet valve to the tube settling tank at the bottom was closed and the outlet valve on the sludge drain pipe was opened so as to drain out the floc and sludge accumulated in the flocculator unit. In addition to this, back wash arrangement was provided in this unit to clean the gravel bed by introducing water through the sludge drain outlet. After day's work the sludge in the gravel bed was taken out by gravity flushing out action. To remove all the accumulated sludge the gravel bed was drained twice by filling the bed again from the top with the tap water. The sludge accumulated in the gravel bed during the each run was measured with the glass measuring cylinders, as explained in the chapter No.4. At the end back wash was given to clean the gravel bed.

The sludge from the tube settling tank was drained through the sludged draining outlet and collected in the buckets till all the visible sludge was removed. At the end the tube settling tank was completely drained out and filled with the tap water for the next experiment. The sludge volume was measured in the same way with the measuring cylinders after decanting the drained water as explained earlier.

8.2.5 Cleaning of the Dual Media Filter Bed and Measurement of sludge volume :

For cleaning the dual media filter unit the inlet and out valves were closed, the back washing valve was opened so as to give about 30% expansion of the filter media. The washing and the sludge measurement process was adopted as explained in the chapter 5 of this thesis.

8.2.6 Hydraulic Design of the Pilot Plant :

a) Gravel bed flocculator - one unit.

i) Size of bed = 9.5 cm x 10 cm

ii) Surface area of bed = 95 cm^2

iii) Depth of gravel = 216 cm.

iv) Water depth at top = 10 cm.

v) Total volume of gravel bed = 20,520 ml.

vi) Actual volume of water upto top of gravel bed. = 8000 ml

vii) Actual Vol. of gravels (in wet condition) = 12520 ml

viii) Porosity = 39% say 40%.

ix) Number of gravels in the bed = 13350

x) Mean dia of the gravels = 1.47 cm.

xi) Surface area of the gravels assuming spherical shape. = $13350 \times 4 \times \Pi \times r^2$ = 91,100 cm^2

xii) Flow rate on the bed = 96 lit/hr.

xiii) Loading on the gravel bed = 10,000 $1/m^2/hr$.

xiv) Volumetric loading on the gravel bed. $= \dfrac{96 \times 10^6}{20,520}$

$= 4700\ 1/m^3/hr$.

xv) Detention period in the gravel bed. $= \dfrac{8000 \times 60}{96,000}$

$= 5$ min.

b) Tube settling tank one unit.

i) Size of bed = 16 cm x 10 cm.

ii) Number of rigid PVC square tubes = 6

iii) Internal size of tubes = 48 x 48 mm.

iv) Total cross sectional area of tubes. = 140 cm^2

v) Flow rate in the plant = 96 lit/hr.

vi) Actual loading on tube surface area. $= \frac{96 \times 10{,}000}{140}$

$= 6850\ l/m^2/hr$

vii) Detention period in the tube settler unit. = 23.5 min.

c) Dual media filter bed = one unit.

i) Size of bed = 9.5 cm x 10 cm.

ii) Surface area of bed = 95 cm^2.

iii) Flow rate on bed = 96 lit/hr.

iv) Surface loading on the bed = 10,000 $l/m^2/hr$

v) Depth of coconut shell media = 40 cm.

vi) Average size of coconut shell media. = 1 to 2 mm

vii) Effective size of the media = 0.95 mm

viii) Uniformity coefficient of media = 1.45

ix) Depth of sand bed = 50 cm.

x) Effective size of sand = 0.5 mm.

xi) Uniformity coefficient of sand = 1.5

xii) Depth of supporting gravel bed. = 15 cm

xiii) Underdrain arrangement = perforated nozzles of PVC type.

xiv) Inlets and outlet pipes = 12 mm dia G.I. pipes.

xv) Control valves = Brass gate valves.

xvi) Water depth over the bed = one meter.

xvii) Headloss measuring arrangements through 3 mm dia. perforated probes from the top of the media at 15,30,45,60,75,90 cm.

8.3 EXPERIMENTAL OBSERVATIONS.

The main purpose of this pilot plant study was to find out the actual performance of such a pilot plant for the same loading adopted for the Varangaon treatment plant and to compare the performances of both the plants. In addition to this the removal of sludge volumes and the proportions of sludge volumes removed at each stage was also studied on the pilot plant as such a study was not possible on the Varangaon treatment plant. From the hydraulic calculations it can be seen that the hydraulic loading given on the pilot plant was little more on gravel bed flocculator and tube settling tank as compared to the hydraulic loadings on the Varangaon treatment plant, while the loading on the dual media filter bed was about 50% more than the designed load. The reasons for these are discussed latter in this chapter.

8.3.1 Head Loss and Turbidity Observations :

Table 8-I, showing the observations carried out for three sets of tests conducted for daily seven hours operation on the pilot plant are given below. Table 8-II showing the removal of turbidity loads is also given. Other observations carried out during these tests are also shown in these tables. Number of filter runs were studied, however observations of three average runs are given in the Table 8-I.

TABLE 8-I

Pilot plant observations on the Varangaon type treatment plant.

Filter Run No.1

Hours of Run.	Head losses in dual media filter bed AT various depths (cm) 15	30	45	60	75	90	Turbidities sett-led.	filt-ered.
0	1.0	2.0	4.0	6.0	8.5	10.5	-	-
1	2.0	3.0	5.0	7.0	10.0	12.0	15	0.8
2	2.0	3.0	6.0	8.0	12.0	15.0	14	0.4
3	2.5	3.5	6.5	9.0	12.5	15.5	15	0.4
4	3.0	4.0	7.0	10.0	13.0	16.0	15	0.4
5	3.5	5.5	9.0	12.0	15.5	18.0	10	0.3
6	3.5	6.0	10.0	14.0	17.0	18.5	8	0.3
7	4.0	6.0	10.0	14.0	17.0	19.5	8	0.3

Filter Run No.2

0	1.0	2.0	4.0	6.0	9.0	11.0	-	-
1	1.5	2.5	4.5	7.5	10.0	12.0	20	0.8
2	2.0	3.0	5.5	8.5	11.0	13.0	15	0.8
3	3.0	4.5	7.7	10.5	13.0	17.0	10	0.7
4	3.5	5.0	8.0	11.0	14.0	17.0	10	0.7
5	4.0	5.5	9.5	13.0	17.0	18.0	7	0.5
6	4.5	6.0	10.0	14.0	17.5	18.5	8	0.5
7	5.0	7.0	11.0	14.5	18.5	19.5	7	0.5

Filter Run No.3

0	1.0	2.0	4.0	7.0	9.0	11.0	-	-
1	2.0	3.0	5.0	8.0	11.0	13.0	20	0.5
2	2.5	3.5	6.0	9.0	12.0	14.0	20	0.5
3	3.5	4.0	7.0	11.0	13.0	15.0	20	0.4
4	4.0	5.0	8.0	11.5	14.5	16.0	15	0.3
5	4.5	6.0	9.0	13.0	16.0	18.0	18	0.3
6	5.0	7.0	10.0	14.0	16.5	18.5	15	0.3
7	5.5	7.5	10.5	14.5	17.0	19.0	15	0.3

TABLE 8-II

Turbidity removal.

Filter Run No.	Pretreatment			Filtration	
	Raw water	Settled water	Removal %	Filter water	%removal
	JTU	JTU		JTU	
1	100	12.2	87.8	0.41	11.79
2	100	12.3	87.7	0.64	11.66
3	100	17.6	82.4	0.37	17.23

Average turbidity removal :

1) During pretreatment : 85.95 %

2) During filtration : 13.56 %

8.3.2 Sludge Load Removed at Every Stage :

The sludge in the pretreator and tube settler units was removed by gravity desludging operation and the sludge in the wash water was collected carefully and was measured in the measuring cylinders in the same procedure as given in the chapter 4. The sludge in the dual media filter bed was also collected from the back-wash water collected in the buckets and was measured in the same procedure as given in the chapter 5. Table 8-III shows the actual sludge collected from the three units along with the percentage removal of the same.

8.3.3 Bacteriological Observations :

The bacteriological observations of the raw, settled and filtered water samples were carried out at the end of day's work. The results of the same are given in the Table 8-IV.

TABLE 8-III

Sludge removed in the pilot plant.

Filter Run No.	Volume of sludge removed in ml				Percentage of sludge removal		
	Gravel bed.	Tube settler	Filter bed	Total sludge	Gravel bed	Tube settler.	Filter bed
1.	1255	1640	585	3480	36.0	47.0	17.0
2.	1300	1640	450	3390	38.5	48.5	13.0
3.	1415	1940	755	4110	34.5	47.5	18.0
Average	1323	1740	530	3660	36.0	48.0	16.0

TABLE 8-IV

Bacteriological observations (MPN)

Filter Run No.	Bacteriological observation.			% Removal of coliform.	
	Raw water	Settled water	Filtered water.	Pretreatment.	Filtration.
1	1.1×10^4	4.6×10^4	4.6×10^3	58.0	Nil
2	1.1×10^4	4.3×10^2	36	96.0	3.6
3	460	150	36	67.5	25.0

Average reduction in coliform by :

1. Pretreatment : 74 %
2. Filtration : 14 %

8.4 DISCUSSION ON THE OBSERVATIONS.

8.4.1 Head Loss Observations :

i) Gravel bed flocculator : The head loss in the gravel bed flocculators was observed from 2 to 3 cm. through out these runs and hence these are not included in the Tables. This head loss may increase slightly more during the further run of the bed for 12 to 16 hours which will be the normal day's run for such plants. At the end of day's run the gravel bed flocculator was drained for gravity flushing out action when all the sludge was completely drained out. To collect all the sludge the gravel bed flocculator was drained twice after refilling with tap water. At the end back wash was given to see if there is any remaining sludge, but it was observed during back wash, that hardly any sludge remained in the bed after carrying out two gravity flushing out operations. Normally one operation of draining may be adequate except when turbidity is very high. Further the back wash can be given once in a week to the gravel bed so as to make effective cleaning of the gravel bed flocculator in a prototype plant. This procedure has been already followed at Varangaon treatment plant and was found to be effective.

ii) Dual Media Filter Bed :

From the head-loss observations at various depths in the dual media filter bed it can be seen that the head loss in the crushed coconut shell media was about 30 to 40% of the total head loss developed in the filter bed. It can also be seen that there was marked increase in head loss between 30 to 45 cm depth, in which the coconut shell depth was 10 cm and fine sand depth was 5 cm. Even due to this 5 cm fine sand depth there was sudden increase in the head-loss. The head losses in the sand depths at 60,75 and 90 cm also show the continuous rise in the development of head loss. This aspect is fully discussed in the chapter 5 and further in the chapter 9 of this thesis.

8.4.2 Turbidity Observations :

i) Pretreatment : From the turbidity observations it is seen that the settled water turbidity was generally below twenty JTU. During the beginning of the plant the turbidity was slightly more and was in the range of 20 to 30 JTU, and after about two hours the settled water turbidity was continuously maintained at about 10 JTU. The reason for this may be the time required for creation of the floc blanket below the tube settler. This was clearly visible from the sides of the transparent model. Further the gravel bed flocculator was also washed at the beginning and after about an hour there was also floc blanket in the voids between the gravels, which was clearly visible from the sides. The flexible sludge blanket gives additional opportunity to the newly created micro-floc particles to come together. During the short period of this continuous contacts with the sludge and the gravels in the gravel bed flocculator, the floc size got increased progressively and when the floc enters at the bottom of the tube settling tank, most of the floc was in settlable condition.

As a suspended sludge blanket was formed below the tube settler, the portion of the incoming finer floc particles got in contact with the sludge blanket and heavier floc particles settled down. The same action was continued up to the top of the tubes when additional surface contact was provided by the side surfaces of the tubes, which were provided at 60° angle, for giving more effective action and to facilitate heavier sludge to flow down due to the gravitational forces of heavier floc.

The comparative observations in the removal of turbidity load are given in the statement No. 8-II. From this statement it is seen that the turbidity load removed during the pretreatment was about 86 % while that during filtration was 13.50%.

ii) Filtration : The settled water turbidity was in the range of 20 to 10 JTU while the filtered water turbidity was below the one JTU. Here also the turbidity during the first one to two hours was in the range of 0.5 to 0.8 JTU, while there after it was generally below 0.5 JTU. The reason for this may also be the same as explained for the gravel bed flocculator. As the top coconut shell media is coarse one, during the starting of the run some finer floc particles enter the small voids and create a flexible blanket in the top layer. This was clearly visible from the transperant sides of the model. Even though the rate of filtration was 10,000 lit/sqm/hr the turbidity of the filtered water was generally below 0.5 JTU.

8.4.3. Sludge Removal :

The sludge from all the units was collected separately as discussed in details in chapters 4 and 5 of this thesis. The figures of sludge removed from the different units are given in Table 8-III. From the total volumes of sludge collected for each run, the percentages of sludge removed from each unit are also given in this table.

The average percentage of sludge removed from gravel bed flocculator was 36% while that through the tube settler was 48% and thus the total sludge removed from the pretreatment was 84%. The average sludge removed from the dual media filter bed was 16%. This shows the sludge load removed during the pretreatment process was quite satisfactory, and shows the good performance of this new technique of pretreatment process with the combination of gravel bed flocculator and tube settler. From the comparative observations of turbidity removal as given in the Table 8-II, it can be seen that the turbidity removal and sludge removal observations from the pretreatment and filtration are fairly comparable. This may be a good measure for comparing the actual performances of the various units in the treatment plant.

8.4.4 Bacteriological Observations :

From the bacteriological observations as given in the Table 8-IV it is seen that the average reduction in coliform count in the pretreatment was about 74% whereas the same during the filtration was 14%. This fairly compares with the actual plant scale performance of the Varangaon treatment plant, as given in chapter 9 (vide Table No. 9-III), where the average reduction of MPN during pretreatment was 78%. Thus the pretreatment with gravel bed flocculator and tube settler was found quite satisfactory in the removal of coliform load in the raw water.

8.5 GENERAL CONCLUSIONS.

i) Gravel bed flocculation unit may be a possible solution to replace the mechanical flocculation unit for the treatment of turbid water sources for the small capacity treatment plants.

ii) There is limitation in the use of size of gravels in the pilot plant study as there is possibility of short circulation of the flow from the sides of the unit. The gravels of 10 to 15 mm dia may give comparable results. It is possible to clean gravel bed flocculation unit by gravity desludging operation. However, back washing arrangements is recommended to clean the flocculation unit occasionally.

iii) The tube settling tank with the use of rigid PVC square tubes of size 50 x 50 mm opening gives satisfactory performance in the treatment of the turbid water sources after the gravel bed flocculation unit,at high surface loading as compared to the conventional settling tank.

iv) Pilot plant study shows the formation of a sludge blanket zone below the tube settler zone for about 1.3 m depth, which is not required to be controlled as in the case of a conventional sludge blanket tank.

v) The dual media filter bed with the use of crushed coconut shell media over the fine sand media shows satisfactory performance for higher filtration rates of 10,000 $l/m^2/hr$ after the pretreatment with gravel bed flocculation and tube settling tank.

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CHAPTER 9

DESIGN AND EXPERIMENTAL OBSERVATIONS ON VARANGAON TREATMENT PLANT.

9.1 INTRODUCTION.

The Regional Rural Water Supply scheme for five villages near Varangaon was sanctioned for the estimated cost of Rs. 41,10,400/- in the year 1974. The population to be served in the immediate and the ultimate stages are 25,000 and 30,000 souls respectively. The scheme is designed for the daily water supply of 4.20 mld to be supplied in 18 hours in the ultimate stage. The source of water supply is the river Tapi and raw water is pumped to the new treatment plant from where the filtered water is pumped to the various elevated service reservoirs for the supply to the five villages near Varangaon.

A new conventional treatment plant consisting of mixing channel, two units of rectangular settling tanks with sixteen hoppers, and six units of pressure filters were proposed in the sanctioned scheme. The turbidity of raw water from the Tapi river source is generally very high and some times reaches even up to 5000 units during the rainy season.

The estimated cost as per the sanctioned scheme for the construction of the conventional treatment plant as stated above was Rs. 6,50,000/-. The actual cost of construction for a conventional plant of this capacity would have been above Rs. 8,00,000/-. Table 9-I showing the tendered costs received for the same capacity plants during the year 1974-1978 in this region is enclosed for ready reference. In view of the very high cost of construction of the conventional plants for such small capacity water treatment plants, the author has proposed to the State Govt. a new simplified unconventional treatment plant for the treatment of the turbid water source for this scheme, as discussed in this chapter.

The new simplified treatment plant near Varangaon consists of mixing channel, two units of gravel bed flocculation units, two units of tube settling tanks and three units of dual media filter beds. The actual cost of construction of this plant was Rs. 4,00,000/- which is less than 50% of the cost of a conventional plant of the same capacity. The chief Engineer (ENE) and Joint Secretary to the Govt. of Maharashtra, Urban Development and Public Health Department has approved this new design and the plant was constructed during the years 1976-77. This new plant was put into trial runs from April 1977.

The details of the pilot plant observations for this type of new treatment plant are given in the chapter 8 of the thesis. The details of design, construction and actual plant scale observations on the Varangaon treatment plant are discussed in this chapter.

9.2 QUALITY OF THE RAW WATER SOURCE.

The source of water supply is the Tapi river which has low turbidity during eight months. However, the turbidity of the river water during the rainy season for four months is very high as can be seen from the plant observations given in the Table 9-V. The typical chemical analysis results are given in the Table 9-II, to get the idea of the changes in quality. The bacteriological observations of the raw, settled filtered and tap water samples are given in the Table 9-III.

The quality of the raw water source for this scheme represents the category II, viz : raw water with high turbidity and moderate pollution as discussed in the chapter 1 of this thesis. The author has designed the Varangaon treatment plant specially to treat the category-II type of raw water sources. This is the most common type of raw water source for water supply schemes in the Maharashtra State.

9.3 THE NEW APPROACH.

The new design adopted for this treatment plant includes baffle mixing channel, gravel bed flocculators, tube settling tanks and dual media filter beds, which are not adopted in the conventional treatment plants. The other special features provided at the plant, are the declining type of rate controlling arrangements for controlling the rate of filtration, control room in which alum solution tanks and pure water pumping machinery are provided. The alum solution and dosing tanks are provided in the first floor room where the alum mixing is proposed to be done by compressed air supply. A small laboratory with normal testing equipments is provided in the same room. A wash water tank of 75000 lit. capacity has been provided on the top of the chemical room. With all these arrangements the plant has became a very compact one and the total area provided for the same comes to about 33% of the area normally required for the construction of a conventional plant of the same capacity. The table 9-IX showing the comparison of the Varangaon plant and a conventional plant of the same capacity on some important aspects is enclosed in this chapter.

9.4 DESIGN ASPECTS.

The treatment plant has been designed for the hourly pumping flow of 1,75,000 litres. The hours of working will be eight and sixteen in the immediate and ultimate stages respectively. The raw water from the Tapi river source is pumped by submerssible pumps, through the intake well to the treatment works situated at a distance of about one k.m. from the river bank near the village Kathora.

Following units are provided in the Varangaon treatment plant.

i) Baffle mixing channel.

ii) Two units of Gravel bed flocculators.

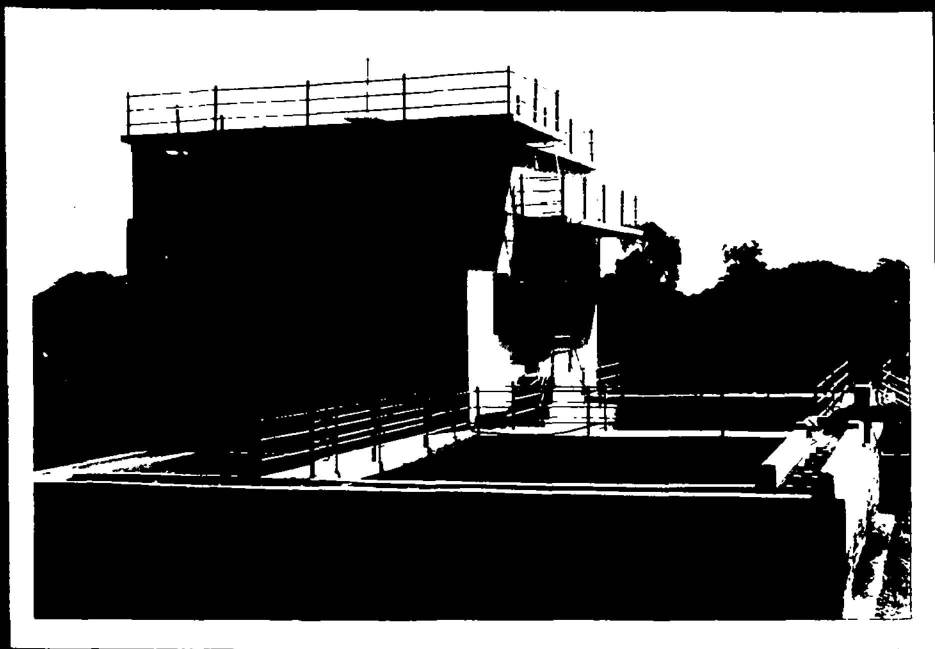
ii) Two units of tube settling tanks.

iv) Three units of dual media filter beds.

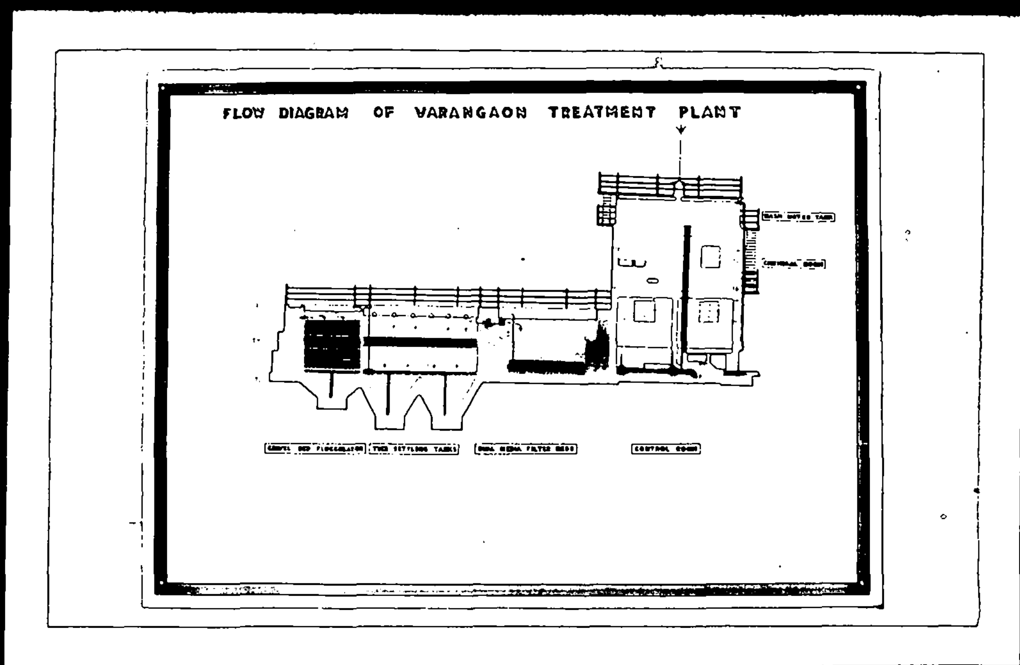
v) Control room and disinfection arrangements.

The detail design calculations are given in the Table 9-IV. The details of the various dimensions of the various units of the treatment plant are shown in the drawing K-2 enclosed in this chapter.

PHOTOPLATE 9-III



Side view of the . . . .
Varangaon treatment plant showing inlet pipe, mixing chamber, gravel bed flocculation units, tube settlers and dual media filter beds including chemical room and wash water tank at the top.



Cross section through the various units of the plant.

9.5 BAFFLE MIXING CHANNEL.

The baffle mixing channel is provided on the top of the two side walls of the plant, as shown on the drawing K-2. The side walls of the channel are of 23 cm thickness and of 0.6 m in height. The width of the channel is 0.6 metre. The baffles of the Shahabad stone tiles are fixed at 60° angle in the side walls of the channel at one metre centres in the staggered positions to accelerate the mixing action, The approximate detention in the mixing channel is one minute and a bed slope of 20 cm is given in the channel to avoid the flooding in the channel. However the baffles created more head loss and to reduce the flooding at the beginning in the channel, A.C.pipes 100 mm dia. were fixed in the vertical positions in place of baffles in the bed concrete in the stagged positions.

The alum dosing tank is provided just near the inlet pipe and the alum dose is given just on the down stream of the weir provided near the raw water inlet-pipe in the channel. A small stilling chamber is formed at the inlet end. It has been found that the alum mixing action is very satisfactory with this arrangement considering the instantanoous chemical reaction of the alum solution with the incoming water.

9.6 GRAVEL BED FLOCCULATION UNITS.

There are two units of gravel bed flocculators of size 3 m x 3 m each with 2.5 m depth of gravels. Graded gravels of 60 mm to 20 mm sizes have been provided in these units from the bottom to the top. The top of the gravels is 30 cm below the F.S.L. The surface loading on the gravel bed is 9700 $l/m^2/hr$ while the detention time considering 40% voids is about 6 min. The volumetric loading on the gravel bed is 4000 $l/m^3/hr$.

At the bottom of the chamber, hoppers are provided with 45° slopes on all sides for the collection and removal of the sludge from the hopper bottoms through 75 mm dia sludge draining pipes. The gravels are placed on the mild steel flat screen placed on the top of the hoppers as shown in the drawing K-2. The gravel bed can be cleaned with the raw water by gravity flushing out action in the bed for about five minutes,through a 200 mm dia outlet pipe provided just below the gravel bed. During such cleaning operation the inlet valves in the tube settling tanks are closed to avoid the back flow of the water from the tube settling tanks.

Gravity flushing out action of the gravel bed is considered adequate. However to clean these beds effectively, a back wash line from the wash water tank is connected to the 200 mm dia wash out pipe, in the gravel bed for giving occasional back washing to these beds. Suitable wash water collection and outlet arrangements at the top of the gravel bed have been provided for giving effective washing.

9.7 TUBE SETTLING TANKS.

There are two units of tube settling tanks of size 3 m x 6 m each with 3 m depth, over the top of the hopper bottoms as per details shown in the drawing K-2.

At the bottom of these tanks four hoppers are provided with 45° slopes from all sides for removal of sludge through 75 mm dia., sludge draining pipes by hydrostatic pressure. A layer of rigid PVC square tubes of size 50 x 50 mm opening and 0.6 m in height is provided covering all the surface area. The top level of the tubes is kept one metre below the F.S.L. in the tanks. The PVC square tubes were first fabricated at 60° angle in the module forms of size 3 x 0.5 x 0.6 m and these modules were then lowered and placed on the angle irons fixed to the sides for supporting the modules. The modules are strong enough to resist the necessary bending moment and separate bottom supports are not found necessary. The surface loading on the open surface area of the tubes is about 6600 $l/m^2/hr$, while the total detention period in the tube settling tanks is about 35 minutes.

The raw water after passing through the gravel bed is introduced through four numbers of 150 mm dia perforated A.C. pipes fixed at the bottom of the tube settling tanks to distribute the flow uniformly. The water after passing through the PVC tubes in vertical direction, is collected through the 100 mm dia PVC pipes with side perforations and fixed at one metre centres, in the central collection channel. The settled water from the central channel is then taken on the filter beds.

9.8 DUAL MEDIA FILTER BEDS.

There are three units of dual media filter beds of size 4 m x 2.2 m each. The filter beds are designed for the filtration rate of 6600 $l/m^2/hr$. However the plant observations given in Table 9-V are based only on two filter beds, when run at a higher filtration rate of 10,000 $l/m^2/hr$. The filter media consists of 40 cm. of crushed coconut shell of size 1 mm to 2 mm over the fine sand bed of 50 cm thick of effective size of 0.5 mm and uniformity coefficient below 1.5. The supporting graded gravel bed is provided for 50 cm thickness over the under drainage system. The under drainage system consists of m.s. manifold pipe of 375 mm. dia with side PVC perforated laterals, 50 mm dia, placed at 20 cm centres on both the sides. The side gutters are provided on all the sides of the filter beds, for wash water collection and further draining out through two numbers of 300 mm dia. outlet pipes and valves.

i) Filter Control : The outlet pipes are of 300 mm dia. and only one outlet chamber is provided to give declining rate controlling effect, with only one control valve before the chamber. Rectangular notch is provided at the centre of the control chamber to control the flow over the weir. The chamber is covered by glass shutters.

Chlorination arrangements are provided by the side of the control chamber. The required chlorine dose is given in the control chamber after rectangular weir, so as to mix effectively in the filtered water before flowing to the pure water sump. All these arrangements are provided in the control room. In addition to these, wash water and pure water pumps are also accommodated in the control room. A liquid chlorine dosing arrangement is provided.

ii) Back Wash : Only hard wash is given to these filter beds for about 10 to 12 minutes to clean the beds. A wash water tank of 75000 lit. capacity is provided on the top of the chemical house for giving effective back wash to the filter beds. The back wash line is connected to the filter outlet pipe line for giving back wash to any one of these filter beds, which is normally done in serial order. The back wash is given at such a rate to create expansion of 30 to 50% of the filter media.

iii) Head loss measuring arrangements : The head loss measuring arrangements are made by providing plastic tubing showing the water levels in the filter beds and before the outlet control valve. Arrangements for measuring head loss in the filter beds and a combined head loss before main outlet control valve have been provided.

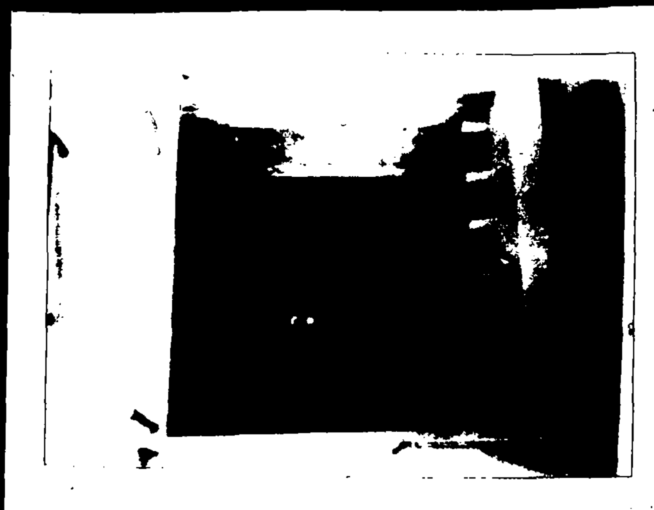
9.9 CONSTRUCTION OF THE PLANT.

The plant was constructed during the year 1976-77 and was put in-to the trial runs from April 1977. The net period of construction was about one year. As shown in the drawing K-2 most of the works are of gravity masonry walls with only R.C.C. structure for the wash water tanks. The work was got constructed through the local contractor by employing local labours.

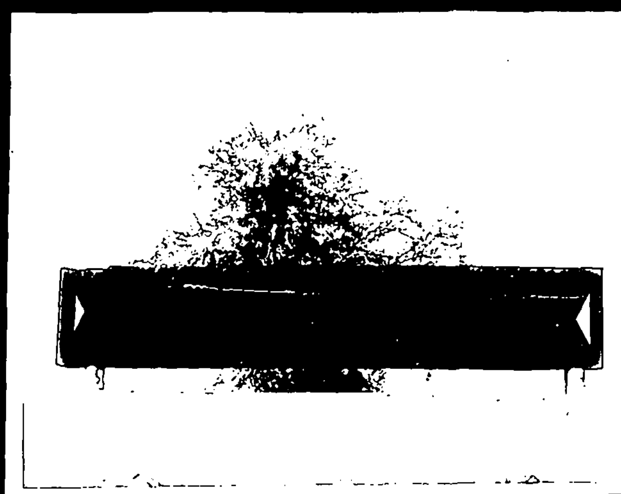
i) Fabrication of Tube-Modules :

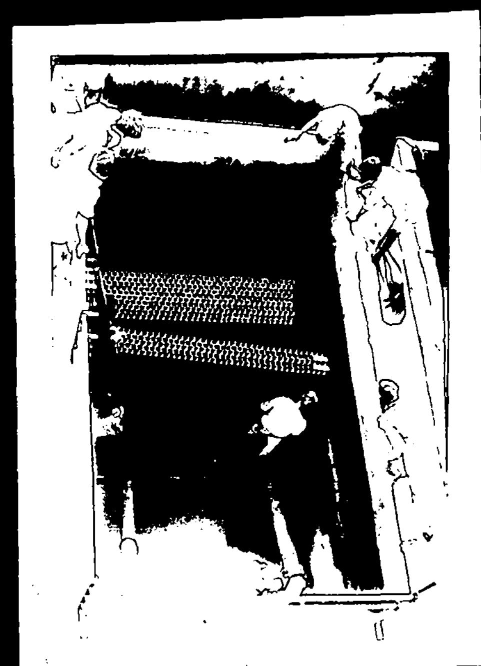
A special mention has to be made about the fabrication of the tube modules which were adopted

PHOTOPLATE 9-II



View of the bottom of the gravel bed flocculator showing supporting perforated frame for gravels and sludge withdrawal pipes below the frame.





LEFT : Tube settler module.

RIGHT : Tube modules under installation in the settling tank unit.

View of the Tube settling tank units from the gravel bed flocculator side showing operating rods, mixing channel and central collecting channel.

probably for the first time in India. The PVC square tubes of 1.5 mm thickness and 50 x 50 mm clear opening size were not manufactured in India before 1975. However special efforts were made by the author to get these tubes manufactured by two firms during 1975 who have supplied the required tubes for this plant. The modules were then fabricated at the site and were installed departmentally in the tube settling tanks. The cost of tube modules came to about Rs. 2000/- per sqm. of the plan area. The cost may be cheaper in future as the tubes can be manufactured on large scale as the tube settlers are likely to be adopted for the construction of new works, and also for the augmentation of the existing water treatment plants.

9.10 PLANT OBSERVATIONS.

Day to day observations are recorded in a register kept at the plant. The proforma for recording the observations along with a typical observation from the register is shown in the Table 9-V. The actual plant observations for nine filter runs, regarding turbidity, head loss, rate of filtration, etc. are given in the Table 9-VI when only two filter beds were operated at the filtration rate of 10,000 $l/m^2/hr$ for the period from 5.9.1977 to 17.10.1977. Table 9-VII showing the results for ten filter runs is also included when all the three filter beds were put into operation for the filtration rate of 6600 $l/m^2/hr$ for the period from 17.10.77 to 2.2.78 and when all the three filter beds were washed on the same day. Table 9-VIII showing the results for the period from 5.3.78 to 2.4.78 is also included when all the three filter beds were put into operation but they were washed separately on alternate day each, so as to operate on the declining rate principle. The bacteriological results are given in the Table 9-III. The Varangaon plant is specially designed for the treatment of highly turbid water sources, and from the results given in the Tables 9-VI to 9-VIII it will be seen that this new plant has given very satisfactory results.

i) Turbidity Observations :

Maximum turbidity was seen up to 4000 JTU from the Tapi river source during the rainy season of 1977. Such a high turbidity was successfully treated to give settled water turbidity below 20 JTU and filtered water turbidity in the range of 0.5 and 1 JTU.

ii) Head Loss Observations :

During first stage observations only two dual media filter beds were run at the filtration rate of 10,000 $l/m^2/hr$ for the period 5.9.77 to 17.10.77 and the results of which are given in the Table 9-VI. From these results it is seen that the initial head loss after washing of the filter beds was in the range of 30 to 40 cm while the average filter run was 40 hours. The filter beds were washed either when the head loss was reached to 2 m. or the filtered water turbidity exceeded one unit, as the plant was run intermittently for about 8 to 10 hours per day. During the first stage observations given in the Table 9-VI it was seen that when the back washing was not given effectively the initial head loss after such ineffective back washing was increased and subsequently the lengths of such filter runs were also found reduced from the normal length of runs. From the second stage observations as given in ~~th~~ the Table 9-VII it is seen that the initial head loss was about 30 cm while the average filter run was 58 hours when all the three filter beds were put into operation. From the table 9-VIII, it is seen that the initial head loss was about 30 cm and maximum head loss about 70 cm when all the filter were run on the declining rate principle and the beds were washed separately on the alternate day each according to serial order. The average filter run of each filter was kept about 48 to 50 hours.

9.11 PERFORMANCE OF THE GRAVEL BED FLOCCULATORS.

The gravel bed unit in the Varangaon plant is adopted as a flocculation unit when the flow is in the downward direction. The floc size gets increased and consolidated as the water passes from the top to the bottom through the gravels and flocculated water is then introduced in the tube settling tanks. From the turbidity reduction in the settled water as shown in the Tables 9-VI and 9-VII it is seen that the flocculation action in the gravel beds is very satisfactory. It is specially to be pointed out that the actual plant scale results of these gravel beds are superior to the pilot plant study on a perpex model of the same height and of 10 cm x 10 cm size as discussed in the chapter 8.

i) Cleaning of Gravel Beds :

There is possibility of clogging of the gravel beds, particularly when the sizes of the gravels are of uneven and of small sizes or when the raw water contains heavy silt during the flodds. From the actual results the clogging was observed in the beds but the beds could be cleaned by gravity flushing operation with the raw water. For such gravity flushing action and to create adequate velocity for the removal of sludge, 200 mm dia. washout pipe is provided below the gravel bed, with a valve outside. Raw water from the mixing channel can be taken on the bed without alum dose for cleaning of the beds adequately.

ii) Back Wash :

From the actual performance of these beds gravity desludging operation was found adequate. However to clean these beds effectively a back wash line from the wash water tank was connected to the 200 mm dia wash out pipe in the gravel beds for giving occasional back wash to these beds. Suitable wash water collection and outlet arrangements have been provided for giving effective back washing.

9.12 TUBE SETTLING TANKS.

The plant scale results from the Tables 9-VI to 9-VIII show very satisfactory performance in the removal of the turbidity load, which shows both the gravel bed flocculators as well as tube settling tanks work in perfect combination. The flocculated water coming out of the gravel beds, when passes through the

PVC square tubes at 60° angle, the floc particles get further consolidated due to the large surface area of the tubes and the heavy floc particles settle in the down ward direction to form sludge. In this process the zone below the tubes becomes a very active sludge blanket zone, as the heavy floc particles flowing in the down ward direction and the new floc particles flowing in the upward direction, further accelerate the flocculation action in this zone. The natural sludge blanket thus formed in and below the tubes is not required to be controlled as in the case of a conventional vertical flow sludge blanket tank.

Due to the accelerated action of the removal of the floc particles in the tube settling tanks the surface loading can be adopted in much higher range of 6000 to 15000 $l/m^2/hr$ through the tube opening area. The surface loading adopted at Varangaon is about 6600 $l/m^2/hr$ as against the normal surface loading of 750 $l/m^2/hr$ as adopted for a conventional rectangular settling tank. Due to the possibility of adopting very high surface loading the detention period is about 35 min as compared to three hours generally provided in a conventional settling tank.

9.13 DUAL MEDIA FILTER BEDS.

The three dual media filter beds are designed for 6600 $l/m^2/hr$. However the performance of these filter beds was found very satisfactory even at a much higher rate of 10,000 $l/m^2/hr$ as given in the Table 9-VI when only two filter beds were run during the first stage observations. The lower filtration rate of 6600 $l/m^2/hr$ has been adopted at this rural water supply scheme, as the operating personnel are not generally trained and considering the possibility of occasional lower performance of the pretreatment works, the filtered water quality should be acceptable, even at higher settled water turbidity. The plant performance for the second stage observations are given in the table 9-VII, when all the three filter beds were run at the designed filtration rate of 6600 $l/m^2/hr$. From these plant observations it can be seen that the dual media filter beds can be safely designed for the high filtration rate up to 10,000 $l/m^2/hr$ after the pretreatment consisting of gravel bed flocculators and tube settling tanks.

The plant performance for the III stage observations are given in the Table 9-VIII when all the three filter beds were run at a designed filtration rate of 6600 $l/m^2/hr$, however the filter beds were run on the declining rate principle and the filter beds were washed separately on alternate days after about 48 hours. From the Table 9-VIII it will be seen that the minimum and maximum head losses were observed between 30 cm and 70 cm. Further range of filtered water turbidity was between 0.5 to 1.0 JTU. Thus the advantages of declining rate operation are clearly seen from the plant observations as given in the Table 9-VIII. The minimum and maximum head loss and turbidity observed during the declining rate operation were observed lower as compared to the observations in the Table 9-VII, when all the three filter beds were run at the same rate of 6600 $l/m^2/hr$ but were washed on the same dates. Therefore the filter beds are proposed to be run on the declining rate principle as stated above during the normal run of the plant.

The author has explained all these design and performance aspects of such dual media filter beds in chapter 7 for Ramtek filter and hence the duplication of the same is avoided in this chapter.

9.14 MAINTENANCE OBSERVATIONS.

From the plant scale observations as discussed in this chapter it is seen that the Varangaon treatment plant is giving very satisfactory performance. Due to the simplicity in the day to day operation of the plant particularly in alum dosing, declining type of filter rate control, sludge draining, hard washing and disinfection arrangements, one operator with one labour assistant can maintain the filter plant efficiently as can be seen from the performance. The operator is of S.S.C. standard level and was trained at site for chemical dosing and filter rate control and washing operations. He maintains the up to date ragister for day-to-day observations of the filter plant. Further he can measure turbidity of raw, settled and filtered water and sends water samples regularly for chemical and bact. analysis. Due to all the simplified arrangements provided at the Varangaon treatment plant, the maintenance of the plant is trouble free, efficient and considerably cheaper as compared to the maintenance of a conventional plant of the same capacity. The maintenance costs of the simplified treatment plants as compared to the conventional plants of same capacity are already discussed in the chapter 7.

9.15 GENERAL CONCLUSIONS.

From the actual plant scale results of this new Varangaon treatment plant, it is observed that the new techniques adopted in this plant may solve some of the important problems in providing simple and cheap water treatment plants for rural and semi-rural areas in the developing countries. Some important conclusions are given below.

i) Gravel bed flocculation chamber may be a promising solution to replace the mechanical flocculation unit for the treatment of turbid water sources for the small capacity plants.

ii) The tube settling tank with the use of rigid PVC square tubes of size 50 x 50 mm opening gives very satisfactory performance in the removal of the high turbidity, after the gravel bed flocculation chambers, at much higher surface loading as compared to the conventional settling tanks.

iii) Dual media filter beds with the adoption of crushed coconut shell media over the fine sand media shows satisfactory performance for higher filtration rates upto 10,000 $l/m^2/hr$ after the pretreatment with gravel bed flocculation and tube settling tank.

iv) The reduction in capital cost by adoption of the Varangaon type treatment plant may be more than 50% as compared to the costs of the conventional plants of the same capacity.

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TABLE 9-I

A comparative statement showing the accepted tendered costs for some conventional treatment plants in the Environmental Engineering Organisation against the cost of construction of the unconventional treatment plant at Varangaon and Bhagur.

Period : 1974 to 1978.

Sr. No.	Name of scheme and year of construction.	Main components of the treatment plants.	Capacity of the plant in mld	Tendered cost. Rs.	Remarks.
1	2	3	4	5	6
		I : CONVENTIONAL TREATMENT PLANTS.			
1.	Improvements to Ratnagiri Water Supply Schemes. (1975-77)	a) Flash mixer. b) Hopper bottom settling tanks. c) Rapid sand filter beds and chemical house. (without wash water tank).	4.36	6,96,000/-	Completed.
2.	Karanja Water Supply Scheme. (1976-77)	a) Aeration fountain. b) Flash mixer c) Clariflocculator d) Rapid sand filters. e) R.C.C.,E.S.R. and f) Wash Water tank.	6.25	11,78,000/-	- do -
3.	Assegaon Water Supply Scheme. (1974-76)	a) Aeration fountain. b) Flash mixer. c) Sludge blanket settling tanks. d) Rapid sand filters. e) Chemical house. (without wash water tank.)	4.9	5,91,500/-	- do -

1	2	3	4	5	6
4.	Augmentation to Shegaon Water Supply Scheme. (1977-78)	a) Aeration fountain. b) Baffle channel. c) Hopper bottom settling and rapid sand filters. (without wash water tank.)	4.8	5,95,000/-	Work in progress.
5.	Regional Rural Water Supply Scheme for 25 villages in Pusad Block. (1974-75)	a) Baffle mixing channel b) Settling tanks c) Rapid sand filter d) Pure water sump and e) Chemical and pump house. and wash water tank.	4.25	8,27,000/-	Completed.
6.	Regional Rural Water Supply Scheme for 13 villages in Degvas Block. (1975-76)	a) Baffle mixing channel b) Settling tanks. c) Rapid sand filters d) Pure water sump and pump house. e) Wash water tank.	2.52	6,06,000/-	-- do --
7.	Ghatanji Water Supply Scheme (1975-76)	a) Aeration fountain b) Flash mixer c) Settling tank d) Rapid sand filter beds e) Pure water sump and pump house and f) Wash water tank.	1.90	5,27,000/-	-- do --
8.	Improvement to Sinnar Water Supply. (1977-78)	a) Flash mixer b) Settling tank c) Rapid sand filters d) Chemical house and e) Wash water tank.	2.70	4,98,000/-	Work in progress.

1.	2	3	4	5	6
9.	Manmad Water Supply Scheme. (1974-76)	a) Flash mixer b) Clariflocculator. b) Rapid sand filters and d) Wash water tank.	7,36	11,33,500/-	Completed.
10.	Malmatha Regional Rural Water Supply Scheme. (1976-78)	a) Horizontal flow settling tanks. b) Slow sand filters c) Pure water sump.	4.90	7,67,000/-	Work in progress.
		II : UNCONVENTIONAL TREATMENT PLANTS.			
11.	Regional Rural Water Supply Scheme for five villages near Varangaon. (1976-77)	a) Mixing channel b) Gravel bed flocculators and tube settlers. c) Dual media filter beds d) Control room-cum-pump house. e) Wash water tank.	4.20	4,00,000/-	Completed
12.	Simplified treatment plant at Bhagur. (1977-78)	a) Mixing channel b) Gravel bed flocculators and tube settlers. c) Dual media filter bed e) Control room.	1.80	1,50,000/-	Completed.

TABLE 9-II

Chemical analysis of raw water of Tapi river source.

Description of Tests. in mg/lit except pH. 1.	28/8/1977 2.	19/9/77 3.	24/10/77 4.	29/11/77 5.	16/12/77 6.	2/1/78 7.
1. pH.	7.9	8.0	8.11	8.5	8.9	8.4
2. Total solids	380.0	325.0	235.00	305.0	270.0	350.0
3. Dissolved solids	180.0	195.0	215.00	225.0	215.0	290.0
4. Total Alkalinity as $CaCo_3$	124.0	130.0	140.0	240.0	244.0	248.0
5. P.Alkalinity as $CaCo_3$	Nil	Nil	Nil	15.0	12.0	16.0
6. Total Hardness	112.0	115.0	130.0	175.0	204.0	196.0
7. Calcium as Ca	27.2	28.0	28.0	40.0	41.6	35.2
8. Magnesium as Mg	10.5	10.80	14.4	20.4	24.0	25.92
9. Iron (as Fe^{++})	10.0	2.0	0.160	0.160	0.48	0.48
10. Sulphate as SO_4	14.0	5.0	16.0	27.0	5.0	19.0
11. Chlorides as Cl	5.6	10.0	25.0	39.0	50.0	44.0
12. Fluorides as F	Nil	Nil	Nil	Nil	Nil	Nil
13. Nitrites as No_2	Nil	Nil	Nil	Nil	Nil	0.1
14. Nitrate as No_3	1.2	1.0	1.0	1.0	0.5	0.5
15. Albuminoid Ammonia as NH_3	0.131	0.129	0.131	0.129	0.005	0.005
16. Free & Saline Ammonia as NH_3	0.012	0.012	0.012	0.012	0.005	0.005

Note : Tests were conducted in the Environmental Engineering Research Division, MERI, Nasik-4.

TABLE 9-III

Bacteriological results at Varangaon treatment plant (MPN)

Period from 28/8/77 to 29/11/77.

Date of collection of samples	Raw Water	Settled WATER	Filtered water	Tap water	Percentage removal of coliform. During pretreatment.	During filtration	During chlorination
1.	2.	3.	4.	5.	6.	7.	8.
28/8/1977	1.6×10^3	430	280	0	73	10	17
12/9/1977	1.5×10^4	430	150	0	97	2	1
19/9/1977	1.1×10^4	2100	1500	0	81	6	13
17/10/1977	9.3×10^2	150	30	0	84	13	3
24/10/1977	1.5×10^3	91	36	0	94	4	2
9/11/1977	9.3×10^2	230	150	0	75	9	16
29/11/1977	4.6×10^3	2100	930	0	55	25	20

General Observations :-

1) Average reduction in MPN during pretreatment : 80%.
2) Average reduction in MPN during filtration : 10%.
3) Average reduction in MPN during chlorination : 10%.

TABLE 9-IV

Hydraulic design calculations for Varangaon treatment plant.

Design flow = 1,75,000 lit/hr. (40,000 gall/hr.) or 4.2 mld.

1. Mixing channel : Provided on the two sides of the tube settling tank as shown in the drawing K-2

Length = 20 m.

Width = 0.75 m.

Approximate detention period = One minute.

Bed slope = 20 cm

spacing of baffles = at One min. centres in staggered positions.

2. Gravel bed flocculators = Two units.

Size of each unit = 3 x 3 x 3 m.

Depth = 2.50 m of gravel.

Surface area of each bed = 9 m^2

Surface loading = $\frac{1,75,000}{2 \times 9}$ = 9700 $l/m^2/hr$.

Volumetric loading = $\frac{1,75,000}{2 \times 3 \times 3 \times 2.5}$ = 3900 $l/m^3/hr$.

say = 4000 $l/m^3/hr$.

Size of gravels used = 50 to 20 mm size, rounded gravel from bottom to top.

Average porosity = 40%

Approximate detention period =

$$\frac{2 \times 3 \times 3 \times 2.5 \times 60}{1,75,000} = 6 \text{ min.}$$

Inlet pipes = provide 4 Nos. 100mm dia pipes.

Outlet arrangements = Provide 4 Nos. of 150 mm dia C.I. pipes with bottom perforation 25mm dia at 10 cm c/c/ for uniform distribution of flow.

Contd..

Sludge removal = Provide four hoppers at the bottom and 100 mm dia. sludge removal pipes with valves and 200 mm dia. outlet for gravity draining and giving back wash with sluice valves.

3. Tube settling tanks = Two units.

size of each unit = 3 m x 6 m.

Depth = 3 m over hopper top

Surface area = 18 m^2 each.

Considering 50 x 50 mm size square tubes, and tube thickness as 1.5 mm. The effective area available of per sq.m. of tank area considering side support reduction in effective area 75%.

$\therefore$ Effective open tube area = 2 x 18 x 0.75

= 27 sq.m.

$\therefore$ Rate flow through the tube per min.

$= \frac{1,75,000}{60 \times 27} = 108$ say 110 $l/m^2/min$.

or 6600 $l/m^2/hr$

(2.3 gall/ft^2/min.)

Actual number of tubes per sq.m. considering side support = 300 Nos.

$\therefore$ Number of tubes of 0.6 m length each

= 2 x 18 x 300

= 10,800 Nos.

Length of tubes considering 0.6 m length each. = 10,800 x 0.6

= 6480 m.

$\therefore$ Number of 3 m. length tubes $= \frac{6480}{3} = 2160$

Contd..

Detention period in the tanks

$$= \frac{2 \times 3 \times 6 \times 3}{175} - 2 \times 3 \times 6 \times 0.6 \times 2.5$$

$$= \frac{108-5.5}{175} = \frac{102.5}{175} = 0.58 \text{ hrs.}$$

$$= 35 \text{ minutes.}$$

$\therefore$ Provide PVC tubes about 10,800 numbers at 60° angle below one metre of F.S.L. in the tank as shown in the drawing K-2. Sludge withdrawal arrangements :

Provide four hoppers of 3 x 3 m. size and 45° slopes at bottom with central sludge collection pits of 0.6 x 0.6 m.

Provide 100 mm dia. sludge withdrawal pipes with sluice valves on the outside in drain chambers as shown in the drawing.

4. Dual media filter beds = Three units.

Size of each bed = 4 x 2.2 m.

Area of bed = 8.8 m^2

Rate of filtration $= \frac{1,75,000}{3 \times 8.8} = 6600 \ l/m^2/hr.$

Rate of filtration when only two beds are in operation $= \frac{1,75,000}{2 \times 8.8}$

$= 10,000 \ l/m^2/hr.$

i) Media details.

Depth of crushed coconut shell media = 40 cm.

Average size of coconut shell media 1 to 2 mm size.

Effective size of coconut shell media 0.95 mm

Uniformity coefficient = 1.45

Contd..

Depth of fine sand media = 50 cm

Effective size of fine sand = 0.50 mm

Uniformity efficient = 1.5

Depth of supporting gravel bed = 50 cms.

ii) Under drain details.

Manifold size = 275 mm dia. M.S. pipe.

Dia of laterals = 60 mm dia. PVC

Number of laterals = 88 Nos. provided at 20 cm c/c on both sides.

Perforations for the laterals = 6 mm dia holes at 5 cm staggered at 90° angle.

Total perforations area = 400 sq.cms.

Ratio of perforated and bed area = 0.045.

iii) Back wash tank.

Rate of back wash = 7000 l/m^2/min. approx. (for 30% to 40% expansion) (or 15 galls/sq.ft./min.)

Capacity of backwash tank = 75000 lit to give a back wash for 10 to 12 min.

The back wash tank is provided on the top of the control room.

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TABLE. 9-V

Statement showing typical results from the day-to-day records at Varagaon plant for two filter runs.

Date	Daily hours of working.	Alum dosein ppm.	head loss in cm (Average) Bed No. 1	Bed No.2	Bed No.3	Combined	Turbidity in JTU Raw	Settled	Filtered.
1.	2.	3.	4.	5.	6.	7.	8.	9.	10
I : During stage I observations when only two filter beds were put into operation.									
12/10/77	8.00	20	-	30	30	28	100	10	0.8
13/10/77	7.30	16	-	50	50	48	64	10	0.8
14/10/77	8.15	16	-	75	75	73	64	10	0.6
15/10/77	8.30	16	-	113	113	111	60	10	0.5
16/10/77	7.30	14	-	175	175	172	55	10	0.5
17/10/77	7.15	14	-	195	195	193	55	10	0.6
II : During stage II observations when all the three beds were put into operation.									
12/1/78	7.15	12	30	30	30	28	33	10	0.8
13/1/78	7.00	12	43	43	43	40	35	11	0.8
14/1/78	7.15	12	60	60	60	58	34	10	0.8
15/1/78	7.15	12	95	95	95	93	34	10	0.8
16/1/78	7.15	12	118	118	116	116	33	10	0.5
17/1/78	7.15	12	145	145	145	143	32	10	0.5
18/1/78	7.00	12	175	175	175	173	32	10	0.5
19/1/78	7.00	12	199	199	199	197	32	10	0.6

TABLE-9-VI

Observations on Varangaon Treatment plant, from 5/9/1977 to 17/10/77.

Filter Run No	Date of starting and washing	Starting head loss cm	First Day					Second Day					Third Day					Fourth Day				
			TH	HL	RT	ST	FT	TH	HL	RT	ST	FT	TH	HL	RT	ST	FT	TH	HL	RT	ST	FT
1.	5.9.77	35	7.0	36	2000	20	0.5	15	76	1500	10	0.5	23	84	1000	10	0.5	30	86	300	10	0.5
2.	10.9.77	53	8.5	85	300	10	0.5	16	87	250	10	0.5	23	89	150	10	0.5	30	160	150	10	0.5
3.	15.9.77	71	9.0	80	1000	40	0.5	18	176	800	40	1.0	27	193	800	25	1.0	36	205	500	10	0.5
4.	19.9.77	60	8.0	107	100	8	0.6	16	153	100	8	0.5	24	200	100	8	0.6	-	-	-	-	-
5.	23.9.77	25	8.0	27	100	8	0.6	16	64	95	8	0.5	24	110	80	8	0.5	33	162	90	8	0.5
6.	28.9.77	48	12	80	60	8	0.5	20	100	60	18	0.5	27	140	50	18	0.5	35	207	50	18	0.5
7.	2.10.77	30	8.0	32	50	10	0.5	16	40	55	10	0.5	22	190	1500	20	0.5	30	200	2000	25	0.5
8.	6.10.77	30	7.0	35	1500	20	0.5	15	57	800	16	0.5	22	67	250	10	0.5	20	108	250	10	0.5
9.	12.10.77	28	8.0	33	100	10	0.5	15	48	64	10	0.5	23	85	64	10	0.5	32	128	60	10	0.5

			Fifth Day					Sixth Day				
1	5.9.77	35	40	96	300	10	0.5	-	-	-	-	-
2.	10.9.77	53	40	170	100	30	0.5	-	-	-	-	-
3.	15.9.77	71	-	-	-	-	-	-	-	-	-	-
4.	19.9.77	60	-	-	-	-	-	-	-	-	-	-
5.	23.9.77	25	40	204	90	8	0.5	45	207	60	8	0.5
6.	28.9.77	48	-	-	-	-	-	-	-	-	-	-
7.	2.10.77	30	-	-	-	-	-	-	-	-	-	-
8.	6.10.77	30	37	138	25	10	0.5	45	190	100	10	0.5
9.	12.10.77	28	40	185	55	10	0.5	48	200	50	10	0.5

General Data

1. Head losses are given in cm
2. Turbidities are given in JTU
3. Area of each filter bed = 8.0 m^2
4. Daily filter run between 8 to 10 hours.
5. Notations given in the above table are :
   a) Total hours of run = TH
   b) Head loss = HL
   c) Raw water Turbidity = RT
   d) Settled water turbidity = ST
   e) Filtered water turbidity = FT.

Flow Data.

1. Total flow = 1,75,000 lit/hr
2. Surface loading on gravel bed flocculator = 9700 $l/m^2/hr$.
3. Surface loading on tube settling tank = 6000 $l/m^2/hr$
4. Rate of filtration on two dual media beds. = 10,000 $l/m^2/hr$.
5. Average filter run during the period = 40 hours.

TABLE 9-VII

Observations on Varangaon Treatment Plant from 17/10/1977 to 2/2/1978.

Filter run No.	Date of starting and washing	Starting head loss cms.	First Day TH	HL	RT	ST	FT	Second Day TH	HL	RT	ST	FT	Third Day TH	HL	RT	ST	FT	Fourth Day TH	HL	RT	ST	FT	Fifth Day TH	HL	RT	ST	FT
1.	17.10.77	28	10	43	35	10	0.5	18	58	35	10	0.5	25	73	36	10	0.5	32	78	35	10	0.5	39	113	35	10	0.5
2.	25.11.77	30	7	35	35	12	0.5	14	63	3000	20	0.5	22	88	2000	17	0.5	30	108	1000	15	0.5	37	132	250	15	0.5
3.	4.12.77	28	11	40	80	10	0.5	19	52	80	10	0.5	26	82	80	10	0.5	33	112	60	10	0.5	41	135	60	10	0.5
4.	12.12.77	28	10	42	50	10	0.5	17	65	37	10	0.5	24	93	40	10	0.5	32	121	40	10	0.5	39	149	40	10	0.5
5.	20.12.77	30	12	37	38	10	0.5	19	52	38	10	0.5	26	72	40	10	0.5	33	92	40	10	0.5	41	115	38	10	0.5
6.	28.12.77	28	8	32	35	10	0.5	15	48	36	10	0.5	22	66	36	10	0.5	29	92	37	10	0.5	36	140	35	10	0.5
7.	5.1.78	28	10	40	35	10	0.5	17	60	35	10	0.5	24	88	35	10	0.5	31	117	35	10	0.5	38	148	34	10	0.5
8.	12.1.78	27	10	40	33	10	0.8	17	60	35	10	0.8	24	80	34	10	0.8	31	100	34	10	0.8	38	131	33	10	0.5
9.	20.1.78	28	10	38	34	10	0.6	17	42	32	10	0.6	24	63	32	10	0.8	31	70	34	10	0.8	37	75	32	10	0.5
10.	2.2.78	28	10	38	30	10	0.7	16	50	30	10	0.8	22	63	32	10	0.8	28	78	32	10	0.8	34	93	30	10.	0.7

Filter run No.	Date of starting and washing	Starting head loss cms.	Sixth Day TH	HL	RT	ST	FT	Seventh Day TH	HL	RT	ST	FT	Longer Run TH	HL	RT	ST	FT
1.	17.10.77	28	43	135	35	10	0.6	53	203	35	10	0.5	62	205	80	10	0.5
2.	25.11.77	30	43	150	250	15	0.5	50	178	120	12	0.5	62	202	50	10	0.6
3.	4.12.77	28	48	157	60	10	0.6	55	187	50	10	0.5	58	208	40	10	0.5
4.	12.12.77	28	47	175	40	10	0.5	54	197	40	10	0.5	63	200	36	10	0.6
5.	20.12.77	30	48	138	40	10	0.5	56	167	37	10	0.5	53	200	35	10	0.6
6.	28.12.77	28	43	168	35	10	0.6	50	193	35	10	0.5	49	195	30	10	0.5
7.	5.1.78	28	45	178	30	10	0.5	49	195	30	10	0.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8.	12.1.78	27	45	157	32	10	0.5	52	183	32	10	0.5	55	197	32	10	0.6
9.	20.1.78	28	43	80	32	10	0.8	48	85	30	10	0.8	80	206	30	10	0.8
10.	2.2.78	28	41	118	32	10	0.8	47	141	40	10	0.8	52	155	40	10	0.6

General Data.

1) Head losses are given in cm.
2) Turbidities are given in JTU
3) Area of each filter bed : 8.8 m^2
4) Daily filter run between 8 to 10 hours.
5) Notations given in the above table are :
   a) Total hours of run = TH
   b) Head loss = HL
   c) Raw water turbidity = RT
   d) Settled water turbidity = ST
   e) Filtered water turbidity = FT

Plant Data.

1) Total flow = 1,75,000 lit/hr.
2) Surface loading on gravel bed flocculator = 9700 $l/m^2/hr$.
3) Surface loading on tube settling tank = 6600 $l/m^2/hr$.
4) Rate of filtration on three dual media beds = 6600 $l/m^2/hr$.
5) Average filter run during the period = 58 hours.

TABLE 9-VIII

Statement showing the plant observations for filter runs on declining rate control from 5/3/78 to 2/4/78. at Varangaon.

flow - 1,75,000 lit/hr.

Date	Head loss in cm				Turbidity in JTU			Filter backwashing for bed No.
	Bed No. 1	Bed No. 2	Bed No. 3	Combined	Raw	Settled.	Filtered	
1	2	3	4	5	6	7	8	9
5.3.78	35	35	35	33	32	12	0.9	1
6.3.78	60	60	60	58	35	10	0.9	
7.3.78	32	32	32	30	36	12	0.8	2
8.3.78	63	63	63	62	34	12	0.8	
9.3.78	37	37	37	35	37	12	0.8	3
10.3.78	60	60	60	58	36	10	0.9	
11.3.78	30	30	30	28	36	10	0.8	1
12.3.78	55	55	55	53	36	10	0.8	
13.3.78	36	36	36	33	36	10	0.8	2
14.3.78	58	58	58	56	35	10	0.8	
15.3.78	35	35	35	32	36	10	0.9	3
16.3.78	63	63	63	61	36	10	1.2	
17.3.78	30	30	30	28	36	10	0.8	1
18.3.78	62	62	62	60	35	10	0.9	
19.3.78	35	35	35	33	36	10	0.7	2
20.3.78	63	63	63	62	32	10	0.8	
21.3.78	36	36	36	34	32	10	0.9	3
22.3.78	63	63	63	61	32	11	0.9	
23.3.78	35	35	35	33	34	11	0.9	1
24.3.78	60	60	60	58	32	10	1.0	
25.3.78	40	40	40	38	36	11	1.1	2
26.3.78	69	69	69	68	33	10	1.2	
27,3,78	42	42	42	40	32	10	1.2	3
28.3.78	72	72	72	70	35	12	1.2	

1	2	3	4	5	6	7	8	9
29.3.78	44	44	44	42	36	12	1.2	1
30.3.78	73	73	73	71	32	11	1.1	
31.3.78	44	44	44	42	31	11	1.0	2
1.4.78	70	70	70	68	32	12	1.0	
2.4.78	43	43	43	42	36	12	1.2	3

Remarks :

1) Each filter bed was back washed after about 48 hours of intermittent run on the 6th day in serial order as shown in this statement.

2) Turbidity was measured by Aplab turbidity meter.

3) Average daily hours of working was 8 hours.

CHAPTER 10

DESIGN OF A SIMPLIFIED TREATMENT PLANT AT CHANDORI VILLAGE.

10.1 INTRODUCTION.

The village Chandori is situated on the bank of Godavari river in the Nasik District of Maharashtra State. The Chandori village water supply scheme was sanctioned for the estimated cost of Rs. 9,82,000/- in the year 1978, under the accelerated programme of village water supply schemes. The population to be served in the immediate and ultimate stages are 11000 and 14700 souls respectively. The rate of water supply will be 40 l/head/day. The scheme is designed for the daily water supply of 0.6 mld in the ultimate stage with daily 16 hours of pumping. The river Godavari is the source of water supply and raw water is proposed to be pumped through a jack well which is a combined headworks for the water supply schemes for Saikheda and Chandori villages.

The raw water from the river is proposed to be taken through a 150 mm dia pumping main 2300 m long from the jack well to the treatment site at an hourly pumping rate of 36,750 litres. The filtered water is proposed to be pumped to the E.S.R. of 2,00,000 lit. capacity situated near the treatment plant. Water will be distributed through the E.S.R. to the Chandori village through stand posts.

A conventional treatment plant consisting of settling tank followed by slow sand filter beds was proposed in the sanctioned scheme for the estimated cost of

Rs. 2,10,000/-. The actual cost of construction for such a conventional treatment plant of one mld capacity would have been about Rs. 2,50,000/- on the basis of a similar treatment plant constructed at Saikheda village situated on the other bank of the Godavari river.

In view of the very high cost of construction of the conventional plants for such small capacity water treatment plants, the author has proposed a new simplified unconventional treatment plant for the treatment of turbid water sources for this scheme, as discussed in this chapter.

The new simplified treatment plant at Chandori village will consist of mixing channel, one unit of pre-treator and one unit of dual media filter bed. The construction of the new treatment plant is likely to be completed by the end of May 1979, and hence the actual plant performance results could not be included in this thesis.

However a pilot plant study has been carried out for this type of new treatment plant and the results of the same are discussed in this chapter.

10.2 THE QUALITY OF THE RAW WATER.

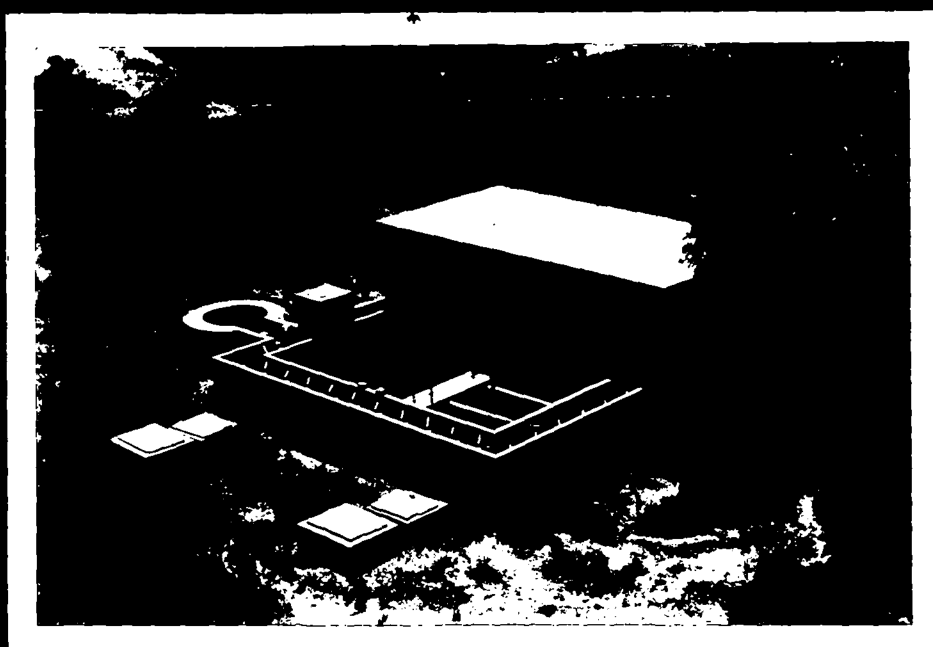
The source of the water supply scheme is the Godavari river which has very high turbidity through out the rainy season of four months. The maximum raw water turbidity is likely to be 5000 JTU, while the average turbidity will be below 100 JTU during the remaining season. The quality of the raw water source for this scheme may be as per category-II viz. the raw water with high turbidity and moderate pollution as discussed in the chapter 1 of this thesis. The author has specially designed this new treatment plant to provide very cheap and simple treatment plants for the small capacity rural water supply schemes for turbid water sources. The typical chemical and bacteriological results of the raw water are given in the Tables 10-I and 10-II.

10.3 DESIGN ASPECTS.

The new design proposed for this unconventional treatment plant includes mixing channel, unit of pretreator followed by one unit of dual media filter bed. The pretreator unit is a totally new feature of the design of this plant and may have been provided for the first time in the field of water treatment. The design of the pretreator has been mainly developed on the basis of the actual plant performances of the Ramtek and the Varangaon treatment plants as explained in the chapters 7 and 9 of this thesis. The new pretreator is a combination of the prefilter of the Ramtek plant and the tube settler of the Varangaon plant. It is a flocculator-cum-tube settler unit. Such a pretreator may be able to treat highly turbid water sources at a higher surface loading rates. The pretreator unit as well as the dual media filter unit for this new plant have been designed for a surface loading of 4500 $l/m^2/hr$. However for the low turbidity water sources the pretreator may be designed for higher surface loading up to 10,000 $l/m^2/hr$.

The detailed hydraulic design calculations for the Chandori treatment plant are given in the Table 10-III

PHOTOPLATE 10-I



View of the Murbad treatment plant showing mixing channel, gravel bed prefilter and dual media filter unit with control room.

The top view of the Chandori plant may be similar as above.

while the details of the various dimensions of the treatment plant are shown in the drawing K.3 enclosed in this chapter. The important design aspects are given below.

10.4 MIXING CHANNEL.

The mixing channel is provided on the top of the two side walls of the plant as shown in the drawing K-3. The side walls of the channel will be 23 cm thick and 50 cm in height. The width of the channel is kept 60 cm and the bottom slope of 20 cm will be given to the channel to avoid flooding of the water. A.C.pipe pieces of 100 mm dia and of 30 cm height will be fixed in vertical positions in the bottom concrete of the channel in staggered positions as shown in the drawing K-3, to accelerate the mixing action.

The alum mixing and dosing tanks will be provided just near the inlet pipe as shown in the drawing K-3, and the alum dose will be given just on the down stream of the weir provided near the raw water inlet pipe in the channel. A small stilling chamber will be available near the inlet pipe due to the weir wall provided in the channel.

10.5 PRETREATOR UNIT.

There will be one unit of pretreator of size 4.0 m x 2.2 m. with 3.6 m depth in the bed. The pretreator is a gravel bed flocculator-cum-tube settling tank. Graded gravels of 50 to 20 mm sizes will be provided at the bottom of the unit for 1.5 m depth. The gravels will be directly placed on the underdrainage perforated pipe laterals as shown in the drawing K-3. The PVC tube settler modules will be provided for 50 cm depth covering all the surface area over the gravel bed but keeping a clear space of 90 cm below the tube settler. Side gutters will be provided on all sides of the bed with the top of gutters 10 cm above the top of the tube settler. Three 100 mm dia perforated A.C. pipe settled water collectors will be provided at 60 cm above the top of the tube settler. The side walls above the gutter level will be provided at 60° angle from the inside face , so as to reduce the velocity of flow towards the collecting pipes. The surface loading on the gravel bed will be 4500 $l/m^2/hr$ while the volumetric loading will be 3000 $l/m^3/hr$. The surface loading on the actual tube opening area will be 5700 $l/m^2/hr$. The total detention period in the pretreator will be about 30 minutes. The tube settler zone will consist of a layer of rigid PVC square tubes of size 50 mm x 50 mm opening and 0.6 m in height which will be fixed at 60° angle in the form of modules as explained in the chapter 9 in connection with the tube settling tank of Varangaon plant.

The raw water after passing through the mixing channel will be introduced at the bottom of the bed through the underdrainage system and will flow in the up ward direction through the pretreator unit. The water after passing through the gravel bed and tube settler will be collected in the perforated A.C. pipe collectors of 100 mm dia, from where the settled water will be introduced on the side dual media filter bed as shown in the drawing K-3.

At the bottom of the pretreator the underdrainage system consisting of 300 mm x 300 mm manifold and 50 mm dia PVC pipe perforated laterals will be provided at 20 cm centre to centre as per details shown in the drawing K-3. The laterals will have perforations of 6 mm dia at 50 mm centre to centre in the staggered positions at 90° angle in the bottom of the laterals.

10.5.1 Sludge Removal From the Top of Gravel Bed :

For removal of the excess floc and sludge from the top of the gravel bed PVC sludge draining pipe 100mm dia with the side perforated laterals of 50 mm dia. with side perforations of 6 mm dia at 10 cm centre on both the sides will be provided on the top of the gravel bed. The operating sludge draining valve will be provided in the side control room. The floc draining operation will be done periodically depending on the turbidity of the raw water. During high turbidity period, continuous sludge draining at suitable rate can be operated.

10.5.2 Cleaning of Gravel Bed :

The gravel bed can be cleaned with the settled water at the top by gravity desludging operation through the underdrainage system for a period of 4 to 5 min. after the day's work. This will be generally adequate for cleaning the gravel bed. However to clean the gravel bed effectively a full back wash can be given periodically for 8 to 10 minutes, so as to remove any clogged material in the gravel bed. The back wash may have to be given once a week or a fortnight in order to confirm the effective cleaning of the gravel bed.

There may be some more advantages in cleaning the pretreator as compared to the cleaning of the gravel bed flocculator in the Varangaon plant, as the required settled water will be available at the top of the gravel bed for cleaning the gravel bed in the pretreator by gravity desludging operation. Further the gravel bed top will always be below the tube settler and hence algae formation at the top of the gravel bed will also be avoided.

10.6 DUAL MEDIA FILTER BED.

i) There will be one unit of dual media filter bed of size 4.0 m x 2.2 m and it is designed for the filtration rate of 4500 $l/m^2/hr$. The filter media will consist of 40 cm of crushed coconut shell of average size 1 to 2 mm over the fine sand bed of 60 cm thick of effective size 0.5 mm and uniformity co-efficient below 1.5. The supporting gravel bed will be provided for 50 cm thickness over the under drains. The under drainage system will be similar to that in the pretreator as explained earlier. The side gutters will be provided on all the sides of the filter bed for wash water collection and further draining out through the 300 mm dia outlet drain pipe and sluice valve or water tight sluice gate. The depth up to the top of the gutter will be 2.1 m., while the water depth over the filter bed will be 2.1 m.

ii) Control Room : One control room will be provided by the side of the filter bed. The outlet pipe will be 200 mm dia and it will have one control valve before the control chamber as shown in the drawing K-3. There will be 'V' notch in the centre of the control chamber to control the flow over the weir . The chamber will be covered with glass shutters. In addition to this, pure water pumps can also be accomodated in the control room. Some space for office accommodation can also be provided in the control room.

iii) Back Wash : Only hard back wash will be given to the filter bed for about 10 to 12 minutes to clean the filter bed effectively. The back wash will be given through 200 mm dia. main from the proposed E.S.R. of 2,00,000 lit. capacity to be constructed by the side of the treatment plant.

iv) Head Loss Measurement : The head loss measuring arrangements will be made by providing plastic tubing showing the water levels in the filter bed and before the outlet control valve. The head loss in the pretreator will be negligible. However a minimum drop of 30 cm at the end of mixing channel will be provided between the F.S.L. in the pretreator and the bottom of the mixing channel at the outlet end of the mixing channel.

10.7 PILOT PLANT STUDY.

In order to study the probable efficiency for the required loading for the Chandori type treatment plant, consisting of pretreator and dual media filter bed, pilot plant study was conducted in the laboratory. The pilot plant as shown in the figure 10-I was fabricated in the laboratory to study the various design aspects. The design of the pilot plant and the experimental observations on the same are discussed in this chapter.

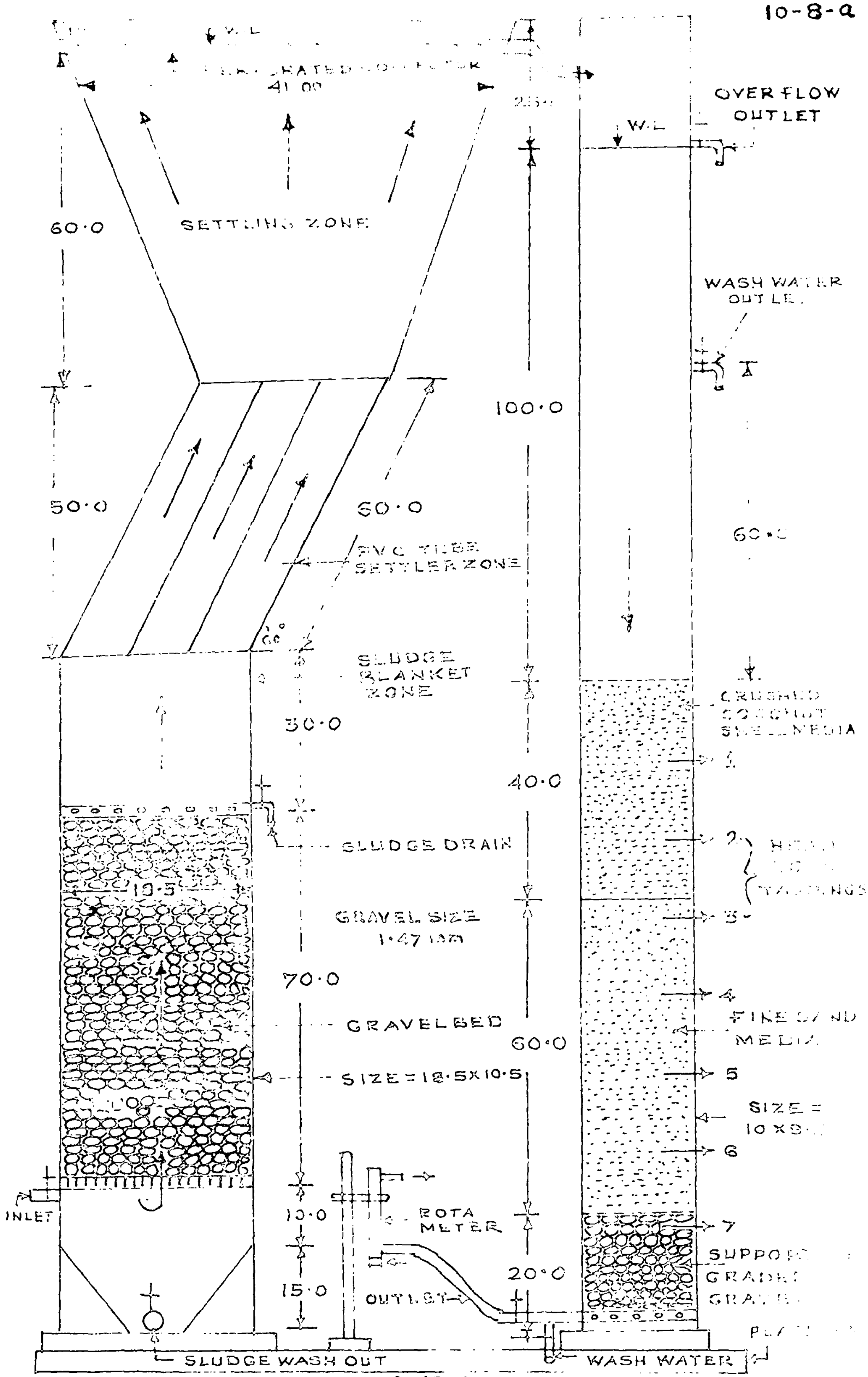


FIG. 10.1

PILOT PLANT MODEL OF CHANDORI TREATMENT PLANT

SCALE VERT. HOR.

10.7.1 Design of the Pilot Plant :

a) Pretreator : The details of the pilot plant are shown in the figure 10-I. The hydraulic design calculations are given in the table 10-IV. The perpex sheet pilot plant units were fabricated in the laboratory so as to observe the effectiveness of the pretreator which consists of gravel bed flocculator at the bottom and tube settler zone provided about 30 cm above the top of the gravel bed flocculator. The settled water was collected through a perforated pipe collector at the top water level. The size of gravels was 1.47 cm average as adopted for the pilot plant study for Ramtek treatment plant.

The tube settler zone was fabricated with six numbers of PVC square tubes of size 50 mm x 50 mm which were fixed at 60° angle as shown in the figure 10-I. Further the special feature of the pretreator was the hopper shape side walls provided for two sides above the top of tube settler zone. In the Chandori plant design the side slopes will be provided for all the sides above the tube settler zone to give improved settlement effect due to the progressive reduction in the upward velocity of water.

For sludge removal and cleaning of the pretreator sludge drain perforated pipe with a gate valve was provided just at the top of the gravel bed, while for gravity sludge draining operation, one sludge outlet was kept at the bottom. The raw water inlet pipe with a gate valve was provided at the bottom of the gravel bed and the same was also used for giving back wash to the pretreator. The wash water outlet was provided about 10 cm above the top of the tube settler. One sludge draining valve was also provided at the bottom of the pretreator. To collect the sludge at the bottom, hopper shape was provided.

At the inlet end one constant flow arrangement and alum dosing and mixing chamber were provided as explained in the chapter 4.

b) Dual media filter unit : The dual media filter unit was provided similar to the dual media filter unit provided for Varangaon pilot plant with 95 cm^2 surface area. Settled water was introduced at the top of the dual media filter unit through the inlet connection. The inlets and outlets of 12 mm dia. G.I. pipes and fittings were provided with brass gate valves to adjust the required flows through the pilot filter unit. At the outlet end of the dual media filter unit one rotameter was fixed to control the rate of filtration.

10.7.2 Pilot Plant Operation :

i) Flow control : For running the pilot plant as shown in the figure 10-I, all the units were first filled with the tap water. Then the raw water from the canal and adjusted to the 100 JTU. turbidity was taken through the constant flow arrangements, in the mixing chamber, in which the required alum dose was given through a separate constant rate controlled solution bottle. After mixing the alum dose the water was introduced from the bottom of the pretreator unit. The water in the pretreator unit flows in the upward direction through the gravel bed flocculator and then through the tube settler zone and the settled water was then collected through the perforated pipe collector from where it was introduced at the top of the dual media filter unit. The settled water was then taken through the dual media filter unit by controlling the required rate of filtration through a rotameter.

ii) Head loss measurement : The head loss in the pre-treator unit was noted from the difference in water levels on the top of the pretreator and in the inlet tubing after mixing chamber. The head loss in the dual media filter unit was observed from the difference of water levels at the top of the bed and in the plastic tubes showing the head losses at various depths in the dual media filter bed. The head loss in the pretreator was between 2 to 3 cm through-out the run and hence these observations were not recorded.

iii) Cleaning of the pretreator unit : The cleaning of the pretreator unit was done by three operations. During the operation of the pretreator the floc and sludge collected on the top of the gravel bed was removed through the sludge draining pipe provided at the top of the gravel bed. Then at the end of the day's run the gravel bed was cleaned by gravity draining operation through the bottom sludge drainy pipe. The gravity desludging operation was found generally satisfactory. However to ensure effective cleaning the backwash was also given from the bottom of the gravel bed and the wash water was taken out through the outlet provided at the top of the tube settler.

iv) Washing of the dual media filter unit : For washing of the dual media filter unit, after closing the outlet control valve the back wash valve was opened so as to give the expansion of the filter media between 30 to 50 percent. During the backwashing operation the fluidised media was kept sufficiently below the washout pipe level, which was kept 60 cm above the top of the coconut shell media. The backwash was given till the clear water was observed at the top.

10.7.3 Experimental Observations on the Pilot Plant :

The purpose of the pilot plant study was to find out the actual performance of the pilot plant for the same loading as proposed for the Chandori treatment plant,viz: 4500 $l/m^2/hr$, so as to predict the probable performance of the actual Chandori plant. Further it was also intended to modify some of the design aspects as adopted for the Chandori treatment plant so as to give desired performance.

As the pretreator will be adopted for the first time for the pretreatment at Chandori treatment plant,it was also proposed to study the removal of sludge volumes and the proportion of the sludge volumes removed at various stages.

Following important observations were conducted for seven hours of daily working as done in the pilot plant studies for Ramtek and Varangaon pilot plants. Further the comparison of the performances of all the three pilot plants viz : Ramtek, Varangaon and Chandori was also possible to some extent as all these studies were conducted for the adjusted raw water turbidity of 100 JTU. Three sets of experiments were conducted for the surface loading of 4500 $l/m^2/hr$ as proposed for the Chandori treatment plant.

10.7.4 Limitations of Pilot Plant Studies :

Even though the aim was to conduct pilot plant studies for the designed rates for the Chandori treatment plant, it was not possible to adopt these rates for all the components. The main reason was the depths of the units. The total working depth in the Chandori treatment plants is proposed as 3.6 m where as the actual depth of the pilot plant was 2.6 m. The reduction of the depth in the pilot plant was adjusted below the tube settler zone. Therefore even though the surface loading on the gravel bed was 4500 $l/m^2/hr$, the volumetric loading was 6400 $l/m^3/hr$, as the depth of the gravel bed in the pilot plant was 70 cm in place of 150cm adopted in the actual Chandori plant. In order to adopt the surface loading of 4500 $l/m^2/hr$ on the dual media filter unit the required flow was adjusted for filtration after by-passing the remaining settled water flow through the over flow arrangement.

10.7.5 Pilot Plant Study for Surface Loading of 4500 $l/m^2/hr$:

i) Head loss and turbidity observations : Table 10-V showing the observations taken for three sets of tests conducted for daily seven hours operation on the pilot plant are given below. Table 10-VI showing the removal of the turbidity loads at different stages of the treatment plant is also given.

TABLE 10-V

Pilot plant observations on Chandori type treatment plant.

Filter run 1.

Hours of run.	Head loss in the dual media filter bed						Turbidities	
	15 cms	45 cms	60 cms	75 cms	90 cms	105 cms	Settled	Filtered.
0	1.0	1.5	3.0	5.5	6.0	8.0	-	-
1	1.5	2.0	4.0	6.0	7.5	9.0	30	0.6
2	2.5	3.0	5.0	7.0	9.0	10.0	25	0.5
3	3.0	4.0	6.0	8.5	10.0	11.5	25	0.5
4	3.0	4.0	6.5	9.0	11.0	12.0	20	0.4
5	3.5	4.5	7.0	9.5	11.5	12.5	25	0.3
6	4.0	5.5	7.5	11.0	12.0	13.0	20	0.3
7	4.5	6.0	8.0	11.5	12.5	13.5	20	0.3

Filter run 2

0	1.0	1.5	3.0	5.5	6.0	7.5	-	-
1	1.5	2.0	4.0	6.0	7.0	8.0	25	0.8
2	2.5	3.0	5.0	6.5	7.5	9.0	25	0.6
3	3.0	3.5	6.0	7.0	8.0	10.0	25	0.5
4	4.0	5.0	7.5	9.0	10.0	12.0	25	0.5
5	4.5	6.0	8.0	10.0	11.0	13.0	20	0.5
6	5.0	6.5	9.0	11.0	12.0	14.0	20	0.4
7	5.5	7.5	10.0	12.0	13.5	15.0	20	0.4

Filter run 3

0	1.0	2.0	4.0	6.0	7.0	9.0	-	-
1	1.5	2.5	5.0	7.0	8.0	10.0	25	0.5
2	2.0	3.5	5.5	8.0	9.0	11.0	25	0.5
3	3.0	4.5	6.0	8.5	10.0	12.0	25	0.4
4	4.0	5.0	7.0	9.0	11.0	13.0	25	0.4
5	4.5	6.0	8.0	10.0	11.5	13.5	20	0.4
6	5.0	6.5	9.0	11.0	12.5	14.0	20	0.4
7	5.5	7.0	9.5	12.0	13.5	14.5	20	0.4

TABLE 10-VI

Turbidity removal in the pilot plant.

Filter run No.	Pretreatment. raw water JTU	Settled water JTU	Percentage removal Turbidity.	Filtration. Filtered water JTU	Percentage removal of Turbidity.
1	100	23.5	76.5	0.43	23.07
2	100	23.0	77.0	0.53	22.47
3	100	23.0	77.0	0.43	22.57

Average turbidity removal :

1. During pretreatment L 76.83 %
2. During filtration : 22.70 %

ii) Sludge removal at every stage : The sludge in the pretreator unit was removed by gravity desludging operation from the top and the bottom of gravel bed and the sludge in the dual media filter bed by back washing. The sludge in the wash water was collected and measured in the mmasuring cylinders in the same procedure as given in the chapters 4 and 5. Table 10-VII shows the actual sludge collected from the two units along with the percentage removal of the same.

TABLE 10-VII

Sludge removal in the pilot plant study.

Filter run No.	Volume of sludge removal in ml. Pretreatment: From the top of gravel bed	From bottom of gravel bed	Total	Filter bed	Total volume	% of sludge removal: Pretreator bed	Filter bed
2	35	1200	1235	640	1875	65.85	34.15
2	90	1150	1240	710	1950	63.60	36.40
3	120	1300	1420	720	2140	66.35	33.65
Average	82	1218	1300	690	1990	65.33	34.67

iii) Bacteriological observations ; The bacteriological observations of the raw ; settled and filtered water samples were carried out at the end of day's work. The results of the same are given in the Table 10-VIII

TABLE 10-VIII
Bacteriological observations (MPN)

Filter run No.	Bacteriological observations.			% Removal of coliform.	
	Raw water	Settled water.	Filtered water.	Pretreatment.	Filtration.
1	2.4×10^4	930	36	96.12	3.72
2	1.4×10^5	24000	9	82.85	17.13
3	2.4×10^4	1500	0	93.75	6.25

Average reduction in coliform count by :

1. Pretreatment : 90.77
2. Filtration : 9.00

10.8 DISCUSSION ON THE OBSERVATIONS ON THE CHANDORI TYPE PILOT PLANT STUDY.

10.8.1 Head Loss Observations :

a) The head loss in the pretreator bed was observed from 2 to 3 cm through out the runs and hence this was not included in the observations. At the end of day's run the pretreator was cleaned by gravity desludging operation when all the sludge was seen to be completely removed. To collect all the sludge in the gravel bed, the pretreator was drained twice after refilling the gravel portion with water. Before desludging the pretreator from the bottom, the sludge from the top of the gravel bed was drained out till the clean water was seen. At the end, back wash was given to see if there is any remaining sludge, however it was observed that there was practically no sludge remained after carrying out two gravity draining operations.

Normally one operation of draining at the end of day's run will be adequate in a prototype plant, and a full back wash can be given once a week, so as to have effective cleaning of the pretreator.

b) Dual media filter bed : From the head loss observations at the various depths in the dual media filter bed it can be seen that the head loss in the crushed coconut shell media was between 40 to 50% of the total head loss developed in the filter bed. This shows that even though the absorption of the sludge load was mainly in the coconut shell media zone the head loss was considerably on the lower side as compared to sand media. It can also be seen that there is marked increase in the head loss between 45 to 75 cm depth, which is the top layer of the fine sand below the coconut shell media. These head losses in the sand media show steep rise in the development of head loss.

10.8.2 Turbidity Observations :

i) Pretreator : From the turbidity observations it can be seen that the settled water turbidity was generally below 25 JTU. During the beginning of the plant the turbidity was slightly more as some time is required to create initial floc blanket in the gravel bed portion. The flocculation action in the pretreator is further accelerated in the tube settler zone and the heavier floc settles down on the top of the gravel bed. This was clearly visible from the transparent side walls. There is sudden reduction in the upward velocity of flow at the top of the gravel bed and then at the top of the tube settler zone. Due to these velocity drops at two stages there is further acceleration in the settlement of the floc formed in the gravel bed and further in the tube settler zone. In order to give further velocity reduction effect the side walls at the top of the gutter level have been provided with 60° slope from the bottom of the gutters up to top water level. Thus the pretreator bed acts as an accelerated flocculation-cum- settling zone and therefore the pretreator may treat highly turbid water sources at higher loading rates as compared to that of the Ramtek type treatment plant where gravel bed prefilter is adopted for pretreatment.

The pretreator in the Chandori type treatment plant is therefore specially designed to treat highly turbid water sources at considerably high surface loading. Thus the removal of such turbidity load was found satisfactory during the pilot plant study.

ii) Filtration : When the settled water turbidity was in the range of 20 to 25 units the filtered water turbidity was between 0.3 to 0.6 JTU. Here also the turbidity removal efficiency was increased after a period of one to two hours and the reasons for this are discussed in details in the chapter 5. The main reason for providing the dual media filter bed after the pretreator is to absorb more load from the settled water at the beginning of the run, and also during accidental higher turbidity load in the settled water due to the operational mistakes. As the detention period is very small in the pretreator bed, due to the failure in giving alum dose even for a short period, there is possibility of sudden increase in the settled water turbidity. These aspects are already discussed in the chapters 6 and 7 of this thesis.

10.8.3 Sludge Removal :

The sludge from the gravel bed pretreator and the dual media filter units was collected separately as discussed in details in the chapter 4 and 5 of this thesis. The sludge from the top of the gravel bed was collected separately at the end of each filter run so as to observe the percentage of sludge removed in the pretreatment. Further this sludge will be generally removed during the running of the plant, when the turbidity of the raw water is on the higher side during rainy season.

The figures of sludge removal from the pretreator and filter units are given in the table 10-VIII. As 50% of the total flow was adopted for filtration the actual sludge removal by filter was doubled to get total value of sludge removed by filter. From the total volumes of sludge collected during each run, as given in this table it is seen that the average percentage of sludge removal from the pretreator unit was about 65% while the sludge from the dual media filter bed was about 35%. Further the sludge removed from the top of the gravel bed was about 6%, of the sludge removed from the pretreator, while it was about 4% of the total sludge removed from the plant.

This shows that the sludge removed during the pretreatment process in the Chandori type pretreator is satisfactory for the treatment of turbid water sources. From the comparative observations of turbidity removal as given in the Table 10-VI, it is seen that the turbidity removal and sludge removal observations from the pretreatment and filtration are fairly comparable.

10.8.4 Bacteriological Observations :

From the bacteriological observations as given in the Table 10-VIII it is seen that the average reduction in the coliform count in the pretreator was about 90% while the same during the filtration was about 9%. This shows that the coliform removal efficiency of the pretreatment is considerably more due to the adoption of the pretreator. Further the coliform removal by the dual media filter bed is also good.

10.8.5 Predictions on the Actual Chandori Plant Performance :

i) Pretreator : The various limitation on the pilot plant studies on the Chandori type treatment plant are given earlier in the para 10.7.4. From these limitations it will be seen that the volumetric loading on the gravel bed portion as given in the hydraulic design was about 6430 $l/m^3/hr$ as compared to 3000 $l/m^3/hr$ as proposed for the actual Chandori treatment plant. This was mainly because the adoption of the 70 cm depth of gravel bed in the pilot plant as against 150 cm. depth adopted in the Chandori plant. Further the clear depth between the top of the gravel bed and the bottom of the tube settler was 30 cm in the pilot plant, where as it will be 90 cm. in the Chandori plant. This clear space below tube settler is a very active zone of the sludge blanket as already discussed in the chapter 4. The depth of the tube settler zone and the clear depth above the tube settler was however same in both the pilot plant and the proposed Chandori plant.

With the above limitations and considering the pilot plant observations on the pretreator the author predicts that the actual plant performance of the pretreator of the Chandori treatment plant may be considerably superior to the results of the pilot plant. The settled water turbidity of the actual Chandori treatment plant may be in the range of 10 to 20 JTU, even during the high turbidity period. This was already observed in the actual performance study in the Ramtek treatment plant as discussed in the chapter 7.

ii) Dual media filter bed : As discussed earlier in the para 10.7.4, the loading on the dual media filter bed was adopted as 4500 $l/m^2/hr$ in the pilot plant study by diverting the remaining 50% flow to waste through over flow arrangement. The author therefore, predicts that, considering the settled water turbidity between 10, to 20 units, and the rate of filtration as 4500 $l/m^2/hr$ the actual plant performance of the Chandori dual media filter bed may also be superior to the performance of the pilot plant observations. Thus the filtered water turbidity of the dual media filter bed of Chandori plant may be between

0.3 to 1 JTU continuously for the filter runs beyond 50 hours. This was already observed in the plant performances for such loadings at Ramtek and Varangaon treatment plants as discussed in the chapters 7 and 9 of this thesis.

10.9 GENERAL CONCLUSIONS.

i) From the study on the Chandori type pilot plant, it is observed that such a complete treatment plant will be a possible solution for adopting the design for the small capacity water treatment plants for the treatment of turbid water sources.

ii) The pretreator as adopted in the Chandori treatment plant may be a possible solution to replace the conventional pretreatment process for the treatment of high turbidity raw water sources for the small capacity plants.

iii) The dual media filter bed is not a necessity in such units after pretreator bed, however it is recommended for economy in the wash water use and general improvement in the treatment process. It will be specially useful to absorb the occasional loads of turbidities in the raw water.

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TABLE 10-I

Typical chemical analysis of raw water samples of Godavari Rivers source.

Description of Tests in mg/lit. except pH	10-7-78	19-9-78
1. pH	7.9	8.4
2. Total solids	388	294
3. Dissolved solids	276	275
4. Total Alkalinity as $CaCo_3$	160	160
5. P.Alkalinity as $CaCo_3$	Nil	10
6. Total Hardness as $CaCo_3$	150	147
7. Calcium as Ca	36.0	32.0
8. Magnesiam as Mg	14.4	16.0
9. Iron as (Fe^{++})	0.2	0.16
10. Sulphate as So_4	20.0	4.0
11. Chlorides as Cl	9.0	10.0
12. Fluorides as F.	0.50	0.45
13. Nitrites as No_2	Nil	Nil
14. Nitrates as No_3	1.0	0.8
15. Alubuminoid Ammonia as NH_3	0.134	0.132
16. Free and Saline Ammonia as NH_3	0.0146	0.012

TABLE 10-II

Typical Bacteriological analysis of raw water samples.

Date	MPN	Plate count
10/7/78	1.5×10^5	TNC
4/8/78	2.9×10^3	TNC
19/9/78	1.1×10^4	TNC

TNC : Too numbers to count.

TABLE 10-III

Hydraulic design calculations for Chandori treatment plant.

1. General : A new simplified plant consisting one unit of pretreator and one unit of dual media filter bed is proposed.

Hours of working = 16 hours in the ultimate stage

Design flow = 40,000 lit/hr.
(The actual flow will about be 36,750 lit/hr.)

2. Mixing channel : Provide on the side of the pretreator unit and dual media filter unit as shown in the Drawing K-3.

i) Length = 13 m.

ii) Width = 0.6 m.

iii) Bed slope : Provide 20 cm drop in the bed and 75 mm dia. A.C.pipe pieces 20 cm in length in vertical staggered positions in place of baffles, for mixing purpose and to avoid flooding in the channel.

3. Pretreator unit : One Number. This is designed on the combination of gravel bed flocculator and tube settler with the flow in the upward direction.

i) Size of unit = 4.0 x 2.2 m.

ii) Area = 8.80 sq.m.

iii) Loading on gravel bed $= \frac{40,000}{8.80}$

$= 4500 \text{ l/m}^2\text{/hr.}$

iv) Volumetric loading on the gravel bed of 1.5 m. depth $= \frac{40,000}{8.8 \times 1.5} = 3000 \text{ l/m}^3\text{/hr.}$

v) Net surface loading on the open tube area of the tube settler consisting 50 mm x 50 mm square tubes of 0.6 m in height and fixed at 60° angle and alternate raws in the opposite directions and considering 80% effective area of the tube modules.

$$= \frac{40,000}{0.8 \times 8.8} = 5700\ l/m^2/hr$$

vi) Total Detention period = 45 minutes.

vii) Provide side wall slope from the bottom of the gutters at 60° angle to reduce the velocity of flow towards the settle water collector pipes 100 mm dia 3 numbers as shown in the drawing.

4. Dual media filter unit : One number.

i) Size of unit = 4.0 m x 2.2 m.

ii) Area of beds = 8.8 sq.m.

iii) Rate of filtration $= \frac{40,000}{8.8}$

$= 4500\ l/m^2/hr.$

iv) Direction flow down wards.

v) Velocity through bed = 4.5 m/hr.

vi) Depth of coconut shell media = 40 cm

Size of coconut shell media between 1 and 2 mm size sieve opening.

Effective size of media = 0.95 mm

Uniformity co-efficient = 1.45

vii) Depth of fine sand below coconut shell media. = 60 cm

Effective size of sand = 0.5 mm

Uniformity co-efficient of sand = 1.5

viii) Depth of supporting gravel bed = 50 cms

ix) Under drain details :

M.S. manifold size = 300 x 300 mm

number of laterals = $\frac{400}{20}$ = 20 in each side

$\therefore$ Total = 20 x 2 = 40 Numbers.

Perforations : for 50 mm dia laterals of P.V.C. pipes tested 6 kg. pressure and 6 mm dia perforations at 50 mm c/c in staggered positions at 90° angle in the bottom side.

Desired capacity of the wash water tank considering back wash flow of 500 lit/sqm/hr.

= 8.8 x 10 x 500

= 44,000

The proposed ESR of 2,00,000 capacity to be constructed near the treatment plant site, can be utilided for giving back washings to the dual media filter bed and the pretreator bed.

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TABLE 10-IV

Hydraulic design calculations for pilot plant study.

1. General :- The pilot plant consisting mixing chamber, pretreator and dual media filter unit was fabricated from the perpex sheets as shown in the figure 10-I. The hydraulic design calculations are given below.

2. Mixing chamber :- Raw water after mixing of alum dose in the mixing chamber was introduced in the inlet plastic tube as explained in the chapter 4.

3. Pretreator :

a) Gravel bed flocculator at the bottom :-

i) Size of pretreator : 18.5 cm x 10.5 cm.

ii) Depth of gravel bed : 70 cm.

iii) Dia of gravels : 1.47 cm

iv) Total volume of gravel bed : 18.5 x 10.5 x 70
= 194 x 70
= 13580 cm^3

v) Actual volume of water in the bed : 5830 cm^3

vi) Actual vol. of gravels : 7750 cm^3

vii) Porosity : 43 %

viii) Clear depth between top of gravel bed & bottom of tube settler. : 30 cm.

ix) Clear depth above tube settler upto F.S.L. : 60 cm

x) Surface area of the bed : 194 cm^2

xi) Loading rate on the bed : 4500 $l/m^2/hr$.

xii) Flow per hour $= \frac{4500 \times 194}{100 \times 100} = 87.30$ lit/hr.

xiii) Flow rate per min. $= \frac{87.30}{60} = 1.455$ lit/min or 1455 ml per min.

b) Tube settler zone :-

i) No. of P.V.C. square tubes : 6 numbers

ii) Length of tubes : 60 cm

iii) Size of tubes = 50 x 50 mm inside.

iv) Total cross sectional area of the tubes. = 6 x 5 x 5 = 150 sq.cm.

v) Surface loading for the flow of = 87.30 lit/hr.

$$\frac{87.30 \times 100 \times 100}{150}$$

$= 5800\ l/m^2/hr.$

c) Surface loading on the top settling zone :

i) Size of bed at the top water level. = 41.0 x 11.5

ii) Surface area at the collecting level . = 471 cm^2.

iii) Surface loading at the top of tube settler. = 4500 $l/m^2/hr$.

iv) Surface loading at the top water level. = $\frac{87.30 \times 100 \times 100}{471}$

$= 1850\ l/m^2/hr.$

d) Dual media filter bed :-

i) Surface area of the bed = 9.5 x 10 = 95 cm^2

ii) Flow rate to be adjusted for the surface loading of = 4500 $l/m^2/hr$.

$$= \frac{4500 \times 95}{100 \times 100}$$

= 42.75 lit/hr.

or 750 ml/min.

iii) Depth of water over the bed = 100 cm.

iv) Depth of count shell media = 40 cms

v) Average size of media = Between 1 to 2 mm

vi) Effective size of coconut shell media = 0.95 mm

vii) Uniformity coefficient of media = 1.45

viii) Depth of fine sand media = 60 cm

ix) Effective size of sand = 0.5

x) Uniformity co-efficient = 1.50

xi) Depth of graded gravels = 20 cms

xii) Inlet and outlet arrangements = 12 mm dia. G.I. pipes and brass gate valves.

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CHAPTER 11.

PLANT OBSERVATIONS ON SIMILAR NEW TREATMENT PLANT.

11.1 INTRODUCTION.

The design and the pilot plant observations and actual plant designs and observations for the Ramtek, Varangaon and Chandori type treatment plants are given in the chapters 6 to 10 of this thesis. The main purpose of the development of these three types of the new treatment plants is to develop very simple and cheap new designs for providing water treatment plant for the rural and semi-rural areas. The actual plant results show very satisfactory performances for the Ramtek and Varangaon plants as discussed in the earlier chapters of this thesis.

The author has given similar as well as some modified designs of these three types of treatment plants to about twenty seven small capacity plants in the Maharashtra State including one plant each in the Gujrat, Hariyana and Punjab States. The Table 11-I showing the capacities of these plants; approximate cost of these plants, and costs of the same capacity conventional plants showing the probable savings due to the adoption of the new designs as developed in this thesis is enclosed in this chapter. The proposals for augmentation in which these new techniques have been adopted are also shown in this Table. It will be seen that there may be a saving over one crore of Rupees due to the adoption of the new techniques for the design of these plants.

In the design of these new treatment plants, the author has given some modifications in the original designs as adopted at Ramtek and Varangaon, The main purpose of these changes in the designs is to see if these can be further simplified and made cheaper in their construction and operation and also if the performances of these plants can be further improved. The author feels that by this approach it may be possible to improve upon the original designs for Ramtek, Varangaon and Chandori treatment plants, so as to develop most economical designs for the treatment of low and high turbidity water sources.

In this chapter it is proposed to give typical modified designs and actual plant observations on some new treatment plants, recently constructed in the Maharashtra State for which the designs have been given by the author. Most of the treatment plants as given in the Table 11-I are under construction. The following treatment plants have been completed recently and it is proposed to give their designs and plant performance results in this chapter.

1) Surya Project treatment plant.
2) Murbad village treatment plant.
3) Bhagur village treatment plant.

11.2 SURYA PROJECT TREATMENT PLANT.

11.2.1 General Design :

The treatment plant is constructed for providing filtered water supply to the staff colony for the Surya Irrigation project in the Thana District. The capacity of the plant is 0.65 mld with the hourly pumping rate of 27000 lit/hour. As the raw water turbidity is low for the most of the period except the rainy season, a simplified treatment plant on the basis of Ramtek filter has been proposed for this scheme. The treatment plant consists of baffled mixing channel, one gravel bed prefilter and one rapid sand filter bed. The hydraulic design calculations are given in the Table 11-II. The prefilter and the filter units are of the size 3.5 m x 2.2 m with 3 m total depth upto the tap water level. A blue print drawing No.11-I is enclosed at the end of this chapter. A separate rectangular masonry wash water tank of 40,000 lit. capacity has been provided on the same hillock at a distance of 30 meters to get the required head of 8 m for giving back wash. The filter effluent is given bleaching powder solution dose of the required quantity in the side control room and then it is stored in the pure water sump. Water from the sump is then pumped to the G.S.R. in the colony for further distribution. Alum dose is given just at the beginning of the mixing channel. The plant was put into operation from the month of December 1976.

11.2.2 Special Design Aspects :

The special design feature of this unit is the provision of rapid sand filter bed in place of the dual media filter bed as provided in the Ramtek filter. The purpose of this change is to see for lower rate of filtration at 4000 $l/m^2/hr$, if the rapid sand filter will give the required performance of this plant. The capacity of the plant being small, the treatment plant will become simple and cheap by the adoption of a rapid sand filter bed in place of a dual media filter bed. Further the same bed can be converted in-to a dual media filter bed for higher rate of filtration in future if it is found necessary.

11.2.3 Plant Performances :

The plant observations for a period of six months are given in the Table 11-III. From the results given in this Table it is seen that the average filter run for a period of four months was 55 hours. The period of study can be said as the worst part of the year as regards the turbidity of the raw water. The filter bed was operated for the head loss of one meter upto 5.10.77 and then it was operated upto 1.5 meters. When the filter bed was operated upto 1.5 m of head loss the filter runs have been increased beyond 100 hours when the raw water turbidity was within 20 JTU.

The special feature of this filter is the rapid sand filter in place of a dual media filter bed as provided at Ramtek. However from the results the performance with the rapid sand filter after the gravel bed prefilter was found to be very satisfactory. The maximum turbidity was found to be about 400 JTU during the study while the settled water turbidity was generally with 20 JTU and the filtered water turbidity was generally less than one JTU. Thus the dual media filter bed is not a necessity for such a simplified treatment plant and for lower filtration rates upto 5000 $l/m^2/hr$ and for the lower raw water turbidity the treatment plant as adopted for Surya project can be provided. However, if a dual media filter bed is adopted in place of a rapid sand filter bed as in Ramtek plant then either the rate of filtration can be increased immediately or in the next stage or the lengths of filter runs can be increased by about 100%. Further for lower rate of filtration the quality of filtrate can also be considerably improved. It is therefore, recommended that a dual media filter bed be generally provided for such a treatment plant unit of Ramtek type. The wash water consumption during this study for washing rapid sand filter bed was seen to be 2.66% of the total water filtered during worst condition which is also seen reasonable.

11.2.4 Construction and Cost :

The actual cost of the Surya Project treatment plant is as given below. The work was got executed through a regular contracting agency. The work was executed by employing local labours from the Adiwasi area.

i) Cost of the treatment plant completed with prefilter, rapid sand filter and control room and inlet and outlet connections.	Rs.	65,000/-
ii) Cost of masonry backwash tank of 40,000 lit.capacity of size 5.0 x 4.0 m inside, including cost of sluice valves and G.I.sheet roofing.	Rs.	22,000/-
iii) Cost of 200 mm dia H.D.Polyethylene pipe line for back washing 65 m.	Rs.	14,500/-
Total...	Rs.	1,01,500/-
say...	Rs.	1,00,000/-

11.3 MURBAD VILLAGE TREATMENT PLANT.

11.3.1 General Design :

The Murbad village is situated about 30 km. from the town Kalyan in the Thana District. The treatment plant was constructed for providing filtered water supply to the Murbad village. The present population of the village is 8500 souls and thewater supply scheme is designed for the ultimate population of 11000 souls. The capacity of the treatment plant is 0.93 mld with hourly pumping rate of 38,500 lit/hour. As the source of water supply is a small storage dam, the raw water turbidity is generally low for the normal period except in the rainy season. Therefore a simplified treatment plant on the basis of the Ramtek plant has been proposed for this scheme. The treatment plant consists of a buffle mixing channel, one gravel bed prefilter unit and one unit of dual media filter bed. The hydraulic design calculations are given in the Table 11-IV. The prefilter and the filter units are of size 3.5 m x 2.75 m with, 3 m total depth upto the top water level. A blue print drawing No. 11-II showing the detailed design aspects is enclosed at the end of this chapter. The existing E.S.R. of 2,25,000 lit. capacity will be used for giving hard wash to the dual media filter hed. The filter effluent is given bleaching powder solution dose of the required quantity in the control room and then it is stored in the pure water sump. Water from the sump is then pumped to the E.S.R. from where it is distributed in the Murbad village, through stand posts and some private connections.

11.3.2 Special Design Aspects :

The special design features of this unit are the provision of two seperate units for prefilter and dual media filter units, in place of a combined unit above gutter level as provided in the Ramtek plant. However the rate of filtration is 4000 $l/m^2/hr$, which is about half the loading as adopted for Ramtek filter beds. The raw water after passing through the gravel bed prefilter in the upward direction is collected in the A.C.perforated pipe collectors at the top water level. The settled water is then introduced in the side gutter of the dual media filter bed as shown in the drawing. The purpose of this change is to see if the moderately turbid raw water can be treated in a better way than in the Ramtek type unit. This aspect is fully discussed in the chapter 6 in which pilot plant comparative study has been carried out on the Ramtek and Murbad pilot plants. For this purpose it was originally proposed to give slope at 60° angle to the inside faces of the prefilter walls, so as to reduce the velocity of approach towards the perforated collecting pipes. However this change was not adopted during the execution and only vertical side walls were constructed.

11.3.3 Plant Performances :

The Murbad plant was completed in July 1978, however the village Panchayat did not agreed to run the plant for some financial difficulties. So the plant was put for a trial run for a period of only ten days and the plant observations are given for this period in the Table 11-V. As the period of study was very short it is difficult to give any conclusive remarks on the plant performance. From the two filter runs conducted on experimental basis it is seen that the plant performance was generally satisfactory. Further plant study will be conducted when the plant will be put in regular operation.

11.3.4 Construction and Costs :

The work was got executed through the regular contracting agency by employing local labours from the vaillage. The period of construction was about one year.

The actual cost of the construction of this new treatment plant including an office room over the control room was about Rs. 1,50,000/-. The provision made in the sanctioned scheme for the treatment plant consisting of settling tank and slow sand filters was Rs. 4,43,700/-. Thus the actual cost of works was about 1/3 of the sanctioned provision, due to the adoption of the new simplified treatment plant at Murbad.

11.4 BHAGUR VILLAGE TREATMENT PLANT.

11.4.1 General Proposal :

Bhagur village is situated about 15 km. from the Nasik City. The present population of the village is 12,800 souls and the water supply scheme is designed for the ultimate population of 17,000 souls. The capacity of the water treatment plant is 1.8 mld with the hourly pumping rate of 75,000 lit per hour. A new conventional treatment plant consisting of settling tank and pressure filters were proposed in the sanctioned scheme. The source of water supply scheme is the Darna river which has very high turbidity during rainy season, and raw water turbidity some times goes beyond 5000 JTU. The Varangaon type high rate simplified treatment plant with some minor modifications have been adopted for this water supply scheme.

11.4.2 Design Aspects :

The new treatment plant consists of mixing channel, one unit of gravel bed flocculator, one unit of tube settling tank and one unit of dual media filter bed. The hydraulic design calculations are given in the Table 11-VI, while the details of the works are shown in the drawing No. 11-III.

The size of the gravel bed flocculator is 3.75 x 3.75 m with 3.0 m depth. The surface loading on the [redacted] gravel bed is 5330 l/m^2/hr, while the volumetric loading is 2130 l/m^3/hr. The size of the tube settling tank is also 3.75 m x 3.75 m with 3 m depth. The surface loading on the open cross sectional [redacted] area of tubes is 7140 l/m^2/hr. The detention period in the tank is about 30 min. The size of dual media filter bed is of 4 m x 2.2 and the rate of filtration is 8500 l/m^2/hr. For backwashing of the filter bed the existing elevated service reservoir of 2,00,000 lit. capacity constructed at the side of the treatment plant is used.

The filter effluent is given bleaching powder dose in the side control room and then it is stored in the pure water sump. Water from the sump is then pumped to the E.S.R. near the plant. The plant was put into operation from the month of August 1978.

11.4.3 Special Design Aspects :

As compared to the design of the Varangaon plant, the special design aspects are the bigger size of the gravel bed for lower rate of loading, and the higher rate of filtration in the dual media filter bed. All the units are open to sky. The plant is a very compact one and can be considered as a very safe treatment plant for the treatment of highly turbid water sources for the small capacity water treatment plants.

11.4.4 Plant Performances :

The typical plant observations for the period from 20.9.78 to 6.11.78 are given in the Table 11-VII. From these results, it is seen that the average filter run for the typical eight filter runs with intermittent operations was 55 hours. The tube settler modules were actually introduced from 10.10.78 and till then the plant was operated without tube settler modules in the tube settling tank. Even though the period of study was not the worst period from the point of high turbidity of the raw water, the maximum turbidity reached during this period was 1500 JTU. The average daily hours of working was about 10 hours. The wash water consumption for the filter wash during this period was about 0.7% of the total water filtered. The wash water consumption for gravel bed cleaning was negligible as the gravel bed was cleaned by gravity deflushing operation after two to three days as required. The sludge from the bottom of the gravel bed and the tube settler units was drained daily by hydrostatic pressure for 2 to 3 minutes till the clear water was observed through the outlet drain pipe. Thus it can be seen that the Bhagur plant gave very satisfactory performance during the typical observations conducted for about 45 days.

11.4.5 Construction and Cost :

The work was got executed through the regular contracting agencies by employing local labours from the village. The period of construction was about one and half year which was some what more. However this was due to the difficulty in setting the proper contracting agencies and normally this type of work can easily be constructed within a period of 8 to 10 months.

The actual cost of construction of the new treatment plant consisting of gravel bed flocculator, tube settling tank, dual media filter bed and control room was about Rs. 1,50,000/-. The cost of the conventional plant of the same capacity may be more than Rs. 3,00,000/- and thus there was a saving of more than 50% by adopting the new design as explained above.

11.5 DISCUSSION.

11.5.1 Background :

The detailed design and the pilot and the actual plant performances on the Ramtek and Varangaon plant have already been discussed in details in the earlier chapters. As explained in the para 11.1, the main purpose of the study of the actual performances of the new plants at Surya project, Murbad and Bhagur was to see if the original designs can still be made simpler and cheaper by carrying out some minor modifications, based on the actual plant performances of the original plants at Ramtek and Varangaon.

11.5.2 Water Quality Aspects :

Out of these three new plants the Surya project and Murbad plants are based on the Ramtek plant design for the treatment of low turbidity and low polluted raw water sources. While the Bhagur plant is based on the design of the Varangaon plant for the treatment of high turbidity raw water sources. The typical chemical and the bacteriological analysis of the water samples of the raw water sources for these three plants are given in the Tables 11-VIII and 11-IX enclosed at the end of this chapter. It can be seen from these results and the raw water quality falls in the category I for the first two plants and the category II for the Bhagur plant, as discussed in the chapter I.

11.5.3 Special Aspects of Designs :

The special aspects of designs of the new treatment plants at Surya project, Murbad and Bhagur and their actual performances are discussed below.

i) Surya project treatment plant :-

As explained earlier in the para 11.2, the main change in this new plant was the adoption of the rapid sand filter bed in place of the dual media filter bed as adopted at Ramtek. Further the rate of filtration was adopted as 3500 $l/m^2/hr$ which is about half the rate of filtration adopted for the Ramtek plant. From the plant observations it is seen that the actual performance was very satisfactory particularly during the worst period of the year when the raw water turbidity reached to 400 JTU. Thus this type of plant can be safely adopted for a filtration rates upto 5000 $l/m^2/hr$. However for better quality of effluent, higher rate of filtration and longer lengths of filter runs, it is recommended to adopt dual media filter bed in place of rapid sand filter bed after the gravel bed pretreator. Further the dual media filter bed with some additional cost of the top crushed coconut shell media, will act as a safety factor against the possible break-through of the rapid sand filter bed in such small capacity plants, in the village as already discussed earlier in the chapter 7 and 9.

ii) Murbad treatment plant :-

As explained in the para 11.3 the important change in this new plant was the adoption of two seperate chambers for the gravel bed prefilter and the dual media filter bed. This change was made to see if such a plant can treat occasionally moderately turbid water up the turbidity of 2000 JTU. From the Table 11-VIII it can be seen that the raw water turbidity can reach to 2000 JTU in the worst conditions. However as the plant was constructed just recently it was not possible to collect the actual plant observations for such worst conditions. From plant observations as given in the Table 11-V it is not possible to give any conclusive remarks as already discussed earlier. However the author feels that if the inside walls of the prefilter are given a slope at

60° angle to increase the surface area in the settled water zone, upto the perforated settled water collectors, it may be possible to treat the moderately turbid water sources satisfactorily when a dual media filter bed is adopted for further treatment. The unit can be designed generally for a loading of 5000 $l/m^2/hr$, however, it may be possible to design upto a loading of 7000 $l/m^2/hr$ for the small capacity water treatment plants. Further a Murbad type treatment plant can be converted into a Chandori type treatment plant as discussed in the chapter 10

iii) Bhagur treatment plant :-

As explained in the para 11.4, there is no basic change in the design of the main components of gravel bed flocculator, tube settling tank and a dual media filter bed. However, the gravel bed loading has been reduced to 5300 $l/m^2/hr$ which is about half the surface loading adopted at the Varangaon plant, while the loadings on the tube settler and the dual media filter bed have been in increased considerably as discussed earlier.

Even though the plant was commended after the worst period conditions, the plant observations as shown in the Table 11-VII show very satisfactory performance, when the raw water turbidity was considerably high and maximum turbidity has crossed 1500 JTU. It was an interesting point to note that even when the PVC tube modules were introduced by about 10.10.78 in the tube settler unit, the settled water turbidity with only 30 min. detention period was within 15 JTU when the raw water turbidity was generally high. These were rather surprising observations and the author feels that this may be due to the lower loading on the gravel bed flocculator as mentioned earlier, and the uniform loading on the settling tank unit with the perforated distribution and collector pipes to avoid short circulation. Thus after placing of the tube modules in the tube settler there was no marked improvement in the settled water quality. Thus the loading on the gravel bed, its sizes and inlet and outlet collections are also the important points for future research in this new treatment process as developed at Varangaon plant.

11.6 GENERAL CONCLUSIONS ;

i) The Surya project type treatment plant consisting of gravel bed prefilter followed by a rapid sand filter bed in a combined unit, can be adopted for the treatment of low turbidity water sources for a loading upto 5000 $l/m^2/hr$. This plant can tackle the occasional turbidity load upto 500 JTU.

ii) The Murbad type treatment plant consisting of two seperate beds of gravel bed prefilter and dual media filter bed, can be adopted for the treatment of moderately turbid water sources for a loading upto 5000 $l/m^2/hr$. Such a plant may be able to tackle the occasional turbidity load upto 2000 JTU. The Murbad type plant may be converted into a Chandori type treatment plant.

iii) The Bhagur type treatment plant consisting of three single units, of gravel bed flocculator, tube settling tank and dual media filter bed, can be adopted for the treatment of high turbidity water sources for higher surface loading rates.

iv) Even though the dual media filter bed is not a necessity in all these plants, it is recommended as a safety factor, against the possible breakthrough, and also for better effluent quality, longer filter runs and the higher surface loadings.

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TABLE 11-I

The probable savings due to the proposals based on the new techniques in water treatment as developed in this thesis.

Sr. No.	Names of water treatment plants (Dist./State	Approx. capacities of plants in mld.	Probable cost as per conventional methods in Rs (lakhs)	Proposed cost as per new techniques Rs. (lakhs)	Probable savings in Rs. (lakhs)
1	2	3	4	5	6
	A : SIMPLIFIED TREATMENT PLANTS FOR SMALL CAPACITIES.				
1.	Ramtek (Nagpur)	2.4	4.5	1.5	3.0
2.	Varangaon (Jalgaon)	4.22	8.0	4.0	4.0
3.	Chandori (Nasik)	0.86	2.50	1.50	1.0
4.	Surya Colony (Thane)	0.65	2.5	1.0	1.5
5.	Bhagur (Nasik)	1.0	3.0	1.5	1.5
6.	Murbad (Thana)	1.0	3.0	1.5	1.5
7.	Peth (Nasik)	1.0	3.0	1.0	2.0
8.	Jejuri (Pune)	2.4	4.5	2.0	2.5
9.	Bhor (Pune)	1.8	3.0	1.5	1.5
10.	Akola (Nagar)	2.3	2.0	1.0	1.0
11.	Mahad (Ratnagiri)	2.16	3.0	1.5	1.5
12.	Mahabaleshwar (Satara)	3.5	2.0	1.0	1.0
13.	Kusumble (Kulaba)	2.2	4.0	1.5	2.5
14.	Deogad (Ratnagiri)	2.68	4.0	1.5	2.5
15.	Taloda (Dhulia)	6.72	10.0	5.0	5.0
16.	Dhulia Dairy (Dhulia)	1.5	3.0	1.5	1.5
17.	Bhatsa Colony (Thana)	2-0	1.0	0.50	0.50
18.	Panshet Colony (Pune)	0.75	2.5	1.0	1.5
19.	Talegaon (Pune)	3.0	10.0	5.0	5.0
20.	Kasbe Sukene (Nasik)	1.04	2.50	1.50	1.0

1	2.	3	4	5	6
21.	Edlabad (Jalgaon)	1.73	4.0	2.0	2.0
22.	R.R.W.S.S. for 49 villages (Nanded)	3.3	10.0	4.0	6.0
23.	Baudhan (Gujrat State)	0.74	2.0	1.0	1.0
24.	Kandla Port Trust (Gujrat State)	2.0	3.0	1.5	1.5
25.	Hissar (Hariyana State)	3.0	5.0	2.0	3.0
26.	Bhatinda (Punjab State)	4.50	8.0	3.0	5.0
			110.0	50.0	60.0

B : AUGMENTATION OF EXISTING WATER WORKS - BY ADOPTION OF NEW TECHNIQUES.

1.	Nasik-Road (Nasik)	27.0	20.0	10.0	10.0
2.	Pune Cantonment (Pune)	130.0	50.0	24.0	26.0
3.	Pashan (Pune)	20.0	16.0	6.0	10.0
4.	Alandi (Pune)	9.0	7.0	4.0	3.0
5.	Udgir (Usmanabad)	4.32	2.0	1.0	1.0
6.	Badlapur (Thane)	50.0	20.0	10.0	10.0
			115.0	55.0	60.0

TABLE 11-II

Hydraulic design calculations for Surya Project treatment plant.

1. Design flow = 27,000 lit/hr or 0.65 mld.

2. Mixing channel = Provided on the side wall of the treatment plant as shown in the Drawing No.11-I slope for channel bed = 20 cm

3. Prefilter bed = One unit.

   i) Size of the bed = 3.5 m x 2.2 m

   ii) Area of bed = 7.7 m^2

   iii) Rate of flow = $\frac{27000}{7.7}$ = 3,500 $l/m^2/hr$.

   iv) Depth of bed = 3 m

4. Rapid sand filter bed = one unit.

   i) size of the bed = 3.5 m x 2.2 m

   ii) Area of the bed = 7.7 m^2

   iii) Rate of filtration = $\frac{27000}{7.7}$ = 3500 $l/m^2/hr$.

   iv) Sand media = 75 cm depth

5. Control room :- Provide manual control for rate of flow by operating control sluice valve. Provide 'V' notch control chamber after sluice valves. Simple head-loss measuring arrangements.

6. Back wash Tank :- Provide 40,000 lit. capacity masonry tank for giving effective back wash with 8 m. head at a suitable location on the same hillock.

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TABLE 11-III

Observations on the Surya Project Treatment Plant, from 2/7/1977 to 24/11/1977.

Filter Run No.	Date of starting and washing.	Starting Head loss cms	First Day TH	HL	RT	ST	FT	Second Day TH	HL	RT	ST	FT	Third Day TH	HL	RT	ST	FT	Longer Runs TH	HL	RT	ST	FT
1.	2.7.77	18	9	20	80	20	1.0	20	28	40	20	0.5	31	36	30	10	0.5	87	90	320	10	0.8
2.	11.7.77	22	10	32	300	10	0.5	20	41	20	10	0.5	52	36	20	10	0.5	95	42	300	15	0.6
3.	18.7.77	10	11	15	400	30	0.5	22	26	20	10	0.5	33	48	20	10	0.5	77	89	300	10	0.5
4.	25.7.77	21	11	35	360	10	0.5	22	41	300	10	0.5	42	59	400	15	0.5	67	77	360	10	1.0
5.	29.7.77	13	9	25	30	5	0.5	18	52	30	5	0.5	28	63	30	5	0.5	56	91	30	5	0.8
6.	4.8.77	5	10	12	30	5	0.5	20	16	30	5	0.5	39	50	30	5	0.5	48	70	30	5	0.5
7.	8.8.77	5	10	15	600	15	1.0	20	28	300	15	1.0	29	29	30	5	0.5	47	72	600	25	1.0
8.	13.8.77	10	9	18	360	10	1.0	18	42	30	5	1.0	27	52	30	5	1.0	..	..	..	..	..
9.	16.8.77	9	9	22	30	5	1.0	18	32	30	5	0.5	28	42	30	5	1.0	65	80	30	5	0.8
10.	23.8.77	12	10	21	30	5	1.0	19	43	180	10	1.0	27	71	300	10	1.0	..	..	..	..	..
11.	26.8.77	10	9	18	300	10	1.0	18	48	400	10	1.0	27	85	200	10	1.0	82	95	600	10	0.8
12.	2.9.77	7	8	22	200	5	0.5	17	44	600	10	1.0	25	25	30	5	0.5	62	92	30	5	0.6
13.	10.9.77	8	9	25	30	5	0.5	18	58	30	5	0.5	28	60	30	5	0.5	68	95	30	5	0.5
14.	17.9.77	13	8	23	30	5	0.5	18	32	30	5	0.5	28	32	30	5	0.5	58	90	30	5	0.5
15.	24.9.77	7	10	20	20	5	0.5	20	32	20	5	0.5	30	55	20	5	0.5	60	88	20	5	0.5
16.	1.10.77	30	10	50	30	5	0.5	20	60	20	5	0.5	40	80	20	5	0.5	..	..	..	..	..
17.	5.10.77	5	11	13	20	5	0.5	22	23	20	5	0.5	33	36	20	5	0.5	200	..	20	5	1.0
18.	24.10.77	5	14	8	20	5	0.5	26	17	20	5	0.5	30	25	20	5	0.5	300	1.5	20	5	1.0

GENERAL DATA

1) Head losses are given in cm
2) Turbidities are given in JTU (Measured by standard suspension bottles)
3) Area of filter bed = 7.70 m^2
4) Daily filter run between 12 to 15 hours.
5) Notations given in the above table are :
   a) Total hours of run = TH
   b) Head loss = HL
   c) Raw water turbidity = RT
   d) Settled water turbidity = ST
   e) Filtered water turbidity = FT

FLOW DATA

1) Total flow = 27,000 lit/hr.
2) Surface loading on both the beds = 3500 $l/m^2/hr$.
3) Average filter run during the period = 55 Hours. (Neglecting the last two runs for 200 & 300 hrs.)

TABLE 11-IV

Hydraulic design calculations for Murbad treatment plant.

1. Design flow : 38,500 lit/Hr. or 0.93 mld capacity.

2.
2. Mixing channel = Provided on the side walls of the treatment plant as shown in the drawing No.11-III.

3. Prefilter bed : One unit.

i) Size of the bed = 3.5 m x 2.75 m

ii) Area of the bed = 9.6 m^2

iii) Rate of flow = $\frac{38,500}{9.6}$ = 4000 $l/m^2/hr$

4. Dual media filter bed = One unit.

i) Size of the bed = 3.5 m x 2.75 m.

ii) Area of the bed = 9.6 m^2

iii) Rate of filtration = 4000 $l/m^2/hr$

iv) Depth of media : a) fine sand = 50 cm.
b) Crushed coconut shell = 30 cm

5. Control room : Provide manual control for rate of flow by operating control sluice valve. Provice 'V' notch control chamber after sluice valve. Provide simple headloss measuring arrangement.

6. Backwash Tank = Existing E.S.R. of 2,25,000 lit. capacity to be used for only hard back washing.

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TABLE 11-V

Plant observations on the Murbad Treatment plant

Period : 24/8/78 to 5/9/78

Date	Hours of run.	Head loss in cm.	Turbidity in JTU			Remarks
			Raw	Settled.	Filtered.	
24/8/78	5	10	70	45	1.0	Filter Run 1
25/8/78	14	11	60	40	0.8	
26/8/78	22	12	80	40	0.6	
27/8/78	31	14	60	30	0.6	
28/8/78	41	16	60	30	0.6	
29/8/78	50	18	80	30	0.6	Filtered washed.
30/8/78	8	9	80	40	0.8	Filter Run 2
31/8/78	18	10	60	40	0.8	
1/9/78	28	12	60	40	0.6	
2/9/78	37	13	60	30	0.6	
3/9/78	46	15	50	30	0.5	
4/9/78	55	17	80	30	0.5	
5/9/78	60	20	60	30	0.6	Filtered washed.

Plant operation stopped from 6/9/78.

TABLE 11-VI

Hydraulic design calculations for Bhagur treatment plant.

Capacity = 75,000 lit/hr. or 1.8 mld.

1. Mixing channel = Provided on the side walls of the the filter unit as shown in the Drawing No. 11-II.

Length = 12.00 m. Width = 0.75 m.

Bed slope = 20 cm.

Mixing arrangements : Provide 75 mm dia RCC pipes (30 cm long) in staggered vertical positions in the bed concrete.

2. Gravel bed flocculator : Length = 3.75 m.
Width = 3.75 m.
Depth of gravel= 2.5 m

Size of gravel provided = 50 to 20 mm size rounded gravels from bottom to top.

Surface area = 14.00 m^2

Surface loading = $\frac{75000}{14} = 5330\ l/m^2/hr.$

Volumetric loading = $\frac{75000}{5.15} = 2130\ l/m^2/hr$

Average porosity = 40%

Approximate detention period = 11 min.

Inlet and outlet = Provide 4 Nos. of 100 mm dia. RCC pipe inlets and outlets.

Sludge removal = Provide two hoppers at the bottom with 100 mm dia. sludge drain pipe and one 200 mm dia outlet for gravity draining and giving backwash.

3. Tube settling tank = One unit.

Length = 3.75 m

Width = 3.75 m.

Depth = 3.0 m over hopper.

Surface area of tank = 3.75 x 3.75 = 14 m^2

Considering 50x50 mm size PVC square tubes and outside thickness of 2 mm

Number of tubes in one sq.m. $= \dfrac{1000 \times 1000}{54 \times 54}$

$= 18.5 \times 18.5$

$= 340$ Nos.

$\therefore$ Open area provided per sq.m. $= \dfrac{340 \times 50 \times 50}{1000 \times 1000}$

However considering average effective open area at 75% on the basis of Varangaon plant experience

$= 14 \times 0.75 = 10.50\ m^2$

$\therefore$ Rate of flow through tube opening area. $= \dfrac{75,000}{10.50}$

$= 7140\ l/m^2/hr.$

The actual detention period $= \dfrac{3.75 \times 3.75 \times 3 \times 60}{75,000}$

$= 34$ min.

Number of tubes to be provided = 14 x 340

= 4760

Length of tubes considering 0.6 m height

= 4760 x 0.6 = 2856 metres.

Add 5% say 140 for adjustment for gaps

$\therefore$ Total tubes required = 3000 metres.

Therefore provide 3000 metres of 50 x 50 mm size rigid PVC square tubes of 60 cm length in suitable rows at 60° angle in module forms below one meter of F.S.L. in the tank as shown in the drawing.

Sludge withdrawl = Provide one hopper with 50° slopes at the bottom with a central pit of 0.6 m x 0.6 m for sludge withdrawal.

Provide 100 mm dia. sludge withdrawal pipe with a sluice valve on the outside.

4. Dual media filter bed :- One unit.

Length = 0.4 m
Width = 2.2 m
Depth = 2.0 m upto gutter level.
Surface area = 8.8 m^2

Rate of filtration = 8500 $l/m^2/hr$

Velocity through bed = 8.5 m/hr.

4.1 Media provided :
Depth of crushed coconut shell media = 40 cm
Effective size of shell media = 0.95 mm
Uniformity coefficient = 1.45
Depth of fine sand below shell = 60 cm
Effective size of sand = 0.45 mm
Uniformity coefficient of sand = 1.50

4.2 Underdrain details :
Manifold size = 300 dia mild steel pipe
Dia of laterals = 63 mm dia PVC tubes.
Number of laterals = 18 Nos. at 20 cm c/c on each side.
Perforations per laterals = 6 mm dia, at 50 mm c/c staggered.

4.3 Backwash tank : The E.S.R. for Bhagur Water Supply Scheme of 2,00,000 lit. capacity is used for giving only hard backwash.

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TABLE 11-VII

Observations on the Bhagur Treatment Plant from 20/9/78 to 6/11/78

Filter Run No.	Date of starting and washing.	Starting Head loss in cm.	First Day					Second Day					Third Day					Fourth Day				
			TH	HL	RT	ST	FT	TH	HL	RT	ST	FT	TH	HL	RT	ST	FT	TH	HL	RT	ST	FT
1.	20.9.78	22	6	41	50	9	0.4	15	56	50	9	0.4	24	65	1500	15	0.5	37	82	1500	15	0.5
2.	27.9.78	20	4	40	70	10	0.4	12	48	1000	14	0.5	24	66	1000	15	0.4	33	105	90	10	0.4
3.	4.10.78	28	11	45	60	9	0.4	21	62	50	10	0.4	30	85	60	10	0.4	41	128	50	10	0.4
4.	9.10.78	30	5	35	60	10	0.4	16	60	60	10	0.4	27	82	60	10	0.4	37	115	60	10	0.4
5.	14.10.78	30	5	35	60	9	0.4	17	58	50	9	0.3	27	71	50	9	0.4	39	92	50	9	0.4
6.	19.10.78	28	5	38	45	7	0.4	15	60	150	10	0.4	26	110	120	18	0.4	36	140	1500	15	0.5
7.	24.10.78	30	5	41	100	12	0.4	10	50	100	9	0.4	15	65	100	9	0.4	23	85	80	9	0.5
8.	30.10.78	28	4	38	50	7	0.3	12	60	65	8	0.4	18	72	50	8	0.3	23	90	50	8	0.4

			Fifth day					Sixth Day					Seventh Day					Eighth Day				
1.	20.9.78	22	45	96	800	15	0.5	54	130	90	15	0.5	65	150	70	12	0.4	70	185	70	10	0.4
2.	27.9.78	20	44	141	80	10	0.5	52	160	60	10	0.4	64	205	55	10	0.5	-	-	-	-	-
3.	4.10.78	28	53	170	50	10	0.4	60	185	60	10	0.4	-	-	-	-	-	-	-	-	-	-
4.	9.10.78	30	48	145	55	9	0.4	54	180	60	9	0.5	-	-	-	-	-	-	-	-	-	-
5.	14.10.78	30	47	140	45	8	0.4	54	185	45	7	0.5	-	-	-	-	-	-	-	-	-	-
6.	19.10.78	28	47	170	450	18	0.5	52	185	120	12	0.5	-	-	-	-	-	-	-	-	-	-
7.	24.10.78	30	33	120	60	8	0.4	40	160	60	7	0.4	45	180	50	7	0.4	-	-	-	-	-
8.	30.10.78	28	29	120	40	8	0.4	35	150	45	8	0.4	46	185	45	7	0.4	Washed on 6.11.78				

General Data :

1) Head losses are given in cm.
2) Turbidity in JTU.
3) Notations in the Table.
   i) Total hrs of run : TH
   ii) Head loss : HL
   iii) Raw Turbidity : RT
   iv) Settled Turbidity : ST
   v) Filtered Turbidity : FT.

Flow Data :

1) Total flow : 1,75,000 l/hr.
2) Surface loading on gravel bed : 9700 $l/m^2/hr$.
3) Surface loading on tube settler : 6600 $l/m^2/hr$.
4) Rate on filter bed was : 10,000 $l/m^2/hr$.
5) Average filter run during the period : 55 hrs.
6) Wash water consumption was about 0.7 %

TABLE 11-VIII

Typical chemical analysis of raw water sources.

Description of tests in mg/lit.	Surya Project Surya River.		Murbad Lake		Bhagur Darna River.
	30-10 1976	13-3 1978	31-7 1978	18-8 1978.	29.8.78
1. pH	8.3	8.2	6.5	7.6	8.5
2. Total solids	312	278	284	274	285
3. Dissolved solids	300	245	268	262	198
4. Total Alkalinity as $CaCo_3$	104	156	120	156	160
5. P.Alkalinity	4.0	Nil	Nil	Nil	15.0
6. Total Hardness	84.0	146.0	102	130	140.0
7. Calcium as Ca	20.4	28.0	16.0	28.0	36.0
8. Magnesiam as Mg	6.72	18.3	14.88	14.4	14.4
9. Iron (Fe^{++})	0.08	0.24	0.24	0.16	0.16
10. Sulphate(SO_4)	4.0	5.0	5.0	5.0	6.0
11. Chloride as Cl	9.0	15.0	6.0	5.0	10.0
12. Fluoride as F	Nil	Nil	Nil	Nil	Nil
13. Nitrite as No_2	Nil	Nil	Nil	Nil	Nil
14. Nitrates as No_3	0.5	0.4	1.0	0.9	0.7
15. Albuminoid Ammonia as NH_3	0.126	0.131	0.126	0.129	0.124
16. Free and Saline Ammonia as NH_3	0.009	0.009	0.012	0.012	0.012

TABLE 11-IX

Typical bacteriological analysis of Raw water samples.

Plate and Date	Raw water		Settled water		Filtered water	
	MPN	Plate count.	MPN	Plate count	MPN	Plate count
1. Surya Project water supply.						
30/10/76	-	-	-	-	4	-
18.12.76	2.4×10^3	TNC	930	TNC	930	210
2. Murbad Water supply						
31/7/78	9.3×10^2	TNC	73	120	0	80
18/8/78	4.6×10^4	TNC	9.3×10^2	TNC	95	210
3. Bhagur Water supply						
17/10/78	3.5×10^2	300	1.4×10^2	120	61	30
24/10/78	1.1×10^4	TNC	1.2×10^3	TNC	2.4×10^2	230

CHAPEER 12.

ANALYSIS OF EXPERIMENTAL RESULTS.

12.1 INTRODUCTION.

After carrying out the pilot plant and the actual field plant study on the three new treatment plants as described in the previous chapters, it is now proposed to do the analysis of the experimental work carried out towards the development of these new methods in the field of water treatment. It is proposed to compare the theoretical aspects in the design of the various units of pretreatment and filtration of the conventional treatment methods and the unconventional methods adopted in the development of these new treatment plants at Ramtek, Varangaon and Chandori, as described in details in this thesis. In short the author feels that this chapter may give the main objectives and achievements of the present study carried out by the author towards the development of simple and cheap water treatment methods for the rural water supply schemes in the developing countries.

12.2 AIM OF RESEARCH AND ANALYSIS OF WORK DONE.

12.2.1 As explained in the chapter 1, the aim of the present study was to develop the new techniques for the better performances of the various processes in the field of water treatment, so as to utilise them in the design of very simple and cheap water treatment plants particularly for the villages and small capacity water supply schemes.

The author has also given in the chapter 1, the important steps in the history of water treatment and the general theoretical aspects in the design of the various units in the conventional treatment plants. The author has then discussed in details the on-plant study carried out by him and the difficulties faced in the design of simple and cheap water treatment plants particularly for small capacity and rural water supply schemes.

It will be seen that the major problems in the field of water treatment are in the design and operation of the pretreatment units than in the design of filtration units. The present pretreatment methods are not only costly with their mechanical mixing and flocculation arrangements, but these are difficult to operate parti-cularly for the small capacity plants. It is therefore very necessary to develop non-mechanical type simple treatment units for the small capacity water treatment plants. It will be seen from the three new treatment plants developed during this study, that the pretreatment units are totally new and different for these plants where-as the filter units are same for all the three plants. As explained in details in the chapter 1, the new techniques in the pretreatment are mainly designed for the treatment of low and high turbidity water sources. The theoretical aspects of the important steps in the conventional methods and the new techniques developed in this study are discussed below in short.

12.2.2 Coagulation and Flocculation :

Cox (5) states, "suspended solids in water range in size from coarse material, which settles readily, to very fine material, which will not settle unless the particles coalesce naturally and precipitate or unless a coagulant is used. The precipitating solids formed by coagulation are finely divided unless they are agglomerated into larger solids or well developed floc by agitation of the water to cause the fine solids to contact and adhere to one another and form progressively larger particles. These larger particles of floc will then settle in sedimentation basins or will be removed by filtration. Flocculation, therefore follows treatment of water by coagulants and is essential for the preparation of the water for sedimentation and filtration at economically high rates of flow through rapid or mechanical sand filters.

An understanding of the coagulation and flocculation processes requires a distinction between successive steps in the process. First a coagulating chemical is applied to the water. In order that the chemical may react uniformly it must be distributed promptly throughout the body of water. This requires rapid agitation or mixing of the water at the point where the coagulant is added. Second, complex chemical and physicochemical reactions and changes occur, leading to coagulation and the formation of microscopic particles. Third, much more gentle agitation of the water causes the agglomeration of the particles; in other words the fine particles are flocculated into settleable floc.

In the past flocculation was termed "Mixing" and the whole process was given that name. It is now realised, however, that mixing for the distribution of the coagulant in the water is only the first step in flocculation. Nevertheless this rapid or flash mixing is necessary, because otherwise the coagulant would diffuse through quiescent water very slowly and the initial chemical reactions would be restricted to that portion of the water in which the concentrated coagulant happened to be introduced. This would produce localized conditions quite unlike those intended, because of the marked influence of the concentration of chemical on the resulting type of reactions. On the otherhand, if flash mixing were followed by quiescent conditions, the fine precipitate would not be agglomerated into sizable floc in a reasonable period of time. Effective and economical clarification therefore requires the completion of coagulation and flocculation before the treated water enters sedimentation basins".

In the existing plant study, carried out by the author on the small capacity conventional plants, coagulation and flocculation was not found effective, as stated above in the most of these treatment plants. The design of flocculation unit is a major problem in the small capacity plants and it was generally found absent in most of these plants studied by the author. Even in the new conventional small capacity plants, the properly designed flocculation units are rarely provided.

The important reason for not providing the proper flocculation units in the conventional small capacity treatment plants is the requirement of mechanical agitators, which has to be provided for effective flocculation, even for small capacity plants as already discussed in the chapter 1. Even the mechanical flocculation units at many small capacity plants are not seen working efficiently due to the improper design.

The author has therefore, developed the gravel bed flocculation units as provided in the Varangaon treatment plant, the gravel bed prefilter unit in the Ramtek filter and the pretreator unit in the Chandori treatment plant. These gravel bed flocculation units have been found very effective in the development of good and settlable floc. These gravel beds are solid contact basins where large surface area is available, which accelerates the formation of consolidated floc particals. Further there is little chance of short circuiting for a portion of water as it is generally seen in the conventional mechanical flocculation units.

The actual detention period in the gravel bed flocculation units is hardly 5 to 7 minutes as compared to 30 minutes detention period provided in the mechanical flocculation units. Thus the surface action is seen to be more effective as seen in the gravel bed flocculation than the detention period. Further the volumetric loading can be given as high as 4000 $l/m^2/hr$, with the surface loading of 10,000 $l/m^2/hr$. Further the upward direction of flow as in the gravel beds at Ramtek and Chandori plants may have some more advantages than that of the down ward direction of flow in the Varangaon plant.

The gravel bed flocculation units will however require the periodic cleaning, either by gravity desludging action or by the back washing of the beds. As the small capacity plants are generally operated for 16 to 20 hours a day, such a cleaning will not be a problem in the day to day operation of the plants.

The author has not seen the use of gravel bed for flocculation purpose in any of the literature references and it may be an original idea in the field of water treatment.

Further from the pilot plant studies carried out by the author (chapter 4), it is also seen possible to adopt non-mechanical and continuous type of flocculation units, viz : the PVC tube surface contact flocculation units and the LDP film surface contact flocculation units, for the design of the simple and cheap small capacity water treatment plants.

12.2.3 Sedimentation :

Regarding principles of sedimentation, Cox (5) states, "The purpose of sedimentation is to permit settleable floc to be deposited and thus reduce the concentration of suspended solids that must be removed by filters. The basins used for this purpose should not be considered coagulation basins, because both coagulation and flocculation should be completed in flocculation basins.

Water does not flow through basins as an undisturbed body but rather by irregular flow. Conditions in flowing through basins, therefore, are quite unlike those prevailing in a vessel in which quiescent sedimentation occurs, the intent is to provide conditions in which the flow is as uniform as possible for a period long enough to permit the greatest practicable amount of the settleable solids to be deposited before the water reaches the effluent end of the basins.

The factors that influence sedimentation are (a) size, shape and weight of the floc, (b) viscosity and hence temperature of the water, (c) effective average period available for sedimentation, (d) effective depth of the basins, (e) their areas, (f) surface overflow rate, (g) velocity of flow and (h) inlet and outlet design. Each of these presents problems of designs and operation. Sedimentation theory is complex and of little avail because floc is not uniform and hence its basic sedimentation properties cannot be given quantitative values, and because the influence of eddy currents can not be predicted. Hence the discussion of these six factors in relation to design and operation relies largely on experience".

From the on-plant study carried out by the author (33) on the small capacity conventional plants, the sedimentation tanks have not been found functioning effectively in many cases. The main reasons for this may be the improper coagulation and flocculation of the water before sedimentation basins as discussed in the earlier para. The other important reasons as found out from the actual plant study are (i) improper inlet and outlet design, (ii) short circuiting due to intermediate baffles provided in the basins and(iii) improper sludge removal arrangements. Due to these important factors the sedimentation is not effective even if other designs factors, viz : the detention period, surface loading and depth of basin, are provided as per standard conventional practice. Even if the above mentioned factors are designed properly the sizes of the sedimentation tanks are considerably big and at many places the wind velocities also disturb the rectangular horizontal flow basins, which are generally provided for small capacity tanks.

Considering all these aspects the author has designed the totally new and unconventional pretreatment basins for the three treatment plants as described in this thesis. The detailed theoretical and design aspects are given in the respective chapters and also as discussed in the later part of this chapter.

The new concept of "tube settler" has been now well accepted in the theory of sedimentation. As in the case of flocculation, the surface contact has great significance in the design, of sedimentation basins, with this new technique of "tube settler" there may be a revolutionary change in the design parameters of a sedimentation basin. The author feels that, by providing tube settler basins the flocculation action is further continued up to the top of the tube settler and the heavy and consolidated floc particals formed in this process get settled in the bottom of the basins which can be removed by hydrostatic pressure.

The surface loadings that can be applied on such tube settlers can be very high and are generally in the range of 5500 to 11000 $l/m^2/hr$ of the open tube area. The detention period in such tube settling tanks is about 30 minutes. Thus it can be seen that the surface loading on a tube settler can be given more than six times than that for a conventional rectangular settling tank.

Even though the tube settlers were not adopted so far in India, in the treatment plants the technique is not a difficult one. The author has therefore provided tube settlers in the new designs of Varangaon and Chandori plants as discussed in this thesis. This item has mainly reduced the total plant area and therefore the cost of these treatment plants as compared to the conventional rectangular horizontal flow settling tanks.

The actual plant performance of the tube settling tanks at Varangaon treatment plant after gravel bed flocculation units showed excellent performance in the removal of turbidity, even when the raw water turbidity reached 4000 JTU, as discussed in the chapter 9. The pilot plant results of the tube settler as provided in the pretreator of the Chandori treatment plant were also found satisfactory even for high surface loading as discussed in the chapter 10.

Regarding the prefilter unit provided at the Ramtek plant, it was mainly designed for treating low turbidity water sources, and only for a short period in mansoons, it should be able to tackle the higher turbidities upto 500 JTU. From the actual plant observations as discussed in the chapter 7, this object is achieved. However, the author has observed a portion of the fine floc was passing from the prefilter unit to the dual media filter bed, as discussed in details in the chapter 7. He has therefore tried to improve this aspect in the design of the Murbad treatment plant by providing a separate unit of prefilter by raising the side walls upto the top, and by taking the settled water through the perforated pipe collectors on the dual media filter bed. With this small modification the performance of the prefilter unit may be considerably improved. The prefilter unit of Murbad plant is likely to tackle moderate turbidity load effectively as compared to the Ramtek plant as discussed in the chapters 6,7, and 11.

The pretreator unit proposed for the Chandori plant is the further improvement on the prefilter unit of the Murbad plant, as a tube settler is introduced above the gravel bed as discussed in the chapter 10. Thus the pretreator of the Chandori plant may be able to treat highly turbid water sources. Thus for the treatment of highly turbid water sources for small capacity rural water supply schemes, the Chandori type treatment plant may be the cheapest and the simplest solution for the treatment of surface water sources.

12.2.4 Filtration :

In all the three new treatment plants described in this thesis, the author has provided dual media, open to sky filter beds, as already discussed in details in chapters 7,9, and 10. The author feels that the dual media filter bed with all its advantages over the rapid sand filter bed as already discussed in the earlier chapters may be the cheapest and the simplest filter unit for the small capacity rural water supply schemes. As there is difficulty in getting the suitable top media, over the fine sand media in India, author has developed a new media of crushed coconut shell over the fine sand media as discussed in details in the earlier chapters. In due course of time it is very likely that similar other suitable top media may be developed as discussed in the chapter 5, where it was tried to find out some other media which can be utilised for the dual and the multi-media filter beds. The present cost of the new media may be comparatively high, however, the cost may come down after finding out other suitable top media for this purpose.

The dual media filter bed is not a must in all these new treatment plants. As discussed in the chapter 11, the rapid sand filter bed provided after the prefilter unit in the Surya project treatment plant gave satisfactory results. The reasons for providing the dual media filter bed in the Ramtek plant have been fully discussed in the chapters 6 and 7. On the basis of the satisfactory performance of the prefilter units of Ramtek plant the author has provided a rapid sand filter bed at Surya project plant as discussed in the chapter 11. However, it can be clearly seen that a dual media filter bed in the Ramtek type plant is bound to give far better performance of the filter bed, both in the higher rate of filtration and better quality as compared to a rapid sand filter bed. It is for this reason that the author recommends to provide dual media filter beds in the Ramtek and Murbad type treatment plants.

As regards the Varangaon and Chandori treatment plants, the pretreatment is of improved and better type and hence the rapid sand filter beds can be safely provided in such treatment plants. However the author has provided the dual media filter beds, mainly because these are cheaper and more efficient methods for high rate filtration purpose. It is for this reason even though the filter beds at Varangaon plant have been designed for 6600 $l/m^2/hr$, the author has given the actual plant performance results in the chapter 9, for the higher filtration rate of 10,000 $l/m^2/hr$ by running only two filter beds out of the three beds.

The other important reason for providing the dual media filter beds for the rural water treatment plant is the safeguard against the breakthrough of the filter bed and therefore preventing the deterioration of the quality of the filtered water. In a rapid sand filter bed such a safety is not available and at many places, filter breakthrough is observed. In a dual media filter bed the top media is a coarse one and the breakthrough does not occur easily. Even if the breakthrough in the top coarse media occurs, the breakthrough in the fine sand media below the top media does not occur immediately and takes further considerable time.

12.2.5 Comparative Design Criteria :

The comparative performances of the new treatment methods as developed in this study are discussed below in short. Table 12-I showing the recommended principal design criteria is enclosed at the end of this chapter for ready reference.

12.3 RAMTEK TREATMENT PLANT.

This was the first unconventional simplified treatment plant that the author has designed and const. ructed for the Ramtek water supply scheme. The main idea was to develop such an extremely simple and cheap treatment plant for adopting for the small community and rural water supply schemes. As already stated in the chapter 7 and 11, number of such plants are now under construction in the Maharashtra State. As the actual cost of construction for Ramtek plant was about 1/4 of the cost of the same capacity conventional treatment plant in 1973-74 ; and the local labours constructed this plant within a period of six months, both the purposes of development of such a simple treatment plant have been achieved to a great extent.

The Ramtek plant is mainly designed for the treatment of low turbidity raw waters. Further the prefilter provided before the dual media filter unit as adopted in this plant is not an ideal pretreatment unit. The reasons for this are already discussed in the chapters 7 and 11, and in the earlier para in this chapter. The settled water zone over the gravel bed prefilter is not utilised effectively in the Ramtek plant as a certain amount of floc is passing over the dual media filter bed just above the gutter level. In order to improve upon this aspect a small modification was made in the settled water flow and collection system in the Murbad treatment plant as explained in details in the chapter 11. As a separate settling zone is provided with side vertical walls over the gutter level, and the settled water perforated pipe collectors are provided, the settling conditions can be considerably improved. This modified form of Ramtek plant is now recommended for the treatment of low turbidity raw waters. The Murbad treatment plant has further advantage, as discussed in chapter 10 and 11 that this plant can further be converted into the Chandori type treatment plant by introducing a tube settler just below the gutter level by reducing the depth of the gravel to about one meter. Thus the Murbad plant is likely to be a popular plant for the treatment of low turbidity water sources for small capacity rural water supply schemes.

12.4 VARANGAON TREATMENT PLANT.

The author has designed this unconventional treatment plant for the treatment of highly turbid water sources for providing cheap water treatment plants particularly for the rural water supply schemes. The plant, though not as simple as that of the Ramtek treatment plant, is considerably simple as compared to a conventional treatment plant for the same capacity. The cost of construction of the Varangaon type plant may be less than 50% of the cost of the conventional plant of the same capacity. From the actual plant performance as given in the chapter 9, it is seen that this plant has shown very satisfactory performance for the treatment of highly turbid water source.

In the Varangaon treatment plant, the gravel bed has been adopted as a flocculation unit, where the flow is in the downward direction. The rate of application of surface loading can be as high as 10,000 $l/m^2/hr$. The detention period is hardly 5 minutes in this unit which shows the surface contact may be the prominent factor in providing effective flocculation.

The important aspect in providing this unit is the effective cleaning of the gravel bed. Even though the gravity desludging operation is found adequate for cleaning the gravel bed, a back wash arrangement is recommended for this unit, so as to give occasional back wash to ascertain the effective cleaning of this bed.

The tube settler as provided in this plant may be the first such unit adopted in India. The square PVC tubes 50mm x 50 mm size were specially manufactured for the first time in India for the fabrication of the tube modules at Varangaon plant. The surface loading on the tube settler is about six times higher than that of a conventional rectangular settling tank, while the detention period is about 30 minutes in the tube settling tank. The inlet distribution and settled water collectors are the special design features of this plant for giving uniform loading, which has mainly avoided the possibility of short circuiting of the flow. The fabrication of the tube modules and the placing of the same in the tank is not a difficult work and can be easily adopted even for rural treatment plants. The fabricated tube modules of required sizes can be supplied either by manufacturers or from the central stores of the departments after fabrication. The main saving in the Varangaon treatment plant is due to the adoption of the tube settler.

The advantages of the dual media filter beds as provided at Varangaon treatment plant have been fully discussed in the chapters 7,9, and 11. Even though the dual media filter beds have been designed for 6600 $l/m^2/hr$ the loading can be increased by 100% if in future the plant capacity is to be increased to that extent. The author therefore feels that the Varangaon treatment plant may be the appropriate treatment plant for the treatment of highly turbid water sources not only for the rural areas but also for the small municipal towns.

12.5 CHANDORI TREATMENT PLANT.

The design of the Chandori treatment plant is the outcome of the actual plant performance results of the Ramtek and the Varangaon treatment plants. As already discussed in the chapter 10, and earlier paras in this chapter, the Chandori treatment plant is a modified form of Ramtek and Murbad treatment plant.

The pretreatment unit viz : the pretreator as provided in the Chandori plant is a combination of the prefilter and tube settler, so as to treat turbid water sources. The details of the design of the Chandori plant are given in the chapter 10. The direction of flow in the pretreater is upwards and the settled water collected through the perforated pipe collectors is taken on the

the dual media filter bed, where the flow is downwards. Both the units are designed for a surface loading of 4500 $l/m^2/hr$. For the cleaning of the pretreator,gravity desludging can be adopted as a routine practice after the day's work. However, for ascertaining the effective cleaning of the bed, back wash can be given periodically say once a week. The sludge settled on the top of the gravel bed can be removed by sludge draining pipes periodically and depending on the raw water turbidity,during the operation of the plant, with the available hydrostatic pressure. With these sludge draining arrangements the pretreator bed can be effectively cleaned. The dual media filter bed is the same as provided in the Ramtek and the Varangaon treatment plants. However for lower rate of filtration, rapid sand filter bed can be adopted inplace of a dual media filter bed.

The Chandori type treatment plant has further advantages of two stage construction. In the first stage for the normal surface loadings upto 5000 $l/m^2/hr$, and for the low turbidity sources, the plant can be constructed without tube settler and the dual media filter bed, but keeping the same dimensions of the plant, In the second stage for higher surface loadings even upto 10,000 $l/m^2/hr$ the same plant can be augmented by introducing the tube settler and the dual media in the respective beds. Similarly when the raw water turbidity data is not available for the new rural water supply schemes, when these are constructed for the normal surface loadings upto 5000 $l/m^2/hr$ the Chandori type plant can be constructed in two stages as explained above. The author feels that this may be the cheapest and the simplest treatment method for the treatment of turbid water sources for the small capacity rural water supply schemes and hence may be a popular treatment plant in the future.

12.6 OBSERVATIONS IN THE SIMILAR NEW TREATMENT PLANTS.

The main purpose of undertaking the study of some new treatment plants designed on the similar lines, is to confirm the results of the Ramtek and Varangaon treatment plants as discussed in this thesis. The further object of this study was to provide necessary changes in the original designs on the basis of the actual plant performances so as to improve upon the original designs towards the better performances of the new plants. The author believes that with this approach it may be possible to make these designs perfect.

12.6.1 Surya Project Treatment Plant :

The detailed design calculations and the actual performance of the plant are given in the chapter 11. The plant is based on the design of Ramtek treatment plant, however only rapid sand filter bed is adopted in place of dual media filter bed as the rate of filtration is only 3500 $l/m^2/hr$. The plant performance shows very satisfactory results of this plant even during the rainy season, when the turbidity of the raw water was between 100 to 600 JTU.

The plant was run intermittently from 8 to 12 hours a day, and the average filter run was found to be

55 hours which is very satisfactory. Even though the working of the plant with the gravel bed prefilter followed by rapid sand filter was found satisfactory the author proposes to improve its performance further by slight modifications so as to adopt the Murbad type plant for such small capacity plants, as discussed below.

12.6.2 Murbad Treatment Plant :

The detailed design calculations and performance of this plant are given in the chapter 11. The filter unit may be able to tackle moderate turbidity load between 1000 to 2000 units during the rainy season due to the improvements in settle water collection system and the provision of the dual media filter bed.

Even though the plant is designed for a filtration rate of 4000 $l/m^2/hr$, the plant may be able to tackle the filtration rates up to 7000 $l/m^2/hr$. This is a modified form of Ramtek filter and the author feels that the unit can be recommended for providing for the small capacity water treatment plant where the raw water turbidity is generally low. Further the cost of the construction of the plant is also considerably low as compared to that of a conventional plant of the same capacity. Hence the Murbad plant being a very simple and cheap water treatment plant can be recommended safely for the small capacity plants in rural areas, for the treatment of low turbidity water sources.

12.6.3 Bhagur Treatment Plant :

This is a Varangaon type treatment plant of

1.8 mld capacity with the hourly pumping rate of 75000 lit/hour. The small change in the design of this treatment plant is the bigger size of gravel bed adopted for this plant. The surface loading on the gravel bed is 5330 $l/m^2/hr$, while the volumetric loading is 2130 $l/m^3/hr$ which is about 50% as compared to the loading at the Varangaon treatment plant. The surface loading on the tube settler is about 7140 $l/m^2/hr$, which is higher than the surface loading of 6600 $l/m^2/hr$ adopted at the Varangaon plant. While the dual media filter bed is designed for 8500 $l/m^2/hr$ which is about 35% more as compared to the rate of filtration adopted at Varangaon.

The plant performance as discussed in details in the chapter 11 is very satisfactory. The cost of construction of the plant may be less than 50% as compared to the cost of conventional plant of the same capacity. The maintenance of the plant is also simple. Thus the Bhagur treatment plant may be a very simple and cheap type of design for the construction of the small capacity treatment plants in the rural and small municipal towns for the treatment of highly turbid water sources.

12.7 MATHEMATICAL APPROACH.

12.7.1 Background :

The purpose of the present study was to develop simple and cheap water treatment methods for the small capacity water treatment plants to be adopted in the rural and semi-rural areas particularly in the developing countries. For this purpose the author has first studied in details the present conventional methods which are being adopted for the small capacity treatment plants. After studying the major difficulties which are being faced in the design and the construction of the present conventional methods, the author has tried to develop new and unconventional methods so as to design and construct very simple and cheap small capacity water treatment plants as discussed in this thesis. From the actual plant performance as discussed in this thesis the purpose of the present study has been achieved to a great extent.

12.7.2 The Role of the Mathematical Theories in the New Developments in Water Treatment :

Ives (19) states, "Filtration theory cannot be expected to be completely predictive. The complexity of partical and fluid motions in filter pores, the randomness of filter grain packing and the variability of natural water quality prevent predictive calculations" Regarding mathematical model of filtration he states Theory can suggest a reasonable mathematical model of filtration behaviour. Together with mathematical models of other unit processes of water treatment the relative role of each treatment can be assessed and economic load-sharing can be planned; e.g. should flocculation sedimentation achieve most of the clarification leaving filtration as a polishing process or should the efficiency of flocculation sedimentation be deliberately reduced to make filtration play a greater part or can either process be eliminated entirely ?"

Huisman,(15) states, "The mathematical theory of filtration is fascinating, helps greatly in a better understanding of filtration phenomena but is (and will long be) insufficient for this purpose".

These short statements give valuable information about the role of mathematical theories in the new developments in water treatment.

12.7.3 Views on the Present Study :

The author has limited his present study to the pilot plant and the prototype studies of the new techniques developed in this thesis. He has tried to find out some references so as to study the possibility of mathematical approaches in the field of the new techniques developed in this thesis. He has already discussed the various theoretical aspects in the design of the various water treatment processes in connection with the present study in the chapter 2. A few aspects about the mathematical approach towards the present study are discussed in short below.

i) Use of the gravel bed for flocculation :

The gravel bed flocculation is one of the important new technique which has been developed in all the three new treatment plants as discussed in this thesis. However, the author has not come across any reference of this new technique in the limited technical literature studied by him. This aspect has been discussed in details in the chapter 2. The author feels that it may be difficult to develop any mathematical model for the gravel bed flocculation as no two gravels are equal in shape and size. However it may be possible to develope such a model with uniform size circular glass balls or PVC balls. It is, therefore, seen that this will be an important field of future research.

ii) Non-mechanical and continuous Type Flocculation Systems :

The development of non-mechanical and continuous type flocculation systems viz : the PVC tube surface contact flocculation units and the LDP film surface contact flocculation units, as discussed in the chapter 4, will be an urgent field of research. It may be possible to develop mathematical models for these new flocculation systems.

iii) High Rate Tube Clarification :

The theoretical aspects of tube settlers have been discussed in the chapter 2. It is seen that the mathematical theories in the tube clarification processes are presently under development. Thus the development of the mathematical theories in tube clarification will also be an important field of research in future.

iv) Dual and Mixed-media Filtration :

The theoretical aspects have been given in the chapter 2. The mathematical theories for the mixed-media or multi-media filtration as discussed by Ives (19) are presently under development and will also be an important field of research in future.

TABLE 12-I

Recommended principal design criteria for the simplified treatment plants.

Principal Design criteria. 1.	Ramtek plant and Murbad plant. 2.	Varangaon plant 3.	Chandori plant 4.
I. RAW WATER TURBIDITY			
I) General Recommendations.	For low turbidity sources.	For high turbidity sources.	For moderate turbidity sources.
ii) Average range in JTU	30 to 50	30 to 100	30 to 100
iii) Maximum range in JTU	300 to 500	1000 to 5000	1000 to 3000
II. PRETREATMENT.			
1) Mixing unit	Baffle channel	Baffle channel	Mixing channel
2) Type of gravel bed units.	Prefilter	flocculator	pretretor
i) Direction of flow	Upward	Downward	Upward
ii) Surface loading in l/m^2/hr.	4000 to 7000	5000 to 10000	4000 to 8000
iii) Volumetric loading in l/m^3/hr.	2000 to 3500	2500 to 5000	2000 to 4000
iv) Depth of the gravel bed in m.	1.5 to 2.0	2.5 to 3.0	1.5 to 2.0
v) Size of gravel in mm	10 to 50	20 to 50	10 to 50

	1.	2.	3.	4.
3.	Tube settling tank	Not adopted	Tube settler	Gravel bed-cum-tube settler.
i)	Surface loading in $1/m^2/hr$	-	5000 to 10000	4000 to 8000
ii)	Detention period in minutes.	-	30 to 40	30 to 40
iii)	Depth of the tank in m.	-	3 m above hopper	3.5 to 4.0
iv)	Direction of flow	-	Upward	Upward.
v)	Size of PVC square tubes	-	50 mm x 50 mm	50 mm x 50 mm
vi)	Depth of the tube settler	-	0.5 to 0.6 m	0.5 to 0.6 m
III.	DUAL MEDIA FILTER BED.			
i)	Surface loading in $1/m^2/hr$	4000 to 7000	5000 to 10000	4000 to 8000
ii)	Dual media details.			
a)	Coconut shell media depth	30 to 40 cm	30 to 40 cm	30 to 50 cm
b)	effective size in mm	1.0 to 1.5	1.0 to 1.5	1.0 to 1.5
	Uniformity coefficient	Below 1.5	Below 1.5	Below 1.5
b)	Fine sand media depth	50 to 60 cm	50 to 60 cm	50 to 60 cm
	Effective size in mm	0.45 to 0.55	0.45 to 0.55	0.45 to 0.55
	Uniformity coefficent	Below 1.5	Below 1.5	Below 1.5
c)	Depth of supporting gravel bed	40 to 50 cm	40 to 50 cm	40 to 50 cm
iii)	Back wash method	Hard wash	Hard wash	Hard wash
a)	Average expansion of media	30 to 40 %	30 to 40 %	30 to 40 %
b)	Average head of water	8 to 12 m	8 to 12 m	8 to 12 m

CHAPTER 13

CONCLUSIONS AND FUTURE SCOPE OF RESEARCH.

13.1 FINDINGS OF THE PRESENT STUDY.

13.1.1 General : The aim of the present study was to develop simple and cheap water treatment methods for the small capacity water treatment plants to be provided in the rural and semi-rural areas. The author has mainly developed three new and unconventional water treatment plants, for Ramtek, Varangaon and Chandori villages in the Maharashtra State in India. In addition to this the author has designed similar new water treatment plants as constructed at Surya Irrigation Project, Murbad village and Bhagur village with a few modifications in the designs of the original treatment methods developed in this study. The detailed designs and the actual plant performances of these plants are given in the earlier chapters of this thesis. From the plant performance results, and as discussed in the chapter 12, it is seen that these new and unconventional treatment methods as developed during this study have shown very satisfactory results. The author feels that these new and unconventional treatment plants developed in this thesis are so simple and cheap for construction as well as maintenance, that these techniques are likely to be adopted on large scale for the design of particularly small capacity water treatment plants in the rural and semi-rural areas in the developing countries.

13.1.2 Main achievements :

The main achievements in the present study are as given below.

i) The use of gravel bed for flocculation is adopted in all the three new treatment methods developed in this study. The interesting aspect in this new technique is that the use of gravel bed is made in different ways in all the three treatment methods developed in this thesis.

The conventional flocculation units are mainly based on the mechanical type of units, which are generally seen deleted in the small capacity water treatment plants, with the result of ineffective clarification in such plants. As the flocculation is an essential process in the water treatment, the gravel bed flocculation may be able to replace the mechanical flocculation in the small capacity plants.

ii) The adoption of a tube settling tank for a rural water supply scheme is the next main achievement, which may have been provided for the first time in India. The surface loading on such tube settling tanks can be 5 to 6 times higher than that adopted for the conventional rectangular settling tank. With this new technique it will be possible to augment the capacities of the existing settling tanks by more than two times.

iii) The pretreater unit with the combination of the gravel bed flocculation and the tube settler, with the hopper shape settling zone and perforated pipe collectors as proposed in the Chandori water treatment plant may be very suitable for the pretreatment of turbid water sources for the small capacity water treatment plants.

iv) It is possible to use the crushed coconut shell media as a top coarse media in the dual media filter bed over the fine sand media for higher filtration rate upto 10,000 $l/m^2/hr$, and better effluent quality. The author has been granted a patent for the use of this new media for filtration purpose in mixed media.

v) The simplification in the design of the structures for the small capacity water treatment plants in the rural and semi-rural areas as developed in this thesis can reduce the cost of construction of these plants from 50% to 75% of the costs of the same capacity conventional plants.

13.1.3 The Ramtek Treatment Plants :

The Ramtek treatment plant has been designed specially for the treatment of low turbidity water sources for small capacity water treatment plants for rural water supply schemes and may be the first such unconventional type of filter constructed in the world. The gravel bed prefilter unit followed by the dual media filter bed with the use of crushed coconut shell media over the fine sand media are the special features of this treatment plant. The crushed coconut shell media has been used for the first time for the high rate filtration in the dual media filter unit at Ramtek.

The Murbad treatment plant is a modified form of the Ramtek plant, with the adoption of separate settling zone on the gravel bed prefilter. With this small modification it may be possible to treat moderate turbid water sources with better clarification. Hence the Murbad treatment plant can be generally recommended for the small capacity water treatment plants in the rural and semi-rural areas for the treatment of low turbidity water sources. The Murbad plant may be the simplest and the cheapest treatment plant for the small capacity water treatment plants among the three treatment plants developed in this thesis.

13.1.4 The Varangaon Treatment Plant ;

The Varangaon plant is mainly designed for the treatment of highly turbid water sources for the design of small capacity water treatment plants. The special features of this plant are the gravel bed flocculation unit, tube settling tank, and the dual media filter bed.

The gravel bed flocculation unit and the tube settling tank are the most outstanding features of this new plant and may have been adopted for the first time in India. The dual media filter beds have been adopted in this plant for the higher rate of filtration and better effluent quality. The plant results show very satisfactory performance and as such it can be recommended generally for the treatment of highly turbid water sources for the small capacity water treatment plants in the rural and urban areas. The most of such a plant may be less than 50% of the cost of a conventional water treatment plant of the same capacity,

The Varagaon Plant can also be recommended for highly turbid water sources for the bigger rural water supply schemes and the small town water supply schemes. The Varangaon type plant may further be recommended even for bigger water supply schemes for continuous operation with the provision of non-mechanical continuous flow flocculation systems in place of the gravel bed flocculator, as developed during this study.

13.1.5 The Chandori Treatment Plant :

The Chandori treatment plant is particularly designed for the treatment of turbid water sources for the small capacity water treatment plants for the rural water supply schemes. The plant can be considered as a further modification over the Murbad plant. The Chandori plant consists of the pretreator which is a combination of the gravel bed flocculator and tube settler unit and is followed by the dual media filter bed. The plant has got an additional advantage of two stage construction as discussed in the chapter 12.

The plant is under construction and is likely to be completed by June 1978. However the author feels that the plant performance may be very satisfactory based on the pilot plant experiments conducted during this study. Thus the Chandori treatment plant can be recommended for the small capacity rural water supply schemes for the treatment of turbid water sources.

13.2 FUTURE SCOPE OF RESEARCH.

The technological developments in the field of water treatment will always be continued and perhaps in the faster rate as compared to the progress in the past.

The present new techniques as developed in the design of the three treatment plants as discussed in this thesis, are bound to be developed further in due course of time towards more simplicity and efficiency. The author himself also intends to work towards this goal. In this respect the author feels that the further study on the below mentioned aspects may be helpful towards the further perfection of the new techniques as developed in this thesis.

13.2.1 Gravel Bed Flocculation :

As already discussed in the earlier chapters, there is a great scope of research in the further development of this new technique in the field of water treatment. The size, shape of the gravels and the direction of flow, the surface as well as volumetric loadings for different turbid waters and cleaning of the gravel bed will be some of the important aspects of research in the development of efficient gravel bed flocculators.

13.2.2 Development of Non-mechanical and Continuous Type Flocculation Units :

The development of the non-mechanical and continuous type flocculation units viz : the PVC tube surface contact flocculation units and the LDP film contact flocculation units, is an urgent field of research, for the design of the simplified as well as conventional water treatment plants, as discussed in the chapter 4.

13.2.3 Development of Cheaper Tube Settlers :

This will include cheaper material of fabrication of tubes, size and shape of tubes, depth of tube settler, relation of the turbidity and surface loading, methods of supporting tube modules, clear depth of water below and above the tube modules, inlet distribution and outlet settled water collection ; and the methods for the conversion of the existing settling tanks in-to the tube settling tanks, will be some of the important aspects of future research in this field.

13.2.4 Development of New and Cheaper Filter Media :

The developments of the suitable cheap media for the dual and the mixed-media filter beds for adopting higher rate of filtration and better effluent quality will be an important field of research in future. This can be considered as the most important problem in the development of high rate dual and mixed-media filters. The sizes and depths of the different filter media with respect to their specific gravities, and the back wash techniques for effective filter washing will be some of the important aspects towards the development of high rate filtration.

13.2.5 Effects of continuous and intermittent flow through the filter beds on the filter effluent, will also be a useful research.

13.2.6 The development of simple, automatic or semi-automatic filter rate controlling methods will also be a useful field of future research. The declining rate controlling methods for the small capacity water treatment plants will also be an interesting field of research.

13.2.7 The mathematical theories in the developments of the non-mechanical flocculation systems, tube settling tanks and the dual and mixed-media filtration, as discussed in the chapter 12 will also be the important fields of research.

13.3 INTERNATIONAL DRINKING WATER SUPPLY AND SANITATION DECADE, 1980-1990.

One of the recommendations of the United Nations Water Conference, which was held in March 1977, was that, priority should be given to the provision of safe water supply and sanitation for all by the year 1990. The conference approved the priority areas for action within the frame work of a plan of Action, outlined the actions to be taken at national level as well as through international co-operation, and made a proposal that 1980-1990 should be designated as the International Drinking Water Supply and Sanitation Decade.

Considering these recommendations and WHO's long-standing commitment to the improvement of community water supply and sanitation, the Health Assembly urged member states to treat this subject as a matter of urgency ; to formulate by 1980, within the context of national development policies and plans, programmes to achieve the target by 1990 ; to impliment during the decade 1980-90, the programmes formulated in the period 1977-1980.

13.4 UTILITY OF THE NEW TECHNIQUES DEVELOPED IN THE PRESENT STUDY.

From the above mentioned programme it can be seen that the provision of safe drinking water supply facilities will be an urgent task before the public health engineers in the world during the next decade. As the position of the safe water supply for the rural communities in the developing countries is very poor, in this respect, a large scale programme will have to be undertaken on top priority.

The rural water supply schemes where the surface sources are adopted, the suitable water treatment plants will have to be provided for such rural schemes. As the conventional water treatment plants, particularly the small capacity plants are very costly and also difficult for construction and maintenance in the rural areas, there is urgent need for the development of the simple and cheap water treatment methods. The author sincerely feels that the new water treatment methods as developed in this thesis may be able to help in solving this great problem of providing very simple and cheap water treatment plants for the rural water supply schemes. In this respect the WHO International Reference Centre has already published in the 'Newsletter' the extract on the Ramtek treatment plant (Feb.1976), and the Varangaon treatment plant (Sept.1978), and the photostat copies (in French and English versions resp.) of the same are enclosed in the Appendix-D for ready reference. At the end of this useful study the author is very happy to dedicate this work to the World Health Organization towards the goal of safe water supply in the rural and semi-rural areas.

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APPENDIX - A

LIST OF SYMBOLS AND ABBREVIATIONS

Symbol	:	
in	:	inch
ft	:	foot
μ	:	Micron
mm	:	millimetre
cm	:	centimetre
m	:	metre
in^2	:	square inch
ft^2	:	square foot
cm^2	:	square centimetre
m^2	:	square metre
in^3	:	cubic inch
ft^3	:	cubic foot
cm^3	:	cubic centimetre
m^3	:	cubic metre
ml	:	millilitre
cc	:	cubic centimetre or ml
vol	:	volume
ft/sec	:	feet per second
m/s	:	metre per second
g/h	:	gallon per hour
l/h	:	litre per hour
gpm	:	gallons per minute
lpm	:	litres per minute
mgd	:	million gallons per day

mld	:	megalitres per day
$l/m^2/hr$	:	litres per square metre per hour
$l/m^3/hr$	:	litres per cubic metre per hour
sec	:	second
min	:	minute
hr	:	hour
rpm	:	revolution per minute
B.S.	:	British standard
I.S.S.	:	Indian Standard Sieves
B.S.S.	:	British Standard Sieves
gpm/sq.ft	:	gallons per minute per square foot
ppm	:	parts per million
MPN	:	most probable number of coliform organisms per 100 ml of sample.

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APPENDIX - B

LIST OF INSTRUMENTS AND APPARATUS USED DURING THE STUDY.

1. Turbidimeter :

Aplab Turbidimeter Type IE2-T supplied by M/s Applied Electronics Private Ltd., Thana, was generally used for measurement of turbidites of raw, settled and filtered water samples for the pilot plant study in the laboratory. For field studies, also generally Aplab turbidimeters were used as available at the sites. However at Ramtek and Varangaon plants standard turbidity suspensions in clear glass bottles were prepared as per procedure given in the standard methods for the examination of water and waste water jointly published by A.P.H.A; AWWA ; WPCF , in the beginning till the date of purchase of Aplab turbidimeters. Turbidity rods were used to measure the higher raw water turbidity during the rainy season.

2. Flow Meter :

The rota-meters made by M/s Associated Inst. Manufactures, (India) Ltd.,Bombay, were used to measure and control the rate of flow at the outlet end of the pilot filter units.

3. Electrical Stirrers :

Electrical stirrers of 1/20 H.P. made by M/s Associated Instrument Manufacturers (India) Ltd., Bombay, were used for mixing of alum dose for pilot plant studies. The speed was kept about 100 rpm.

4. Electrical Pumping Sets :

Small capacity (1/20 HP) Tulu make electrical pumping sets were used for pumping raw water to the balancing tank in the pilot plant study.

5. Jar Test Equipment :

The special jar test equipment supplied by The Kadungaigar sewdse Reenamantion Research Unit T.W.A.D. Road Madras, was adopted for finding the optimum alum dose for the pilot plant study.

6. pH Meters :

Lovibond disc type pH meters were generally used for field study.

7. Pipes and specials for laboratory Study :

Galvanised iron and plastic pipes and brass gale valves,with plastic nozzles and specials were used as found suitable for the pilot plant study,for connecting units, backwashing and measurement of head losses.

8. Laboratory Facilities :

The laboratory facilities including various standard equipments such as ovens,incubators,autoclaves, furnaces, microscopes, and various glass ware and chemicals required for the standard chemical and bacteriological tests for pilot and prototype plant study were available in the laboratory of the Environmental Engineering Research Division, in the Maharashtra Engineering Research Institute,Nasik-4, where the author has carried out the major study.

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APPENDIX - C

REFERENCES.

1 Babbitt, Harold, J. and Doland, James. J.,
'Water supply engineering',
MCGRAW-HILL Book Company, INC.
Asian Students' Edition. (Fifth Edition, 1955).

2. Camp, T.R.,
'Theory of water filtration',
Jour. San.Eng.Divn., ASCE, Proc.Vol.90,
No.5 A.4, (August 1964).

3. Camp, T.R.,
'Discussion on experience with anthrocite sand filters',
Jour. AWWA, Vol.53, No.12, (Dec.1967).

4. Conley, W.R.,
'Experience with anthracite sand filters',
Jour. AWWA, Vol, 52, (Dec.1961).

5. Cox, Charles. R.,
'Operation and control of water treatment processes',
World Health Organization Monograph series No. 49, (1969).

6. Culbreath, M.C.,
'Experience with a multi-media filters',
Jour. AWWA, Vol. 59, (Aug.1967).

7. Culp, G.L. et al.,
'High rate sedimentation in water treatment works',
Jour. AWWA, Vol.60, No.6, (1968) p.681.

8. Culp, G.L. et al.,
'Tube clarification process operating experiences',
Jour. ASCE, San. Eng. Divn. (1969) p. 829.

9. Culp, G.L. and Culp, R.L.,
'New concepts in water purification',
Van Nostrand Reinhold company
New York/London etc. (1974).

10. Diaper, E.W.J. and Ives, K.J.,
'Filtration through size graded media',
Jour. of San.Eng. Divn., Proc.ASCE.
91 (S A3) 89 (1965).

Contd..

11. Diaper, E.W.J. and Ives, K.J.,
'Discussion on filtration through size graded media',
Jour. of San.Eng.Divn. ASCE. Vol.92 S A.4(Aug. 1966).

12. Fair, G.M. and Gayer, J.C.,
'Water and waste water disposal',
John Wiley and Sons, Inc. New York.(1959).

13. Gomella, C.,
'Recent developments related to pre-clarification',
General report No.1
Tenth congress of International Water Supply Association at Brighton (Aug. 1974).

14. Hansen, Sigurd. P. and Culp, Gordon,L.,
'Applying shallow depth sedimentation theory',
Jour. AWWA, Vol.59, (Sept.1967) p.1134.

15. Huisman, Ir.L.,
'Trends in the design construction and operations of filter plants',
Special subject No.8.
Proc. of the Eighth International Water Supply Congress. Vienna,(1969).

16. Ives, K.J.,
'Progress in filtration',
Jour. of AWWA, Vol.56, p.1225 (1964).

17. Ives,K.J., Diaper, E.W.J.,
'Filtration through size graded media',
Jour. of San.Eng.Divn.ASCE. Vol.91, (SA-3) (June 1965).

18. Ives, K.J. and Sholji, I.,
'Research on variables affecting filtration',
Jour of San.Eng.Divn. ASCE. Proc.Vol.97, (SA.4) (1965).

19. Ives, K.J.,
'Theory of filtration',
Special subject No.7,
Proc.of 8th I.W.S.Congress, Vienna (1969).

20. Ives, K.J.,
'Problems in filtration',
Jour. IWWA, Vol.II, No.4, (1970).

Contd..

21. Joseph, T.L., 'Encourage applied research and publish the findings', Jour. San.Eng.Divn. ASCE. (Aug.1966).

22. Kardile, J.N. , 'Problems in water treatment for individual house and rural communities', Proc.Sump. Problems in water treatment., (Oct.1964) (CPHERI, Nagpur).

23. Kardile, J.N., 'Observations on some semi-rapid and slow sand filters in Maharashtra State' Jour. IWWA, Vol.II, No.4, (1970).

24. Kardile, J.N., 'Crushed coconut shell as a new filter media for a dual and multi layered filters', Jour. IWWA, Vol.IV, No.1,(1972).

25. Kardile, J.N., 'Simplified rapid sand filters for rural areas', Jour. IWWA, Vol.IV, No.3,(1972).

26. Kardile, J.N., 'Water treatment problems of rural areas', Jour. IWWA, Vol.V, No.1,(1973).

27. Kardile, J.N., 'An unconventional 0.50 mgd treatment plant for Ramtek town, Nagpur', Jour. IWWA, Vol. VI, No.1, (1974).

28. Kardile, J.N., 'One year observations on filtration plant at Ramtek near Nagpur', Jour. IWWA, Vol. VIII, No.1, (1976).

29. Khare, S.T., 'Some thoughts on rural and urban water supply', Sixth Association lecture at the Sixth Annual convention of India Water Works Association at Baroda, (1974).

30. Khare, S.T., Presidentialaddress at the Eighth Annual convention of the Indian Water Works Association at Nagpur, (1976).

Contd..

31. Losnier, M., Jeffery, J., and Laburn, R.J., 'Cost and treatment : actual experiences in increasing the capacity of existing treatment plant at water works', Special subject No.4 Tenth congress of International Water Supply Association at Brighton, (1974).

32. Laughlin, J.E. and Durall, T.E., 'Simultanious plant scale tests of Mixed-media and rapid sand filters', Jour. AWWA, Vol.60, No.9, (Sept.1968).

33. M.E.R.I. report on the evaluation of the efficiency of the serrated and hopper bottom settling tanks', A special report By P.H. & R.E.R.Divn. (1976). M.E.R.I. Nasik-4, India.

34. 'MERI report on the evaluation of the efficiency of the slow sand and semi-rapid filters in the Maharashtra State', A special report by P.H. & R.E.R.Divn., M.E.R.I. Nasik-4, India.

35. Manual of British Water Engineering Practice, Volume III, (Fourth Edition 1969). Heffer & Sons Ltd : Cambridge, England.

36. Manual and code of practice on water supply section I-A. By Ministry of Health Govt. of India (Ed. 1962).

37. Mintz, D.M., 'Some results of research into drinking water purification and disinfection ', Aqua, IWSA, No.2, (1962).

38. Mintz, D.M., 'Modern theory of filtration', Proc. of I.W.S.Congress, (1966).,

39. Mohanka, S.S., 'Theory of multilayer filtration', Jour. San.Eng.Divn., ASCE, Vol.95, No.SA.6, (Dec.1969).

40. Mohanka, S.S., 'Theory and design of multilayer filters', Jour. IWWA, Vol.II, No.4, (1970).

41. Mohanka, S.S., 'Multilayer filtration design', Jour. of Water & water Engineering.

Contd..

42. Mohanka, S.S.,
'Study of a three layer filter',
Jour. of Inst. of Eng. (India); (1968).

43. Nashikkar, J.T., Bhole,A.G., and
Paramshivam, R.,
'Performance of a dual media filter',
Jour. IWWA, Vol.VIII, No.1, (1976).

44. Majumder, N.,
Presidential address at the seventh
convention of Indian water works
Association at Madras, (1975).

45. Paramsivam, R. et al.,
'Research on filtration at CPHERI,Nagpur',
Jour. IWWA,Vol.II,No.4,(1970).

46. Paramsivam,R., and Deshpande, A.W.,
'Augmentation of water supply by two layer
filtration ',
Jour. IWWA, Vol.IV, No.1, (1972).

47. Paramsivam,R.,
'Treatment alternatives for waters of
low turbidity',
Jour. IWWA, Vol.VII,No.1, (1975).

48. Patki, P.V.,
'Rigid P.V.C. Granules a new filter
media for two layered filtration',
Jour.IWWA, Vol.VI,No.1, (1974).

49. Proceedings of the Ninth Congress
of International water supply Association,
at New York (1972).

50. Ray, W.J.F.,
'Recent advances in methods of
filtration',
General report No.2.
Tenth congress of International water
supply Association, At Brighton. (Aug.1974).

51. Rimer, A.E.,
'Filtration through a trimedia filter ',
Proc. of ASCE, Jour.San.Eng.Divn., 94,
SA.3, (June 1968).

Contd...

52. Robeck, G.C., Dostal, K.A., and Wordword, R.L., 'Studies of modifications in water filtration', Jour.AWWA, Vol.56, No.2,(Feb.1964).

53. Richard, Yres., 'Smaller capacity water purification installations for the supply of water to rural communities and domestic consumers', Special subject No.14,Eighth congress of International Water Supply Association at Vienna (Sept.1969).

54. Shull, K.E., 'Experiences with multiple bed filters', Jour. AWWA, Vol.51, No.3, (March 1965).

55. Van de Voled, A., 'Comparison between slow and rapid filters', General report on the subject No.7, at the Third congress of International Water Supply Associations at London (1955).

56. Verheul, Ir. I., 'The water supply situation in developing countries', Subject No.1, Ninth congress of International Water Supply Association at New York. (Sept.1972)

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APPENDIX - D

COPIES OF PAPERS AND REPORTS

(For the University submission only)

I	Papers published by the author on the subject of this thesis.	Copies enclosed.
1.	'Observations on some semi-rapid and slow sand filters in Maharashtra State'. Jour.IWWA,Vol.II,No.4,(1970).	Photostat copy.
2.	'Crushed coconut shell as a new filter media for dual and multi-layered filters; Jour.IWWA,Vol.IV, No.1, (1972).	-do-
3.	'Simplified rapid sand filters for rural areas'. Jour.IWWA, Vol.IV, No.3,(1972).	-do-
4.	'Water treatment problems in rural areas'. Jour.IWWA,Vol.V, No.1, (1973).	Reprint copy
5.	'Development of ground water sources for rural water supply schemes', Jour. IWWA, Vol.V,No.2,(1973).	-do-
6.	'An un-conventional 0.50 mgd treatment plant for Ramtek Town,Nagpur', Jour.IWWA,Vol.VI, No.1, (1974).	-do-
7.	'One year observation on filter plant at Ramtek near Nagpur', Jour.IWWA, Vol.VIII, No.1,(1976).	-do-
8.	'A new unconventional treatment plant at Varangaon', Jour.IWWA, Vol.X, No.1,(1978).	-do-
9.	'A new unconventional treatment plant for Chandori villages . Paper accepted for publication in the Jour.IWWA, Vol.XI, No.1,(1979).	--

II	News letters of WHO International reference centre for community water supply.	
1.	News letter No.62 for February 1976 for Ramtek treatment plant (French version).	Photostat copy.
2.	News letter No.91 for September 1978 for Varangaon treatment plant (English version).	-do-
III.	Reports.	
1.	The report on the evoluation of the efficiency of the serrated and hopper bottom rectangular, settling tanks. Departmental report of MERI, Nasik.	Reprint copy -do-
2.	The report on the performances of existing semi-rapid and slow sand filters in the Maharashtra State. Departmental report of MERI, Nasik.	Reprint not available
3.	Final report on WHO Fellowship for three months in Yugoslavia and United Kingdom during May 1976 to July 1976 on 'Village Water Supply' submitted to the WHO by the author.	Copy not enclosed.

N.B. : The copies of papers, news letters and reports as stated above are enclosed in the Appendix-D in a separate folder only for the University submission.