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Eighth Public Health Engineering Conference

held in the Department of Civil Engineering
Loughborough University of Technology

January 1975

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Aspects of Sewage treatment

proceedings

edited by John Pickford

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contents

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opening address

Professor D. C. Freshwater,
Head of the Department of Chemical Engineering.

Professor Freshwater said it was his pleasant task to welcome everyone on behalf of the University.

He made two points in welcoming the participants. Firstly he stressed that the University regarded sewage treatment as important and worthwhile. As a chemical engineer and hence rather an observer standing on the side lines and looking at specialized aspects of the problems, he could pick out the bits of the problem which were particularly interesting (e.g. flocculation aspects or the fundamental features of packed beds or the scientific aspects of filtration) and ignore all the rest of it. But there was tremendous scope in this subject area for the best sort of engineering - the science which went as far as possible with analytical equations and then allied it to experience and creative design to find engineering solutions to the problems. Loughborough as a University of Technology was peculiarly interested in this sort of problem.

This interest led the University to a self-imposed mission of furthering the cause of continuing education. Universities and all Institutes of higher education needed to concern themselves far more than they ever had in the past, not only with the education of the graduate (three years and he's finished for life) nor even with the education of the post-graduate (another three years and he's ready for a university career or a career in a high-powered design office) but rather more with the concept that the university career was only the beginning and was only a part of our function. Universities did not know more than anybody else about sewage treatment or filtration or flocculation - they knew a little bit of some things that other people did not know! The one thing they knew more about was teaching and more particularly training, and part of their function was to act as the catalyst for continuing education which had to go on throughout the whole of people's professional life.

Professor Freshwater hoped it would be a successful conference, although he was sorry to see it was exclusively male.

Copies of the Proceedings of previous Conferences may be obtained from the Department at £3 each, cash with orders please.

1st PHE Conference 1967	SURFACE WATER AND STORM SEWAGE
2nd PHE Conference 1969	TERTIARY SEWAGE TREATMENT AND WATER REUSE
3rd PHE Conference 1970	INDUSTRIAL WASTE WATER
4th PHE Conference 1971	SLUDGE TREATMENT AND DISPOSAL
5th PHE Conference 1972	ECONOMICS AND MANAGEMENT IN PUBLIC HEALTH ENGINEERING
6th PHE Conference 1973	BRITISH AND CONTINENTAL PROGRESS IN WATER POLLUTION CONTROL
International Conference September 1973	ENVIRONMENTAL HEALTH ENGINEERING IN HOT CLIMATES AND DEVELOPING COUNTRIES
7th PHE Conference 1974	EDUCATION AND TRAINING FOR PUBLIC HEALTH ENGINEERING AND ENVIRONMENTAL MANAGEMENT

P. COACKLEY

developments in our knowledge of sludge dewatering behaviour

INTRODUCTION

One of the largest problems in wastewater engineering is the dewatering of the sludges produced in the various purification stages. Improved standards of effluent quality lead to more efficient waste treatment operations which invariably produce larger volumes of sludge. The cost of sludge treatment and disposal can represent fifty percent of the total cost of construction and operation of a sewage treatment plant, and further studies both into the plant scale behaviour and into the fundamental nature of the various sludges is required.

All the sludges produced on sewage works are pseudo homogeneous materials and many are non-Newtonian fluids with plastic rather than viscous flow properties; they exhibit thixotropic properties and their resistance to flow is a function of their concentration.

The water in the sludges is in various forms. For example, Wilson and Heisig(1) suggested that there was

1) Capillary water, removable by mechanical means

2) Adsorbed water which cannot be removed mechanically.

Rudolfs and Lacy(2) classified the moisture as being in the form of

1) Free water which could be removed by drainage

2) Capillary bound water which required a greater force than gravitational force to remove it

3) Combined water which cannot be drained off or readily removed by evaporation at normal atmospheric temperatures.

Pearse at al(3) divided the water in a granular bed into three classes:

1) The pendular form in which water is held as a discrete ring at the points of contact of the particles

2) The Funicular form where the rings have increased to the point where many coalesce to give a continuous network of liquid through the bed interspersed with air

3) The Capillary form where all the pore spaces are completely filled with water.

Coackley(4) as a result of studies on the filtration and drying characteristics of sewage sludges classified the moisture as

1) Free or readily drained moisture, the lower limit of which is defined by the first critical moisture content

2) The Capillary water which is the bulk of the water held between the first and second critical moisture contents

3) Floc or particle moisture which is that water held internally by osmotic and hydration forces within the body of the flocs.

4) Chemically bound water.

In any studies of dewatering processes, the concept of these various classes of water should be kept in mind as there is a considerable difference in the degree of ease with which the various classes of water may be removed. For example, the water represented by that proportion between starting moisture content and the first critical moisture content is readily removable by drainage or low pressure filtration processes; significant removal of moisture below the first critical moisture content requires the application of much greater pressures such as occur in filter presses. Below the second critical moisture content moisture removal is probably restricted to evaporative processes.

Separation of the solid and liquid phases of sludges is carried out by the use of equipment which can be simply described as strainers or filters. The most frequently used "filter" in the past was the drying bed which allowed for a simple drainage or filtration process whilst at the same time providing for loss of moisture by evaporation.

More advanced mechanical filtration operations depend for their success on the increased speed of water removal which in most cases occurs because of an increase in the force applied to the interstitial liquor. This principle is the same whether the operation is by vacuum filters, filter presses, coil spring filters, filter belt presses, centrifuges or screw presses; other mechanical methods such as the Roto plug thickener and vibrating screen units depend, for part of their effect, upon the straining action as does electro-osmosis.

To understand the behaviour of sludges under various conditions of filtration, the author(14) advocated and demonstrated the value of the Carman filtration equation when applied to studies of sewage sludge dewatering, and many studies have since been made of specific resistance and its application to sludge dewatering problems.

Although many workers now use specific resistance to describe the behaviour of sludges, little attention has been paid to studies of the compressibility coefficient of the sludge, the nature of the sludge particles or the structure of the sludge cake and its behaviour after formation but while still under pressure. If development in plant design as well as in economic plant operation are to be ensured, then continuing studies into the nature and behaviour of sludges is still necessary.

Pressure and Compressibility

The filtration pressure is the force which causes filtration and its function is to drive the filtrate through the cake and septum. The ease with which this occurs is largely dependent upon the compressibility of the sludge and on the size of the sludge particles.

The compressibility of a sludge depends upon the relation between the filtration pressure and the specific resistance. The most practical method of determining the coefficient of compressibility is to use the equation

$$r = r_o P^s$$

where:

r is the specific resistance at pressure P

r_o is a constant

s is the coefficient of compressibility.

For compressible sludges the specific resistance is not constant but it changes with the pressure at which the filtration is carried out and the coefficient s is a measure of the susceptibility of the cake to deformation; when $s = o$ the cake is incompressible, specific resistance being independent of pressure. When $s > o$ the cake is compressible. The importance of the compressibility coefficient to filtration operations was shown by Jones(5); an example of its importance is that for a sludge with a compressibility coefficient $s = 0.9$ the time taken to press a cake to a given solids content at 138 kN/m^2 will be only 1.2 times that at a pressure of 690 kN/m^2.

Compressibility values vary from sludge to sludge and in the case of activated sludges they vary with degree of "freshness". Some examples of the values of the compressibility coefficient are given below:

Sludge Type		Compressibility Coefficient
Digested Sludge		0.7 - 0.9
Crude sludge		0.85
" "	+ lime and copperas	0.67
" "	+ ferric chloride	0.95
Activated sludge	Fresh	0.6
" "	Septic	0.8
" "	Well oxidised	0.5 - 0.6

The values listed are examples for, like specific resistance, the value changes with the nature of the sludge, method of treatment, and with certain sludges, the age.

In addition to particle size, the structure and compressibility through the cake affects the filtration rate. Gale(6) has shown that the moisture content of raw conditioned sewage sludge varies from the cake surface to the filter septum.

If the mechanism of water removal is considered when pressure is first applied to the sludge, it is obvious that with high water content sludges, where in fact the water is the continuous phase, very little compression of the particles or solid phase can take place due to the fact that the force distribution is hydrostatic in nature and consequently it acts in all directions.

When some filter cake has been formed and the moisture distribution becomes uneven, some of the force is transmitted by the particles; consequently, as filtration proceeds, the proportion of the force transmitted hydrostatically decreases whilst that transmitted via the particles increases. This effect first becomes noticeable in the layer of cake adjacent to the filter septum. Depending on the compressibility of the particles constituting the sludge, a particle in the bottom layer of the cake will be more compressed than its counterpart in the top layers. This results in an increase in specific resistance from top to bottom of the filter cake. The stability of the packing of the particles in the cake depends on various factors, the principal ones being particle strength, compressibility and the friction between the particle surfaces.

Table 1 shows the value of the specific resistance and compressibility coefficient for three sludges together with the values for constituent particle size fractions within the sludge. These results indicate that for any particular sludge, the smallest particle size range has the highest specific resistance. The compressibility coefficient tends to be lower for the smaller than the larger particles and this indicates that the smaller particles are less deformable than the larger particles. In the case of all three sludges the original specific resistance is greater than the specific resistance of the separated particles; this suggests that a small proportion of the very small particles has a disproportionate effect on the total specific resistance of the sludge.

Table 1. Values of specific resistance and compressibility coefficient for various types of sludge particle.

Sludge description	Specific resistance $r \times 10^{13}$ m/kg	Compressibility coeff.
Primary sludge	16	0.73
" " particles > 100 μ	8.7	0.84
" " particles 5 - 100 μ	13.1	0.78
	14.2	0.49
Primary digested sludge	20.0	0.63
" " " particles > 5 μ	14.8	0.66
" " " particles 1 - 5 μ	16.0	0.56
Secondary digested sludge	9.8	0.57
	6.0	0.70
	7.0	0.54
	6.9	0.49
Sludge from biological filter	49.30	0.24
Activated sludge	46.70	0.67

Studies of the particles under the microscope suggest that many of the larger particles are agglomerations of smaller particles and, if this is the case, it would explain the higher coefficients of compressibility obtained for the larger particles. It has been suggested that it is the presence of bacteria in sludges which leads to the slower filtration rates; however, Althausen and Boswell(7) found that although there was an increase in bacterial numbers during the controlled anaerobic digestion of cellulose, the filtration rate of the digesting mixture was not altered. Table 2 shows the effect of artificially increasing the number of bacteria in aerobically digested sludge and the increase in bacterial numbers does not affect the filterability.

Table 2.

Sample	Specific Resistance $\times 10^{13}$ m/kg	No. bacteria added	Total No. of bacteria per ml.
Original	16	0	9×10^9
Original + bacteria	16	2×10^{10}	29×10^9
" + bacteria	16	2×10^{11}	209×10^9
"	20	2×10^{12}	2009×10^9

These data indicate the importance of size distribution and nature of the particles to the dewatering behaviour of sludges.

It is well known that the addition of another type of solids to the sludge can alter the filterability of the sample. The addition of compressible solids will not reduce the specific resistance as much as an incompressible material, and in fact it may well cause an increase in the specific resistance.

Sludges which have been elutriated are generally found to dewater more easily after elutriation than before. It has been stated that this effect is due to the washing out of ammonium and other ions(8) but it is more likely to be related to the removal of the finest particles in the sludge which have the highest specific resistances. Recent research into the properties of sludge cakes during various operations have been made (11,15) and some of these findings are now referred to.

Figure 1 shows the results of an experiment in which a sample of sludge having a specific resistance of 46.5×10^{13} m/kg was fractionated by centrifuging at 2000 r.p.m. for 5 minutes and at 3000 r.p.m. for 5 minutes. The coarse and fine fractions resulting from the treatment were mixed together in various proportions and the specific resistance determined. The effect of the fines can be readily seen together with the effect of the fines fraction of smaller particle size. The filtration of many sludges can be improved by the use of an appropriate filter aid. Filter aids are finely divided materials which may be added to either the filter septum before the addition of the sludge, or to the sludge as a whole. Both types of addition are expected to improve the filtrate flow. The first type of application is known as a pre-coat filter aid, and the second type is a body aid. Some examples of physical types of filter aid are: wood flour, diatomaceous earth, fly ash and expanded perlite.

Pre-coat aids are added in order to protect the filter septum against the blockage of the septum pores by fine particles. In rotary vacuum filters, as the filter cake is removed, the doctor blade skims off a small amount of the pre-coat surface, thereby leaving a new surface for the next filtration cycle.

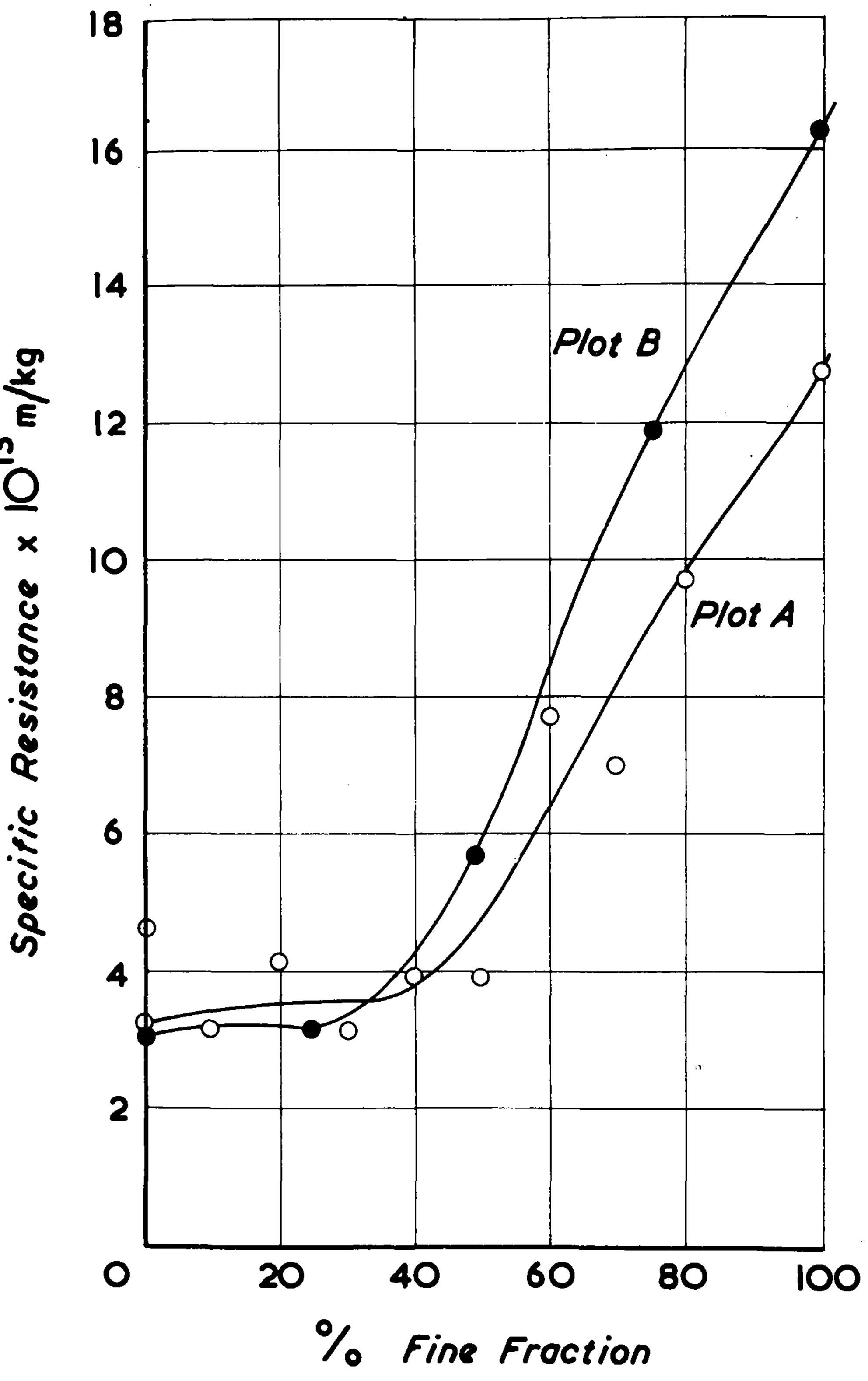
Body aids are added to the unfiltered sludge to form intimate mixtures of sludge/filter aid particles. The action of the filter aid solids in this case is to form a more porous filter cake which allows higher flow rates and, with the appropriate filter aids, the use of higher filtration pressures. The main function of a body aid is to improve the characteristics of the filter cake with particular emphasis on the rigidity and porosity of the cake structure. Filter cakes formed from a mixture of compressible sludge and rigid filter aids will be less compressible than cakes formed of sludge particles alone. The decrease in compressibility is due to the rigid filter aid absorbing the greater proportion of the compression force which arises as the filtration proceeds and the pressure changes from the purely hydrostatic force to an inter-particle force system. It can be considered that the matrix of filter aid particles provides "protection" for the sludge particles and so creates a filter cake which dewaters relatively easily at high pressure without too much deformation. The concentration of filter aid added to a sludge is critical if its rate of dewatering is to be a maximum.

Figure 2 shows the effects of adding fly ash to sludge where the fly ash is acting as a filter aid, and this indicates the most economic proportion of aid to be added to the sludge, i.e. 20%. Moehle(9) carried out tests in the USA and found an optimum fly ash addition to wet sludge (by weight) to be 20%

In work carried out by Tenney(10) on the use of fly ash as a sludge conditioner, it was found that the optimum size of fly ash particles was between 5μ and 20μ , and that the most desirable size would be one having a close approximation to the size of the sludge particles.

Figure 1. VARIATION IN SPECIFIC RESISTANCE r WITH DIFFERENT PERCENTAGES OF FRACTIONED DIGESTED SLUDGE:

DIGESTED SLUDGE FINE FRACTION

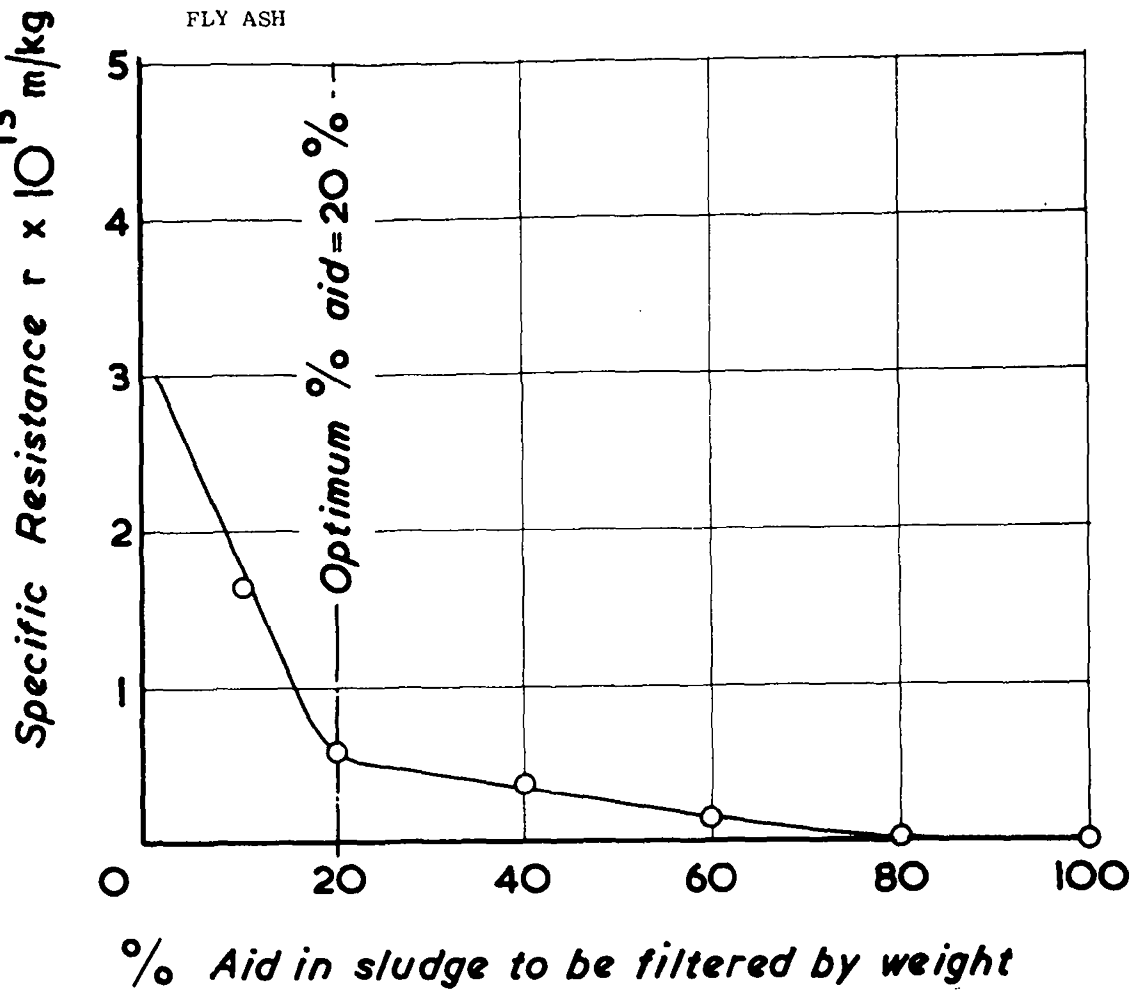


Plot A: digested sludge separated by centrifuge rotating at 2000 rev/min

Plot B: digested sludge separated by centrifuge rotating at 3000 rev/min

Figure 2: VARIATION IN SPECIFIC RESISTANCE r WITH DIFFERENT PERCENTAGES BY WEIGHT OF FILTER AID:

FLY ASH



The effect of fine fly ash particles on the filterability of digested sludge has been studied(11). Fly ash was sieved to give fractions with particles of the following characteristics:

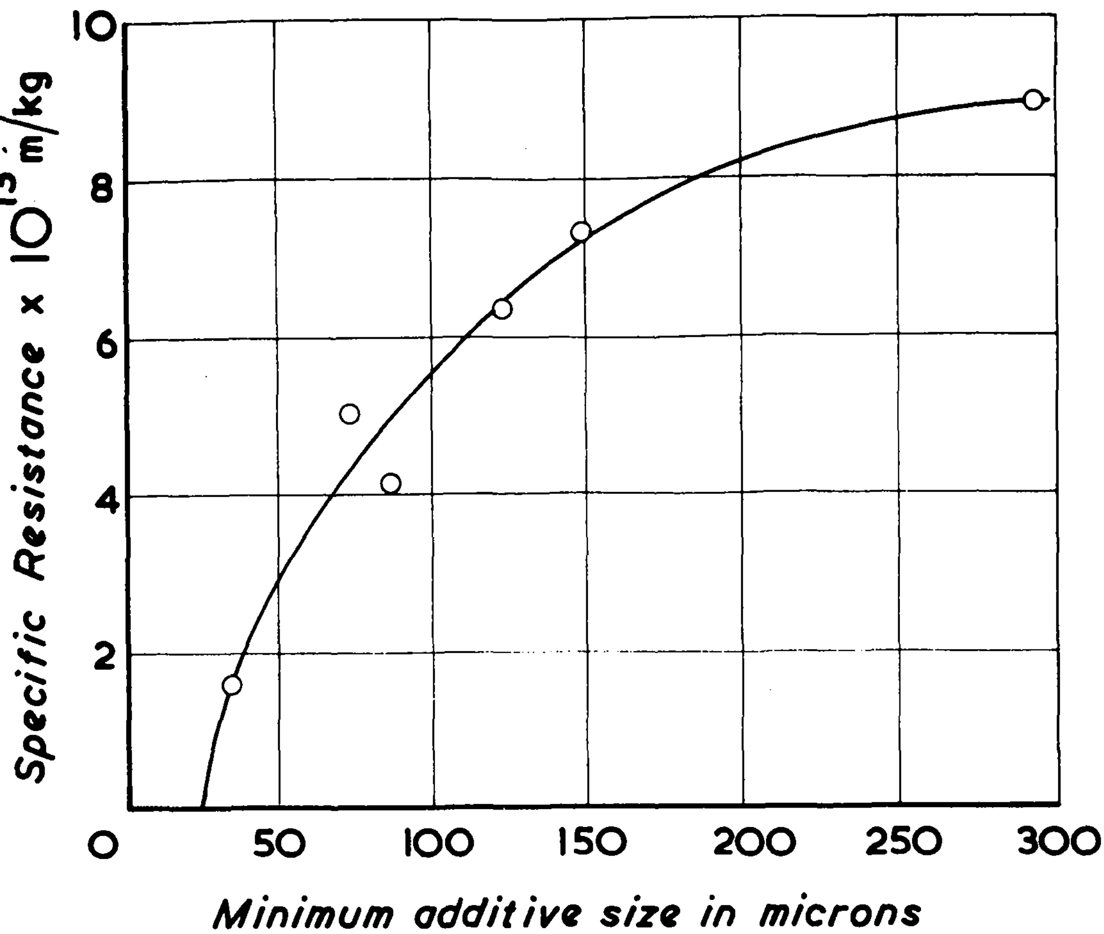
Fraction	1	Size $>295\mu$
"	2	$>150\mu$
"	3	$>125\mu$
"	4	$>89\mu$
"	5	$>75\mu$
"	6	$<75\mu$*

* It was assumed that the maximum percentage of particles in the $<75\mu$ range were of 35μ diameter.

The fly ash fractions were added to digested sludge to give a fly ash proportion of 20%. Figure 3 shows the effect of additive size on filterability. The greatest reduction in specific resistance occurred with the fraction of fly ash containing the smallest particle size range.

These results indicate that the presence of fines in a sludge does not necessarily indicate that the sludge will be difficult to dewater. It is the nature of the particles that is important. If the fine particles are compressible, then a greater resistance to filtration will be experienced resulting from closure of the pores as the particles collapse. Rigid granular particles will create a stronger cake, the rigid structure transmitting the forces without deformation. The pore spaces remain open and allow for the relatively easy passage of the water from the upper layers of the cake.

Figure 3. AFFECT OF ADDITIVE SIZE ON FILTERABILITY

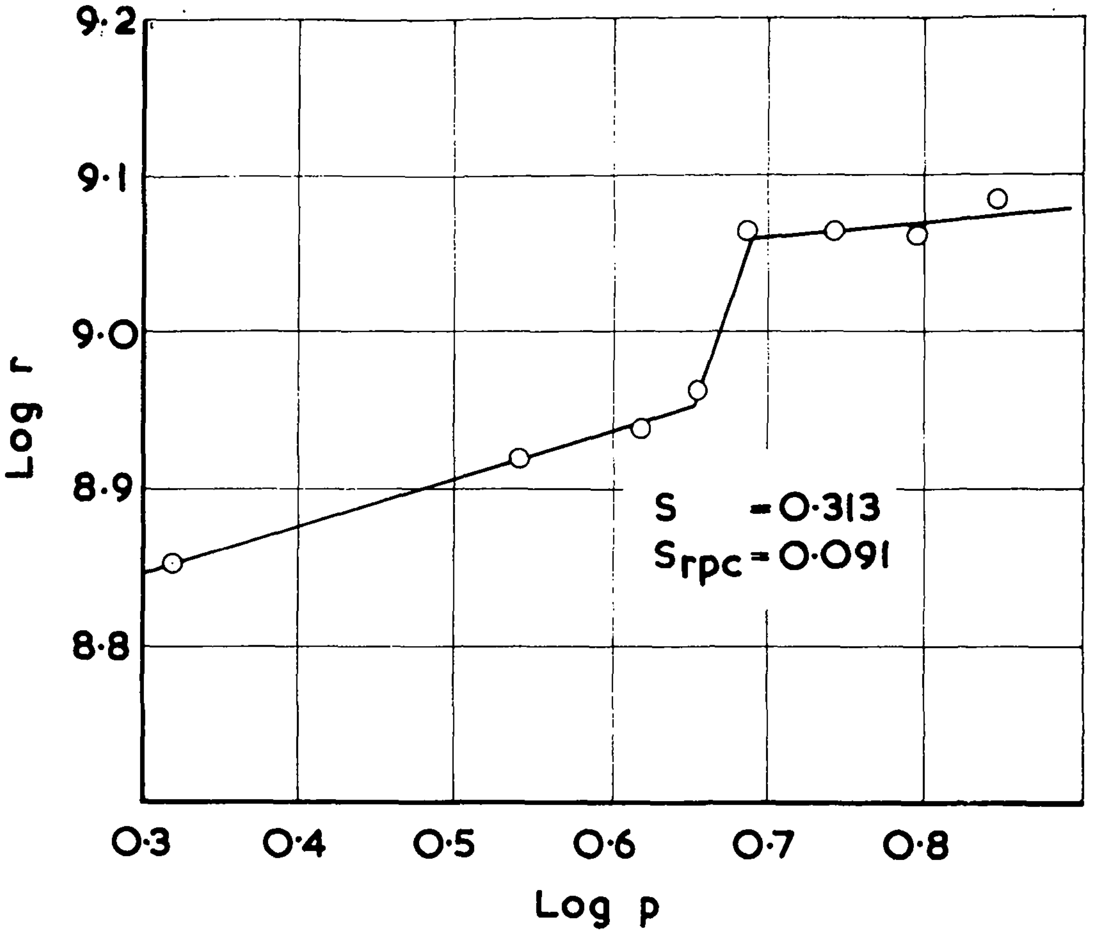


Blackadder(12) has reported that a small proportion by weight of fine particles has a substantial effect in increasing the strength of the filter cake, whereas a small number of larger particles reduces the cake strength. The physical nature of the fine particles is not described.

The compressibility of sludge/fly ash mixtures is of interest in relation to the fundamental behaviour of the cake. Figure 4 shows the relation between log r and log P. A continuous relation is not obtained, the plot shows a discontinuity, and this suggests that at a critical stage in the filtration process and at a particular pressure the packing of the particles is altered. The force distribution in the cake alters as a result of the change in flow pattern around the particles. This type of phenomena was observed by Rietema(13) who referred to it as Retarded Packing Compressibility. The change in pressure distribution throughout the cake can have a significant effect on the behaviour of the cake during filtration, and in the field of sewage sludge dewatering nothing is known of the nature of the change.

The moisture content and porosity distributions give an indication of the type of pressure distribution through the sludge cake. In the case of digested sludge the moisture content and porosity decrease slightly from the filter cake surface to the middle of the cake and then a greater decrease occurs towards the filter septum. Digested sludge/fly ash mixture show a rapid decrease in moisture content in the top part of the cake and then a slow decrease through the remainder of the cake towards the filter septum. This indicates that in the lower layers of the cake the load is being transmitted from one particle to another; the fly ash in the cake transmits the load through the rigid, low compressibility skeleton. The nature of the skeleton is such that the pore spaces remain open and allow the passage of filtrate from the upper cake layers, even under high filtration pressures.

Figure 4. COMPRESSIBILITY OF DIGESTED SLUDGE/FLY ASH MIX



Reduction in moisture content and porosity of the cake might possibly be related to particle migration within the cake, and further studies of the digested sludge and digested sludge/fly ash mixtures indicated a movement of smaller particles towards the filter septum. This data was obtained by sectioning the cakes and analysing the particle size distribution in the sections. The movement found for the particles in the 1.2 - 10μ range was little or none; the particles showing migration were those $< 1.2\mu$. This again points to the significance of the small particles in the sludges. The behaviour of sludges when drying has also been investigated(16) and part of this investigation was concerned with the effect of additives. The rate of removal of moisture from the solids depends upon two groups of factors. Firstly, there are the external factors such as

1) Air temperature

2) Air velocity

3) Humidity

The second group are those related to the material, e.g.

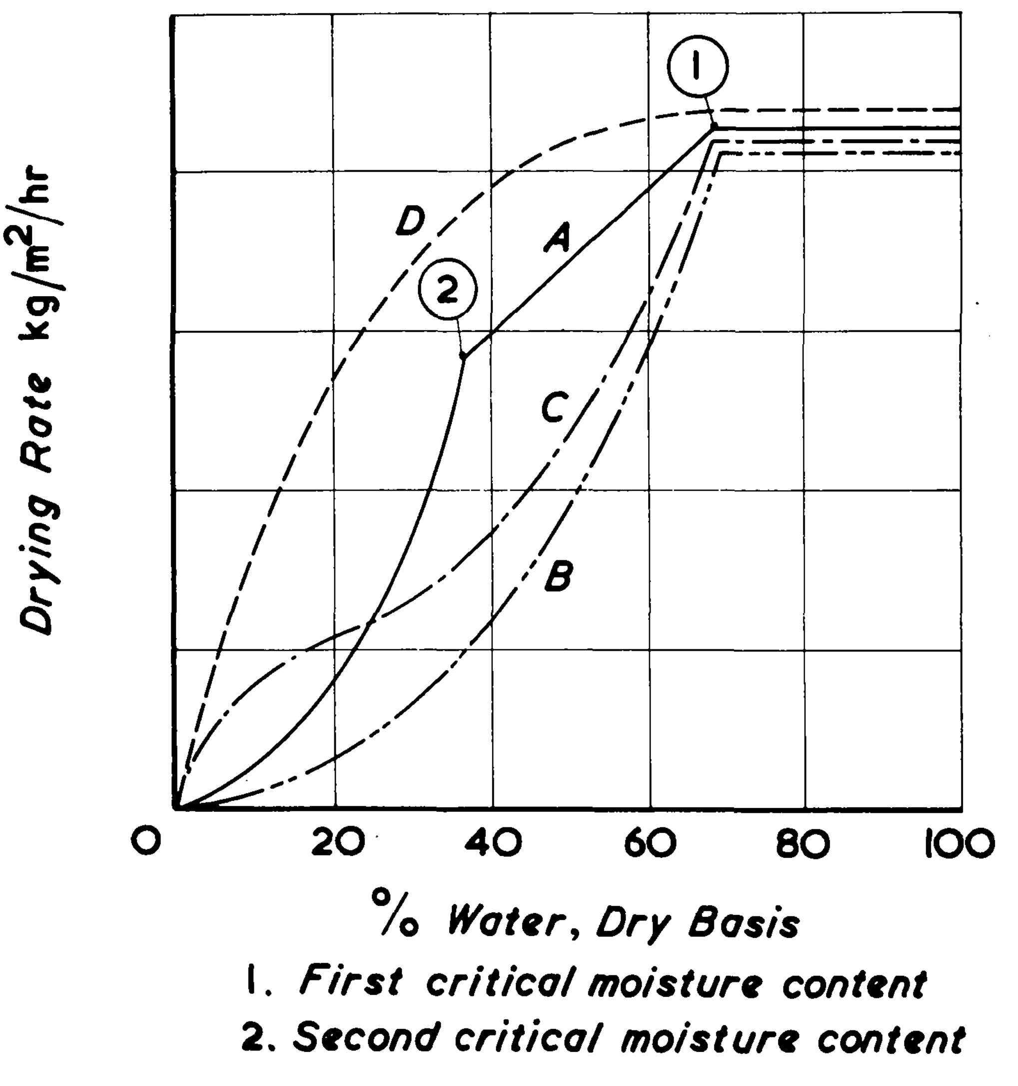
1) The chemical and physical nature of the solids

2) The internal structure of the particles and size distribution

3) The bed dimensions, in particular the depth and shape of the drying surface in relation to the air flow.

It is convenient to represent the drying process by plotting the rate of drying against the moisture content. Typical drying curves are shown in figure 5. Curve A shows the shape of the curve for a digested sludge. The first critical moisture content occurs where the constant rate of drying changes. The second distinct change in the slope of the drying rate curve occurs at the second critical moisture content. In digested sludge the first critical moisture content occurs around 75%, the second critical moisture content being around 50%

Figure 5. TYPICAL RATE-OF-DRYING CURVES OBTAINED IN THE DRYING OF VARIOUS SUBSTANCES.



In the case of sewage sludges it is usually found that during the constant rate period of drying the evaporation rate is greater than that which would occur at a free water surface; this is probably due to surface roughness which increases the theoretical evaporation area, and depends mainly upon the particle size and shape.

During the first falling rate period, the moisture retreats into the surface voids thus decreasing the theoretical drying surface; as soon as the moisture has retreated into the surface voids, a suction potential is created as a result of capillary action and surface tension. The moisture movement to the surface under these conditions is controlled by factors such as particle size distribution and surface tension.

The investigation of the effect of additives included the effect of adding 15% of lime by dry weight, 2% of aluminium oxide, 0.2% Teepol solution and the effect of freezing and thawing.

The results obtained for the digested sludge samples are shown in figure 6. When the drying curves for the digested sludge in its original condition are compared to the results for the sludge containing drying aids or treated by freezing and thawing, it can be seen that freezing does not alter the drying rate curve although the starting moisture content was reduced from 88.3% to 79.6% for the frozen sample as a result of more rapid drainage.

The sludge particles in the frozen sample are reduced in number (Fig. 7) and the size is increased. In consequence the surface area during the constant rate period is decreased and the drying rate decreases. The addition of lime or Teepol considerably improves the drying properties of the sludge. During the constant rate period the drying rate increases from 0.22 $kg/m^2/hr$ for the untreated sludge sample to 0.32 $kg/m^2/hr$ for sludge with lime or Teepol additions. The particle size analysis shows some small change in the distribution of particle size after the addition of lime; there is no change in size as a result of the addition of Teepol. In the case of the addition of lime, a skeleton of less compressible material is formed; as drying proceeds, the moisture moves to the surface by capillary action causing a pressure gradient through the cake. The downward forces between the particles increase and a pressure gradient is formed. In the presence of lime, the deformation of the particles under the applied load is decreased. This ensures a stable voidage and hence a decrease in the resistance of moisture movement to the surface and increased rate of drying. In the case of Teepol, the surface tension of the capillary water is reduced and this leads to a reduction in the interparticle forces which again leads to a reduction in the deformation of the particles and also decreases compaction. The result is again a higher void ratio and decreases in moisture flow to the surface.

When activated sludge was examined it was found that the addition of lime and Teepol created a similar effect to that observed in the digested sludge experiments. Both materials increased the drying rate of the sludge during the constant rate period from 0.27 to 0.32 $kg/m^2/hr$ (Fig. 8). The addition of aluminium oxide was found to be very effective. The aluminium oxide helps to create a structure having a low compressibility and a greater resistance to the deformation caused by interparticle forces, and again a more porous cake is produced leading to the increased rate of drying.

The change in particle size distribution in activated sludge is shown in figure 9. The addition of lime causes little change in the particle size distribution. The lime will lend stability to the structure as it dries. Addition of Teepol resulted in some reduction in particle size; this leads to a decrease in void size and an increase in resistance to moisture movement with a decrease in drying rate during the falling rate period. However, as Teepol reduces the surface tension of the water, there could well be an improvement in drying rate. The total effect will depend upon the relative actions of surface active agents upon the void size and surface tension.

Figure 6. EFFECT OF DRYING AIDS ON THE DRYING RATE CURVES: DIGESTED SLUDGE.

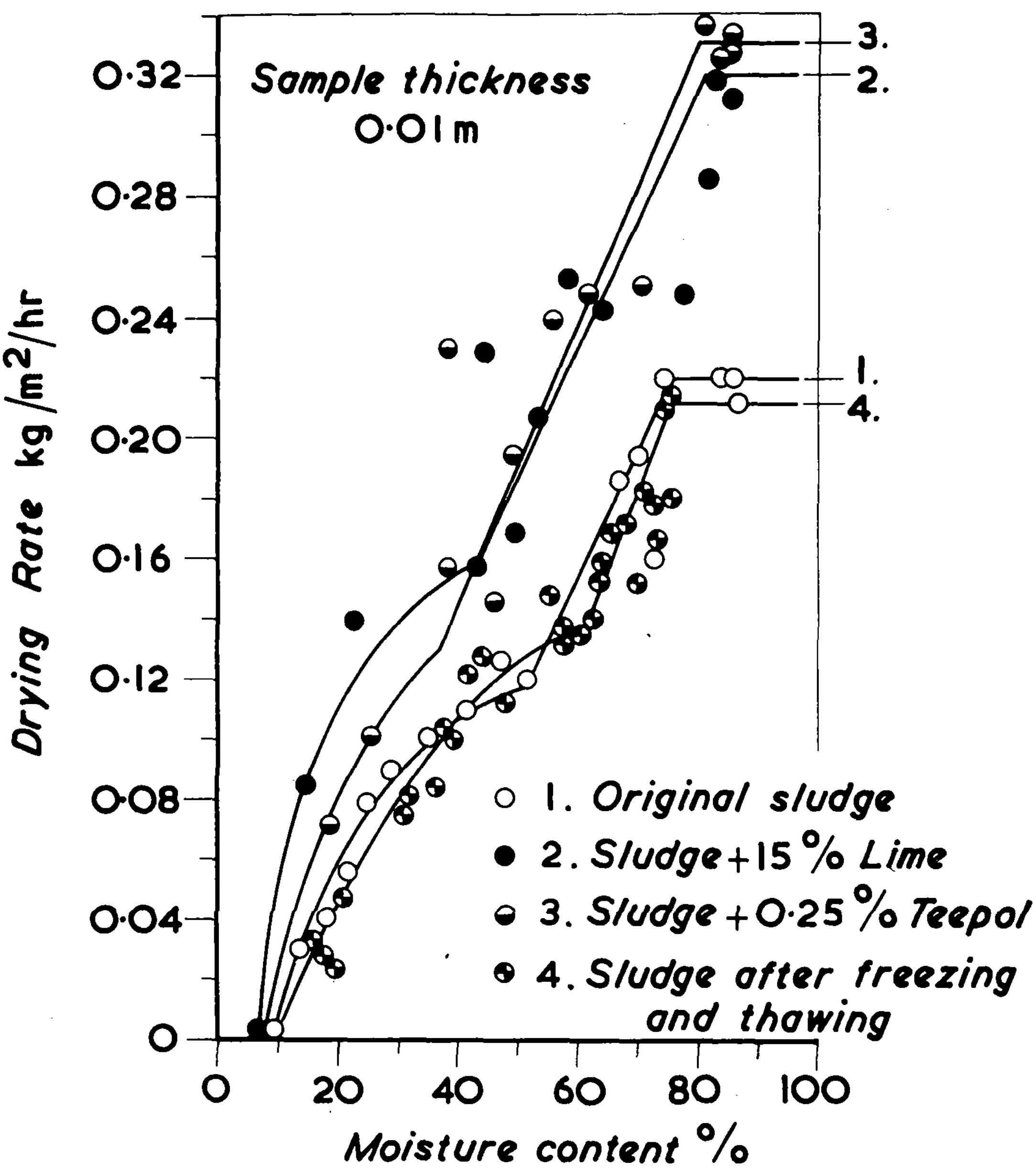


Figure 7. PARTICLE SIZE DISTRIBUTION:
DIGESTED SLUDGE

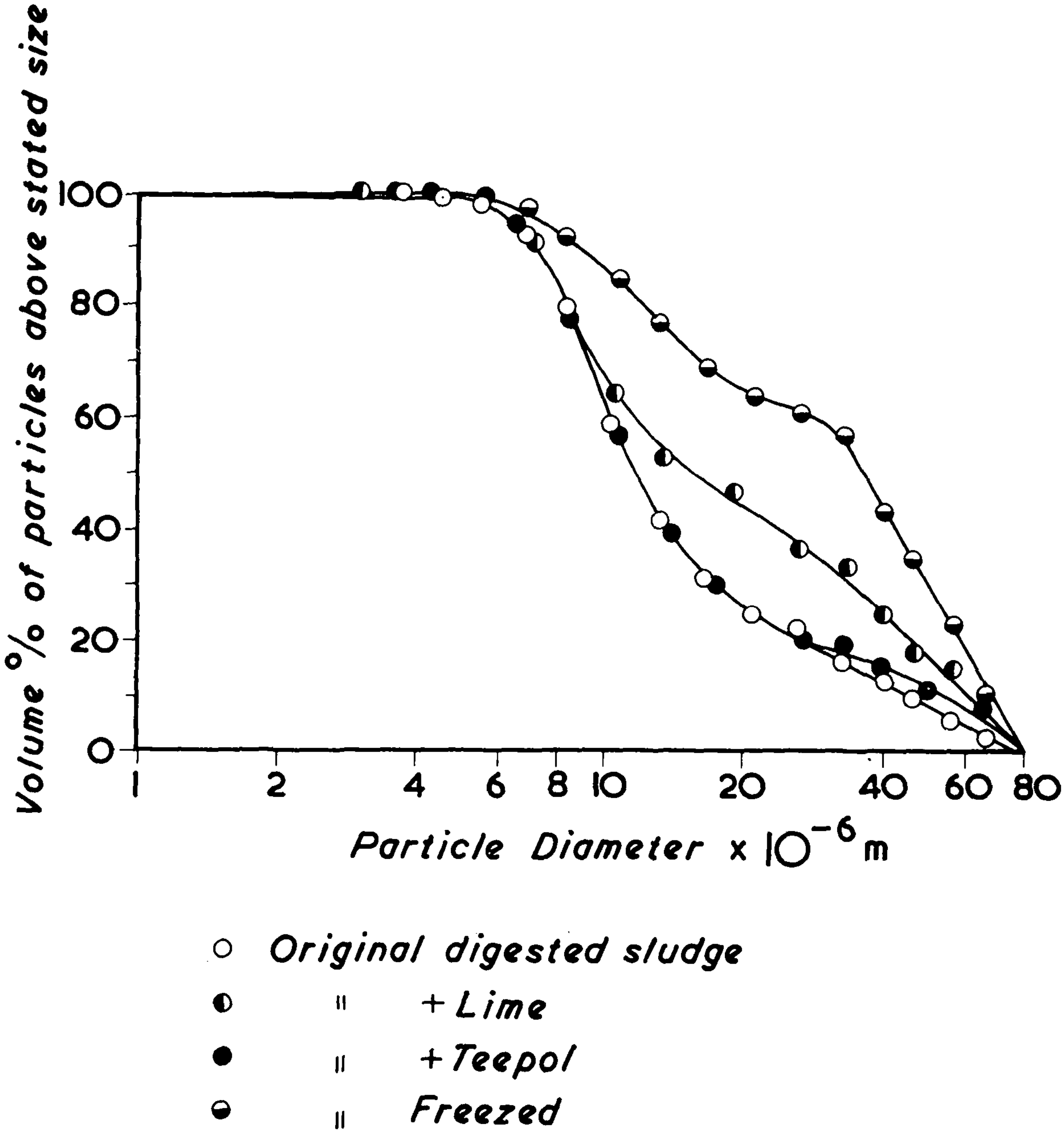


Figure 8. EFFECT OF DRYING AIDS ON THE DRYING RATE CURVES: ACTIVATED SLUDGE.

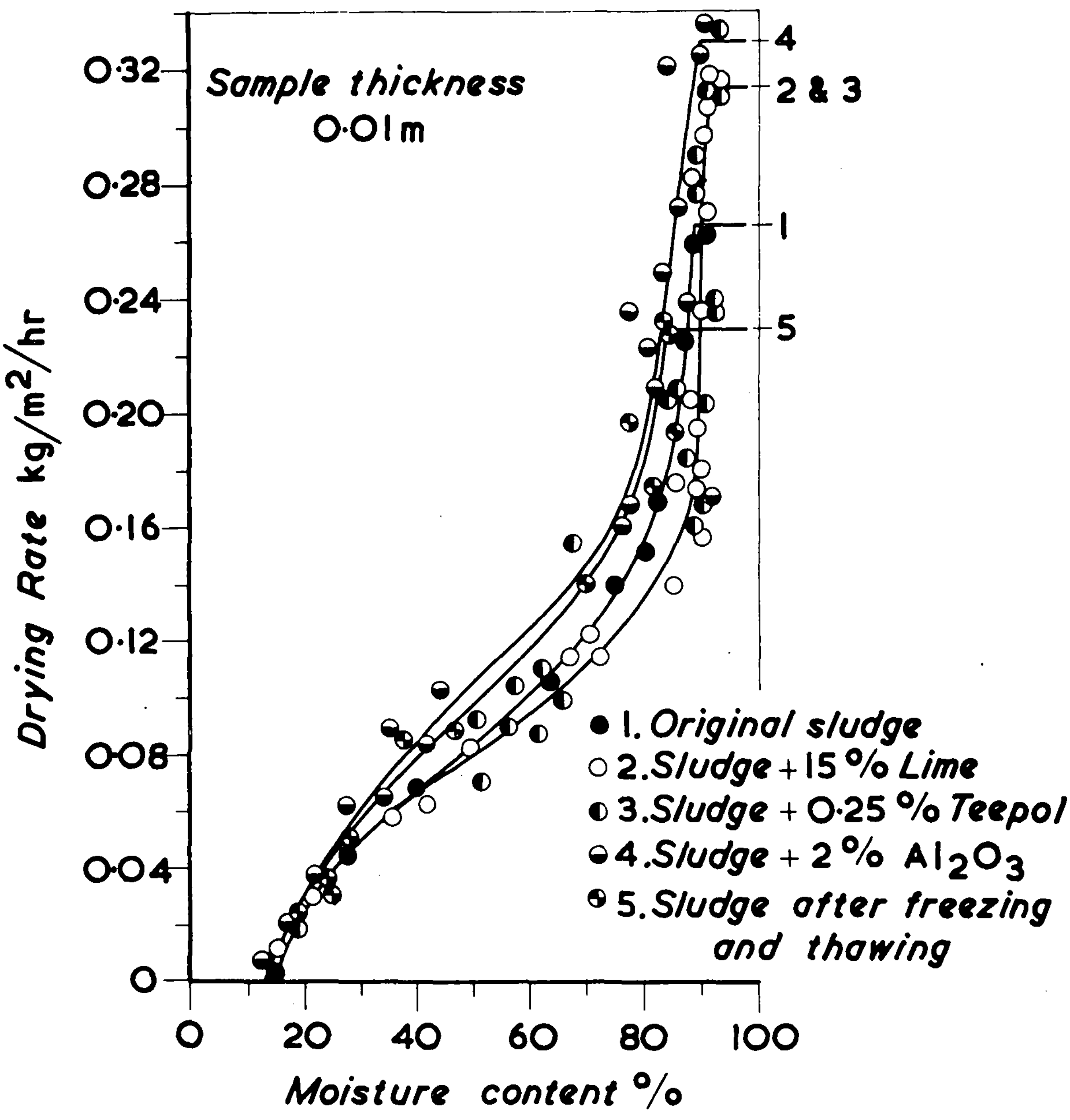
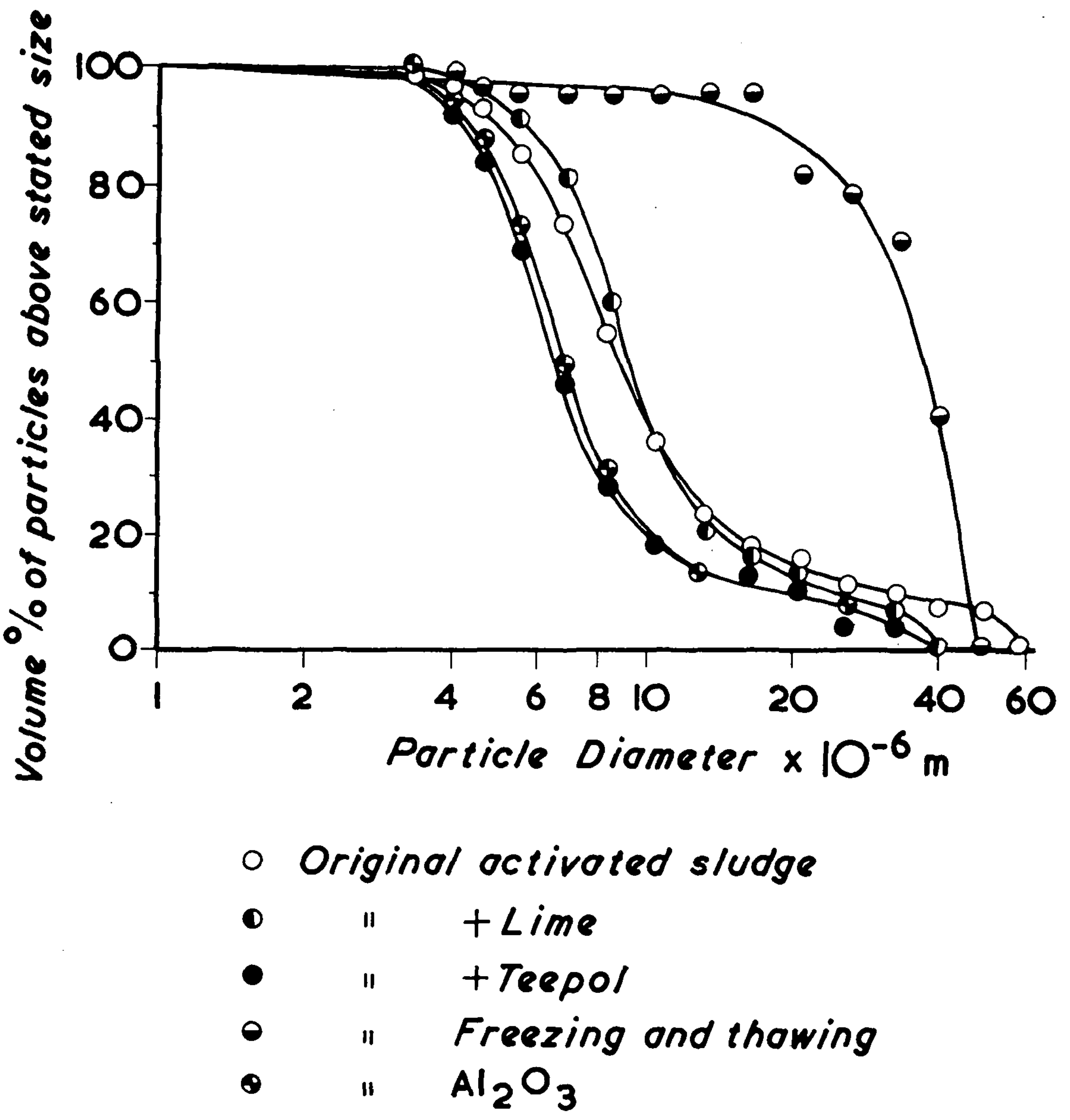


Figure 9. PARTICLE SIZE DISTRIBUTION: ACTIVATED SLUDGE



Freezing and thawing again shows a large effect on the particle size distribution. In the case of Al_2O_3 addition, the number of smaller particles increased. A stable structure is created which can resist the deformation caused by the interparticle forces and a more porous cake results in an increase in drying rate.

SUMMARY AND CONCLUSIONS

Research into the fundamental nature of sewage sludges carried out over the last twenty-five years has produced a clearer understanding of the factors which are of importance in influencing the dewatering behaviour of various types of sewage sludges. The introduction and use of the Carman filtration equation has led to more efficient filtration operations and the use of specific resistance as a filtration parameter has shown how various treatments may improve or worsen the filtration characteristics in a quantitative way.

However, little attention has been paid to the importance of sludge compressibility and cake structure and the relation of this to porosity and rate of filtrate removal. A sludge having a high compressibility will not give a proportionate yield of filtrate in a given time as pressure increases. The cake structure and mode of pressure distribution within the cake can be altered by the use of inert incompressible additives. Fly ash has been examined but the use of lime and ferrous sulphate for conditioning before filter pressing may be a combination of physical and chemical conditioning actions.

Sludges coagulated with iron and aluminium salts, although showing big reductions in specific resistance, invariably show increases in compressibility coefficient. The results of studies on the use of inert additives suggests that part of the function of the lime, most of which is insoluble and remains as finely divided solid in the cake, is to reduce the compressibility of the cake and create a stable structure which expedites the passage of the filtrate through the cake at high pressures.

More detailed studies of the cake during filtration suggest that critical conditions can occur in which there may be collapse and re-arrangement of the particle structures. These critical conditions may be controlled by pressure and rate of removal of filtrate. Cake collapse with a highly compressible cake in the early stages of filtration can lead to a decrease in permeability and an increase in filtration or pressing time or in a lower yield.

Experiments on the drying of sludges have shown that cake structure and strength is as important in this dewatering operation as in the mechanical dewatering processes. In addition, surface tension can have a considerable effect upon the movement of water in the cake.

Much work remains to be done on the other factors of treatment which can affect particle "quality"; the work carried out so far indicates possible lines of development for the increase in efficiency of existing types of filtration operation and will perhaps suggest novel approaches to the dewatering problem.

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discussion

CHAIRMAN: R. BEST, BSc(Eng), FICE, FIWE, MInstWPC
Department of the Environment

The CHAIRMAN regarded it not as a duty but as a very sincere pleasure to welcome Dr Coackley for the first session of the Conference, and to invite him to present his paper on Developments in our Knowledge of Sludge Dewatering Behaviour. As many of the delegates were aware, Dr Coackley had had a deep interest in this subject for many years. This probably started with his Chadwick Fellowship at University College 25 years ago when Professor Collins suggested he should look at dewatering of sludge, as he then felt it would be an emerging problem in wastewater treatment. How right he was on present experience! The recent CIRIA optimisation study had given some indication of the scale of this emerging problem now. Dr Coackley continued this interest during his Readership at Strathclyde and had worked extensively on it for the last six years. The CHAIRMAN said one should not be misled by this apparently wholly academic background to the work; Dr Coackley was obviously a very sound research worker, but he had a lot of wider interests so that he could present his research work in a form in which field engineers could make direct use of it.

2. Dr P. COACKLEY said that although he had been working in this field for 25 years, there was no easy solution to the sludge dewatering problem. Sludge was a very complex material. He believed that the majority of engineers and sewage works managers still did not accept that sludge was a complex material. When an investigation into a sludge dewatering problem arose, at the very best the works laboratory looked at specific resistance, but specific resistance had been expounded for 25 years, and was only now coming into common use. Many workers in the field of sewage treatment when considering a dewatering problem did not even look at specific resistance. They borrowed and in some cases purchased a piece of machinery to dewater sludge (it might be a filter press or a vacuum filter or a centrifuge) and put the sludge in and pulled the levers, and if the thing did not work, it was written off, and if it did work, papers were produced which in many cases were written to recommend that this latest method for dewatering was the solution to all the problems.

3. Recently Dr COACKLEY went to a paper on dewatering. The author spoke very highly of the centrifuge, a small experimental centrifuge run by a graduate chemical engineer. During the period of operation apparently there were no problems. The centrifuge was able to take different sorts of sludges and dewater them. In the course of the discussion a manager of a sewage works who had a larger centrifuge said that in his case even with a lot of development effort the centrifuge had never operated successfully and he felt that centrifuges could be written off. Development engineers were not getting to grips with the fundamental behaviour of sludges. With the new Water Authorities there should be the time and expertise available to make proper investigations of dewatering equipment and of the dewatering processes, and the relation of these to particle properties.

4. He emphasized the Chairman's point about the cost of sludge treatment. It was apparent that as effluent standards had been improved, there had been a tendency to produce more sludge. In many cases these sludges were more difficult to dewater, and from the best information available to the Ciria Working Party, something like 50% of the cost of sewage treatment was spent on sludge treatment and disposal. It seemed to Dr COACKLEY that the approach to design

should swing more towards a consideration of the nature of the sludge, and then to design works which produce sludges which would be easy and cheap to dewater. Some of the fundamental work his group had done showed some of the ways in which this sort of study and development might take place.

5. Dr COACKLEY referred to a research worker at Liverpool University who was sterilizing his own faeces and eating it! This material, like concentrated bacterial and yeast foods produced from waste materials, was not at the moment fit food for human beings. Bacterial or yeast cells have a much greater proportion of the nucleic material than for example beef cells. The nucleus of the cell contained nucleic acids which in excess were harmful to the human liver. At the moment there seemed to be no easy and cheap way to remove the cell nucleus from bacteria and yeast materials. When one ate animal protein, the proportion of the nucleus to the cell itself was very small, but in the case of bacteria and yeast the nucleus formed a very high percentage of the total weight of the organism.

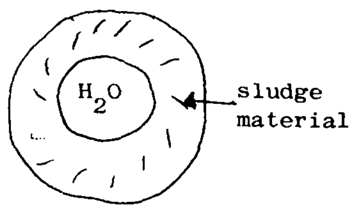
6. Dr COACKLEY enlarged on one or two points in the paper and said he would like to see the discussion opened on a wider basis than just on particles and particle size distributions in sludge and the nature of the sludge cake. He was interested in the whole of the sludge problem.

7. Sludges were described as pseudo-homogeneous materials and many of them were non-Newtonian fluids with plastic rather than viscous flow characteristics. There were still engineers who designed pipe systems for the removal of all types of sludge on the principle that the viscosity was similar to that of water. However, sludges from adjacent works were often widely different, both in terms of viscosity and in dewatering characteristics.

8. Research was necessary and needed to be published on the factors which influenced the flow characteristics of sludges. His own department at Strathclyde had done work on sludge viscosity particularly in relationship to the problems of pumping in the fairly long pipeline in which Glasgow Corporation took their sludge to the sludge boats. In 1945 Inkster(16) published a paper in the Journal of the Institute of Sewage Purification on the measurement of viscosity of sludges, and the application of viscosity measurements to the choosing of the optimum coagulant dosage prior to pressure filtration. Dr COACKLEY had never seen this paper referred to and he had often wondered why Inkster's work had not been followed up. He thought Inkster was probably the first worker to look at the theological properties of sludges and to relate these to the dewatering characteristics. This was an area where much fruitful work could develop.

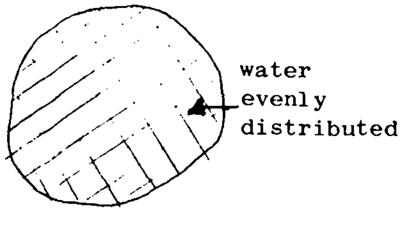
9. It was important that anyone looking at a sludge dewatering problem should understand the different types of water. His own views given on page 6 were similar in many ways to the views of Pearse. The first item in the classification was water which was readily drained. Curve A on figure 5 was a typical drying curve for a digested sludge or some types of primary sludge provided there was not too much grease present. The point marked (1), the first critical moisture content, appeared to be the limit of the moisture content which could be classified as the free and readily drainable water. The water held between the first and second critical moisture content (points (1) and (2)) could be removed by pressure filtration type of processes; it was capillary water. Very high pressures could remove a small fraction of the remaining water but generally it could only be removed by a process related to evaporation. Below the second critical moisture content the water was predominantly within the sludge particles. Dr COACKLEY did not wish anyone to be misled by the term 'within the sludge particles'. There were still practitioners in the sewage treatment field who thought that figure 10(a) represented sludge:

Figure 10(a)



Sludge was not of this form at all. The sludge particles had the water evenly distributed through them, as shown in figure 10(b)

Figure 10(b)



16. Inkster, J.E., Journal of Institute of Sewage Purification. Pt II. p.177 1945.

Recently Dr COACKLEY had heard an author of a technical paper talking about a heat treatment process saying that the heat treatment process operated by bursting the sludge particles like a balloon, thereby liberating the water so that the solids would settle out! Heat treatment did not work like that at all.

10. Over a period of time Dr COACKLEY had been using a method of measuring the in situ water-content of sludge (i.e. the water in the particles) which was based on interference microscopy. His most recent piece of work had been an investigation of particles from the final settlement tanks of biological filtration and activated sludge processes and the relation of particle properties to particle removal in tertiary treatment. One of the interesting points was that the bigger the particles of these biological materials (whether they be activated sludge or humus sludges) the more water they contained. There appear to be simple particles with a moisture content in the region of 60/70%, and the bigger particles were agglomerations of these smaller ones. As far as Dr COACKLEY had been able to determine with activated and humus sludges, there was no real basic difference between the fundamental nature of the sludges. Their chemistry seemed to be the same, the moisture contents were the same and the surface charges were the same. The only difference was in particle size distribution.

11. Dr COACKLEY then went on to deal with pressure and compressibility. Whilst working at Davyhulme on experimental vacuum filters he had used cracking tests for control. Later he decided to find out what cracking time meant and investigated all the standard methods used in Britain and the USA. It was apparent that cracking time was an empirical approach, like CST, and was not a comparative method by which one sludge could be compared with another.

12. Dr COACKLEY had proposed the use of specific resistance for measuring sludge dewaterability, and that sludge compressibility should be recorded. Unfortunately no-one recorded compressibility, and in more recent work it was apparent that compressibility was important, because sludge did not filter as well with compressible particles as with more rigid particles. Part of the paper was designed to show that by using rigid additives the cake could be kept open so that the filtration properties would remain acceptable during filtration or filter pressing.

13. The compressibility of the solids was related to a number of factors: moisture and porosity variations through the cake, solids concentration, the chemical nature of the sludge and surface phenomena related to the electrical charges on the surface. Sludge particles in general carried a negative charge. Dewatering could be carried out by electro-osmosis, applying a potential across the sludge; particles which carried a negative charge tended to be attracted to the positive electrode and water drained to the negative electrode. When filtering a sludge, water was pushed through the sludge system creating a back pressure; it was the converse of applying an electrical potential and the water moving through. If water was pushed through, a potential in the cake was generated, opposing the flow of the filtrate. If pressure was applied for a period and then reduced, the filtration characteristic improved for a short period when the pressure was applied again. This was because the charge which had been generated was neutralized.

14. Figure 1 was obtained by adding various proportions of the fine fraction to the course fraction of the separated sludge. The finer material in plot B had much higher specific resistance, and was of great importance in influencing specific resistance. If that fine material could be eliminated from the sludge (possibly by shortening the period of sedimentation) its dewatering characteristics would be improved; it might even improve to the stage where no, or very little coagulant, was needed.

15. Dr COACKLEY next looked at the addition of various inert materials as filter aids; it appeared that the proportion added had to be fairly high, but once a rigid cake was obtained, the cake performed much better in pressure filtration operations. In terms of particle size distribution the conclusion was reached that the particle size which needed to be added to give the appropriate rigidity to the cake should be such that it was comparable to the smallest particles in the sludge.

16. Figure 3 illustrated the effects of addition of inert particles to the resistance of sludge.

17. Another important phenomena was that of retarded packing compressibility. With cakes subjected to high pressures there was a sudden jump in specific resistance as shown in figure 4. It appeared the cake collapsed, and the increase in specific resistance was irreversible. Dr COACKLEY considered that inert conditioners

(including lime) tended to strengthen the cake and prevent the collapse. Filtration generally started with a liquid and so the pressure was applied hydrostatically. Once cake started to form in the filter press the cake adjacent to the filter had a lower moisture content and a lower porosity than the cake in the layers away from the filter surface. There was hydrostatic distribution of pressure in the liquid layers of the sludge, but the distribution of pressure in the cake changed from hydrostatic to being carried by the particles, and this eventually caused a collapse of the particles.

18. Dr COACKLEY said one of his students had been investigating the problems of drying. The figures given in the paper were from the experimental beds in the laboratory; this work was associated with full-scale work on the drying beds at East Kilbride. Although the laboratory beds in general were very small (20 mm thick), the results were related to the beds at East Kilbride, 19 metres long by 12.2 metres wide with $\frac{1}{2}$ metre stone covered by 0.1 metre ash. In the laboratory the humidity and velocity of the air passing over the sludge were controlled, but at East Kilbride they could do no more than put up wet and dry bulb thermometers, find the wind velocity with anemometers, and record the hours of sunshine. An empirical equation was obtained:

$$T = 0.8767t \times d(100-0.5324m)$$

where T = drying time in hours for full-scale bed

t = drying time on 0.02 m bed in laboratory

d = applied depth on the full bed in metres

m = required final sludge moisture of the dried cake

The depths that the equation applied to were up to 0.2 metres. In fact the deepest bed looked at was 0.33 metres. Swanwick had shown that for optimum drying conditions, the depth of application of the sludges was about 0.15 metres. The significant factor to take account of in drying was the first critical moisture content. On beds of 0.15 m and 0.33 m depth the first critical moisture content was 89-90% moisture, which was the same as with the 0.02 metre depth in the laboratory. Dr COACKLEY was surprised to see any relationship between experimental results obtained on small shallow beds in a laboratory and the beds which were actually used in practice.

19. Dr COACKLEY said he had made several points in the summary and conclusions. There were not enough fundamental investigations related to the problems of sludge; at the very best people were producing results in terms of specific resistance alone. Parameters which should be investigated included surface charge - useful results could be got quite rapidly by knowing the nature of the surface charge of the sludge.

20. He had found the Coulter-counter to be a very reliable device for measuring particle size distribution in sludges. Dr COACKLEY did not recommend interference microscopy on a routine scale as the technique was rather trying on the eyes.

21. In any development work Dr COACKLEY would like to see information collected on particle size distribution, surface charge and compressibility in addition to specific resistance. If a body of knowledge of this sort was collected and the type of sludges dealt with specified, sooner or later someone might make a rational theory of sludge dewatering and the behaviour of different sludges.

22. Dr COACKLEY thought chemical engineers did not generally appreciate the nature of sewage sludge. It had been shown often enough that sewage sludges were amongst the most difficult sludges to dewater - he believed them to be <u>the</u> most difficult. They were unlike many of the sludges that chemical engineers dealt with. Dr COACKLEY could not yet put his finger on what the real problems were; probably they were largely due to the fine nature of the particles plus the distribution of water through the particles. He likened sewage sludge to a table jelly chopped up and suspended in water! If one thought of the problems in dewatering a chopped up jelly then it was easy to imagine the problems in dewatering sludge.

23. <u>The CHAIRMAN</u> thanked Dr Coackley for presenting his paper; the message had been put over very clearly that it was important to find a lot more about sludge before attempting to deal with it. Secondly the question had been posed "were designers paying enough attention to the design of sewage treatment plants to produce a more easily dewaterable sludge?" If he had read correctly the aim was to produce a stable sludge cake, of low compressibility, with good filtrate flow at high pressures. <u>Dr COACKLEY</u> replied that in terms of filter pressing this was so. In connection with this, a recent paper by Gale and Baskerville studied a section of a full-scale filter and it would be of benefit if their work

were united with a study of particle size distribution and inert fillers.

24. Mr G.F.G. CLOUGH said he was both honoured and pleased to be asked to open the discussion on Dr Coackley's paper. He had known of his work in this field for the last ten years or so and had the greatest respect for what he had produced in that time. Much mechanical ingenuity had been applied to sludge dewatering equipment, but he felt sure that really worthwhile advances would now come from the process side.

25. Improvements in effluent standards meant inevitably that more sludge would be produced and this, coupled with rising energy costs, meant that the economics of sludge disposal were becoming progressively more important. Mr CLOUGH said he was not surprised that 50% of sewage treatment costs were involved in sludge. In the physical-chemical treatment of sewage, where the production of sludge was greater than in the case of biological treatment, it was becoming apparent that the costs of sludge dewatering would govern the viability of the process.

26. Mr CLOUGH thanked Dr Coackley for his fascinating introduction. Turning to the paper, he said that in figure 2 variations in specific resistance r with different percentages by weight of filter aid was most interesting but he hoped that the curve had been based on rather more points than were shown, particularly in the region of 20%. He also wondered what 'optimum' meant in this instance because no information was presented on the costs and benefits of adding fly ash. These could be derived if the cost of fly ash and a curve of specific resistance to filtration against cost of dewatering were provided. Until Mr CLOUGH knew how much the filter press installation would cost for varying proportions of fly ash added, he had no idea how much he ought to add.

27. Figure 3 was also interesting, particularly considering that the removal of fine material was said on page 9 to reduce the specific resistance. Fly ash was a relatively general term for material carried out of a furnace with the waste gas and its characteristics varied with the type of fuel used. The Central Electricity Generating Board had published an excellent booklet(16) containing a series of microphotographs of different types of fly ash. It showed that although fly ash had a very small particle size, a large proportion of those particles were in the form of small glassy spheres. Presumably this was where the high strength and relatively little resistance to flow of the filtrate arose. Mr CLOUGH said if Dr Coackley would like to try some experiments with a very small size of ballotini he might throw some light on the subject.

28. Mr CLOUGH said he had found figures 5, 6 and 8 a little difficult to understand until he realised that they had to be read backwards, i.e. from right to left. In figure 5 the two rate points in curve A did not coincide with the figures given in the text. He asked which was correct and what curves B, C and D referred to.

29. Going on to drying, Mr CLOUGH said the increase in surface area due to roughness was probably responsible for drying or evaporation rates in excess of those from a free water surface. He wondered, however, whether the presence of sludge might result in the presence of small differences in temperature, due either to continuing biological action or a lower coefficient of reflectivity (i.e. conversion of incident light to heat) which might not also have some effect. He believed also that the rate of evaporation from a curved surface was greater than that from a plane one, i.e. a droplet of water would evaporate in air which was in saturation equilibrium with a plane water surface. Mr CLOUGH asked if the author would state under what conditions of air temperature, velocity and humidity these drying tests were carried out.

30. In the paper reference was made to aluminium oxide. He asked if this was added as a solid or in the form of a precipitate from aluminium sulphate or chlorohydrate.

31. He said that in figure 6 the drying rate of sludge that had been frozen and thawed was seen to be similar to that of the original sludge. He thought most sewage works managers operating drying beds would say that freezing helped; i.e. if a bed had been frozen it seemed to dewater more quickly. In this case the depth of bed was likely to be of the order of 200 mm and he wondered whether the effect of bed depth on drying had been examined. The rate of freezing was also relevant. It would seem that the bigger the ice crystals formed, the better.

16. CEGB Monograph. The identification of atmospheric dust by use of the microscope, E.M. Hamilton and W.D. Jarvis, CEGB Research & Development department, reprinted 1964.

It was exactly the contrary case of freeze-drying where one was interested in very rapid freezing to avoid destruction of the cells during that process.

32. Two other points on which Mr CLOUGH asked the author to comment were filter cloth blinding and electro-osmosis. In a recent article(17) Messrs White & Baskerville showed in one particular case a very big difference between aluminium chlorohydrate and ferric chloride and lime in respect of filter cloth blinding. Electro-osmosis should, on the face of it, provide a useful method of sludge dewatering. Although various attempts had been made to make it work in practice, none yet seemed to have been successful. Mr CLOUGH asked Dr Coackley to comment on this.

33. In conclusion Mr CLOUGH thanked Dr Coackley for a most interesting and useful paper and hoped that he would continue his work in this field and Mr CLOUGH personally looked forward to hearing more of it in the future.

34. In reply Dr COACKLEY agreed that energy costs were very important. When referring to the optimum addition of fly ash, Dr COACKLEY had not referred to a cost optimum. He had also used powdered coal and various materials which were readily available. They added the material and found how the specific resistance changed with the percentage material added: the optimum was based on the minimum specific resistance point.

35. The fly ash used came from the South of Scotland Electricity Board and as far as could be seen it was the glassy sphere type of material. The investigation with ballotini was not pursued because it was felt that ballotini, apart from any expense involved, would not be a readily available material. If anything useful was to come out of this fundamental look at cake structure the additive must be as cheap as possible.

36. The drying rate curves were represented as they were because this was the method used since they were first produced in the 1920's by the people working on drying at Imperial College. He had no objection to turning the graph round the other way, but if this was done they would appear in a different form to all those in chemical engineering literature. The other curves shown were curves which had been obtained by workers for other types of material. It was found that activated sludge when it dried followed a curve of the type of curve B. Curve D was obtained from drying a material like soap. Figure 5 was a 'text book' diagram; it was not based on sludge experiments.

37. Dr COACKLEY did not think that there was any evidence that bacterial action raised the temperature during drying, but the surface temperature did tend to be higher than the body temperature of the sludge because of solar radiation and also in the laboratory experiments there was a tendency for surface temperatures to be slightly higher. They had looked into the heat transmission properties of the sludge.

38. In the experiments with frozen and thawed sludge the sludge was not allowed to drain. After slow freezing and thawing to maintain the large particle sizes produced, there was a watery film on the sludge as particles tended to settle. As the sludge dried and irregularities in the surface occurred, Dr COACKLEY had expected that the drying rate would increase, but this did not appear to occur. Once the irregularity became apparent to the eye, the water had sunk into the sludge below the surface and there was resistance to movement of the vapour up through the capillaries.

39. Powdered aluminium oxide was not used as a coagulant; specific care was taken to make sure it was used as an inert additive. Whilst on the subject of additives, Dr COACKLEY said that these same additives had an effect on drying in the same way that they had on filtration. The addition of a surface active agent such as Teepol reduced surface tension and so increased the ease with which water may be drawn up the capillaries to evaporate. Maybe a very cheap synthetic detergent could be mixed with sludge to improve the overall drying and draining performance.

40. Dr COACKLEY was unable to suggest why aluminium chlorohydrate on a particular sludge appeared to give a cake which produced cloth blinding. No-one really knew what happened in these sludges unless investigations into particle size and cake structure were carried out. Possibly with the work done by White and Baskerville, where ferric chloride and lime were added, the lime had kept the cake more open. Dr COACKLEY had looked at particle migration in cakes; it might be that with a

17. White, M.J.D. and Baskerville, R.C., A solution to a problem of filter cloth blinding. Effluent and Water Treatment Journal September 1974, p.503.

more porous cake, fine particles that had not been entrapped in the conditioning process would move through the cake. If more was known about the particle size of the sludges, and what happened after conditioning, the work might have been more valuable.

41. Dr COACKLEY had a particular interest in electro-osmosis, which was a first class process except that it did not work over extended periods. A small-scale continuous electro-osmosis device, which had since been patented, had been built at Strathclyde and some years ago it cost about £10 per dry tonne to dewater sludge, which was much cheaper than vacuum filtration (£30 - £40 per dry tonne). When driving fluid through charged particles the drainage membranes should be kept clear, but it was difficult to keep the screen clean, although there were various devices for brushing and scraping the screen. Dr COACKLEY thought that if the problem of migration of fines could be solved, electro-osmosis might turn out to be a much superior method of dewatering than any available now. Also, due to electrolysis the liquor which came off contained a large amount of ammonia; it was one way of getting nitrogen out of the sludge for re-use.

42. Dr P.R. HELLIWELL asked whether Dr Coackley's principal method of size measurement was the Coulter Counter, and if so could he get the particles from the sludge through the tube of the Coulter Counter without disrupting them, and were there other ways of measuring sludge particle sizes, particularly for activated sludge particles? Dr HELLIWELL also asked Dr Coackley to expand on the nature of sludge floc. When was a particle an aggregation of particles?

43. Dr COACKLEY replied that the Coulter Counter method was not his sole approach because the larger particles were broken down when dealing with "weak" sludge particles. He first separated the larger particles either by a sedimentation process or, if the particles were not too weak, by a wet sieving type of operation which was no more than a cheap and simple orifice approach like the Coulter Counter. However, the Coulter Counter had been found to be very effective for the lower size ranges right down to particles of the size of bacteria. The sample was separated and usually put through two or three tubes so that a picture was obtained of the distribution without too much breakdown.

44. Dr COACKLEY said it was very difficult to measure particle sizes in sewage sludges; only the Coulter Counter and sedimentation approaches were readily usable. It was no good drying the particles and sieving the dry material because the distribution did not represent that of the original sludge. Sludge density measurements had been looked at, but difficulties arose because solutions of different densities were used and the sludge particles were altered in nature. With interference microscopy, a beam of light was used and this did not alter the nature of the sludge.

45. Dr COACKLEY did not think activated sludge formed big flocs. In the settlemnnt tube there was an even distribution of quite small flocs, but as a result of the settlement of the particles, water had to be dispersed. Thus there was a flow of displaced liquor from bottom to top in sedimentation, and therefore collections of tiny particles were moving in a fluid flowing in the opposite direction. This caused the particles to be brought together and they appeared to make big flocs, but the size of the flocs depended upon any binding strength there was between the flocs. There were large molecules on the surfaces of all sludges which linked the particles and gave weak binding just as polyelectrolytes did. As the particles settled the stability of the larger aggregations that formed depended on the nature of these large molecules and the strength of binding. During settlement of sludge it could be seen that some small pieces broke away and joined adjacent pieces. The whole system was in motion; large flocs did not form and remain whole all the way to the bottom, and at the bottom the settled sludge was very similar in appearance to the original material. There was a homogenous distribution at the start and end. Dr COACKLEY thought that much research could be carried out on a laroratory scale to measure the nature of the forces and the velocities during sedimentation, and this could lead to the production of parameters for measuring sludge strength.

46. The Water Research Centre, Stevenage, stirred sludges and found out what happened to filterability before and after. In digested sludge the particles were linked together and Dr COACKLEY thought the linking applied to all sludges. In 1928 Inkster showed that a plot of the viscosity of digested sludges started high and then after being stirred for a while it levelled off. Inkster reported that after the sludge had been allowed to stand for a while, the viscosity returned to its original level, and he postulated the idea of bonding between the particles in the sludge and referred to the importance of it. Inkster reduced the viscosity of sludge and then

added iron or aluminium as a coagulant. At the optimum dosage, the viscosity increased and this was tied up with the bonding between particles.

47. Mr G.L. SYMES said that at Manchester in 1972 they considered pumping sludge through a long pipeline, and were worried about thixotropic properties. Sludge from about a dozen different works were put through a viscometer and then through a pumping circuit. It was found that if the sludge was left in the pumping circuit, it could be left for a week with no increase of pressure, i.e. it was not displaying any thixotropic properties whatever.
Dr COACKLEY said it appeared that these sludges behaved differently from those at Glasgow. He asked if the results had been published, and Mr SYMES replied that they were published in the Appendix to Binnie & Partners' Report. Dr COACKLEY pointed out that this had not got into the press generally, and suggested that this sort of information should be available for all engineers.

48. Mr K.J. FLEMONS said his firm had carried out an earlier study for the GLC in connection with a long distance pumping main for digested sewage sludge. In conjunction with the GLC and the British Hydro-Mechanics Research Association they had undertaken laboratory tests and field tests at the Perry Oaks Treatment Works using sludge of 2½% and 5% solid content by weight. They tried to get both turbulent and laminar flows in both runs, but with the 5% solid content this was not possible, and they were only able to check on laminar flow effect. It was found that these sludges exhibited characteristics corresponding to Bingham plastic and pseudo-plastic conditions - at 2½% solids there was not much difference and head losses were low. The 5% sludge was close to the Bingham plastic conditions.
Dr COACKLEY said his experiences had been identical to those of Mr Flemons

49. Mr FLEMONS wondered whether different industries in various parts of the country might affect the sludge characteristics, but Dr COACKLEY replied that their findings had been much the same.

50. Mr M. SANE asked Dr Coackley to expand on the engineering steps that he would take in the consideration of sludges with a view to recommending a treatment plant for sludges emanating from an existing works and from a works to be designed, bearing in mind that the types of plants available for sludge treatment were limited.

51. Dr COACKLEY said that with the current state of the art he thought the only thing that could be done was to try small-scale units. Manufacturers of plant tended to work in this way; samples of sludges were taken, conditioned in various ways and treated in their particular units, and recommendations were based upon the results obtained.

52. Dr COACKLEY hoped in the long term to collect more data on particle size distribution, on the general nature of the sludge (i.e. how much protein, carbohydrate and grease was present), find out what the surface charges were, and then study the behaviour of the sludges in the various types of equipment available. Also, if the right number of students and finance were obtained, he would investigate the nature of chemical and heat treatment. He did not think the last of heat treatment had been seen, although this view was unpopular at the moment. He thought it might be possible to treat sludges at lower pressures when the mechanics of the process might be greatly simplified.

53. In reply to another question from Mr Sane, Dr COACKLEY said that he had not studied the corrosion and erosion effects in the transportation of sludge on steel structures. However efficient grit separation was, sludge carried some fine hard material, which could have an effect on ensuing structures, particularly in heat treatment processes where the sludge became much more fluid and there was centrifugal effect.

54. Mr E.I. CLARK asked for Dr Coackley's thoughts on how existing sewage treatment methods might be modified to produce sludge which was more amenable to dewatering and subsequent disposal.

55. Dr COACKLEY said his own theory was that where the activated sludge process was used sedimentation tanks should be less efficient. This would let the finer particles carry forward to the activated sludge plant, which should be run under a condition of reasonable sludge age, if possible in the nitrifying stage. He thought that this would produce sludges from the primary tanks that could be dealt with without too much conditioning, and from the activated sludge plant which could be dewatered on vacuum filters with little conditioning. It was interesting that in the early days of the activated sludge process there were a number of papers that recorded the full-scale dewatering of activated sludge on vacuum drum filters

without any conditioning; as the sludge age had been reduced flocs were obtained which were not as dewaterable as those from older sludge ages. In Dr COACKLEY's own work at the University College many years ago it was possible after quite long periods of aeration to produce activated sludge which had filterabilities which were nearly as good as those obtained by using quite high dosages of ferric or aluminium salts. Thus sludges could be conditioned biologically. Increasing the sludge age would mean an increase in the aeration volume, but if sludge treatment cost 50% of the total, perhaps it would be better to increase the aeration volume and detention time for the sludge. Dr COACKLEY said he would like to see the reduction of sedimentation time to ½ hour or less tried on a large scale.

56. Mr D.J. GRIFFIN thought it was significant that CIRIA were currently engaged on optimisation of sewage works design. The most expensive parts of the total process were biological treatment and sludge disposal. Extension of the biological phase in order to improve the sludge phase had been suggested, and this called for further detailed study and economic analysis in the interests of optimisation of the whole process.

57. Mr V.H. LEWIN said that now that the water and sewage functions were combined, he would like to see more work done on the most neglected problem of sludge disposal in this country - alum sludges from water treatment. He would like Dr Coackley to do some work on this as in his paper he referred to 'inert materials' being added to sludges; misinformed water engineers would suggest that water alum sludges were 'inert materials' which were very good additives for sewage - they were not!

58. Mr LEWIN did not agree with Dr Coackley on the question of having less efficient primary sedimentation. This was the cheapest form of sewage treatment, and he suggested it should be tackled the other way; having removed primary sludge, it should be aerated; this technique quickly converted it to an activated sludge, simultaneously fully nitrified and denitrified, and having very rapid settling and draining characteristics. Rather than studying dewatering characteristics, designers should look at what their ultimate aim was in sludge disposal, and did sludge need to be dewatered. Sludge needed only to be concentrated to a point where it could still be agriculturally dispersed. Sludge could be dewatered too much from the point of view of agriculture and economics of dispersal.

59. Mr LEWIN asked Dr Coackley to expand further on his little balloons and uniformally dispersed moisture through the particles. There was little doubt that in activated sludge a large proportion of the solids were bacteria and protozoa, and therefore they were little balloons which heat treatment would burst allowing the moisture to come from the interior.

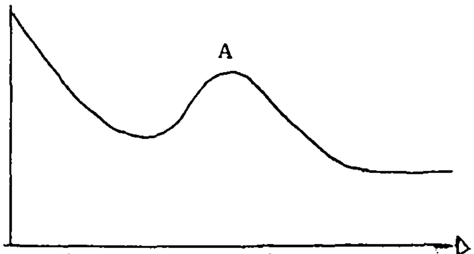
60. Mr LEWIN could not understand from Dr Coackley's exposition why these 'fundamental biological particles' had a moisture content of about 50%, but when they were larger the moisture content was higher. Where was the additional water? It must be aggregated between the various fundamental particle conglomerates and therefore it seemed to Mr LEWIN that a physical approach to this was probably the answer. He suggested ultrasonic techniques might assist.

61. On Mr Lewin's idea of getting as much out in the primary tanks as possible, Dr COACKLEY concluded from laboratory experiments in deep settling tubes that 100% of the solids material could not be removed by settlement. So whatever was done in the way of settlement, some fine solids in solution were always left, and these needed to be reduced in some other way; traditionally this had been biological. There was currently a big interest in treatment by physico-chemical procedures by coagulation or flocculation. Dr COACKLEY felt there might be a good reason for adding alum sludge to primary sludge. He thought there could be quite a future for aerobic digestion. At a sewage works Dr COACKLEY had been associated with, digested sludge was put in the aeration unit for a week or fortnight, and he agreed from his own experiments that when these sludges were aerated for a reasonable period of time very stable materials were produced. Dr COACKLEY had aerated a sludge for 3-4 months, and at the end of this time the material was most stable, with no obnoxious smell and very few bacteria. It was kept in the laboratory for six months and there was no sign of any further breakdown. By a process similar to the activated sludge process, it should be possible to condition sludge on a continuous basis quite readily, and this was an extension of his view that a sludge of good age and in the nitrifying condition had improved filtration characteristics.

62. If the specific resistance was plotted against increasing sludge age, a very young sludge had a high resistance. As age increased the resistance fell and then increased, followed by a long fall-off to

quite a low value (see figure 11). It would be interesting to find out what happened in the zone marked 'A'.

Figure 11 Variation of specific resistance with sludge age for an aerated digested sludge.



To start with some of the particles were quite stable, and Dr COACKLEY's own experiments suggested that in zone A the particles themselves started to break up, so if aeration ended up in this area the sludge had worse filtering characteristics than unaerated sludge. With sludge ages of six days and more the specific resistance dropped and the sludge settled well as there was no fine material.

63. Returning to balloons, Dr COACKLEY said that the idea that the water was spread evenly through the particles was an over-simplification. He took issue with Mr Lewin regarding the proportion of bacteria in activated sludge, as the WPRL had shown that a maximum of 15% sludge solids by weight was bacteria. 15% was not an awful lot, 85% of something else had to be accounted for. At Strathclyde 150-200 electron-micrographs of activated sludge were taken. Some of the pictures looked like sets from 'Sleeping Beauty' before the Prince arrived, with huge drapes of material, but very few bacteria had been seen. Several experiments had been done to make sure the sludge nature was not disturbed during the process, some of the bacteria stuck up like sausages on the edge of the floc, and others lay surrounded by mucous. Dr COACKLEY had come to the conclusion that the micro-biologists had been off beam for the past 15 years in explaining activated sludge; physical chemists should look at sludge again. The surface area per unit weight was very great and adsorption reactions must be very important.

64. Dr COACKLEY said that when he said that water was evenly distributed in sludge particles this was over-simplification. In fact the sludge particle, even a 'fundamental particle', was like a sponge. Thus there was a colossal adsorbing area; when the particles came together water was trapped between the particles. Looking across a large sludge particle with the interference microscope, the phases indicated differences in properties across the particle.

65. Points were coming to light from recent investigations with the electron microscope and interference microscope, but Dr COACKLEY did not agree that the bacteria burst like bubbles. If pressure was applied and then taken away quickly so that there was a high temperature inside the bacteria and the water would turn to steam and burst it, that would be an explanation, but it did not work like that. Most of the material inside the bacteria was not in a pure liquid form; it had a structure which was brought about by proteins, polysaccharides etc. and transport was by diffusion rather than by turbulence.

Dr COACKLEY thought alum sludges were not as difficult to dewater as sewage sludges; alum and ferric hydroxide sludges had lower specific resistances than sewage sludges. Certainly alum sludge was not an inert material.

67. Mr A. MURRAY said there was no doubt that if an inert filler was added, whether it was fly ash or ground silica, some advantage was gained. What was the percentage of advantage against the percentage of inert filler? Plant had to be installed to take care of the volume, and it had to be carted away from the site; this had to be paid for. Therefore it was necessary to quantify and compare this work with improvement of specific resistance by chemical addition.

68. Mr MURRAY had been intrigued with some of the early results with lime addition, and had attempted to do away with lime to find if the effect was due to pH. He had adjusted sludge pH with caustic and added inert filler in the form of ground silica, (which was freely available), but there was no improvement in filtrability, so he suggested that lime did something more than inert filler, as Dr Coackley had suggested. Mr MURRAY said he knew of half a dozen plants where work had been done with lime and aluminium chlorohydrate.

69. He suggested that in White and Baskerville's work the high amount of fat coming from a chicken factory influenced the results; the lime was tying up the fat.

70. Dr COACKLEY said he was not trying to get people to use inert fillers in preference to coagulants, as both had a part to

play in dewatering. Compressibility came in and an inert additive was important in stabilizing this. In other work results had shown that the addition of inert materials altered the basic nature of the cake but work had not yet progressed to the point where they could recommend a particular type of inert filler. However all the work indicated that it had to be finely divided, and it seemed to Dr COACKLEY that the best material for this was lime because there was a very fine particle distribution.

71. Mr MURRAY suggested that silica was also suitable, but Dr COACKLEY would be surprised if the silica-particles got down much below the size of the fly ash particles. Particle size was very important, and by adding larger inert particles no effect was gained; sometimes it even worsened the effect. Lime had other effects; the calcium would react with grease.
Dr COACKLEY did not support the idea of a charge neutralization theory between the negatively charged particles and positive sodium or positive potassium. In the water field enough conditioner was added to completely coat the particles with ferric or aluminium hydroxide. There was an increase in viscosity because iron and aluminium got into something in the sludge (possibly an amino-polysaccharide) and the energy involved caused proteins on the surface of the particles to become broken or unravelled, and allowed a strong combination between adjacent protein or polysaccharide bonding. If iron or aluminium was added to sludge under controlled conditions, there would be an increase in temperature because energy was liberated, so some sort of chemical reaction was taking place, and the energy liberated was not that which would be got by hydration of ferric or aluminium ions.

72. Dr COACKLEY did not want to expound the virtues of inert materials. He was merely trying to throw light on where some of the current work was going in development technology. The compressibility was greater after coagulation than it was before, although the specific resistance had dropped. This was important to a man working with a high pressure filter because if he pushed water through too quickly and got compression and retarded packing compressibility, he could end up with a very dry layer of the filter septum and a wet sludge cake in the interior.

73. The CHAIRMAN thanked Dr Coackley for going through the 'Developments in our knowledge of sludge dewatering behaviour' for the last 25 years and more particularly for drawing attention to the lines on which we ought to look in the future. He had mentioned a number of specific programmes for what the CHAIRMAN called 'field research workers' to tackle and he had also given a line of approach for the engineering workers by posing the question 'how does one design a sewage treatment plant to produce a more easily dewaterable sludge at less cost?' It was certainly food for thought and it gave the CHAIRMAN the opportunity to re-emphasize that he regarded it as every engineer's duty to his profession to experiment in all the work he did, to produce a better optimized design in the future. He thanked all those who had made a useful contribution to the session.

P. COTTON

automation

INTRODUCTION

The most easily understood description of Automation is that devised by the GLC(1) viz:-

"The direct operation in response to the measurement of parameters without the intervention of manual controls."

Many reasons(2) have slowed down the application of automation in the waste water treatment industry, but these apart, the future, given sufficient capital finance, is inevitably, to apply and extend the concept of Automation.

It is, therefore, timely to reflect, discuss and consider the following:-

(a) The Social Implications of Automation;

(b) The Potential Benefits and Disadvantages of Automation;

(c) The Instruments and Sensors Available/or Needed for Automation;

(d) The Methods Available for Process Automation;

(e) The Use of Computers.

SOCIAL IMPLICATIONS OF AUTOMATION

John F. Kennedy once said, whilst he was President of the United States of America, "The great enemy of truth is very often not the lie deliberate, contrived and dishonest, but the myth persistent, persuasive and unrealistic". Few myths have been more unrealistic etc. than those concerning the effects of automation and technological change on the social lives of the human population. Without doubt modern technology has caused changes to affect the lives of us all. Civilisation itself has been reformed many times from the discovery of fire to the harnessing of atomic energy. Every important discovery has profoundly affected man's whole way of life.

The heavy plough introduced early in the Christian era and the use of steam for motive power in the eighteenth century dramatically altered standards and patterns of living. It took decades, however, if not centuries, for the effects of these to be fully experienced. When a radically new technology, for example the generation of electricity, is first introduced only a few people are affected. Eventually the entire society is changed. On the other hand this rate of change is rapidly increasing. It is less than twenty-five years since the transistor left the research laboratory and it would have been difficult to predict at that time the numbers of radio-controlled teenagers who now inhabit our towns and seaside resorts.

Twenty-five years ago, it would not have been possible to give today's talk without the ability and foresight of George Orwell, who at that time wrote his novel '1984' and predicted the situation where war-mongering dictators would use morons operating computers to devastate each other's countries. We still have ten years to go and perhaps this situation is getting close. It is certainly technologically possible which wasn't the case in 1949. These dismal views of the effect of automation are, I believe, incorrect for the following reasons. Automation is an extension of mechanisation. Mechanisation is a process which can take the tedium and repetition out of monotonous jobs. The jobs which are left involve direction of whole processes, invention, understanding and application of highly developed skills. To this end there is an increasing demand for the trained professional both in the technological subject and within ancillary services. The automation of a process as will be shown later, demands that for economic reasons there is an increase in the size of the unit involved. This means that where a process of manufacture was labour intensive, but was not capital intensive, requiring a large outlay of machinery, then cottage industry was a satisfactory approach. When mechanisation became involved, there was a need to bring the production processes under one roof to supply the essential services to the machinery. As automation is incorporated the economics of automating demand even larger operating units. The effect of these changes is that the work force becomes located in smaller areas of greater population density.

An industry, which has gone through this change, is the textile industry. In fact the metamorphosis is as yet incomplete, since only now is the production of Harris Tweed moving out of the Crofters' cottages of the Hebrides into Factory situations. The mill towns of Lancashire and Yorkshire have moved through the intermediate stage where small highly mechanised factories produced the fabric. Textile manufacture is now carried out in relatively few factories on fully automated looms producing vast quantities of material in wide variety of fibres. If we develop further the two ideas presented so far, one shows a greater cause for alarm than the other. The implication of this concentration of a production process in one factory, gives rise to the problems of supply of large amounts of raw materials and the dissemination of large quantities of end products. As industries became more inter-related, it is logical for transportation costs to be minimised. Hence there is a greater concentration of production into industrial estates. The value of industrial land increases as demands exceed supply. Likewise that of land for domestic use. As costs increase wages must do so, hence there is further increase in costs of consumer products and we are on the familiar economic spiral. The social implications here are the most severe for those members of the community who remain out in the cold away from the industrial conurbations with their associated high standards of living but who nevertheless are an important part of integrated society, for example the farm labourers. In the first instance, I referred to the mythical aspect of the effects of automation. I have suggested that the time scale before major technological changes percolate society can be considerable. In general it can be said technological progress replaces skilled labour by unskilled labour at the same rate as it replaces unskilled by skilled labour. There is, however, a general trend towards increasing the skill in the community in as much as the standards of education of those classified as unskilled gradually increases.

Contrary to popular belief, unemployment has not generally increased due to automation. The genesis and cure of unemployment is economic. If we consider that a human working life occupies fifty years then the minimum labour turn-over is 2% represented by recruitment and retirement. Re-deployment due to automation has not yet reached anything like this figure so that there should be adequate buffering to smooth the social implications of automation.

It may also be said that automation allows the work force to do an old job cheaper or better at the same cost, or to do a new job. In these circumstances there must be increased diversity of the labour force rather than the trend towards monotony and repetition which has been frequently proposed.

In the sewage treatment sphere the following can be said:-

(a) There is unlikely to be large savings in labour - although economically significant savings;

(b) The staff required on future automated plants will operate and maintain more sophisticated equipment, and even the so called mundane tasks will be at a significantly higher level than previously;

(c) The management of automated plants will fall into three distinct but overlapping functions:-

   (i) To initiate, evaluate and implement control strategies;

   (ii) To optimise existing strategies and thereby optimise the sewage treatment processes;

   (iii)To maintain, diagnose and correct faults on all equipment.

   These spheres of operation requiring a higher intelligence and application than previously occurring.

(d) The traditional pyramid of responsibilities will be modified to give fewer lower paid labourers and many more higher paid technically qualified operators and maintenance staff. There will be a higher level of remuneration for these staff who will have safer and cleaner working conditions.

(e) As with many already highly technical professions, job satisfaction is likely to be increased as the individuals' responsibility increases.

POTENTIAL BENEFITS AND DISADVANTAGES OF AUTOMATION

Whilst this section gives many examples in every day life of advantages and disadvantages - significant social implications are inevitable.

Technological innovation has increased the degree of mechanisation to a high level and to cope with this increase there has been a steady demand for greater control of the processes involved. There is no sensible reason to employ a production process which produces a large number of units with such a lack of built in control that the quality of the product or the effectiveness of the system is unacceptable. The aim of mechanisation may be said to be the production of a large number of units at the minimum of cost. Since the raw material costs of the consumer product usually form a relatively small proportion of the cost of the final article, and the labour, handling, marketing and packaging costs contribute a major proportion of the cost, there has not been a great desire to alternate as such. The addage "time is money", and has been uppermost in the minds of managers.

In these days of fuel crises and raw material shortages, with spiraling costs of both, there is now the need for more effective use of resources. It is at this stage where automation in its broadest sense can contribute.

The sophisticated automation of industrial processes using the modern technologies of instrument control and micro-electronics is able to lead to a more uniform product with a minimum of fuel and/or raw material wastage.

One of the earliest examples of industrial automation was in the petro-chemical industry where great accuracy of control is needed to maintain predetermined values of the pressures in reaction vessels, rates of flow in pipe-work, levels and temperatures in supply tanks etc. These must be controlled with a great degree of accuracy and such a degree can most easily be achieved through automation - a closed loop system.

The early method of control used up to about 1920 was for a man to watch an instrument, measuring temperature for example, and when he noted that the reading was dropping he would open a valve that would increase the heat supply. He would continue to watch his instruments and make further adjustments as necessary. It was a slow process whose success depended upon the skill of the operator.

Automation has taken over here so that by means of suitably sited sensors the process control computer calculates the best possible adjustment to make, for the particular conditions prevailing. This example of early automation in the chemical industry presents a fairly typical picture of improvements which are possible with more accurate measurement and control of operational parameters. The examples may need be no further than our own homes. Compare the greater comfort and efficiency available from a domestic central heating system operating under the automatic control of thermostats (and incidently mechanical control of clocks) with that obtainable from an open fire whose heat output varies with the size of the fire in the grate or the time relative to stoking.

One of the earliest examples of automation, was the centrifugal govenor developed by James Watt to control the speed of the steam engine. The system is an excellent example of automation because it provides a steadily increasing amount of control, a greater constraint on the system as it approaches the pre-set condition. The govenor thereby carries out two functions. It maintains the machine and ancilliary equipment at a safe operating speed and it reduces fuel wastage.

The broad examples given indicate several of the advantages which follow from automation in manufacturing industries, namely economy of materials, safety of operating personnel, safety of the machinery and efficiency of operation which may result in a cheaper product or processes with reduced labour requirements.

Other potential advantages are in the spheres of communication, travel, health, food production, warfare and pollution control. I propose to indicate briefly where these benefits exist but since there comes a point in some subject areas where it is difficult to distinguish between benefits and positive disadvantage, these following notes should be regarded from a technical point of view rather than a subjective stand point.

Modern society is based very much on the ease of communication, sometimes over long distances. Telecommunication has developed to such an extent that it is now quite feasible to interrogate a remote monitoring instrument by telephone. The system can be automated to the extent that the instrument itself will telephone a central control point to indicate the presence of a fault or an abnormal condition; it can be programmed to take a course of remedial action under a given set of circumstances and report on the effect of this action.

In the situation where the communication involves travel, then we see some of the more sophisticated automated systems in operation; systems where feedback and corrective action has developed to an extreme degree of accuracy with resultant increased safety for the travellers. The speed of an underground railway train is accurately controlled from a central computer as are the routes and the station halts. The roles of the driver and guard become those of train supervisors rather than operators. As far as the traveller is concerned he benefits by greater safety, speed and efficiency. More trains can be operated on a given length of track when there is computer control rather than random operation.

When the Wright brothers crossed the Atlantic they navigated as mariners had done for centuries previously by means of star fixes. Modern aircraft navigation relies on Decca navigation, an automated system of direction finding which constantly up-dates a record of the aircraft's position. The pilot of the aircraft leaves the flying to the automatic pilot and becomes merely an instrument supervisor. The auto pilot, having been programmed with the course and speed etc. automatically monitors and then compensates for changes in the aircraft's condition. On the approach to the airport, the pilot merely points the plane in the right direction as it were, and sits back. The blind landing system does the rest. The result of this automation amongst other things is that less people are killed per passenger mile of air travel than are in the more randomly human controlled road travel.

If your name happens to be Smith or Jones then you probably think nothing of going to Heathrow and flying half way round the world. If your name is Armstrong or Aldrin you may be used to going a little further. Under these circumstances, navigation reverts again to the use of star fixes but the system exhibits a degree of automated sophistication which would have been impossible twenty years ago.

Perhaps morally, one disadvantage of automation is that the fineness of the art has come about from military needs. The orbital and lunar space missions are but extensions of the technology needed to carry a pay-load of plutonium with the devastating power of several megatons of TNT around the world. From a technical view point, we cannot but admire the degree of automation required to do this. The highly developed sensors and associated control systems. The same systems which perhaps guide a heat seeking missile to the exhaust emission of an enemy aircraft can very easily be modified, mounted in a satellite and used to guide a trawler to an area rich in fish to feed the worlds ever increasing demand for food. Similar satellite systems to those used for military surveillance can under different circumstances be used to plot the path of good or bad weather conditions enabling timely warnings to be given to people in danger.

The potential benefits of these systems derived for or from military use, are concerned with the preservation of humanity or at least one part of it. The tracking of warm ocean currents with their plentiful supply of fish or the pin-pointing of outbreaks of fire in the vast wooded areas of North America can surely be construed as benefits of automation with a more universal effect.

The steadily increasing demand for food has lead to more sophisticated growing techniques. The automated control of the environment may be used to produce large but good quality crops in greenhouse conditions. The production of meat on a large scale relies to some extent on intensive feeding units in which the food and water may be automatically metered to the units for individual animals depending on their requirements and rate of growth etc.

On a more personalised basis, the automation has aided the medical profession. Radiographical techniques using computer control can provide three dimensional location of brain tumors etc. Patients being cared for in an intensive unit are subject to measurements of metabolic processes, respiration, temperature, heart rate and activity of the central nervous system. Abnormalities in these processes stimulate at least an alarm system to summon aid or may in fact make adjustments to a controlled environment to off-set a deteriorating condition.

The health of the individual has been very briefly touched upon but we must return in the long run to the health of the community, the former being a function of the latter. In this context, the use of automation in pollution control, and public health, should be discussed. The succeeding sections of this paper will deal comprehensively with the range of instrumentation and sensors available in this field, but consider the advantages of incorporating these into a large chemical manufacturing complex.

In such a chemical factory the effluent, be it trade effluent to sewer or a surface drainage system to river, is subject at all times to the possibility of contamination due to accident or intent. It is understood one American factory introduced a network of sensors into the sewerage system to detect such leaks. These consisted of selective-ion electrodes and total organic carbon monitors. The sensors were programmed to trigger alarms indicating the source of the problem to close valves and cause diversions of the effluent if either the absolute values of measured parameters or the rate of change of these values exceed present levels. The system proved to be so successful that the number of accidents which had previously resulted in river pollution of one sort or another were reduced from about sixty per week to less than one per month. In one particular instance, rumour has it that a plant operative illegally disposing of a load of waste chemical down a manhole was surprised to feel a tap on his shoulder to have a security man breathing down his neck before he had actually finished his disposal.

This example indicates the environmental safeguards which can be instituted through automation. The variety of instruments and sensors available for use in the field of sewage treatment will be discussed in some detail and it is sufficient to say at this stage that the range is comprehensive enough to enable considerable automation of the process to be introduced. The benefits of this again cover the area of environmental protection through greater control of a process which is potentially detrimental to the environment. The processes of sewage treatment have to be continuous and on a large works it would be necessary to have large numbers of men working a shift system to keep the works under control at all times. On an automated site, the bulk of the labour force is able to work a normal day and the only night workers required are security men.

The operation of a sewage treatment works requires some men to carry out particularly unpleasant tasks which result in there being some stigma attached to the job. The introduction of mechanisation has reduced the number of such tasks and indeed the requirement of men to do them. Automation can further reduce the numbers of men required by making the machinery operate in a more co-ordinated way with possibly less wear and tear. The net result of these improvements is to reduce the numbers of men doing unpleasant jobs and to increase the numbers of technical or semi-technical staff. These changes should make for easier recruitment of labour.

I have indicated at some length some of the potential benefits of automation in various spheres of modern life. There are one or two disadvantages which have to be considered. These potential disadvantages are problematical more from a political point of view than a purely technical one, and they give rise to a few road blocks in the way of further automation of some processes.

A fully automated installation often requires the outlay of vast resources because of the great deal of technological innovation which is involved. For this reason the adoption of such techniques is usually restricted to larger than average establishments because the management of a small concern may not be willing to risk resources to adapt modern technology to their needs, or more importantly may not have sufficiently long production runs to justify, economically, the incorporation of a process using highly automated techniques. These factors become even more important in a lean economic period such as we are experiencing at present.

Another consideration is that automated processes in the manufacturing industry are inflexible and are expensive to re-engineer and change systems which are designed to operate on continuous flow may not suffer from this problem, since they have been designed to be versatile. Nevertheless it may be considered to be a potential disadvantage of automation.

In some areas such as data processing, the technology favours the larger organisation. The unit cost of throughput of a larger machine is much lower than that of a smaller machine and only a large organisation can afford large machines. The cost of automating such machinery is to some extent independent of the size of the unit because the cost of programming is proportional to the complexity of the job, not to its volume.

Automatic techniques and advanced mechanisation such as that used in the motor industry, require the raw materials of a uniform quality to be fed into the production line. For example minor adjustments of a machine tool to compensate for excessive hardness of steel cannot be made as easily by machines as by human operators. In most manufacturing industries the instrumentation of advanced techniques is only feasible when precise techniques of measurement are developed and when the number and quality of parts are standardised.

In the design stage of a new project, when the decision has to be taken as to whether to automate or not, some of the foregoing points have to be considered. One of the guiding codes, as to the degree of automation to be incorporated, must be the law of diminishing returns. The greater the extent of automation the more expensive any increasing sophistication must become to achieve a diminishing improvement in the degree of control. The extra control gear incorporated into the system the greater the requirements for maintenance, simply because there is more to go wrong. Perhaps the converse is true of course in that the greater the degree of complexity the greater the incentive to maintain the equivalent in good working order. One sees more batered taxi cabs than battered airliners!

To summarise:-

On the sewage treatment plant, in addition to the potential advantages listed under Social Implications, it is likely that:-

(i) There will be an overall cost benefit(2)

(ii) That job satisfaction in the majority of cases will be increased;

(iii) That trial processes will be more efficiently controlled, and thereby optimum plant operation achieved;

(iv) That the flexibility built into 'non-fixed' logic control spheres will increase the use and application in changing society;

(v) That more stable and consistent performance will enable better overall water quality and river system management to be planned.

(vi) That significant process information will become available enabling considerable design changes to be made on future plants with potential capital savings.

The potential disadvantages that can be foreseen may be:-

(i) That the increased skill, for more sophisticated operation, may not be available without significant training and retraining programmes;

(ii) That the remoteness and inactivity of operators on highly automated plants, may lead to boredom and inability to act in case of emergency breakdown.

The effect of industrial action on highly automated plants is extremely difficult to evaluate, and so as not to influence this factor it is considered that:-

(a) Automated plants could become more vulnerable to the effects of industrial action, since fewer more highly skilled operators are involved;

(b) Automated plants could become less vulnerable to effective industrial actions, since they are less labour intensive and can operate for continuous periods with minimal or no maintenance procedures being undertaken.

INSTRUMENTS AND SENSORS

Many of the instruments necessary for the automation of sewage treatment processes are already in existence, many commercially and are well known. Some are considered sufficiently reliable for use "on-line", and will be described later.

Other instruments such as in-situ repirtmeters, and those to measure ammonia, nitrate organic carbon, sludge solids and sludge level still require further development - but are nevertheless described in this section.

It is anticipated that many technical advances in instrument development will be made in the near future, especially since 'automation' is becoming more widespread although severely limited by lack of reliable sensors.

1. Flow Recording

(a) Mechanical float operated instruments are well established (e.g. Kent Lea range). A float rotates a grooved drum by means of a chain and sprocket connection. The groove converts float movement to rate of flow. As the level varies a cam follows the groove, driving a spindle to which the indicator pointer is affixed. It can monitor flow in conjunction with any form of standing wave flume, weir, V-notch or open channel orifice. These instruments can provide a current output signal for use with analogue display instrumentation and control systems or merely integrate and record the flow on a chart. The accuracy of this type of meter is generally not more than $\pm$ 2%.

(b) Pressure operated recorders (eg. Arkon) operate in conjunction with a flume or V-notch, but in this case, the head above the flume is detected by the pressure in a dip-tube bubbler, the air being provided usually by a small compressor. The pressure variations are converted to a rate of flow and displayed on a chart. These instruments are popular for measuring the smaller trade effluent discharges and have the advantage that the recording and indicating equipment may be remote from the actual point of measurement of the flow.

(c) Electromagnetic flowmeters (e.g. Kent Veriflux) will measure the flow of any electrically conducting liquid or slurry, i.e. sewage or sludge. They consist of sensing unit and a transmitting unit which fit as a single module into the pipeline carrying the flow to be measured, and operate in conjunction with receiving instruments, e.g. flow integrator, recorder or indicator. The principle involves the detection of the induced current produced by the passage of the electronically conducting fluid across an applied magnetic field, the current being proportional to the velocity of the conductor. The meter offer no obstruction to flow or head loss and the relatively high accuracy is unaffected by variations in density, viscosity, pressure or temperature. They can suffer disadvantages from incorrect location, interference with output signals from extra-peripheral cabling and equipment and from fouling of the electrodes (especially when used on sludge). The latter can be overcome by passing a current through the electrodes periodically to burn off accumulated fat and grease.

(d) Venturi tubes (Kent Dall tube) can measure sewage flow based on the detection of the pressure differential as the flow passes through a constriction in a measuring tube which fits into the pipeline carrying the liquid to be measured. When used for sewage, the design of the tube has to be such that solids cannot accumulate and render the readings inaccurate.

2. Level Sensors and Capacity Gauges

(a) Electronic level indicators are well established, consisting of electrodes set at various levels, e.g. in wet sump of pumping stations. These perform a digital function only e.g. starting and stopping of pumps, high level alarms etc. They cannot provide an analogue output such as absolute capacity or level unless many electrodes at different levels are used. These can malfunction due to fouling by grease, rags etc. although they are reliable on the whole.

(b) (e.g. Kent Instruments Deltapi range) One range of electronic transmitter provide an electrical output from a variety of inputs, e.g. differential pressure, pressure, level etc. They work on the force principle, providing an output signal which is proportional to the measured condition. Used in conjunction with various diaphragm type measuring elements or dip-tube bubblers, a variety of differential pressures, flows and static pressures can be measured, and thus when used in tanks with the diaphragm or dip-tube at floor level, the instrument will act as a capacity gauge, the pressure on the sensor increasing as the tank fills. A similar range of pneumatic transmitters is also available. Experience has shown that the diaphragm type sensors are affected by accumulations of rag etc. and thus should be washed down at regular intervals.

(c) Sonic level gauges are available which are set up above the tank or channel concerned and emit echo pulses downward which are propagated through the air and reflected by the solid or liquid surface, returning to the sensor after a time delay. This delay is evaluated electronically and indicated as a level in the tank or channel, the former being translatable to a capacity and the latter indicating flow rate if used in conjunction with a flume. These gauges have no contact with the liquid or sludge under measurement and therefore do not suffer from fouling.

3. Suspended Solids and Sludge Density Probes

(a) Optical type suspended solids monitors generally suffer from fouling of the optical surfaces by grease, slime or algae when immersed in sewage or sewage effluents, but if the principle of surface light scatter is employed, (such as in the Partech MkIV Sensor,) no part of the sensing head need come in contact with the fluid being measured, hence eliminating the need for cleaning of the optics unit. Conventional optical types using IR instead of visible light are less susceptible to trouble from optics fouling due to the greater penetrating power of IR radiation.

(b) The specific conductance measurement type of sludge density meters can be unreliable as the conductivity of sludge varies with slight pH change. Instruments based on gamma rays are also used for sludge density measurement.

(c) Ultrasonic sludge density meters (e.g. Nishihara or Mobrey-Sensall), which can be incorporated in sludge pipelines, are based on the attenuation of an ultrasonic wave by the sludge, which is proportional to the solids content of the sludge. Ultrasonic signals are generated by a transducer and propagate in the pipeline where attenuation takes place by scattering caused by the sludge solids. These signals are converted to high frequency voltage signals by a receiver and are finally converted to D.C. current, indicating either as an empirical thick - thin sludge scale or directly as % D.S. on a meter. This principle is useful in control of sedimentation tanks desludging, activated sludge plant mixed liquor solids content, and sludge blanket levels in tanks. (The instrument can be set to send out an appropriate control signal at a particular sludge density indication or % D.S.)

4. Dissolved Oxygen Sensors

These operate by a well established electro-chemical method based on two different metals being employed as cathode and anode, surrounded by a suitable electrolyte. The complete electrode system is surrounded by a gas permeable membrane. When the electrode system is polarised with a D.C. voltage of the correct magnitude, the cathode attracts any available oxygen ions outside the membrane, and as a result the magnitude of the polarisation current changes proportionally to the volume of oxygen. This current change is converted to indicate e.g. mg/1 dissolved oxygen. Two electrode systems commonly employed are silver/gold and silver/lead. For continuous monitoring work robust construction is necessary and, as with all types of electrode system, membrane and electrolyte changes must be quick and easy. Temperature compensation is carried out automatically in most D.O. meters by use of a temperature probe in conjunction with the D.O. electrode. A method of dissolved oxygen measurement incorporated into a probe manufactured by Ionics Inc. relies on the principle that the corrosion potential developed between an exposed thallium metal electrode and a reference electrode is proportional to dissolved oxygen concentration. The sensor is reported to be self-cleaning since thallium metal is inhibitory to biological growth. The electrode does not employ a membrane containing a liquid or solid electrolyte.

5. Ammonia Probes

These develop a potential, proportional to the concentration of ammonia in a sample in which it is immersed. This potential can be measured by conventional pH meter equipment. An E.I.L. example consists of an end-faced pH electrode inside a tube containing ammonium chloride solution in which a silver/silver chloride reference electrode is immersed. The end of the electrode is protected by a membrane. Ammonia in the sample passes through the membrane until equilibrium is attained with the ammonium chloride solution between the pH electrode and the membrane. The ultimate pH of this layer gives a measure of the ammonia concentration in the sample. It is possible to incorporate ammonia probes into a continuous monitoring set-up utilising automatic self-calibration using standard ammonia solutions. One disadvantage is that the sample aliquot generally needs buffering before passing on to the sensor, or if total NH_3 is required, 0.IN sodium hydroxide must be added to the sample.

6. Ion Selective Electrodes

These comprise liquid or solid crystalline membranes, and although promising for continuous on-line monitoring, they do at the present time suffer from periodic drift, membrane erosion, and interference. They are also fragile and need frequent recalibration. When stable, long-life electrodes are developed they could be used as continuous monitors especially in conjunction with a computer to process, record and act on signals and possibly control auto-calibration.

Actually, nitrate, chloride and various other ions (eg. silver, sulphate, cyanide, fluoride) and ammonia can be continuously monitored in sewage and effluent using selective ion probes and using an appropriate automatic analyser but the electrodes must be well maintained.

7. Organic Carbon

(a) The W.R.C. sensor makes use of the correlation between U.V. absorption at 254mm and the organic carbon content of sewage effluent. A mercury discharge tube acts as a U.V. source which is directed through the sample and the absorption determined. Compensation is made for the scattering of light by particles in suspension by a detector at right angles to the U.V. source. This detector can also give a measure of the suspended solids concentration in the sample. As the U.V. absorption is compared with the equivalent absorption in the visible range, fouling of the optical surfaces and variations in light output are accounted for.

(b) A Beckmann Instrument is also available for the individual determination of organic and inorganic carbon based on combustion and infra-red spectroscopy. Concentrations of up to 4000 mg/1 C can be determined and the results displayed on a chart recorder.

8. C.O.D.

The Axel Johnson C.O.D. meter is an automatic sampling and analysing instrument employing the standard method of C.O.D. determination. A sample is taken at intervals, oxidised by dichromate/sulphuric acid, and the resulting chromium III ions are determined colorimetrically. The only manual operation is the periodic supply of reagents. The instrument could be applied to the monitoring of sewage effluent quality or the control of aeration in an activated sludge plant.

9. Mercury

Wallace Instruments Ltd. manufacture an analyser for mercury in solution up to 0.5 mg/1 is available. It is based on atomic absorption technique and results are displayed on a meter and/or chart recorder.

10. pH

Continuous pH monitors are all based on the familiar and well-proved proton responsive glass electrode.

11. Oils

(a) Bailey Meters and Controls Ltd. offer an instrument which determines oils in concentrations greater than 2 mg/1, in solution or suspension in water, to ± 1% accuracy is marketed. The method is based on U.V. irradiation of the liquid under test and photocell detection of any fluorescence. The method is not in fact specific for oils as any fluorescent species will be detected. Meters, chart recorder and alarm relays can be fitted.

(b) G.E.C. Elliott is an alternative instrument employing the principle of light reflectance onto a photocell. The monitor floats on the water and detects visible floating oil, giving an output signal proportional to the quantity of oil.

12. Multi-parameters

The Technicon Instruments C.S.M. 6. On-site auto-analysers (which need housing in a weather-proof installation) continuously samples and monitors up to six parameters from a choice including ammonia, oxidised nitrogen, phosphates, C.O.D. and various metals and anions. Results are recorded on a chart and the instrument will operate unattended for up to a week.

13. Respirometry

Much work is being carried out into the development of this potentially useful technique. Future years may well see continuous on-line respirometers for assessing treatability and toxicity of sewage or biological activity of activated sludge plants.

As new sensors are developed and existing ones improved, the time will come when the centralised control of sewage works operation by a computer utilising meaningful and accurate data from a variety of sensors around the works is widespread practice.

METHODS OF PROCESS AUTOMATION

Mechanisation of sewage works processes has in many cases drastically reduced the manual labour requirements of those processes. Automation is a natural and logical progression of mechanisation. The development of automation in water pollution control applications has not matched that in many other industries for a variety of reasons(2), but such applications as are in use or are proposed will be discussed according to the process involved.

1. Flow Measurement and Proportionment

Flow measurement is probably the most important parameter that can be used to automate some sewage treatment processes, and therefore the equipment used should be unaffected by the heterogeneous nature of raw sewage and be accurate over the wide range of flows obtained. Any inherent inaccuracy should not be overlooked in any subsequent use of this parameter in later-stage process control.

Rate of flow measurement is often used to operate a main inlet penstock to allow a predetermined maximum rate of flow to pass for treatment. Some 'time delay' must be installed to prevent hunting of the penstock when flow is hovering around this set value.

Flow proportionment of sewage to two or more different parts of the works can be carried out using flow recorder data to control the setting of the appropriate penstocks or valves.

2. Screening Plant

Mechanical raking gear on bar screens can be made to start automatically and stop automatically by a signal from liquid level detectors sensing differential level across the screen or the head upstream of it. Rotary cup screens can be automatically started and stopped at a particular rate of sewage flow, the screen coming on stream when the pre-set flow rate is reached on a rising flow and shutting down when the flow rate is achieved on a decreasing flow. Standby rotary screens can also be signalled to start if the measured differential across the duty screen should reach a certain pre-set value, such differential measurements could over-ride the cutting in of a rotary or raking of a bar screen which is normally on a simple timer control.

The equipment generally used for level detection is usually trouble-free, but cases of malfunctioning caused by grease and debris fouling the sensors can occur(2).

3. Grit Removal

The operation of grit removal machanisms can be controlled by a timer or on the basis of flow passed since the previous operation. Standby grit channels or detritors can be brought on-line when a particular flow, as indicated by a flow record, is reached.

4. Primary Sedimentation

Simple time control could be used to start scraper gear prior to the commencement of a desludging cycle, which itself could be a timer initiated, the scrapers stopping again by timer control, sufficient time being allowed between the scraper start/stop signals to accommodate the desludging operation. Such timer control could be over-ridden by a signal from a suspended solids probe situated in the tank effluent or from a sludge blanket detector or sludge density meter in the tank itself.

Once desludging has commenced by the lowering of a bellmouth or the opening of a valve, the problem is when to stop desludging. An advantage over time control would be control by density or viscosity of the sludge being removed. A magnetic flux flow-meter senses the rate of flow of the sludge, and when the flow increases indicating a thin sludge, a signal is sent out to stop desludging. Similarly an ultrasonic sludge density meter installed in the desludging main indicates whether the sludge is 'thick' or 'thin' and when a pre-set sludge density is reached, the meter initiates a signal to stop desludging.

In both cases a suitable time delay must be incorporated into the system to allow for the presence of water bands or strata of thinner surplus activated sludge in the tank, otherwise premature cessation of desludging would result. Alternatively a 'short' second desludging could be carried out a little later. Various other sensors could be used also e.g. electrical conductivity meters, conductivity of sludge being proportional to water content; or gamma-ray meters which relate the gamma-ray absorption of sludge to its water content.

5. Percolating Filters

The mode of operation of biological filters, ie. straight filtration, recirculation or A.D.F. can be chosen automatically based on the rate of flow of settled sewage to the filters. A flow recording device can send the appropriate signals at the required flow rates via e.g. mercury switches to operate the appropriate flow direction gates, penstocks and effluent pumps to give the required mode of operation for that particular flow. Alternatively, flow meter readings can be continuously scanned by a central programmable control unit, which will select the method of treatment required and open the close in sequence all the necessary valves etc. to enable the chosen method to operate. Too frequent changes in mode of operation must be avoided otherwise less successful treatment will result with attendant disadvantages in terms of electricity costs and stable biomass on the filter media.

6. Activated Sludge Plants

There are several aspects in the automation of an activated sludge plant.

(a) Flow proportioning In multi-channel plants equal distribution of the settled sewage feed is important for maximum plant efficiency. This can be achieved by equipping each individual channel feed with a butterfly valve and magnetic flowmeter. The flowmeter signals are sent to a control unit which compares the actual flow with the desired flow and then adjusts the electrically or pneumatically powered valve to give the required flow. The greater the frequency of flow check and valve adjustment, the more accurate will be the flow control.

(b) Control of dissolved oxygen The stable environment occasioned by D.O. control leads to superior effluent quality and probably superior sludge quality as well. Mackereth D.O. probes have proved quite successful for the purpose of monitoring this parameter. Redox potential has also been used(3) but does not correlate very well with dissolved oxygen concentration in excess of 10% saturation. Also readily oxidisable substances in the sewage will significantly affect the redox potential.

Having installed the chosen sensors in suitable position, and the best situation of D.O. probes within the plant is always a problem, they can then send their signals to a control unit which calls for the appropriate action to maintain the D.O. at the required level. The action depends on the type of plant. In a diffused air plant, air supply can be controlled either by the use of variable speed blowers or by adjusting butterfly valves in the air feed line. No economic advantage is gained by the latter method. In the case of mechanically aerated plants D.O. control can be achieved either by adjusting the depth of immersion of the aeration cones, or by altering the speed or number of rotors operating.

D.O. Control becomes inefficient where some inhibitory material present in the settled sewage lowers the respiratory activity of the bacteria and protozoa. The D.O. would then rise, the rate of aeration would reduce and the situation would be aggravated. A possible future answer to this problem would be the use of in-line treatability/respirometry techniques to distinguish this type of situation.

(c) Control of mixed liquor suspended solids This can be basically achieved by using a sensor such as a suspended solids probe to determine the sludge concentration in the mixed liquor and thence controlling the rate of activated sludge return or surplus. Control of sludge return rate can be achieved by the adjustment of variable speed sludge return pumps or by using motorised valves to control the rate of sludge flow to the wet sump of fixed speed sludge return pumps. The latter is probably the more economical method as variable speed pumps have a greater power consumption at lower speeds than at higher ones. The control of depth in the wet-sump of a screw pump will control the pumping rate at any fixed speed.

For a multi-channel plant the return sludge flow to each individual channel can be controlled in the same way as the settled sewage feed, described earlier. Also, where the return sludge pump sump is direct coupled to the final settling tank sludge withdrawal system, photoelectric or ultrasonic sludge blanket level probes in the final tanks would safeguard the system from sludge build-up causing excessive solids in the effluent, by signalling for increased rate of sludge return or surplus.

Activated sludge process control should not rely merely on one parameter when several other important parameters are ignored. While D.O. control ensures a satisfactory effluent with respect to BOD and suspended solids, it does not necessarily ensure full oxidation of ammonia to nitrate. If this becomes a requirement, knowledge of ammonia levels will be needed and thus an ammonia monitor will be essential. However, for control purposes the probe must be situated in the mixed liquor and present ammonia monitors are prone to blockage in such conditions. Present ammonia and nitrate monitors are quite effective in plant effluent and in conjunction with D.O. and S.S. probes can provide continuous effluent quality monitoring.

7. Sludge Digestion

This is essentially a batch process and is not entirely amenable to automation. In-line gas chromatography to give continuous volatile acids measurement coupled with carbon dioxide content of the gas have possibilities as a control system but corrective action is probably limited to reduction of feed or recycling of healthy actively digesting sludge to the affected digestor. Other possibilities include monitoring the calorific value of the digester gas, (if this falls too low, auxilliary fuel would be used in the burners), thermostatic regulation of temperature and sludge recirculation rates, and time switch or flow regulation of feed and displacement. If feeds amounts are not decided by an operator, gas flow measurement could actuate an over-ride cut-out of excessive feeding.

An American idea for possible digester control using pH monitoring involves the concept of gas scrubbing. When the pH of the digester contents drops below a predetermined level, the digester gas is scrubbed with lime water or sewage effluent to reduce its carbon dioxide content leaving a gas rich in methane, which is recirculated to the digesters, reducing the partial pressure of carbon dioxide in the system. This causes dissolved $C.O._2$ to be liberated as gas to restore the original equilibrium in the gas phase, causing a raising of pH due to removal of the weak acid, carbonic acid. This method while allowing a sizeable increase in organic loading without failure, can only postpone failure due to hydraulic or toxic overload, not prevent it.

Addition of a base is an alternative to the above remedial action for low pH. It is a more simple procedure but has the disadvantage of a possibility of inducing cation toxicity, precipitation of inorganic material (reducing the effective digester capacity), or local zones of high pH. Base addition is not a popular means of control in this country.

8. Level Control

Using liquid level sensors, in conjunction with a control unit, a process of tank filling (e.g. sludge consolidation) can be initiated, and when the selected tank registers full, the remaining flow can automatically be diverted to another empty tank with the aid of power actuated valves. If the control unit takes the form of a computer, it can also automatically update its information on levels in tanks and thus calculate and record e.g. volumes of water drawn off or volume of sludge added to various tanks.

The use of liquid level sensors in pumping station sumps to automatically control the starting and stopping of pumps, is well established.

Sand filters can be automatically backwashed if a liquid level sensor is used to detect the operational head. When this head reaches a certain level, an automatic backwashing sequence can be initiated and the filter returned to service on its completion.

9. Sludge Treatment

Filter pressing of sludge is a batch process and therefore not possible to automate completely, although a high degree of mechanisation can be incorporated. All relevant pumps, storage tanks and chemical tanks can be selected on a control panel prior to a pressing cycle, which when initiated would see itself through without further intervention. Sludge could be conditioned in-line or batchwise using high/low level detectors in the conditioning tank, in the latter case a control valve in the sludge feed line automatically regulates the flow of sludge so that a constant rate of addition of conditioner yields a constant dose in terms of % on dry solids to give the optimum C.S.T. or specific resistance to filtration. The pressing cycle can finish on a timer control, the sludge pumps 'holding out' when the required filtration pressure is achieved.

Vacuum filtration of sludge using a rotary drum is a continuous process and can be made completely automatic from sludge conditioning and feeding to cake removal and weighing.

The Porteous process and sludge incineration plants are available as continuous and fully automatic units.

10. Co-ordination of Individual Automated Processes

It must not be overlooked that automation of individual processes may influence and affect subsequent processes and the co-ordination of this aspect is described in the succeeding section.

THE USE OF COMPUTERS

The concept of applying computer techniques to the control of waste water treatment plants was first postulated in 1956(4), but lack of reliability, non-availability of sensors and restriction of capital expenditure made the idea slow to be utilised. However, during the past five years, much development work has been done on a variety of sensors and in bringing down the cost of mini computers not only to acceptable levels, but even to compete favourably with fixed logic systems for sequential control(2). In the United Kingdom, two works have utilised computers in differing ways(5,6) not only to extend the concept of automation, but significantly to modify and to improve management techniques applied to the operation of waste water treatment plants.

The advantages considered to be derived from using a central process unit (mini-computer) at Norwich (Whitlingham Treatment Works), are:-

(i) Improved process control;

(ii) Consistent process performance;

(iii) Improved process optimisation;

(iv) Co-ordination of plant operations;

(v) Increased flexibility of plant operation;

(vi) Extensions of process knowledge;

(vii) Improved plant security;

(viii) Improved plant maintenance;

(ix) The potential development of cheaper and more reliable plant instruments;

(x) An overall cost benefit.

To demonstrate how these advantages are to be achieved, the Norwich treatment plant is now considered.

Much has already been published of the Norwich waste water treatment plant and control system (2,5,7) and therefore only a brief description will be given to allow further expansion of the potential management advantages.

The sewage treatment facilities at Norwich are designed to treat 55,000 m^3/day DWF of sewage from a contributing population of approximately 197,000.

Sewage flows of up to 5 DWF are screened and pass through detritors before storm sewage separation. Sewage flows of up to 3 DWF are then proportioned between two separate treatment plants, each of 27,500 m^3/day DWF capacity; one comprising radial flow sedimentation tanks, biological filters and humus tanks with effluent pumping facilities (on ADF or recirculation basis) and the other comprising radial flow sedimentation tanks, diffused air activated sludge plant and final settlement.

Raw sludge from each works, along with either humus or surplus activated sludge can be passed either to heated anaerobic sludge digestion plant with subsequent disposal in liquid form (distribution on farmland) or to a pressure filtration plant where chemical coagulation and pressure filtration are followed by final disposal in solid form on farmland.

The wide variety of processes utilised have been automated, as far as is currently possible, and interlinked together into one central control system with inbuilt spare cabling and process control capacity to accommodate experimental projects and any newly developed sensing and control systems. All multi-cored cabling is protected from external influence by copper-braided screen and is placed at least 450 mm from any AC source.

The control system used is the Kent K70 which can be described as a complete range of both hardware and software for computer process control. It is compatible with most digital computers and comprises modular and easily extendable units. The central processor unit (CPU) is the heart of the system and contains all the arithmetic and logical processing hardware, together with the core storage required to contain the basic programmes and data. The CPU uses the Digital Equipment Corporation PDP-8/E mini-computer, which is a 12-bit machine with a maximum core memory capability of 32K words (K is approximately 1,000) of which initially only 28K will be used. Core memory can be easily supplemented by various forms of bulk-storage device such as a disc, to allow additional operational programmes and plant data to be stored.

The operator can communicate with the CPU by means of a monitor teletype typewriter which incorporates a low-speed paper-tape reader and punch in addition to the keyboard and page printer. A thermal printer and three three-pen independent trend recorders are also to be included. Considering the system as a black box, the computer acts as a powerful and fast calculating machine. The great advantage over a calculating machine is the high speed of operation, capability of storing a mass of information (in the core store), the ability to hold and obey a long list of instructions (the programme), and to print out all information that is gathered instantly or at predetermined intervals. The main interface of the system deals with 339 digital inputs, 183 digital outputs, 88 analogue inputs and 17 analogue outputs.

The control system is unique in the field of water pollution control because there is central control and monitoring of all processes. The system provides for the automatic sequential control of all transfer procedures such as sedimentation tank scraper start up, desludging procedure and transfer of raw sludge via a central pumping station to either consolidation tanks and thence an anaerobic digestion plant, or to storage tanks prior to pressure filtration, and also the necessary sewage flow divisions not only between the two separate treatment plants but also a settled sewage and returned activated sludge between each channel of the five-channel activated sludge plant. Process selection and on-line control is another feature of the system which hitherto has been the dream of many process control designers and operators.

The computer is only part of the system and relies heavily on the many and varied sensors and measuring instruments. These include magnetic flow meters, diaphragm level sensors, Mackereth DO electrodes and ultrasonic sludge density detectors. However, scope for any additional sensors has been catered for by providing additional suitable screened cabling and civil engineering designs such that there would be minimum disturbance to existing plant.

A manual back-up system is provided in the event of computer or peripheral equipment failure. This comprises a full working mimic diagram which contains push buttons and indicators for the operation and observation of all essential plant. A further manual back-up system is available by the operation of each item of plant on site from the local control system.

The system's data logging facility is an added bonus and provides up-to-date information from any or all the sensors included, either on demand at any time or on a pre-timed programmed order. All information can also be graphed independently.

Interfacing the Computer and the Plant to the Operator

The use of computers raised particular problems which at the moment have to be experienced before solutions can be found. However, the system at Norwich has highlighted the following points that are worthy of mention:-

1. Communication with the computer must be easily undertaken in plain or simple coded (termed "high level") language.

2. Programmes and sub-routines must be easy to amend and should not require a full-time programmer.

3. Maintenance of the whole system must be undertaken and not of isolated parts.

4. Control parameters that require frequent change must be easily isolated from core store, displayed and altered easily from the control panel whilst the computer is on line.

5. Both semi-automatic and manual back-up systems must be utilised in regular training schedules, so that when the need to use them arises no confusion or anxiety exists. This particular aspect can be confusing initially - experience thus far gained at Norwich, lengthy detailed discussions with manufacturers have been necessary in order to establish precisely what the state of the various items of plant might be when the computer comes back on line after failure.

6. The training of CPU operators must be thorough, not only in operating procedures but in waste water treatment fundamentals. The recruitment of operators must not be jeopardised by setting rates of pay too low by comparison with those at present existing in the sewage treatment field. Such comparisons cannot be made. A separate paper on Interfacing Problems was presented at the International Workshop on Automation(8).

Management Advantages by use of Computer

As many sewage works managers will admit, the operation and management of waste water treatment plants is often done by "experience" and practical application of the few fundamentals that are understood. The day-to-day operating problems are often unique, particularly to each plant and/or each distinctly separate sewage and most plants base their treatment and management strategies on historical records. Whilst the statement has some truth, many of the recurring problems are common ones which are camouflaged by the particular design parameters and characteristics that are used. This has occurred in the U.K. because designers still continue to use civil engineering aspects of design only and all too often neglect process design fundamentals. The use of computers dictates that at the design state both process and operating principles are integrated with the civil engineering principles to give an ultimate plant that has the best of all requirements. This will give management greater opportunity to provide a better service not only of operation and maintenance, but of future design applications and philosophy. The use of computers will provide the maintenance of optimum treatment conditions in the plant at all times and will enable the plant to operate at optimum efficiency almost immediately.

Some of the major advantages offered to the plant manager by an installation such as exists at Norwich might be conveniently discussed under the following headings, some or all of which could have a significant effect on the design parameters of future works.

1. Multi-Sensor Application

This is perhaps the most significant aspect of automatic control of sewage treatment processes in the sense that it is the slow development of reliable sensors that is preventing computer application to the field of water pollution control from being more rapid than at present.

Ironically, the main reason for failure to develop such sensors in the past has been lack of process control information. The computer can be said to provide a hitherto missing link in this respect by serving to store and to provide on request all information gained (using reliable sensory equipment) on process control statistics. This information in turn can be used to develop knowledge of all processes (chemical and biological) and thereby indicate, through mathematical models for instance, further parameters which might be studied to advantage.

2. Diurnal Flow and Load Changes

Whilst this is closely related to the previous statements it seems particularly important to mention because both parameters are not generally controlled but have absolute determination of the function efficiency and effectiveness of all processes used. It seems foolish to try and relate plant or process efficiency to load, when this parameter is itself not controlled and rarely considered in technical calculations. Average flows and loads are invariably used for design, with perhaps the one exception in hydraulic terms of peak flow.

3. Settlement of Waste Water and Desludging of Primary Sedimentation Tanks

Whilst the division of flow between tanks and the periodic removal of sludge and storage of settled sludge significantly affect performance of this stage of treatment, perhaps the most important consideration is the effect of those operations on the secondary treatment plant and on the sludge treatment and disposal facilities. The application of automatic desludging, flow division and so forth can greatly add to overall plant management by providing flow equalisation and a more consistent sludge for treatment and disposal. Whilst the computer may not be directly effective in those spheres, it can greatly improve the application of automation to flow division and balancing, particularly in the situation where plants are being extended. Thus, in such cases, significant cost savings could be made in any direct comparison of computer and fixed logic systems.

4. Anaerobic Sludge Digestion Plant

Here control is usually one of detecting operating difficulties after they have occurred (viz. pH changes, volatile acid concentration changes and gas composition and production volume). However, when such changes occur the relevant facts can be much more easily controlled, collated and displayed when using a central processor unit than with any currently-used system. A much clearer picture can thereby be obtained as to circumstances under which observed changes have taken place.

The potential improvement in digestion plant operation may prove to be significant because this process is so sensitive to the infinite number of variables which are, as yet, not even considered interlinked, that the reported problems with detergents and halogenated hydrocarbons may be of less importance than currently considered.

5. Activated Sludge Plant

For many years, the activated sludge plant has been controlled through the dissolved oxygen concentrations using Mackereth electrodes. Little has been attempted in the monitoring and use of returned sludge rates, sludge growth characteristics and the apparently insoluble problem of "bulking" or poorly settleable sludges.

The variables of load, retention time, temperature, mixed liquor solids concentration and DO concentrations are only part of the picture that can emerge from the use of multi-sensor application and computer use, to relate the many variable parameters that all in some way affect the performance and efficiency of the activated sludge plant.

6. Cost Effectiveness and Economics

The advent of computer application to sewage treatment has been closely related to the steady decline in availability of manual labour. The former has been considered by some as a satisfactory and acceptable counter for the latter. In industrial chemical process plants, for instance, it has become evident that exclusion of the manual element has generally had the effect of increasing reproducibility of an operation and, to a certain extent, its efficiency.

Consequently, on sewage works where computer use would involve potentially full automation and certainly a high degree of mechanisation, it is considered that not only can process efficiency be markedly improved in many areas but that significant savings in operating costs are also potentially available.

Where plants of a different type operate in parallel, as at Norwich, a computer can serve to provide much of the information necessary for a direct cost effective comparison of the plant over an extended period. Such long-term investigations can offer valuable assistance in the design and construction of future sewage treatment plants employing similar processes.

7. Investigating Process-Fundamentals

Mention has been made briefly of the facility afforded by the computer for automatic control of sewage treatment so possibly increasing process efficiency and potentially effecting substantial savings on both operating and design costs.

Another important advantage of its use is that by means of its data logging and monitoring system it presents to the works manager in a clear and easily observable form much more information than is normally available to him even in random or diverse fashion. From this it is anticipated that parameter patterns would be more easily correlated and significant connections more easily observed. Out of this approach might evolve inter-relationships between process parameters hitherto thought to be non-existent. The causes and control of bulking activated sludge for instance is a particularly relevant problem which might be successfully pursued with such facilities.

8. Plant Maintenance

The computer, by the nature of its basic method of functioning, also provides the plant manager with a ready means of monitoring and checking the state of the plant. Where faults occur, therefore, the operator is made immediately aware of them in most cases via some form of teletype or CRT display thereby assisting with preventative and breakdown maintenance. The computer can be made, by use of the programme, to differentiate between various alarm states. Thus a mains power failure might be an alarm state of high priority requiring immediate attention whereas the failure of a relatively unimportant valve or penstock to open or close might be an alarm state such that it could be left unrectified for perhaps 24 hours and only require routine logging. In addition, the computer has the ability to locate and diagnose faults within its own mechanism. Given correct programming, it is impossible for partial failure, leading to incorrect monitoring, to occur whilst the computer remains on line since the "watchdog" system would "time out" throwing the plant into manual operating mode.

FUTURE DEVELOPMENTS

The concepts of automation, using the valuable tool called a computer, must receive more consideration by the many water pollution control experts and much research and investigation must be undertaken before advancing further. But the scene is set and the application and extension of the use of computers is almost unlimited.

The application of dual computer systems to the control and operation of treatment plants is logical and easily applied to the system described at Norwich. The advantages of providing an off-line computer to provide back-up for the on-line machine and use to other research or investigational work seems almost Utopian.

Computer use for the wider sphere of water and water pollution control seems unlimited when one considers the establishment of data storage and processing at central points and satellite or worker computers on potable supply, waste water treatment plants, river water quality and so forth, feeding information to assist with the complete and scientific management of an entire river basin.

CONCLUSIONS

The paper has attempted to highlight the social implications of automation, which are undoubtedly significant and far reaching. It has attempted to catalogue the potential advantages and disadvantages, but so as not to create a pre-conceived idea where waste water treatment plants are concerned that some considerations may be disadvantageous, it has deliberately either not been mentioned or listed separately. The appreciation of various instruments and techniques have been described - the majority being fairly widely used and understood.

The application and use of computers as described does appear to enhance, project and extend the advantages of automation, but is clearly receiving cautious attention since the very term "computer" conjures up the wrong idea and certainly prevents its application from being the logical solution to many present day sewage treatment problems.

Many authorities condemn the use of such sophisticated machines as computers, by saying the economics are not viable.

Because of the inevitability of automation in some degree on every sewage treatment works, automation should not be undertaken for the sake of fashion. It should be clearly understood that automation in its various degrees, the use of computers and techniques to improve the application should be only undertaken where the advantages are guaranteed to give an overall cost benefit to the community.

The following list indicates the addresses of the suppliers mentioned in the paper. The products mentioned have been used as examples to illustrate a particular technique. The list is not considered to be exhaustive or to indicate a preference for the products cited.

Kent Instruments Ltd., Biscot Road, Luton, Beds. LU3 1AL.

Arkon Instruments Ltd., Whaddon Works, Cheltenham, Gloucs.

Partech (Electronics) Ltd., 11 Doors, Charlestown, St. Austell, Cornwall.

Ronald Trist Controls Ltd., Bath Road, Slough, Bucks.
(for Mobrey Sensall Sludge Density Meter).

E.I.L.,Hanworth Lane, Chertsey, Surrey.

Beckman R.I.I.C. Ltd., Eastfield Industrial Estate, Glenrothes, Scotland.

Techmation Ltd., 58 Edgeware Way, Edgeware, Middx. HA8 8JP.
(Axel Johnson C.O.D. Analyser)

Bailey Meters & Controls Ltd., 218 Purley Way, Croydon, CR9 4HE.

Technicon Instruments Company Ltd., Hamilton Close, Houndmills, Basingstoke, Hants.

Acknowledgements

The author wishes to acknowledge the Anglian Water Authority for permission to publish this paper.

He is also greatly indebted to Dr A.J. Bates, ARIC, Scientific Officer, Anglian Water Authority, Norwich Sewage Division and Mr A. Latten, LRIC, A.M.InstWPC(Dip)., Works Manager, Whitlingham Sewage Treatment Works, Anglian Water Authority, Norwich Sewage Division, for their substantial contribution to the broader and specific aspects of this paper.

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discussion

CHAIRMAN: W.A. Feather, GM, BSc, FICE, FIWE, FIPHE, MConsE
President, Institution of Public Health Engineers

The CHAIRMAN said he thought the paper would point the way to the future in the use of electronics in the design and control of the automation of sewage treatment plants. In particular it showed the more careful control that was possible with automation as compared with manual control.

2. Mr P. COTTON said a great deal had been written about automation of sewage treatment processes during the past two years, and this paper had been generalised and been broadened in its context. He hoped it would encourage further deliberations on the application and benefits and perhaps disadvantages of automation in the field of water pollution control.

3. Mr COTTON emphasized one or two of the sections in the paper and started with the definition of automation; he had chosen the ex-GLC definition because he could understand it. He had given two lists of potential advantages and disadvantages of automation. Regarding overall cost benefit on an automated system, at the Norwich plant there had been capital savings in the plant; with a different method of automation or manual operation the equipment needed would have been more expensive than the mini-computer that was purchased. There was an apparent reduction in nine manual employees saving expenditure of about £15 000 per year, and there were potential savings from reduction in power costs and better use of materials. There was also a potential capital savings on re-designed plant as a result of information gained from the operation of this plant. The apparent economy of automation depended on where one started on the mechanisation/automation spiral; in the south of England where works tended to be larger and where a high degree of mechanisation had been usual, automation would apparently not save as much as more northerly works where mechanisation had not been as far advanced.

4. Mr COTTON said that at Norwich the process operators, computer operators, chemists, maintenance engineers and managers had all expressed a feeling of involvement and satisfaction in their jobs; they were involved together as a team. The design engineers for the plant were greatly involved in close detail with plant operation, management and maintenance, and they found this greater involvement gave them better ultimate designs and greater job satisfaction. In these days of multi-disciplinary and multi-functionalized set-ups, it seemed to Mr COTTON that this was the sort of thing which should be encouraged; people working together to solve a problem in all their different ways. The traditional family tree of responsibility had changed. Much of the change could be attributed to the re-organization of the water services, and in many cases this had emphasized the advantages of automation. The Whitlingham plant at Norwich was the only one in the Norfolk/Suffolk area that could be used as a headquarters or base for servicing smaller works.

5. The management of automated plants fell into three distinct but overlapping functions: to initiate, evaluate and implement control; to optimise existing strategies and associated processes; and to maintain, diagnose and correct faults on all equipment. As the plant at Norwich was not fully operational, Mr COTTON could not claim improved management or consistent performance.

6. In the paper Mr COTTON had listed potential disadvantages. Recruitment and retraining of personnel to operate highly mechanised or automated plants had been undertaken; in four months two men were selected, trained and introduced to automated sequences as an experiment. Mr COTTON felt they had coped very well and at a recent Department of the Environment Working Party visit to the works, those two plant operators explained the operation in a way which the committee could understand. They knew what they were talking about and could act in an emergency, what to do or not do under what circumstances, or to tell someone else about it. Mr COTTON thought that the manual back-up system was important. It had proved invaluable in retraining, by showing people that when they pressed a button something happened.

7. The remoteness, inactivity and boredom of operators was a problem for management. If this was looked at with a fresh mind it could often be found that if a works was working satisfactorily on an agreed labour force, then the labour force could probably be cut by 20% and it would still work alright. The stage of inactivity or boredom of knowledge had not yet been reached at Norwich as the plant was still being commissioned.

8. Mr COTTON had deliberately expressed the problem of industrial action in two opposing ways. He hoped that the two people who controlled 90% of the work and process control at the Norwich plant would transfer to another Union at their request, their status would be changed slightly and several other people could do their job in the case of industrial unrest.

9. The section on instruments and sensors was by no means complete and the exclusion of a particular instrument or manufacturer had no implications. Process automation was well documented and had been well discussed.

10. On the use of computers perhaps the most important point to note regarding the use of any automated process was the flexibility and non-rigidity of the logging system. The system at Norwich could relatively easily be re-programmed to operate in any mode of the physical facilities. This had far-reaching consequences, particularly at the design stage. Flexibility in the physical sense as well as in the control was essential. Generally speaking the changes that could be made on re-programming the method of operations were probably more significant on the larger than the smaller works, and from the manager's point of view they could have far-reaching consequences in the economics of the operational aspects of sewage treatment. The data logging facility was an added bonus. To have the facility to present in a reasonably coherent form all the relative data required to operate a plant threw up the inter-relationships between parameters, that would have been missed without this information.

11. Mr COTTON stressed the manual back-up; if everything else failed a particular machine or machinery could be operated by pressing a button. If people were shown that the plant was reliable and that the equipment was workable and working, then all anxiety disappeared; and if the operators, designers and managers were got together it was surprising how attitudes changed. At Norwich many ideas came from grass roots level as to the best method of disposal of sludge, or to save power, labour and time.

12. In his closing remarks to the first Session Mr Best had said it was the duty of all engineers to design or modify designs of sewage treatment plants to provide sludges that were more amenable to dewatering and disposal. Mr COTTON said that if an automated plant had more consistent operation then they would provide sludges which should be more consistent themselves and respond more consistently to a chosen method of treatment and disposal.

13. Mr COTTON added that in the Norwich Sewage Division they inherited two plants which aerated sludge. Raw and humus sludges were passed into aerobic digesters with a ten day retention period. It had been found that if sludge was put in straight from the sedimentation tanks at about 4% dry solids, the air did not distribute as the sludge was too thick. Therefore the aerobic stage was limited to perhaps a foot either side of the diffuser and the liquor between the diffusers was anaerobic. These plants were made to work by diluting the sludge to 2% solids and putting it in the aerobic digesters for ten days and then trying to decant the water. They only succeeded in achieving 3½% solid content, and therefore a lot of money was spent doing nothing and ending up with more sludge than was originally there. It was being put to agricultural land. If the nitrogen and ammonia had been blown off it was to the detriment of the farmer who wanted the nitrogen.

14. Mr R.A.R. DRAKE was astonished that the author could have found time to produce such a massive paper. He was a member of the DOE's Working Party on control systems,

and he had produced a paper at the Public Works Congress in November, and at the same time he was settling down as the manager of 300 sewage treatment works.

15. Naturally as the Chairman of the GLC's Working Party on automation, Mr DRAKE agreed entirely with the opening sentence of the paper. His Working Party spent a considerable time arriving at their definition for automation, and would be disappointed if the DOE Committee was not prepared to accept it. Mr DRAKE thought "the direct operation in response to the measurement of parameters without the intervention of manual controls" was what most public health engineers understood automation in sewage treatment to mean. The DOE's Working Party had not finally decided on the definition, and it would be interesting to have other opinions.

16. Mr DRAKE said that two years ago he went to the USA and amongst other things spent time at a well-known instrument manufacturer's factory. He had a day with the Marketing Manager of their Digital Systems Division visiting a computer controlled plant on Long Island. He returned entirely convinced that computer control was what we should be striving for. He did not think that the fact that automation might make savings in manpower should be worried about. Over the last 150 years machines had made man rich enough to increase social services and leisure, and Mr DRAKE believed that workload should be reduced. The Industrial Revolution reduced the physical workload, and the move towards full automation reduced the mental workload.

17. In two places the author said that automation of sewage treatment must show an overall financial advantage, and in the light of technological development there could be no doubt at all that it would, but there was still a long way to go. Much research was required, many sensors needed developing and much development expense must be incurred. The controllers of purse strings should be prepared not to judge the present schemes on an immediate financial benefit basis; they must give the money so that it could be got right.

18. The CIRIA optimisation design study had shown boundary information was lacking. For example, much was known about primary tanks with retentions of two hours upwards; but nothing was known about retention of half-hour to one hour. This sort of information was needed, and could only be obtained by experiment, and if those experiments were carried out at existing works, how would the gamekeepers be mollified if effluent quality went off?

19. Mr DRAKE was not as sure as Mr Cotton that significant process information would become available as a result of computer control. If reams of paper came out, would it really be much good?

20. At the ICE Conference on Advances in Sewage Treatment in November 1972, Dr Singer said "There are two aspects of sewage treatment which have never ceased to astonish me. First, speaking in chemical engineering jargon, one is asked to operate a continuous process with a precise narrow product quality specification. At the same time one is asked to accept as a matter of course a feedstock which can vary in quantity by a factor of as much as three or possibly six, and so far as quality is concerned, by a factor of X in which X can sometimes be surprising. These facts of life appear to be accepted with a degree of equanimity that merits congratulations. A petro-chemical engineer would not put up with such a situation". He went on to say that flow balancing might be important. Mr DRAKE said that with a variable feedstock, automation and optimisation became more difficult. Computers were one of a very small number of things which were becoming cheaper and there should be no difficulty in providing a secondary computer as back-up to the on-line computer; the second computer could be useful in connection with such things as financial analysis.

21. He asked what the author meant by his statements in the paper that maintenance must be undertaken on the whole system rather than isolated parts, and that some operating problems occurred because designers only used civil engineering aspects of design.

22. Finally Mr DRAKE said he found it a little hard to reconcile the statements in the first paragraph of Future Developments and the last paragraph of the Conclusions. The author wanted us to get on with computer control in one breath, and in the next he only wanted us to get on with computer control if it showed an overall financial benefit. This appeared to be an attempt to have one's cake and eat it. Mr DRAKE's view was to get on with computer control in the sure knowledge that it would ultimately show a financial benefit, apart from all its other benefits.

23. Mr COTTON replied that it had been a busy time and he wished to make it clear that he was not the only party involved in the paper. He now had 300 sewage works, and Mr COTTON felt this highlighted the problem

of automation being well down the list because they were still trying to find out how many sewage works there were and where they were.

24. The CIRIA research study called for more data, not only on the efficiencies of sedimentation tanks after half-hour retention but also how much sludge was produced from a given flow for a given population. It had been his experience on many sewage works that operators and managers always got a tank full of sludge whatever size the tank was. Replying to Mr Drake's question about the effect of experimentation on the river, Mr COTTON said that the Yare at Norwich was receiving an effluent which was far inferior to what would be produced from the new works and there was therefore latitude for experimentation, especially as the Yare was one of the cleanest rivers in England.

25. Mr COTTON said that maintenance should be carried out for the whole system including control, operations, electrical equipment, mechanical equipment and site maintenance. If a piece of equipment, such as a tank or a lane of an aeration system were to be taken out of service, it had to be locked out of the control system, and all other parameters that would change as a result of that change must be allowed for. From the safety aspect with an automated plant, where machinery could stop and start without any apparent manual action, it was important that when people were working on a pump, gearbox or electrical plant, that someone would not switch it on.

26. Going onto civil engineering design, Mr COTTON said in the Norwich Sewage Division they had inherited schemes done by consultants, district councils and larger local government organizations, and as far as he could see a lot of them still used Escritt. He had two works which had no facilities for desludging sedimentation tanks at all. It was the old argument of "you build it we'll operate it", which must change. Engineers, operators, chemists and maintenance people should work together so that if there was a fault, be it civil, chemical, electrical or bad operating practice, the whole team would try to solve it, or at least not reproduce it.

27. Mr D.J. GRIFFIN said the author referred to the fact that diurnal flow and load were not generally controlled. The control of flow by balancing would also tend to control load to a more steady state, which would offer opportunities for economy in size of plant. Such load and flow balancing was not a completely new concept and had been implemented to some extent in some systems in this country already. Did the author see the opportunity to apply some degree of automation in achieving load and flow balancing in sewerage systems as opposed to sewage works and thereby achieve optimisation of the whole system in an economic sense?

28. Was a cost benefit analysis carried out to jusiify the degree of automation carried out at Norwich and if so had any subsequent appreciation been made as to whether the economic or other benefits had justified the cost? What was the capital cost of automation at Norwich? Finally, was power generated in the Norwich plant, and if not, what happened during a power cut?

29. Mr COTTON replied that diurnal flow and variation of load and flow together were controlled in one or two places where balancing tanks had been installed. The Oxford works had balancing tanks which apparently did have some effect on improving the activated sludge process. A lot had been said about balancing and balancing tanks from the WPRL and the general conclusion was that it did not appear to give as much benefit as people thought it might, but Mr COTTON thought if some of the peaks and troughs could be smoothed then automation would be a better tool at the treatment works. Small computers could be used within the sewerage system so that the entire system formed a large balancing tank. In future sewage treatment processes and sewerage systems would have to be more closely integrated.

30. Mr COTTON said that a cost benefit study was undertaken for the Norwich plant but one had not been done since to prove that it was economic, because it was not yet finished. Changes to the original design had been made and their cost recorded so it would be possible to assess whether the original cost benefit study was true or not. The capital cost of the control system at Norwich (i.e. cabling, C.P.U., sensors, all the mechanisation associated with valves and penstocks that would not normally have been required) came to about £168 000, including modifications to the old works. There were two works at Norwich and two separate sludge treatment plants and four separate processes: a filter plant, an activated sludge plant, a digestion plant and a pressure filtration plant. About 5% of the capital spent on the present enlargement of the works was for automation, but it only amounted to about 2% of the capital cost of providing

the entire works with automatic control. Normally measuring devices came to less than 1% of the total capital spent on a scheme, which was atrocious from an operator's point of view.

31. Mr COTTON said that at the moment power was not generated at Norwich. This was one of the modifications which were made. Four or five years ago the Electricity Board offered two supplies each capable of running 75% load for the two works, and at that time industrial action was not considered. It now was, and there were two portable generators each capable of providing about a 75% load. The consultants were investigating the provision of permanent stand-by generation.

32. Mr G.L. SYMES said a simple application of automation was flow proportioning. The usual way of doing this was to measure the flow through two openings controlled by penstocks. Normally one of the penstocks would be left alone and the other would be controlled by signals from the recorders with a pre-determined time-lag. However, with higher flows it was necessary for the penstock to move further, and Mr SYMES wondered whether a computer could vary the time-lag according to the flow.

33. Mr COTTON replied that flow proportionment was more difficult than people thought. The flow varied diurnally at a rate which was not constant, and trying to divide this flow into proportions by simply opening one valve on the penstock and adjusting the other on a time delay, was rather crude. The computer had an inbuilt delay because it was so fast. For example, opening a penstock took 400 seconds, but it took the computer about a millionth of a second to issue the instruction, so a delay of 400 seconds had to be allowed before the penstock was assumed open. The computer easily distributed the flow between the two works equally at all incoming rates of flow, because Mr COTTON wanted to make sure that the load went to these two plants at the same time in equal proportions, so he could compare the efficiencies of one works with another. At Norwich a fixed logic system would not give the flexibility of flow proportionment at all rates of flow.

34. Mr K.V. ELLIS said that Mr Cotton had repeatedly stated that automation did not lead to an increase in unemployment. What happened to the really low-intelligence workmen - the brush and shovel man and squeegee man? Could he be adequately re-employed in this new computer-controlled system?

35. In the paper Mr Cotton suggested that ammonia or nitrate probes were necessary to control the nitrification of the ammonia. Mr ELLIS suggested that these probes could only be for recording purposes and that nitrification at that level was only governed by such things as dissolved oxygen concentration and the concentration of the solids in the mixed liquor.

36. On the automation of desludging primary tanks, Mr ELLIS asked the author to comment on the possibility of using a flow recorder in conjunction with a suspended solids recorder on the flow of sewage going into the primary tank.

37. Mr COTTON replied that at Norwich the size of the works had been doubled and this would normally mean doubling the labour force. They did not recruit any more brush and shovel men, but recruited a higher level of operator for the automated sections of the plant. On the majority of works brush and shovel men were still needed for there was still grass to be cut and painting to be done, and fitters and electricians were needed as well as electronics and systems maintenance people. At Norwich there had been 26 men, and it was anticipated that 43 would be needed for the enlarged works. Eventually 38 were employed and out of the new recruits only one was a brush and shovel man, whose main duties were cleaning round the aeration plant - the mundane tasks that could not be automated. At other places where an existing works was automated and mechanised there might be redundancies depending on the particular circumstances.

38. Mr COTTON apologised if he had given the impression in the paper that ammonia and nitrate probes were necessary. He thought they were desirable in controlling undue growth of activated sludge which could be linked to the sludge disposal facilities available, and/or the production of nitrate or reduction of ammonia. The computer gave the facility to investigate what were considered the fundamentals of the activated sludge process: carbonaceous and nitrogenous oxidation stages, the weight of solids produced, the weight of solids destroyed and the amount of sludge that had to be passed for treatment and disposal. The plant could be optimised and operated to provide a sludge which was more amenable to the available methods of dewatering or to provide less sludge by a modification to the operation of the biological system, and measuring the change in the nitrogen balance was one way to find out the characteristics of the sludge produced.

39. Mr COTTON said it was possible to measure the flow and suspended solids of what went in and came out of primary tanks. In trials carried out several years ago at Norwich, these results were considerably disturbed by the diurnal variation of flow and load, by uneven settlement and by uneven rate of removal. Desludging of tanks must bear some relationship to the shapes of the tanks and an acceptable level of tank effluent quality. Full-scale experimental work at the Skelmsdale New Town had used a fancy-shaped sedimentation tank which apparently gave improved hydraulic settlement characteristics and room for the settled sludge out of the sphere of influence of the settling solids. At Norwich the tanks were conventional, with a hopper for a day's make of sludge. Perhaps automation could be used to relate what went in and what came out to the shape and the performance of a particular tank, but it was not straightforward.

40. Mr G.F.G. CLOUGH picked up Mr Drake's point that experiments on a half-hour retention in a primary tank would presumably have to be done on a full-scale work to get full-scale results. That was the case at the moment, but a plant of the Department of the Environment was being built specifically to deal with this problem. It had two parallel streams each handling 100 000 gallons per day (i.e. 454 m^3/d) to allow full-scale experiments to be done on a realistic scale, and two different methods of treatment to be compared. At the same time there were extensive flow balancing and load balancing facilities in the system, facilities for sludge dewatering, taking back the liquors from the sludge dewatering system and putting them through the process plant. It would be possible to see the effect any particular change in method, either process or sludge dewatering, had on other parts of the works.

41. Mr CLOUGH agreed with the definition of automation. It was important to distinguish between automation and mechanisation as many of the problems which were blamed on automation were in fact problems of mechanisation. He thought the economics of large units might in some circumstances be illusory for several reasons. Firstly, the costs of industrial labour trouble were not usually taken into account. Large production units were economic provided they were producing units of the same type in large numbers, but once there was variation in units the economics rapidly started to deteriorate. In the communications field the economics of scale were, on occasion, reversed; a very large telephone system was more expensive for a subscriber than a small one because each subscriber had access to many more numbers. However, in the future energy saving would be much more important and relatively little energy was needed in communications. Therefore in the sewage treatment field Mr CLOUGH saw one of the major scopes for automation being in the control of a large number of rural works. Joining works by pumping sewage for many miles was economic from the point of view of employment of labour, but it was not economic in terms of energy employed. Moreover, Mr CLOUGH thought most river systems would prefer to have a series of small doses of effluent than one large one. This left the problem of controlling a large number of small works; telemetering would at least tell what was going on in each case.

42. One of the problems of rural works was grass cutting, and therefore one of the major needs was for a self-propelled grass cutter capable of sensing the grass growth, disposing of the cuttings, with a low energy consumption, low initial cost and a high scrap value; Mr CLOUGH suggested sheep.

43. Finally Mr CLOUGH asked Mr Cotton to expand on his comment in the paper which implied it was possible to assess causes and control the bulking of activated sludge.

44. Mr COTTON said that in the Norwich Sewage Division communication was the biggest problem with 300 sewage works spread over 2 100 square miles. The distances involved were so great that all sewage could not possibly be treated at one site. When the system had been rationalised during the next five to ten years there would be some grouping together of works under a series of central controls.

45. Mr COTTON said that when they decided to have activated sludge at Norwich they had tried pilot plants that produced bulking sludge. In spite of reading every available piece of literature and consulting the WPRL for their help, they were unable to discover why the sludge bulked. However, should bulking occur they put sludge level detectors in the final settlement tanks, mixed liquor solids detectors and dissolved oxygen probes in the aeration channels, and linked the rate of return of activated sludge either as a proportion of the flow going into the plant or a fixed volume or a fixed percentage, whichever they chose. If the flow of sewage into the tanks was less than storm conditions and the rate of change of returned activated sludge increased to maintain a predetermined level of mixed liquor solids, then it could only be because the density of the sludge had decreased

thereby indicating bulking. If this increased rate of return exceeded a pre-set condition, it could be translated into some means of alarm, action or change. The levels were not yet known because the plant had to be operated to find out what the norm was, and the diurnal variations to achieve optimum performance under given circumstances.

46. Mr A.P. MICHAELSON mentioned the use of computer automation for linking works on a regional or sub-regional basis. This principle was being practised to a small extent in experiments at Motherwell where three works were currently linked. This was the possible future application of this technique. At Norwich a high capital sum was invested for one works and Mr MICHAELSON felt that capital plant may be very much under-utilized and great benefit might be obtained by bringing information in from a whole series of works.

47. Another point mentioned earlier was cost-effectiveness and Mr MICHAELSON wondered if in the original stages of deciding whether this scheme was cost-effective, particularly with regard to man-power, whether or not a full Organization and Method study had been undertaken. Mr Cotton had mentioned a reduction of staff from the proposed 43 to 38. Was this a saving which Mr Cotton hoped to obtain by virtue of mechanisation and computerisation? Also what was the dry weather flow for the Norwich Works?

48. Replying to Mr Michaelson's suggestion of linking groups of works to provide information to the central point, Mr COTTON affirmed that Motherwell were doing this. It was perhaps more vitally used for monitoring in the clean water industry. Its application was more complicated in waste-water treatment plants. Under no circumstances could any of the software developed for the Norwich plant be used for any of the other 300 works. Software was expensive and difficult; if it was decided to operate a process or plant in a particular way for a particular length of time, then a sub-routine or a main programme could be written and superimposed and modified, without buying any further hardware. The plant was not under-utilized or over-capitalized in the sense that it was an on-line computer. It was working on that programme 24 hours per day. Perhaps an advantage not yet attributed to this system was that at the moment all the major labour intensive jobs were done on a day-work basis as there was no shift working. If the system proved itself and worked, there was no reason why all the other jobs could not be spread over 24 hours, or twice as many done by some being done at night.

49. Mr COTTON said the capital cost was not high as Mr Michaelson had suggested; 2% of the total capital cost on instrumentation and substantial automation was, in Mr COTTON's opinion, low. It was about time sewage treatment was made more of a science. Perhaps if Mr Clough asked him in five years what to do about bulking sludge he may be able to tell him not how to prevent it but possibly what to do about it. It was very easy to say that it was not necessary, under-utilized and cost too much, but it depended on what one wanted to do and how much one was prepared to pay to achieve it. Perhaps the scheme at Norwich when compared with that at Motherwell was different only in respect of scale.

50. Mr COTTON said a full O and M study had not been carried out, but the cost-effective study prior to automation was done by himself and the consultants, along with other engineering staff in the City Engineer's Department at Norwich.

51. The 43 men were for the works as it was designed without automation. An automated plant was not proposed originally, but extensions to the major plant were designed and then when it came to the question of how to operate the plant, the possibilities of what could be automated, why they wanted to automate and what the facilities were for automation, were delved into, and the computer was arrived at as a development of the design programme. Both the old works and the new design were modified in minor ways to accommodate some of the mechanised gear - for example valve gear on the inlet works was much larger than it would have been had it been manually operated, and in the desludging set-up on the sedimentation tanks the chambers intended for telescopic valves had to be slightly modified to provide access to the ultrasonic detector heads. The design capacity was 54,500 cu. metres per day.

52. Dr P. COACKLEY asked Mr Cotton what sort of relationships he would expect between the various parameters. For some time he had seen that it was of little use trying to express relationships on sewage works based on bulked 24-hour data when the process time lasted anything from half-hour to 4-hours. There were statistical laws which governed the frequency of collecting information and the time required for a process. Some years ago Professor Hamlin studied input and output across the primary sedimentation tanks at one of the Birmingham

works and could find no relationship between them. Dr COACKLEY thought the problems of finding relationships were very great, although these relationships were necessary to go to the next stages of operating the plant on the basis of what was happening in the various sections.

53. Dr COACKLEY was very disturbed about the poor equipment available for chemical and physico-chemical measurement and wanted to know what standard deviations had been found at Norwich for the various types of sensors. He had had very detailed looks at the performance of suspended solids sensors, which worked well for a period but his investigation needed results continuously over periods of up to five days. Problems could arise before the five days because the sensors had to be cleaned. He was not happy with ammonia probes and other ion-selective electrodes on sewage treatment plants. Dissolved oxygen sensors and pH recording seemed to be quite satisfactory, but Mr Cotton had mentioned organic carbon and Dr COACKLEY's impression was that TOC's could only be obtained for an hour or two with the equipment available. On-line respirometers gave trouble with reliability when they were operated over one or more days on a continuous basis.

54. Mr COTTON replied that relationships might not exist between all the parameters that they hoped to measure, but some relationships could already be observed. These were generally associated with changes in process and process control and interlinked processes. In one of his papers Mr COTTON had referred to automation as piecemeal or interlinked, and it had been noticed with the computer only one third on-line that one process had affected another. Mr COTTON hoped to establish a relationship between nitrification, settleability of activated sludge and sludge production, and to relate this to the available methods of sludge treatment and disposal, with its effects and costs on sludge treatment. At Norwich, being an agricultural area, they had chosen disposal by dispersion to agriculture, and the treatment processes had been designed with that in mind. However both pressure filtration and anaerobic digestion were prone to certain problems which they thought could be accommodated by interlinking the method of operation to preceeding processes. In the laboratory it had been found that raw sludge could not be pressed if the proportion of surplus activated sludge solids was more than about 12% by dry weight.

55. At the Norwich works, being an experimental plant, they were measuring not only the technical parameters but the cost effectiveness of every section of the work. Collaboration of financial with technical data could form a fundamental basis for optimisation. The present process controller was on a 24-hour daily operated basis, and a day's record for all the parameters could be put on paper or punched on a tape. Further analysis of the data and relationships between measured parameters could be sorted out either by adding a small part to the computer or by the Water Research Centre undertaking this as a research study.

56. Mr COTTON had done quite a lot of work on suspended solids meters, measuring suspended solids in final effluent of perhaps 100 mg/l, and in mixed liquor up to 10 000 mg/l. He understood that Mr Lewin had conducted trials with an ammonia probe. Magnetic flow meters were fairly straightforward and appeared to be giving true results. Mr COTTON hoped to use respirometers in determining on-line treatability with assistance from the Water Research Centre, but there was still a great deal to be done and it was difficult to obtain instruments even for trial periods.

57. Mr G.F.G. CLOUGH wished to comment on the reams of paper which came out of the computer. An alternative approach which he had been looking at was the production of graphs from the punched tape. Mr COTTON replied that they did not have reams of paper; a complete log of the Norwich Plant on a normal print-out was 24" x 6".

58. Mr P.R. BUSBY advocated the use of a back-up computer for plant maintenance. This was essential throughout the works and if the operations staff got together once a week and discussed the maintenance programme for that week, then plant would not be taken out without other people's knowledge. For many years the practice in the Metropolitan Public Health Division had been that all instructions went through the assistant manager of operations.

59. Mr BUSBY supported the philosophy of the paper, but he thought initially the computer had to be used on a trend basis and he did not agree with the idea of modelling the system. He felt it was important to remember that the control of a sewage treatment works was an art and not a science and suggested that the experienced man with good eyes, ears and a sensitive nose still had a valuable contribution to make.

60. It had been suggested that the sewerage system could be utilized for reducing the diurnal variation. On a new system which could be designed to be self-cleansing at

all times, this was fine, but Mr BUSBY sounded a note of warning not to try it on an existing system. He knew five miles of triple sewer (10'6" diameter) which by force of circumstances had been used in this way and there was three foot of detritus in the bottom. It was much more expensive to clean a sewer than a balancing tank.

61. Mr BUSBY agreed that the sewerage system should be integrated and controlled, and thought the American programme employed computer control to use the sewerage system to the full before discharge to the river. In a combined system the works would have to play its part because on warning of an approaching storm all pumping stations should be going flat out to bring the flow level down to give the maximum volume available in the sewers to take the storm flow before discharge to the river. That rather knocked the idea of using a combined system for easing variations in flow at the works.

62. Regarding the 2% on instrumentation, Mr BUSBY imagined that whether there was automation or not, one would like instrumentation, so automation itself was probably an even smaller percentage of total capital cost.

63. Mr COTTON said the back-up computer at Norwich was bought as spares but was a complete system and cost £2000. It was used for off-line work including plant maintenance. They did not have the problems that were present in the old GLC set-up insofar as the maintenance engineers and the managers were all in operations in the Anglian Authority, and were responsible to the works manager or an area manager, and exercised and incorporated management at that level. The works manager mainly controlled the labour, the selection of processes, movement of labour and co-ordination of the maintenance and scientific aspects. They all sat round a table and discussed each others' work - where it overlapped and where it interfered. It was taken further to involve the men and the trade unions where significant changes could affect earnings and/or performance.

64. Mr COTTON was not sure that they controlled automatically by trend, but by acting on information as it was received. When operating by trend there was a tendency for an answer to be got before the problem was known.

65. Mr COTTON said the two computer operators at Norwich were interchangeable, in the case of illness etc, and operated a certain series of functions at weekends. One man was normally operating the box on a day-to-day basis for changes in operation parameters, and the other man was out on site physically looking, listening and smelling and was in radio communication with the man in the control room. They alternated so that there was no feeling of being a man and his assistant; each did the same job in different ways. It was partly designed this way to give confidence in the system, and also it was anticipated that once the system had proved itself to these men they would suggest methods and ways by which the system could be improved.

66. Regarding the 2% capital cost, Mr COTTON agreed that had they not had automation, some of this would still have been spent on a certain amount of flow measuring, sensing of volume, etc.

67. Mr N.W. ANDREWS asked the name of the computer language used, and whether a programmer was employed part-time as a programmer and part-time something else, or was someone hired to do the programming.

68. Mr COTTON said the system was the K70 system and the language was prosel and prolog. It was a system developed by Kent themselves on technical installations with that particular series of control. It was a semi-high level language using technical symbols, like calculus in the sense that there were a certain series of instructions and definitions that had to be learnt by heart in computer language, which were mainly abbreviations of familiar terms. Once learnt, flow diagrams could be drawn and checked and written in this language, and therefore a programmer was not employed at all. The biggest problem was not so much learning the language but thinking in a logical way. So far they had endeavoured to retain the major programs but change sub-routines. They had now changed all the parameters in the existing program, which were written by the computer manufacturers. Several people had been sent on familiarization courses and a software course, as well as a course on maintenance of the hardware system. The biggest problem was going back to school to learn binary notation. Subsequent programs could be tried out. For different methods of operation, sub-routines or programs could be simulated, written out and checked on the off-line computer. If they were logical and would work, the sub-routines in the main cores could be replaced by new ones.

69. Dr P.R. HELLIWELL suggested that the computer control system had been superposed on a works designed for manual operation

using the computer to replace the actions that would have been done by people in the absence of the computer. Mr Cotton had said earlier that if he had been designing with a clean sheet, he would not have done this, and Dr HELLIWELL asked him to give some indication of how his approach would have differed had he been designing a sewage treatment plant from scratch to operate as a fully-automated system.

70. Mr COTTON said he would have gone to CIRIA and looked very closely at their optimisation study. It would have started with the civil engineering design. They would have gone back to basic fundamentals which in some respects they had had to do when converting from manual operation to automation. In fact automation was not an after-thought; it came about by the design engineers asking questions about operating an activated sludge plant. When he was not sure of certain fundamentals, Mr COTTON had used belt and braces.

71. Mr R.C. RAMSAY asked whether in Mr Cotton's belt and braces there was enough spare capacity in various units to enable him to use the plant at Whitlingham as a research tool. For example was there enough spare capacity in pipework etc to run a settlement tank at a half-hour retention? Therefore, in addition to having basic records of how the plant was operating as designed, could Mr Cotton produce research information on the operation of the settlement tanks at half-hour retention, or by additional loading on the aeration tanks? Was this something which could be done with the software and/or hardware which was fitted up in the computer control?

72. Mr COTTON said that the official design capabilities of the two separate treatment plants at Norwich was 6 mgd in each plant. One plant at the moment was taking 10 mgd and was originally designed for 14 mgd. Much more could be got through certain units than was officially allowed; hydraulically they could get 28 mgd through the filter plant. The new plant was designed on the conventional system, but they could interrelate the two plants insofar as on some channels of the activated sludge plant there were facilities for pumping back to the inlet of the filter plant any effluent that was particularly bad. There were reserves by an accident of design. The activated sludge plant was designed on 10-hour retention of dry weather flow as it had to achieve nitrification. It could probably still be done by using half that plant and using the other half for experimental work. As far as the software was concerned, Mr COTTON thought there was endless flexibility, particularly with the off-line computer. They could re-write complete new programs and methods of operation or simulate operational problems. Over the past 12 months there had been some delay in settling down due to re-organization, with a lot of new people who needed to become familiar with what they were doing. Worthwhile experimental procedures would probably be seen in another year's time.

73. The CHAIRMAN said a number of problems had been brought out during the discussion. Perhaps when re-organization had settled, automation would show how to do more with sewage treatment plants. He thanked Mr Drake for opening the discussion and the contributors to the discussion and finally thanked Mr Cotton for dealing so ably with all the questions that had come up.

A. M. BRUCE &
J.C. MERKENS

developments in sewage treatment for small communities

INTRODUCTION

In recent years, many small rural communities in this country have been included in area main-drainage schemes and connected to a 'central' sewage-treatment works serving a sizeable though widely scattered population. These area works, though not of major size, are usually large enough to be designed and operated on the same lines as urban works and to receive daily supervision and expert control. They normally perform satisfactorily and present no special technical problems. By assent, this arrangement represents the best means of sewage disposal in rural areas.

The extent and coverage of such schemes is, however, limited by economic and geographical considerations and there remain, still, numerous isolated populations from a single household to a few hundred people who depend entirely on a small-scale, locally-installed plant for treatment of their sewage. In many situations, the plant is too remote and too small to receive more than an occasional visit of inspection or more than the minimum of maintenance; not uncommonly, especially in the case of privately-owned plants, it will remain totally neglected for long periods. It will, however, still be expected to produce an effluent of satisfactory quality at all times and not represent any form of nuisance.

In addition to these factors, small domestic treatment plants are invariably subject to the strain of very wide variations in the rate of sewage flow, ranging perhaps from practically zero flow to 6-8 times the average rate - reflecting the intermittent usage of water by the population and the short length of connecting sewer. The sewage will usually also be strong in character and the production of an effluent of the '30:20' standard (suspended solids not greater than 30 mg/l, and BOD not greater than 20 mg/l) will require at least 95 per cent BOD removal during treatment, which is close to the upper limit of efficiency for biological systems.

The key requirements for small plants are clearly, therefore, reliability without frequent supervision or maintenance; simplicity, and adequate resilience and capacity to give very high purification efficiency under all flow conditions. For small sites, compactness and unobtrusiveness are also important requirements, as is the ease of sludge disposal. Their usual proximity to habitations makes it particularly desirable that such plants do not give rise to nuisance from odour, flies or noise. All this should, of course, be achieved at acceptable cost.

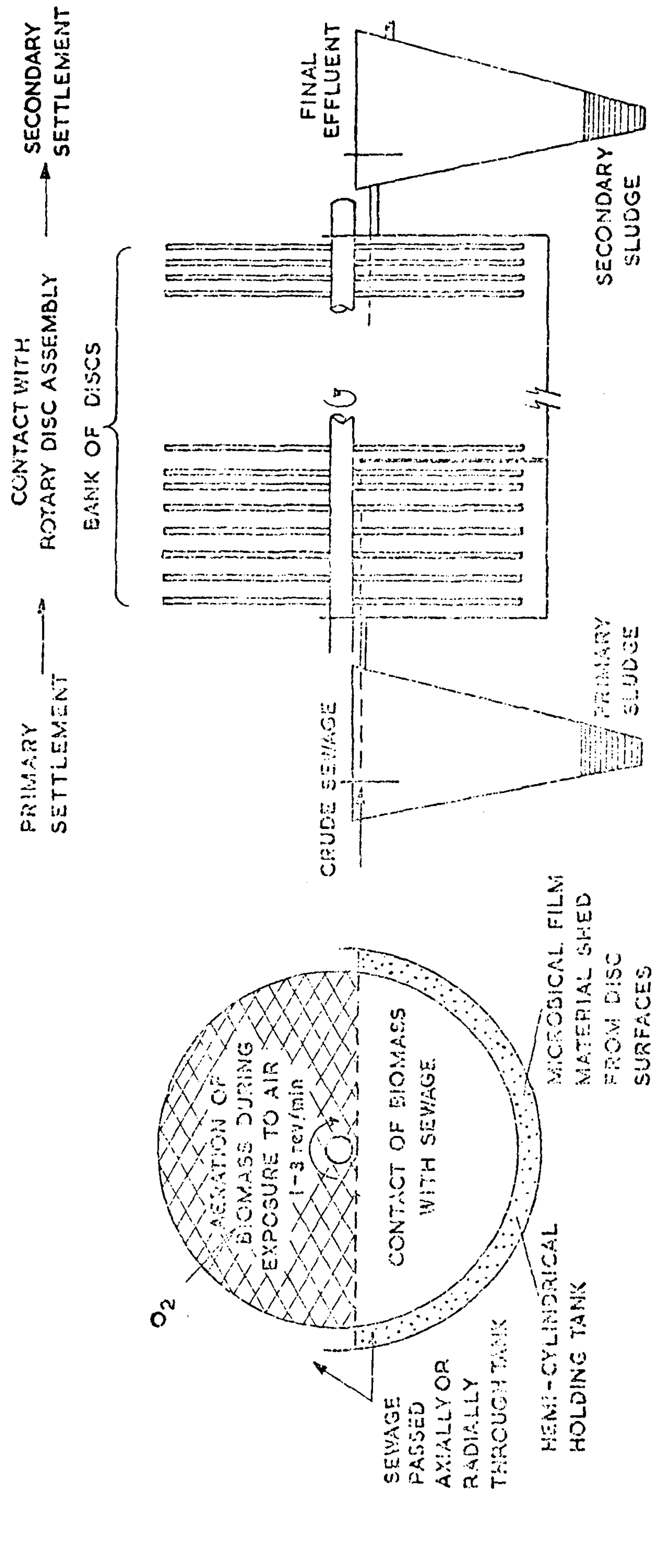
The market for small sewage-treatment plants is very extensive (including, typically, single isolated houses, small estates, institutional establishments, holiday and recreational sites, temporary construction camps and the like) and it has attracted a good deal of commercial interest. A wide variety of proprietary systems have appeared over the years and there is a continuing search for a system which will come close to satisfying all the requirements mentioned earlier. There is, as yet, no 'best method' for all circumstances. The 'established' systems of treatment for small communities(1), namely the septic tank installation, the percolating filter, and the extended-aeration variants of the activated-sludge process (mainly in the form of package plants) - are each suitable for certain, but not all, applications, though each system has been subject to continual improvement in design and reliability over the years. This paper is concerned mainly with some alternative methods of treatment of sewage which have been developed and marketed in this country in recent years, more specifically for use by small communities. The first and main section of the paper concerns 'rotary biological contactors' which represent perhaps the most radical departure from conventional biological systems. Two other systems are then discussed: firstly, that of 'extended filtration' and secondly the 'submerged-bed aerated filter' both of which have also been subject to some research at the Laboratory. Finally, the complete spectrum of treatment systems now available to the public health engineer is briefly reviewed in relation to some of the selection criteria that might be applied in choosing a plant for a particular application.

ROTARY BIOLOGICAL CONTACTORS

Rotary biological contactors (RBC's) were used experimentally for sewage purification as far back as the beginning of this century, but there was no significant application of the principle until some 15 years ago when rotary-disc (or 'dipping-contact') biological filters were produced and installed in some continental countries, particularly Germany where they originated(2). Since then, this type of plant has been introduced to a number of other countries including the UK and the USA. Two proprietary systems, of basically similar form, have been available in this country for the past 4 or 5 years. In both cases, emphasis has been given by the manufacturers to the particular suitability of the plants for treating sewage from small isolated communities - mainly because of the claimed simplicity, robustness, ease of operation, and low maintenance and supervision requirements of the plants - though the principle is not restricted to small-scale application. Most of the versions marketed are complete package-plants, though separate disc-assemblies are also available for installation in existing septic tanks. The total number of plants in operation in the UK now is probably around 100, but experience of their field performances is still extremely limited and little has been reported so far. Their status, in relation to other biological treatment systems, has not therefore been fully established.

The design and method of operation of the rotary-disc biological filter is essentially simple (Fig. 1). Following screening and grit removal (if necessary) and primary settlement, either in an integral settlement-zone of the plant or in a separate primary tank, the sewage passes through a contact tank in which a large number of closely-spaced vertical

Figure 1: PRINCIPLE OF OPERATION OF ROTARY BIOLOGICAL DISC FILTER



discs supported on a horizontal shaft are continuously rotated semi-immersed in the liquid. The shaft is actually positioned just above the top level of liquid in the tank so that just under 50 per cent of the surface area of the rotating discs is at any one time immersed while the other portion is exposed to the air. Normally, the rate of rotation is about one rev/min. Like the medium in a conventional biological filter, the discs serve essentially as physical support surfaces for the growth and attachment of a film of micro-organisms which effect biological purification. Rotation of the discs brings about periods of immersion and direct contact of the microbial film with the sewage, alternating with periods of exposure of the film to the air to provide oxygenation. The alternating immersion-aeration phases give the system some basic similarity to the old contact-bed system of treatment.

After passage through the contact tank or, in some cases through a number of tanks in series each containing discs, the purified effluent passes through a secondary settlement tank to allow removal of any biological solids (humus) which have become detached from the discs and carried out of the tank with the liquid phase. Both primary and secondary sludges are required to be removed from the plant at regular intervals; in one design of plant, sludge from the secondary compartment is returned automatically by a re-cycle system to the primary tank.

The configuration of the contact tank is normally hemi-cylindrical with the wall fitting fairly closely to the edges of the discs so that there is little 'dead' volume within the tank. In some designs, slots are provided along part of the base of the contact tank in order to permit some of the biological solids to fall through into a lower sludge-storage zone inter-connected with the primary tank, rather on the Imhoff-tank principle. In other designs, all of the biological material which becomes detached from the discs is passed through the tank as a suspension with the liquid phase. The presence of this suspended biological matter is not thought to be detrimental but, on the other hand, neither does it contribute significantly to the purification capacity of the plant. The biomass of the solids is very small compared with that adhering to the discs.

The discs may be fabricated from metal-mesh or plastics-mesh material or from expanded polystyrene. They are usually spaced on the shaft at 3-5 cm centres, leaving a sufficient gap between each to prevent bridging growth of biological film. The diameter of the discs may range from 1 m in the smallest plants, to as much as 3 m. Most plants are dependent on a mains electrical supply for the power necessary to rotate the discs, though a plant relying on water-wheel drive using the available head of sewage has been reported. The normal loss of head of liquid through rotary-disc plants is very small, amounting to a few centimetres.

Typically, disc-assemblies are enclosed by a ventilated cover which provides protection against the effects of the weather (particularly rain and frost) and other forms of interference and also helps to make the plant as unobtrusive as possible.

Performance Characteristics

The performance of a proprietary 'BioDisc' plant, when treating a crude domestic sewage, has been investigated in trials carried out at the Laboratory and results have been described in detail elsewhere(2). The plant involved was a package unit designed to serve 25 persons. It comprised a primary settlement zone (1.5 m^3 in volume), a contact (or 'biological') zone containing 100 expanded-metal discs of 1 m diameter, and a final settlement zone 2.7 m^3 in volume. The contact zone was sub-divided by baffles into 5 equal-aize compartments with 20 discs in each.

The floors of the first two compartments were provided with narrow slot openings to permit biological solids released from the discs in those compartments to fall into a sludge storage zone below.

Over a seven-month period of study, comminuted Stevenage domestic sewage was fed to a plant at an average rate of 2.7 m^3/d, calculated to be equivalent to the daily flow from some 25 persons. For the initial five-month period of operation, sewage was pumped to the plant at a uniform rate every 5 min throughout each 24 h. In two subsequent, shorter, phases of operation, the rate of sewage flow was varied diurnally to simulate more closely the conditions that would occur in practice. In the first of these phases, all of the daily flow (2.7 m^3) was passed to the plant at a uniform rate during 16 out of each 24 h, with no flow occurring during the 8-h night period. In the next phase of operation, a marked variation in the daily flow pattern was introduced by increasing the rate of flow to 3 times the average rate during three 2-h periods in the morning, afternoon, and evening; in the intervening periods, the flow was reduced to 0.6 times the average rate.

After start-up, about 6-8 weeks of operation were required for the discs to develop a full growth of biological film and for the plant to mature. During the following months of operation under steady 24-h flow conditions, the effluent produced by the plant was usually of satisfactory quality in relation to the 30:20 standard and there was a partial degree of nitrification (Table 1). During the phase with a steady flow during 16 h only of each day, performance continued to be satisfactory. In the next phase, however, under the conditions of the 'wave' flow-pattern, the effluent showed a noticeable deterioration in quality, though 50 per cent of the samples still had BOD values of 20 mg/l or less and a small degree of nitrification was maintained.

Further investigations with the plant showed that, if the sewage loading was increased to significantly more than 2.7 m^3/d, even with uniform flow conditions over 24 h and during relatively warm weather, the quality of effluent became very unsatisfactory. It was concluded therefore that the maximum daily average sewage loading suitable for a plant of the size tested was about 2.7 m^3/d or, in terms of crude sewage BOD loading, 1.5 kg/d.

Design Loadings

The most appropriate plant loading parameter to consider in the case of rotary biological contactors is the daily weight of BOD applied, after primary settlement, per unit area of surface of the contact medium. This parameter indirectly represents the biomass loading - to which BOD removal efficiency is normally inversely related - since the weight of active biomass in the plant can be assumed to be proportional to the area of surface available for microbial growth. In the 'BioDisc' investigation described earlier, the average settled sewage BOD loading was 6 g/m^2d which, on the basis of a *per capita* daily settled sewage BOD load of 37 g, is equivalent to about 6 m^2 of disc surface area per person. It might therefore be concluded, tentatively at least, that a BOD loading of 6 g/m^2d after primary settlement would represent, for design purposes, a reasonably safe upper limit for small rotary disc plants required to treat strong domestic sewage and to produce an effluent of 30:20 standard; this would probably allow for variations in flow of up to 3 times the average rate. However, much more field experience of the performance characteristics of rotary-disc plants is obviously needed in this country before design parameters can be codified. The influence of seasonal temperature change has not, for example, been fully quantified, though one report(3) from the USA indicates that a 30 per cent reduction in loading might be necessary to achieve the same quality of effluent at 7°C as at 18°C.

Table 1. Average conditions of operation and performance of a 'BioDisc' plant working under various daily flow regimes (ranges of values in brackets)

Phase	Period	Average volume of sewage treated per day (m^3)	Flow regime	Average temperature of sewage (°C)	Sample	Average result of analysis				
						BOD	COD	SS	Ammonia (as N)	Oxidized nitrogen
						(mg/l)				
I	April-July	2.7	Steady over 24 h	14	Crude sewage	544	1056	534	50.0	-
					Effluent	19 (32-9)	93 (130-64)	27 (52-14)	24.1 (40.2-12.8)	12.2 (25.0-2.6)
II	July-August	2.70	16 h per 24 h	16	Crude sewage	477	1034	474	39.0	-
					Effluent	14 (19-4)	74 (108-58)	21 (50-8)	15.8 (22.8-1.8)	13.1 (17.1-7.7)
III	September	2.69	16 h per 24 h + 3 peak-flow periods	14	Crude sewage	478	1188	552	48.7	-
					Effluent	23 (39-17)	134 (214-86)	35 (52-10)	28.4 (48.4-22.0)	9.9 (12.4-7.0)

It is relevant here to consider briefly the basis for design of rotary-disc plants which has been adopted in Germany, where there has been much more operational experience, although without the general requirement to produce effluents of quality as good as 30:20 standard. Steels(4) has recently described the design calculations which are employed in that country and which are based on the findings of Hartman. The calculations are based on empirical curves which have been established from field observations, relating percentage BOD removals to the rate of flow and the BOD of the sewage, and to the surface area of discs: plant size and diurnal variations in flow are factors which are also taken into account in the design calculations. Inspection of the curves indicates that if an effluent with an average BOD of 15 mg/l is required to be produced from a domestic sewage with a BOD, after settlement, of 300 mg/l (i.e. a BOD reduction of 95 per cent) then, if the plant is to serve a population smaller than 400 persons, the design specific BOD loading should be about 6 g/m^2d - a value which is in good agreement with that indicated from the 'BioDisc' study described earlier. However, for plants serving large urban populations, and where an effluent with an average BOD of 20 mg/l would be satisfactory, the specific BOD loading indicated by the design calculations would be much higher at between 12 and 18 g/m^2d. Indeed, many plants in Germany are designed on the basis of the higher loadings indicated.

It is of interest to note that Krauth and Staab(5) reporting on the operating results of a number of rotary-disc plants in Germany, found that few plants achieved a removal of BOD as high as 90 per cent. In a statistical analysis of their observations, they concluded that an effluent with a BOD of 25 mg/l or less would only be obtained if the BOD loading was 10 g/m^2d or less and that if 90 per cent of all values were not to exceed 25 mg/l, the loading should not exceed 4 g/m^2d. It is also relevant to note that observations of a rotary-disc plant treating sewage in the USA showed that a BOD loading of 2.7 g/m^2d was appropriate to achieve a 95 per cent reduction of BOD.

Operating Features

The investigation of the 'BioDisc' plant at the Laboratory broadly confirmed the advertised claims that rotary-disc systems are simple to operate and require only minimal supervision and maintenance. Routine operational procedures are confined to desludging at intervals and cleaning down of channels and weirs as necessary; no skilled control is required.

It is essential, of course, that the discs are kept in motion for the biological treatment efficiency to be maintained, but stoppages of up to a few hours do not normally cause serious after-effects. Longer break-downs, however, may result in the biological film on that portion of the discs exposed to the air becoming partially dehydrated, causing it to fall from the discs. The resultant unequal distribution of weight on the discs can place a serious mechanical strain on the disc assembly and drive motor.

Plants of the rotary-disc type have been found to be quiet in operation and subjectively, at least, seem to produce no unpleasant odours, apart from those occurring at the time of desludging. Claims that plants of this type are able to withstand 'shock loads' or prolonged underloading without ill-effects have not been substantiated.

In the tests at the Laboratory, the rate of production of sludge by the 'BioDisc' plant was estimated to have been about 0.6 kg dry matter per kg BOD applied in the crude sewage. Steels(4) has indicated a rate of 0.8 kg/kg BOD removal, based on observations of plants operated at low loadings. Both values are within the range normally found for other types of biological treatment plant.

Other Forms of Rotary Biological Contactors

Although most of the practical applications of rotary biological filters so far have centred around the use of disc assemblies as the contact surfaces, some other forms of 'media' are potentially suitable for this function and a number of possible alternatives have been explored from time to time. Early in this century, for example, treatment plants incorporating rotating bundles of brushwood or straw were constructed; in later years, rotating lattices of wooden laths were employed experimentally, though without notable success. Very recently, treatment systems utilizing rotating drums filled with small plastic spheres, or rotating reels of spirally-wound plastics tubes, have been marketed commercially as alternatives to 'disc' plants. Little information is available, however, about the performances of plants of this particular type.

In recent years, some studies have been made at the Laboratory of a number of pilot-scale rotary contactors employing plastics filter-packings as the contact media. These packings have, of course, been developed mainly for use as media in high-rate biological filters and are available now in a variety of forms. Most of the studies involved the so-called 'random-fill' media which comprise essentially aggregates of small thin-walled hollow plastics cylinders with internal cross-septa. Such media have a relatively low bulk density and possess high voidages and specific surface areas. It was of interest to determine the suitability of these media in comparison with that of spaced discs for rotary biological filtration.

For one of the main studies, a pilot-scale 'Biobasket' plant was designed and built at the Laboratory and operated in the open for about 9 months using settled Stevenage sewage as the feed.

The 'Biobasket' plant (Fig. 2) consisted essentially of a hemi-cylindrical tank (1.87 m in length and 0.92 m in diameter) within which were suspended 3 rotary cylindrical baskets (each 0.55 m in length and 0.88 m in diameter) filled with plastics media. All 3 baskets were supported in line on a common axial drive shaft which was positioned just above the top liquid level in the tank so that, in operation, just under half of the basket volume was submerged. Each basket had side and end walls of rigid wire-mesh with wide openings to facilitate free movement of liquid into and out of the plastics medium which was retained inside. Sewage entered the tank at one end and effluent was discharged at the other; a transverse baffle was located in the tank between each basket so as to reduce forward mixing and promote plug-flow conditions. In operation, the baskets were rotated at 0.3 rev/min - a slower speed than is normally used for rotary systems but desirable on account of the greater drag effects of the random packing. The basket nearest to the inlet of the tank was filled with the medium 'Filterpak' 1127 (specific surface area 112 m^2/m^3) and the other 2 baskets were filled with 'Biopac 50' (specific surface area 124 m^2/m^3). The total volume of medium in the 3 baskets was 1.025 m^3 and the total nominal specific surface area of the medium was 131 m^2. The effective liquid volume in the tank was about 0.45 m^3 - taking into account the volume occupied by the medium itself.

During the initial 3-month operating phase of the plant (February-May 1973), a sewage loading of 2.1 m^3/d was employed, all the flow being delivered in 16 h of each 24 h. The loading selected represented a volumetric loading on the medium of 2 m^3/m^3d and a specific surface BOD loading of 5 g/m^2d. Even at the end of the 3-month maturation period, however, the quality of the effluent from the plant was still much inferior to the '30:20' standard and it was concluded that the plant was overloaded. During the following 4 months, a range of lower loadings was employed until it became apparent that the rate appropriate to the production of a 30:20 standard of effluent was about 1.2 m^3/d, which actually represented an average specific BOD load of about 3.1 g/m^2d.

Figure 2: DIAGRAM OF PILOT 'BIOBASKET' PLANT

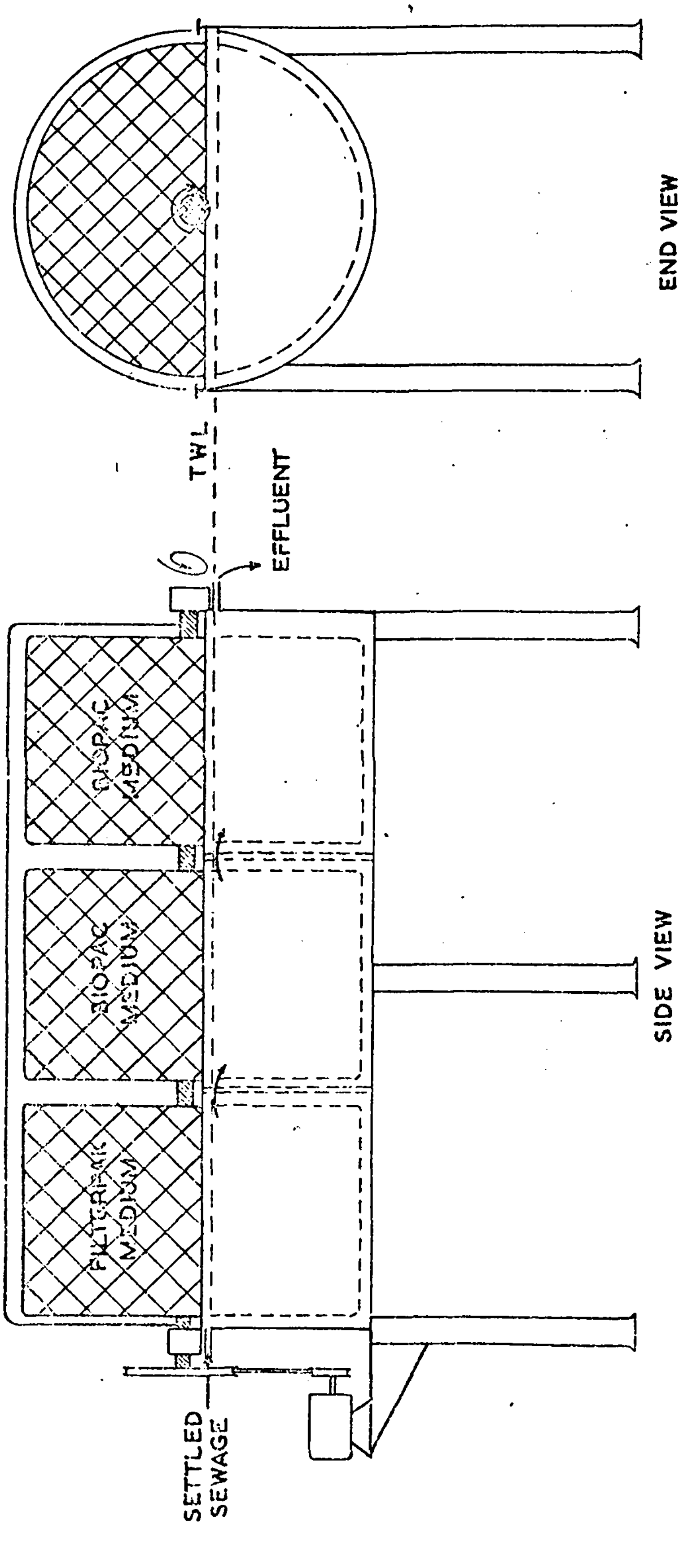


Table 2(a) indicates the mean conditions of operation and performance of the plant for a 4-month (autumn-winter) period at that loading. The results are based on weekly analyses. In comparison, the mean quality of effluent produced during the same period from a pilot low-rate percolating filter, containing 5-cm gravel medium and treating the same sewage at a volumetric rate of 0.26 m^3/m^3d and at a specific BOD loading of 0.96 g/m^2d, is shown in Table 2(b).

Table 2. Mean operating conditions and performance of (a) a pilot 'Biobasket' plant and (b) a pilot percolating filter, when treating settled domestic sewage during the 4-month period October 1973 - January 1974. (Average temp. of sewage 12°C).

(a) Pilot 'Biobasket' plant

Total volume of media in baskets	1.025 m^3
Total surface area of media	131 m^2
Daily flow of sewage	1.2 m^3
BOD load per unit surface area	3.2 g/m^2d
Rotational speed of baskets	0.33 rev/min.

Results of analysis (Mean values and ranges)

	BOD (mg/l)	Suspended solids (mg/l)	COD (mg/l)	Ammonia (as N) (mg/l)	Oxidized nitrogen (mg/l)	Anionic detergent (as Manoxol OT) (mg/l)
Settled sewage	353 (242-433)	203 (102-312)	621 (494-825)	52 (39-59)	- -	31.0 (20-42)
Settled effluent	19 (10-28)	22 (14-29)	80 (64-96)	27 (12-43)	13 (7-28)	2.1 (1.5-2.9)

(b) Pilot percolating filter

Total volume of medium	12 m^3
Sewage hydraulic loading	0.27 m^3/m^3d
BOD loading per unit volume of medium	0.1 kg/m^3d
BOD load per unit surface area of medium	0.96 g/m^2d

Results of analysis (Mean values and ranges)

Values for settled sewage feed as above)

	BOD (mg/l)	Suspended solids (mg/l)	COD (mg/l)	Ammonia (as N) (mg/l)	Oxidized nitrogen (mg/l)	Anionic detergent (as Manoxol OT) (mg/l)
Settled effluent	6 (2-14)	22 (4-64	37 (18-68)	1.0 (0.4-3.0)	31 (23-43)	0.9 (0.6-1.8)

Although the quality of the effluent from the percolating filter was marginally better than that from the 'Biobasket', the volumetric loading was only one quarter of that on the rotary plant, thus demonstrating the greater efficiency of utilization of surfaces in that type of plant. It is appropriate to note here that the plastics medium in the rotary filter developed only a very thin biological film on its surfaces and there was certainly no tendency for an excessive accumulation of biological material. The possibility that random media might become clogged is therefore an unlikely one in this type of plant.

During the period of operation of the 'Biobasket' referred to, there was no simultaneous comparison made of the performance of a rotary-disc plant, but on the reasonable assumption that a rotary-disc plant of the same physical size as the 'Biobasket' would contain 75 discs of radius 0.89 m, then at the same sewage loading (2.1 m^3/d) as that employed on the 'Biobasket, the specific BOD loading would have been 4.5 g/m^2d. At this loading, a 30:20 standard of effluent would have been expected. In other words, the indirect evidence suggested that 'disc' and 'basket' systems would be of comparable effectiveness.

In another programme of investigations at the Laboratory, a more direct comparison of the treatment efficiency of a disc assembly with that of a random plastics-packing was obtained by the concurrent operation of similar-sized pilot plants of each type, both plants receiving the same feed at the same rate of flow. In these particular studies, the feed employed was settled Stevenage domestic sewage which had received partial treatment (about 50 per cent BOD removal) by passage through a larger primary-stage rotary-disc plant operated at a relatively high loading. Both of the smaller plants had hemi-cylindrical tanks of 0.83 m in length and 1.15 m in diameter; one plant contained a single cylindrical open-mesh basket (0.77 m in length by 1 m in diameter) packed with a random plastics medium which provided a total surface area of 96 m^2, and the other plant contained 30 discs of 1 m in diameter which provided a total surface area of 47 m^2. In the case of the disc plant only, the contact tank was divided by transverse baffles into 3 equal-size compartments with 10 discs rotating in each compartment; liquid flowed in cascade fashion from one compartment to the next. The rotary assemblies of both plants were driven by the same motor at a speed of 1 rev/min.

Table 3 indicates the performances of both plants during two successive phases of operation after the commissioning and maturation phases had been completed. The flow of partially-treated sewage to both plants was 1.45 m^3/d. During Phase A, of 108 d duration, the flow to the plants was introduced at a steady rate over a 16-h period each day; in Phase B, of 36 d duration, a wave-flow pattern was introduced by increasing the rate to three times the average rate over three 2-h periods during each 16 h.

The results showed that the two plants gave effluent of similar and generally satisfactory quality in both phases, although the rotary-basket plant was, in each phase, rather more effective with respect to nitrification. The earlier indirect evidence that the two forms of contact media were of similar effectiveness was therefore confirmed. However, since the total surface area available in the discs plant was only about half that available in the basket plant containing the random plastics medium, it may be concluded that in relation to surface area (rather than to volume of medium), the discs showed the greater efficiency. Indeed, in other tests, when the rate of flow of sewage to the rotary-basket plant was increased so that the load per unit surface area was the same for both plants, the quality of effluent from the plant became much inferior to that from the discs. However, one factor which might account for the apparently greater effectiveness of the discs in the tests described is that the tank of the disc-plant was baffled to produce plug-flow characteristics, whereas the basket plant was unbaffled, and forward-mixing of the incoming sewage would have been a possibility. The general conclusion from the tests is that the rotary-basket system with a random plastics medium could serve effectively as an alternative to disc assemblies in practice, at least on a small scale, and might possibly be somewhat more effective in performance than discs and perhaps more economic in terms of manufacturing costs, although there is no specific information on that point. It is of interest to note that in another investigation, the effectiveness, as a medium for rotary biological contactors, of an assembly of tubular plastics media arranged horizontally, was tested but without success. Apart from the failure of the system to produce effluents of satisfactory quality the power requirements to rotate the assembly were much greater than those for other forms of media.

Table 3. Comparative performances of pilot rotary-disc and rotary-basket plants of equal size when treating partially-treated sewage at a rate of 1.45 m^3/d. Results based on weekly analyses of 24-h composites.

Phase A : Steady flow of feed for 16 h each 24 h

Phase B : Irregular ("peaky") flow pattern for 16 h each 24 h

	Mean and ranges of values (mg/l)					
	BOD	COD	Suspended solids	Ammonia (as N)	Oxidized nitrogen	Anionic detergent (as Manoxol) OT
PHASE A.						
Feed to both plants*	110	250	109	44	-	21.5
Settled effluent from Discs plant	18 (8-41)	81 (60-148)	23 (8-34)	17 (5-38)	15.8 (6.5-23)	3.6 (2.0-6.3)
Settled effluent from Basket plant	17 (7-42)	77 (60-124)	29 (14-30)	2.7 (1-6.0)	36.3 (21.5-43.0)	2.4 (1.7-4.5)
PHASE B.						
Feed to both plants*	111	268	81	40.5	-	18.7
Settled effluent from Discs plant	19 (13-27)	79 (68-100)	18 (7-24)	21.8 (16.6-27)	10.9 (8-15.2)	3.7 (3.2-4.4)
Settled effluent from Basket plant	15 (10-19)	73 (56-88)	20 (16-24)	14.7 (5.5-19)	32.5 (28-38)	2.4 (1.5-3.2)

* Sewage partially treated by a first-stage plant

EXTENDED BIOLOGICAL FILTRATION

The principle of this process, which was originally devized at the Laboratory, is essentially the same as that of ordinary biological filtration, except that comminuted crude sewage rather than settled sewage is applied to the filter and the unsettled filter-effluent is recirculated at a very high rate in relation to the sewage flow. The purpose of recirculating unsettled effluent is to promote the aerobic oxidation of crude sewage solids and humus solids to produce a stabilized secondary sludge of inoffensive character. The absence of a primary sludge to dispose of gives the process an advantage over conventional biological filtration and makes it somewhat analogous to 'extended aeration' activated-sludge systems. In order to minimize the risk of clogging of the filter by accumulated solids, a high-voidage plastics medium is employed.

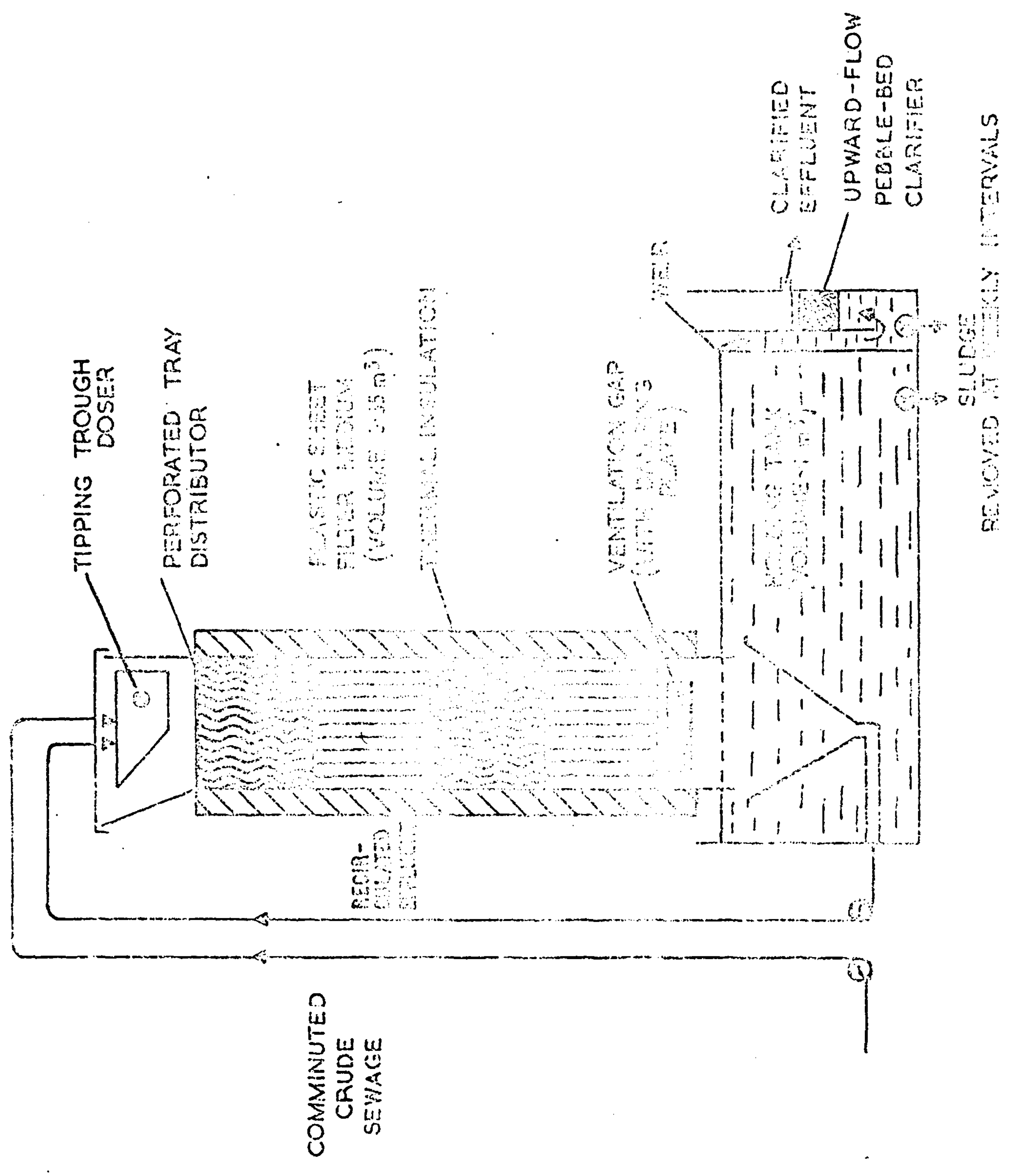
At least two commercial versions of the system, in the form of package units, have been marketed in the UK and a number of plants are known to be in operation in the field. In all cases, a small proprietary combined macerator/pump unit is used to feed the crude sewage to the filter and a random plastics packing is used as the medium. A basically similar type of package plant employing biological filtration and using redwood bark as the medium, has been developed in the USA(6).

Some indication of the satisfactory performance of a number of plants already in use for various small communities has been given(7), but otherwise little is yet known of the behaviour of this type of plant in the field. Most information has been obtained from a pilot-plant study at the Laboratory carried out some years ago. The plant used for these studies consisted (Fig. 3) of a filter tower, 2.1 m in depth and filled with 0.54 m^3 of a plastics sheet medium (specific surface area 187 m^2/m^3), supported over a holding/settlement tank of capacity 0.97 m^3. An inverted pyramidal hopper was positioned in the tank immediately below the base of the tower; the bottom outlet of the hopper was connected to the recirculation pump so as to ensure that the solids discharged from the filter and settling in the hopper were recycled through the filter. The holding/settlement tank was of sufficient capacity to provide a period of settlement of 24-26 h for the filter effluent before passage through a small upward-flow pebble-bed clarifier, prior to final discharge. Distribution of crude sewage plus recirculated effluent over the surface of the filter was achieved by a two-way tipping trough which discharged its contents about every 30 s on to a perforated tray covering the medium; the tray served both as distributor and rag trap.

Performance Characteristics

In a series of operational phases, lasting a total of 13 months, crude Stevenage domestic sewage was applied to the filter at various rates of flow between 0.9 and 1.9 m^3/m^3d; the rate of recirculation was generally maintained at between 6 and 12 times the rate of sewage flow. The main conclusion from the results was that an average rate of application of crude sewage (mean BOD 459 mg/l) as high as 1.9 m^3/m^3d (over a 16-h period each day) could be employed during the summer months, with the production of an effluent of 30:20 standard and partial nitrification. However, for maintenance of that quality of effluent during the winter months, a lower rate of about 1 m^3/m^3d (equivalent to a BOD loading of about 0.5 kg/m^3d) was found to be more appropriate. Even at that loading, however, the rate of treatment was still about 4 times higher than would normally be employed on a conventional biological filter; this higher efficiency is probably attributable partly to the high specific surface area of the medium employed in the pilot filter and partly to the high rate of recirculation which ensured full wetting of the medium.

Figure 3: SCHEMATIC DIAGRAM OF A PILOT 'EXTENDED FILTRATION' PLANT



The main operational problem encountered with the plant related to the 'rising' of humus sludge in the settlement zone of the tank and the clogging of the upward-flow clarifier. To avoid these difficulties it was necessary to desludge the plant completely at least once each week. The rate of production of secondary sludge was estimated to be about 0.6 kg dry matter per kg BOD removed from the crude sewage. However, although it was dark and humus-like in appearance, it was not as well oxidized as sludge from an extended-aeration plant. The sludge had an average proportion of organic and volatile matter of 76 per cent and it tended to become malodorous on standing.

Despite the use of comminuted crude sewage, there was no indication of clogging of the plastics medium at any time over the whole (13-month) period of operation: it is understood that this is the general experience also with plants in the field.

The broad general conclusion from the investigation was that this type of plant is much more efficient than a conventional biological filter in terms of the volume of medium required to treat a given flow of sewage to a 30:20 standard. The sludge produced is also partially stabilized and less offensive than the primary sludge from a conventional filter. This is at the expense, however, of higher operating costs for recirculation and the need to desludge quite frequently. The complexity of operation is also greater than that of a conventional filter, so that the frequency of inspection required would be higher.

SUBMERGED-BED FILTERS

The practice of using submerged beds of contact media, with artificial aeration, for biological treatment of sewage is not new (the 'Emscher' process and the 'Hays' system are 40 to 50 years old) but proprietary package plants of this type have only recently been produced specifically for treatment of sewage from small communities. The extent of their usage is still very restricted, however, and apart from one brief report about operational performance(8) little information is available on their operating characteristics in the field. Some indication of possible performance is available, though, from tests carried out in the past at the Laboratory with a small-scale unit based on the same principle.

In the commercial package plant now marketed, crude sewage after comminution is passed through a series of flooded compartments in a tank; each compartment contains a high-voidage plastics medium of the random-fill type. The contents of the compartments are continuously aerated by means of diffused air issuing from diffusers located beneath the base of the medium; air flow and liquid flow may be either counter or co-current according to the particular compartment. After passing through the contact tanks, the effluent passes to a separate clarifier for settlement and final discharge. Sludge from the clarifier is not returned to the contact zones but passed to a separate aerobic-digestion zone integral with the rest of the plant. Purification in this type of plant depends essentially on the contact of the sewage with an active biological film on the surfaces of the medium (as in a conventional biological filter), with the diffused air supplying the necessary oxygen. Operation as a submerged-bed system ensures complete utilization of the contact surfaces of the medium and a uniformally controlled retention period for the sewage passing through the system. Both factors would be expected to contribute to a higher efficiency of treatment than that of conventional biological filters. Although submerged-bed filters require the provision of an air compressor (a disadvantage shared with the activated-sludge systems) it is claimed that volumetric air requirements are 75 per cent less than those which would apply to activated-sludge systems treating the same BOD load. This is because air flow is not required to mix and maintain the biological solids in suspension, as it is for mixed-liquor solids in the activated-sludge process. The claim is also made that the intensity of BOD loading employed for this type of plant is much higher than for other systems, resulting in a more compact plant for a given size of community.

In the trials at the Laboratory, already referred to, a very small experimental bed was used (Fig. 4) comprising a tube of 67-mm internal diameter and 1.5-m depth filled with small plastics cylinders which provided a specific surface area of 540 m^2/m^3. Settled sewage was passed at a steady rate downward through the bed, which was totally submerged, and air was passed continuously upwards as fine bubbles from a diffuser in the base. The effluent from the bottom of the bed was discharged through an inverted siphon at a level above that of the top of the medium, and then passed to a settlement tank. At intervals of a few days the bed was scoured with an increased air flow to remove surplus solids; this procedure would not be required, however, in large-scale plants employing a medium of large size.

Over a period of several months, the filter was operated at increasing high loadings. The conditions of operation and performance of the plant are summarized in Table 4.

Table 4. Results of operation of a small submerged aerated-bed filter for treatment of domestic sewage.

Filter medium, plastic cylinders; specific surface area, 540 m^2/m^3

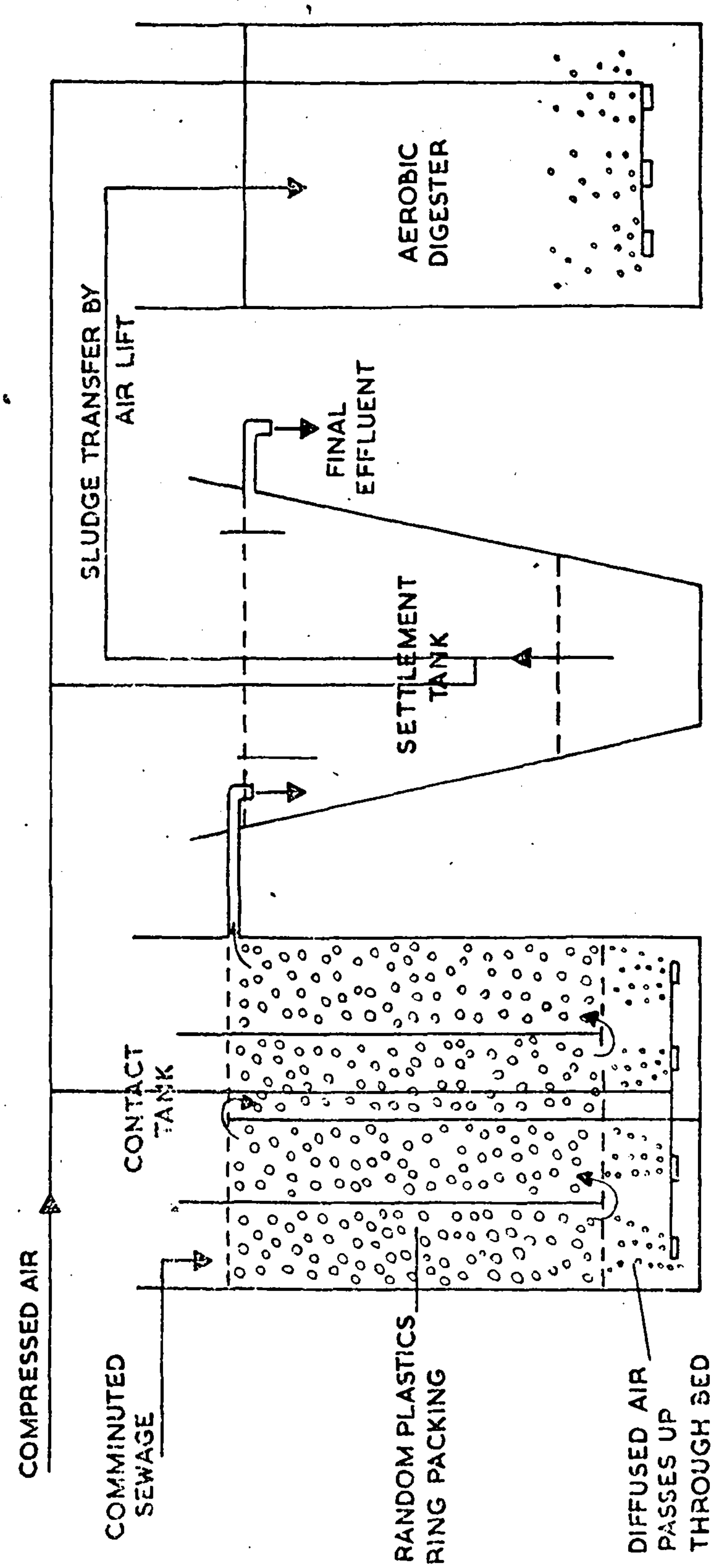
Hydraulic loading (m^3/m^3d)	BOD loading		Suspended solids (mg/l)		BOD (mg/l)	
	kg/m^3d	g/m^2d	Feed	Settled effluent	Feed	Settled effluent
7.85	2.8	5.1	246	13	352	9
11.80	3.3	6.1	270	6	277	8
15.70	3.9	7.2	117	12	248	15
23.50	6.5	12.1	202	11	275	15
31.40	7.8	14.6	-	-	250	42

The most striking feature of the results is the ability of the filter to produce effluents of 30:20 standard at BOD loadings as high as 6.5 kg/m^2d - some 60-70 times higher than that normally employed for ordinary biological filtration. However, the plant was operated under fairly warm conditions and therefore it might be more appropriate to regard the lower loading of 3 or 4 kg/m^3d as perhaps more applicable to practice. It is seen that at this loading the BOD per unit of surface area of medium was 6-7 g/m^2d - a very similar load to that deemed appropriate for rotary biological disc filters. In full-scale plants, of course, a much larger size of plastics medium is employed to reduce the risk of clogging; the specific surface area of such media would be of the order of 70-100 m^2/m^3. Thus a suitable BOD volume loading for a submerged-bed filter required to produce effluent of 30:20 standard might be about 0.4-0.6 kg/m^3d. This is about 4-6 times the loading employed on a conventional percolating filter and demonstrates the higher efficiency of the submerged-bed system. The additional capital cost of constructing a plant involving both a filter medium and a diffused-air system is one possible disadvantage of the system.

CURRENT CHOICE OF PROCESS

The established systems of treatment of sewage for small communities (i.e. those systems included in the B.S. Code of Practice(1)) were briefly referred to in the Introduction, and the main new developments have since been considered in some detail. It seems appropriate in conclusion to scan briefly all of the systems together to show the full spectrum of

<u>Figure 4</u>: DIAGRAMMATIC REPRESENTATION OF AN AERATED SUBMERGED-BED FILTER



possibilities now presented to the public health engineer when considering the choice of a plant to serve a particular situation. Table 5 identifies the established and 'new' methods and lists some of the individual characteristics which are likely to be given consideration in the selection process. No attempt has been made to include estimates of the individual or comparative costs of the systems, although obviously these will often be crucial determining factors in selection. Some of the statements about some of the characteristics of the newer developments are necessarily conjectural and subject to further discussion. However, it is hoped that they reflect the true situation.

It is important perhaps to note finally that simple 'lagoon' systems of treatment have not been included in the 'spectrum' of possibilities, mainly because they are not generally regarded as suitable for the conditions attaining in the UK, though they might well be satisfactory in other warmer climates. Omitted also are the very new and more sophisticated physico-chemical systems of treatment which are available as package units for small-scale use in the USA, and possibly in this country, but about which little is known as yet. However, it is recognized that they could become part of the normal spectrum in due course.

Acknowledgements

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Table 5: Some features of various sewage-treatment systems at present available for small communities (excluding lagoon systems and physico-chemical methods).

		Established methods				New developments		
			Activated-sludge processes					
Characteristic	Septic tank	Biological filter	Extended aeration	Contact stabilization	Oxidation ditch	Rotary biological disc 'filter'	Extended biological filtration	Submerged-bed filter
Standard of effluent achievable without 'polishing' stage	Primary * treatment only	'30:20'	'30:20' (but polishing process desirable)	'30:20'	'30:20'	'30:20:	'30:20'	'30:20'
Approximate population range to which plant is most suited — Lower	Single house	Single house	Single house	500	100	Single house	20 ?	200
Approximate population range to which plant is most suited — Upper	~100 persons	No limit	~1000	No limit	No limit	~300 persons (as pkge unit)	500 ?	600
Supervision requirements	Very low	Moderate (weekly visits)	High (Daily visits desirable)	High	High	Low	Moderate (weekly)	? (probably moderate)
Operational complexity	Very low	Low	Moderate	High	Moderate	Low	Moderate	Moderate
Standard design requirements formulated	Yes CP:302†	Yes CP:302†	Yes CP:302†	Yes CP:302†	Yes CP:302†	No (Tentative proposals based on specific BOD ldg)	No	No
Typical period required for 'maturation' after start-up	None ?	6 weeks	1-2 weeks (or less if seed sludge is imported)	1-2 weeks	1-2 weeks	6 weeks	6 weeks	2-3 weeks
Significant seasonal variations in performance	No	Possibly	Unlikely	Unlikely	Unlikely	Possibly	Probably	Unknown
Mains electrical supply required	No	Not necessarily	Yes	Yes	Yes	Yes	Yes	Yes
Types of sludge produced and character	Primary Malodorous	Primary + secondary, Malodorous	Secondary, Inoffensive, Stable	Secondary, Inoffensive, Stable	Secondary, Inoffensive, Stable	Primary + secondary, Malodorous	Secondary (Slightly unstable, Malodorous)	
Head loss (nominal)	~10 cm	2-3 m	~10 cm	~10 cm	~10 cm	~10 cm	~10 cm	
Broad advantages	Simple Reliable Low cost	Simple, Fairly reliable. Low running cost	Compact, No primary sludge	Compact, No primary sludge	Low capital cost, No primary sludge	Simple, Reliable, Low running cost	Compact, No primary sludge	Compact, Low air requirements
Possible disadvantages	Sludge odours. Loss of solids	Possible odours & flies. Clogging of media. Humus sludge rising.	Instability through bulking sludge				Needs frequent desludging	Capital cost ? Clogging ?
Commercial pkge or prefabricated plant available	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

* Full treatment possible with secondary biological stage or soak-aways.
† Ref. 1

discussion

CHAIRMAN: C. Spens, CB, FICE, HonFIPHE, FIWPC, FIWE, FGS
President, Institution of Water Engineers

The CHAIRMAN introduced Mr Bruce who had been at the Stevenage Laboratory since 1956. At present he was on secondment to the Research Management Division of the D.O.E. Mr Merkens was working at the Stevenage Laboratory.

2. Mr A.M. BRUCE said that provision of satisfactory sewage disposal facilities for the communities of small size was a long-standing and well-recognized problem in public health engineering, for which there was a variety of possible solutions. This paper was about some of them and possibly in the discussion all of them would be dealt with.

3. The ultimate and ideal solution to the problem was to eliminate the need altogether for the small isolated works by installation of rural sewerage schemes and centralized treatment facilities wherever practicable and economic. Then design and operation could be carried out on the same basis as an urban works though on a small scale, and the treatment plant could be given all the necessary supervision, control, maintenance etc. Such works should not present such a problem as did the small isolated works. Mr BRUCE quoted from a report of a large River Authority "Most village schemes are normally satisfactory but very small plants are generally very ineffective and variable in effluent quality". This reflected the general situation as Mr BRUCE saw it, although one should not generalise too much for there were cases where such plants worked very efficiently.

4. While rural drainage schemes had increased in recent years, there must remain for the foreseeable future thousands of situations where isolated treatment plants would be necessary for small groups varying from just the single household up to a few hundred or so, for example groups of houses, small estates, institutional establishments, schools, hotels, golf clubs etc. Each presented a slightly different problem. In some cases the plant would receive a satisfactory degree of skilled supervision, but in many cases, particularly with private plants, they would be subject to a marked disinterest, possibly neglect, and even if there was some regular inspection this probably would not be very knowledgeable. In general Mr BRUCE's experience had been that nobody really wanted to know about the very small plant, and this was the first problem to be faced.

5. In addition there was the well-known problem associated with the small treatment plant of extremely wide diurnal variations in flow and load, particularly at institutions and schools where virtually all the flow occurred in two short periods of the day, and flows could rise to well above six times the normal average rate of flow, with often no flow at all at night. Together with that the sewage itself was usually very strong with BOD values even after settlement usually well above 300 mg/l, yet the normal requirement was to produce an effluent of 30:20 standard. This represented something like 95% removal of BOD which was close to the upper limit achievable by biological systems, and the plant therefore needed to perform extremely efficiently. It was clear that the small plant ideally required the following characteristics:

a. Reliability of operation without frequent supervision or the need for much maintenance.

b. Simplicity. Sophisticated systems had been used, but the more sophisticated and complicated they were, the more likelihood of their breaking down. Therefore simplicity with resilience and an adequate capacity to deal with the variations of flow experienced in practice were necessary. At the same time the plant should give the high purification efficiency necessary to produce a 30:20 effluent.

c. Generally such plants were required to be unobtrusive and compact, and to operate without any nuisance from noise, flies, or smell.

d. The sludge they produced should be as small in volume as possible and as well stabilized as possible for easy disposal.

6. Returning to the matter of flow and load, Mr BRUCE said that it was often claimed that plants were robust and able to withstand shock loads etc, but such claims did not often stand up to close examination. Either flow balancing had to be employed, which was likely to lead to more efficient operation with a smaller overall size of plant, or else the plant had to have sufficient capacity to provide for the maximum flow.

7. The design was not just a scale-down of municipal works, although the principles employed so far were exactly the same as those used for large-scale sewage treatment i.e. solids-liquid separation and biological oxidation. A search for the ideal system which would satisfy all the requirements mentioned had been going on for many years. The small plant problem had received some attention from the Stevenage Laboratory and from others, and there had been quite a few papers on this specific subject over the years. There was also a British Standard Code of Practice. Because small plant represented a large market, they had interested many commercial plant manufacturers and numerous types of package plant had been produced over the years. It was said that 3 million people in this country were not served by main drainage systems, and in the USA there were reportedly 25 million single-house plants in use.

8. Mr BRUCE said that in the paper they had not defined exactly what was meant by small-community plants; there was no sharp demarkation between a large small works and a small large works. The B.S. Code suggested a size of less than 300, but that was somewhat arbitrary. Mr BRUCE when looking at small works tended to think of rather smaller ones than that - and particularly the privately-owned plants.

9. Going back twenty years there was then virtually only one treatment system and that was the septic tank (and for the larger system the Imhoff tank) and the biological filter, or in some cases the soakaway system. There were thousands of such plants still in use and in Mr BRUCE's experience they were often very successful, although not suitable for every situation. This system still featured in the B.S. Code of Practice and doubtless many more would be constructed. Package varieties of septic tanks and biological filter systems were available now.

10. Twenty years ago systems based on the activated-sludge process came along in the form of package extended-aeration plants and later contact-stabilization and the oxidation ditch, though the latter was not in Mr BRUCE's opinion a plant for very small communities. There were initial difficulties with some of these activated-sludge systems owing to a misunderstanding of the design requirements, but in the last fifteen years design had improved enormously and many such plants were operating extremely well given adequate supervision and maintenance which was essential.

11. Mr BRUCE then turned to recent developments in small sewage treatment systems. At Stevenage they had experience of all the systems mentioned in the paper, although the experience of them in the field was not very great up to now. It was wrong to expect new systems to be developed and understood completely within a year or so.

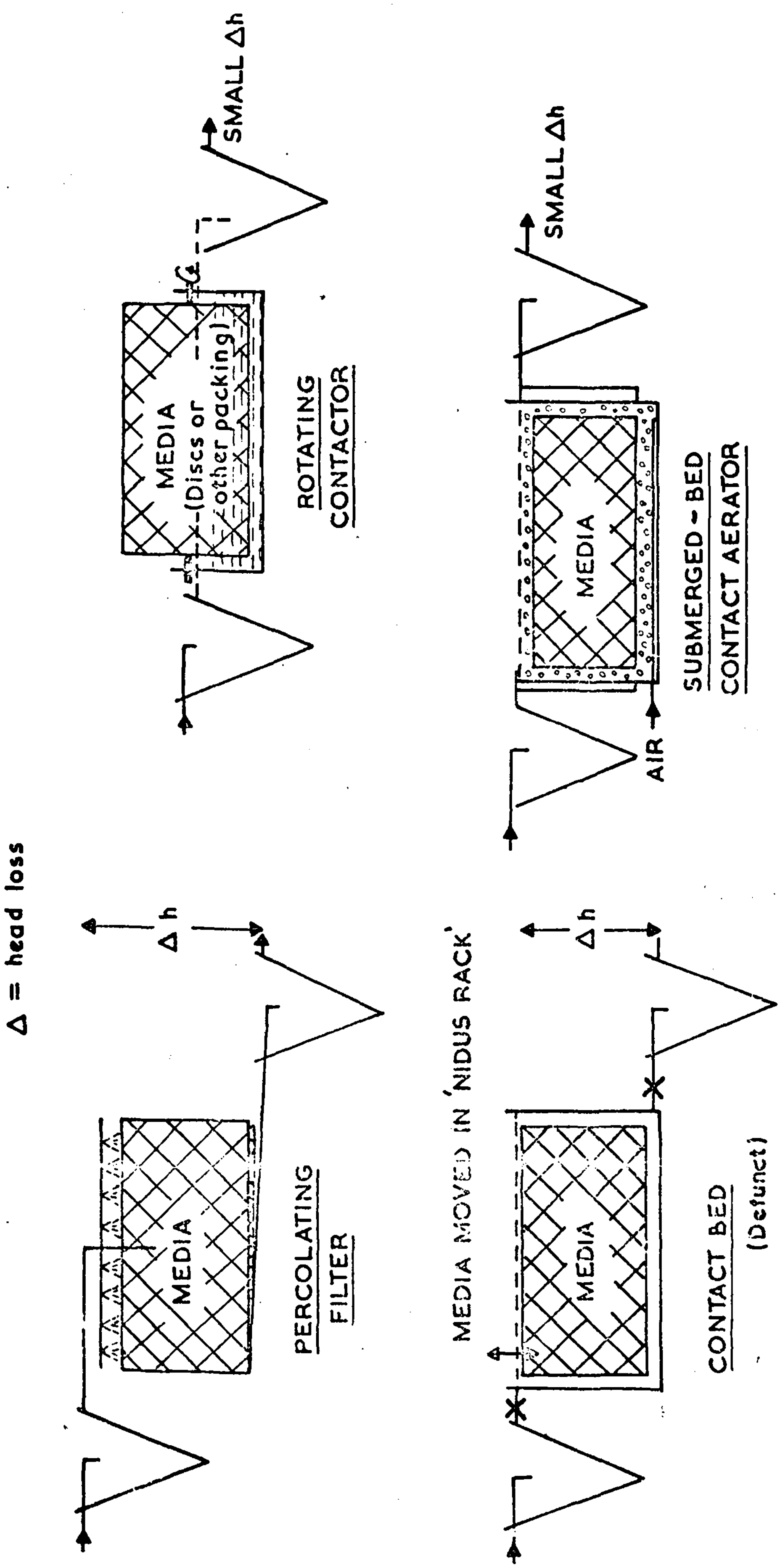
12. Before going on to talk about the systems in detail Mr BRUCE showed figure 5 which showed the link between the various systems. They were all "captive film" systems, i.e. the biomass which was necessary for oxidation was present as a film on an inert support medium. In the conventional percolating filter the head loss was represented by the depth of filter; the medium was static and the liquid passed through the bed.

13. In the rotary contact system, the medium was set in the tank through which the waste water passed and was rotated, aeration being provided during the period in which the medium was exposed to the air.

14. The third alternative was to pass the liquid through a tank and to move the medium in and out physically. The system used the principles of the contact bed where the liquid itself moved into the tank and then drained. However, Mr BRUCE did not regard this system as very practical or successful.

15.The fourth principle was where the medium was totally submerged and the necessary air

<u>Figure 5</u>: SCHEMATIC DIAGRAMS OF VARIOUS TYPES OF "CAPTIVE FILM" SYSTEMS FOR TREATMENT OF SEWAGE



supply was provided by diffusion as in the submerged contact aerator.

16. The rotary biological contactor itself had been in existence since the early part of the century in various forms, but not used to any extent until the experimental work carried out in about 1929 in the USA. The major development occurred in Germany after the war which led to the development of commercial forms of the rotary disc system. The design principle was demonstrated in figure 1; the medium took the form of discs supported on a shaft, the discs being separated and set at about 20-30 mm centres and rotated in a tank which generally closely conformed to the shape of the discs (i.e. hemi-cylindrical). Liquid wastewater was passed through and came into contact with the rotating discs on which a microbal film grew. Rotation was normally at about 1-3 revolutions/minute and alternate contact and aeration phases occurred as the discs rotated. The microbal film which developed on the discs grew to a certain thickness and then sloughed off at intervals. In most cases the solid sludge from the discs passed through with the liquid as a suspension until it was removed by a secondary settlement stage as the humus tank. In other cases some humus solids were removed by allowing them to pass through a slot at the base of the biological zone tank. The disc material might be expanded metal, plastic mesh, or in some cases expanded-polystyrene to give extreme lightness.

17. Mr BRUCE described a system which was investigated at the Laboratory. In the first two stages of the Bio-zone, slots in the bottom of the tank allowed film solids to fall through (on the Imhoff tank principle) to mix with the primary sludge in the primary tank. Any solids which fell from the discs in the last three stages passed out and were settled in the final settlement zone. Thus sludges produced were both primary and secondary sludges as with a biological filter. The primary sludge was not stabilized and the secondary sludge was of the same character as a humus sludge. There were probably about a hundred plants in operation in this country now. So far, there was little published information about these plants in the U.K. and Mr BRUCE looked forward to hearing about peoples' experiences with them.

18. Results were reported in the paper of trials carried out at the Laboratory on the 'BioDisc'. The plant was operated on strong domestic sewage with a BOD after settlement of something of the order of 300 mg/l under a variety of conditions over a period of about two years. The object was to establish the performance of the plant, its size and load capacity and this was done. Results given in Table 1 were with a throughput of 2.7 m^3/day, which represented the flow from about 25 persons, for which the plant was designed. It was operated over three separate phases after maturation, which took 6-8 weeks during a winter period. The first phase was with steady flow throughout the 24 hours which was somewhat unrealistic although it could be achieved in practice with flow balancing. Secondly, the flow was introduced to the plant for 16 hours a day with no flow at night and finally with three peak flow periods which represented more closely the situation occurring in practice. The results in Table 1 were generally satisfactory. The average BOD/suspended solids were in most cases less than the 30:20 standard and there was a degree of nitrification. The performance was perhaps not ideal at all times but with 'polishing' treatment, which was often employed in small plants, significant improvement would be achieved.

19. The rate of flow of 2.7 m^3/d of sewage represented a BOD loading after settlement of 1.5 kg/d. For rotary discs and other rotary contact systems it was now conventional and very appropriate to express loadings in terms of the BOD load per unit of contact surface per day (i.e. g/m^2 surface per day). For the BioDisc system that was tested that would be equivalent to 6 g BOD/m^2d, taking both sides of the disc as different surfaces. On the basis of 37 g settled sewage BOD per person per day, that would mean 6 sq metres of surface per head were required; that was quite a useful design parameter. Although some of the experiments were carried out in winter, performance might well have been worse if the winter had been more severe. There was an indication from the USA that something like 30% reduction in loading was necessary to achieve the same performance at 7°C as at 18°C.

20. The German experience was quite extensive with 300-400 plants operating in Germany, Austria and Switzerland, although in Europe they were not so concerned with absolute standards for effluents. Steels had recently published calculations based on empirical data from Germany which suggested that for plants serving populations of less than 400 the design BOD loading would be about 6 g/m^2d which was a reasonable confirmation of Mr BRUCE's findings. Plants in Germany were normally designed on BOD loadings of 12-18 g/m^2d; the loadings were higher because the

quality of effluent required in Germany was usually not so stringent as 30:20. Indeed Krauth and Staub showed that loadings of the order of 4-5 g/m^2d were needed to get BODs of less than 25 mg/l. Therefore 6 g/m^2d was not unduly conservative and represented something like four to six times the loading on a percolating filter in terms of grams of BOD per sq. metre of surface area per day. Indeed one would expect rotary surface to be more efficient because submersion of the surfaces in the liquid meant full utilization of surfaces for contact and during the period of exposure there was complete aeration.

21. It was claimed that the rotary biological disc system was a simple system needing little maintenance; it was quiet, and did not give rise to fly or noise nuisance. It needed routine desludging at regular intervals and the sludge produced was usually malodorous and needed further treatment or at least could not be disposed of locally without causing nuisance. Mr BRUCE had found that most of the claims of its simplicity of operation were borne out in practice. However, the discs had to be kept turning and power failure for a long time would be serious. Cases had occurred where the power had failed, the upper part of the surface of the disc had dried out and the slime fell off, causing an imbalance in weight distribution and severe strain on the shaft. Mr BRUCE showed some slides of plants in the U.K. and in Germany. In one plant which had been in operation for some time there was a pronounced gradation in the colour of the biological film from the inlet end where there was heavy film growth of grey-white colour, to the outlet where nitrification was occurring with dark-brown well oxidized slime.

22. Some work had been done at the Laboratory on other forms of rotary biological contactor, using random plastic packings for the contact surfaces, There was no absolute necessity to use discs; the principle was the same using other types of medium. Mr BRUCE showed slides of early prototype systems and the "Biobasket", which consisted of three drums with perforated side and end walls containing random plastics media and which were rotated in a hemi-cylindrical tank through which settled sewage was passed. The system had been demonstrated to work quite successfully and a comparison between discs and random packing was carried out at the Laboratory by placing the two systems on the same shaft, the sewage passing through a simple tank divided by a baffle. Mr BRUCE said it was found that the random packing Biobasket system was not quite as effective as the discs in terms of loading per unit of surface area, but because the packing had higher specific surface area the two systems had about the same efficiency. The results given in Table 3 demonstrated that the effluent from the basket plant was about the same quality as that from a disc plant, and was slightly better in relation to nitrification. However if the loading per unit surface area was the same for both systems then the random basket system was not as efficient as the disc system. The random media system was possibly an economic alternative to discs, and was certainly very easy to operate without any clogging problems. Several other systems comprising horizontal tubes had been tried at the Laboratory, and found to be unsuccessful.

23. Mr BRUCE then turned to so-called 'extended-filtration'. There had been two commercial versions of this system in this country. Figure 3 showed the drawing of the pilot unit, which worked on the principle of ordinary biological filtration, but used comminuted crude sewage and a plastics medium. Sewage passed through the filter into a collecting trough which concentrated the humus solids and enabled them to be recycled at a high rate, the object being to oxidize the sludge solids and produce a stable secondary sludge without any primary sludge, in the same manner as an extended-aeration system - hence the term 'extended-filtration'. This had advantages over the activated-sludge system, being easier to operate, easier to control and less likely to give problems. The treated sewage then received secondary settlement to remove solids, and at the Laboratory it was passed through an upward flow clarifier for final polishing.

24. During the summer effluent of 30:20 standard could be obtained at rates of treatment as high as 1.9 m^3 of crude sewage per cubic metre of medium per day, which was about six times the rate employed on a biological filter. To achieve 30:20 standard throughout the year a more realistic rate of treatment would be 1 m^3/m^3d which still represented about three times the efficiency of a conventional filter. The disadvantages were that it needed higher rates of re-circulation which could be quite expensive, it was slightly more sophisticated than the conventional biological filter and it needed to be desludged fairly regularly. There was no clogging of the media experienced in these systems, even though crude comminuted sewage was being employed. This system was an efficient compact system, easier to

operate than an activated sludge system, and producing a sludge which was fairly well stabilized, although not as well stabilized as that from an extended aeration activated sludge plant; it was slightly malodorous and contained a relatively high proportion of organic and volatile matter.

25. Mr BRUCE then discussed the submerged bed aeration biological filter. It was valid to refer to it because the Laboratory had done experiments with it, and it was being marketed as a commercial system for small communities. The principle was used as the Hayes process many years ago, but now random plastics filter media with lightweight high voidage could be employed conveniently for such systems. The Laboratory had experimented with a very small system which indicated that it was likely to be highly efficient. Sewage was passed through the medium and air was bubbled through at the same time. The system employed secondary settlement of the sludge which was similar to that from a conventional biological filter. The system was found to be sixty to seventy times as efficient as a biological filter, but the very small medium employed could not be used in practice.

26. Results given in Table 4 showed that various loadings were tried on the system and achieved remarkably good effluents at astonishingly high BOD loadings of 2.8 to 6.5 kg/m^3d. Mr BRUCE felt the valid parameter was loading in terms of g/m^2 of surface per day which showed that better than 30:20 effluent was achieved at 6-7 g/m^2d which was very similar to those found appropriate with the other systems referred to earlier. In practice using a larger medium, which would be necessary, the loading to produce 30:20 effluent would be 6-7 g/m^2d which would still be about 0.4-0.6 kg/m^3d or something of the order of four times the loading employed on a conventional filter. The system represented an improvement on conventional filter in terms of efficiency but at the expense of complexity because a compressed air system would be needed. Mr BRUCE was not certain how the capital cost of power to the filter affected the overall costs. The system required in practice shown in the paper by figure 4 was slightly more complicated than the system used in the Laboratory. The sewage was comminuted but settled sewage was more usual. Sludge was air-lifted to an aerobic digester so the initially unstable sludge would be stabilized.

27. Table 5 showed the spectrum of choice the engineer was faced with when deciding about plant for small communities. Mr BRUCE had excluded stabilization ponds and oxidation ditches and some of the very sophisticated physico-chemical systems which had been marketed in the United States and to a limited extent in Britain. For the time being mainly biological systems were being dealt with, but there were other possibilities. One of the noticeable "blanks" in the table was that relating to the possible disadvantages of rotary biological disc filters. He thought capital cost was a possible disadvantage. All the other comments were really personal views and open to argument. The approximate minimum population for contact stabilization was given as 300, which was probably too high; the Code of Practice gave 70 people as the lower limit. In theory it was suitable for very small flows but in practice there was a tendency to think of contact stabilization as being a system for rather larger small communities. The same applied to the oxidation ditch.

28. Mr R. HATTERSLEY had never operated or seen in operation any of the treatment methods described in detail in the paper, but he had a fairly wide experience of the operation of small treatment plants of other types, and the latest count of installations of all types in his Division was 313.

29. His experiences had left him with some quite strong views about the design of small treatment plants; on the whole the operation was fairly straightforward if the design was right. Septic tanks, settling tanks, percolating filters and some types of extended aeration plant were all satisfactory. It was what happened before and after which normally caused trouble. All these plants were sensitive to high storm water and other intermittent flow characteristics. Far too many so-called separate sewerage systems were so un-separate that all the solids were washed out of the aeration plant to the humus tank every time it rained. For plants of this size it only needed one roof to be connected to the sewer to wreck the calculations. Small plants to which the flow was pumped were hardly ever equipped with a balancing tank, and yet all too often small treatment plants were ruined by intermittent excessive hydraulic loading, bearing in mind the usual very strong dry weather sewage. Mr HATTERSLEY admitted that he had not yet come across an ideal design of a balancing tank for a small works, because any orifice small enough to be appropriate quickly became blocked by debris. He felt that there was a case for the interposition of a balancing tank between the settling or septic tank and

the biological stage, because in this position there was less likelihood of interference by debris and the primary settling stage was less susceptible to upset by 3 or 6 dwf flows.

30. Many rural works had no electricity supply laid on and it was difficult therefore to arrange for satisfactory operation of the humus tank, because of the difficulty of arranging for desludging at sufficiently frequent intervals. Far too often the answer had been to omit a humus tank altogether with the result that an otherwise satisfactory tank and filter installation could not possibly produce a good effluent. Grass plots were a wise safeguard against accidents, but even these quickly became a quagmire when there was a constant discharge of humus solids.

31. Mr HATTERSLEY mentioned filter distribution mechanisms, noise nuisance and non-existent sludge removal facilities. Access was a very severe problem not connected to the design of the actual treatment plant, but which caused more trouble to the operator than many other things. He knew of plants where the only effective solution appeared to be to use a helicopter. It was an irritating habit of the designer to buy a lot of land to facilitate construction, then simply put a fence around it and leave the operator to cut the grass for evermore.

32. Mr HATTERSLEY said the universal application of the 30:20 standard should be questioned, because he was sure that in many cases, particularly for very small plants, a relaxed standard would be quite appropriate, and the only reason for choosing the 30:20 standard was because it was the custom.

33. Mr HATTERSLEY wondered if the author would comment on the need for screening and grit removal for the rotary biological contactor, and whether it was practical to incorporate primary settlement in the integral settlement zone. The speed of rotation of the discs had been variously given as 1 rev/min, 1-3 rev/min and 1-2 rev/min, and he wondered if any investigation had been made as to the optimum rotational speed.

34. In the paper there was a reference to a plant being offerred with waterwheel drive and this raised the question of the length of time which the plant would survive with no rotation at all. Mention was made of several hours being a reasonable time but Mr HATTERSLEY suggested that if a plant was waterwheel driven it was likely to be stationary during the night for longer than that. He was a little concerned about the effects of frost on these plants. It seemed to him that any damage would be severe both to the mechanical parts as well as to the treatment process.

35. Mr HATTERSLEY queried the recommended loading of 6 g/m^2d. U.S.A. investigations into the effects of low temperatures had shown that a 30% reduction in loading was needed at 70°C which was likely to be a regular wintertime condition since the rate of cooling in this type of plant would be quite high due to the alternate exposure to the atmosphere. In a reference to the German experience it was said that "If 90% of all values were not to exceed 25 mg/l, the loading should not exceed 4 g/m^2d". In the next sentence, referring to the U.S.A. experience, it was stated that 2.7 g/m^2d was appropriate to achieve 95% reduction in BOD. All these references called into question the recommended loading and Mr HATTERSLEY asked for Mr Bruce's views about this.

36. There was mention of the ability of the plant to withstand shock loads and it was said that claims that plants were able to withstand shock loads had not been substantiated. Mr HATTERSLEY did not know what was meant by shock loads in this particular sense, but it seemed to him that intermittent discharges of 6-7 times dwf at maximum strength would be shock loads and such discharges were not uncommon in small treatment plants.

37. The comparison with the percolating filter seemed to Mr HATTERSLEY to be a little unfair in that it was described as being marginally better than the percolating filter although considerably less loaded. The comparison of BOD from 19 to 6 and of ammonia from 27 to 1 did not really describe a performance which was only "marginally better".

38. Mr HATTERSLEY remarked that one thing missing from the paper was a comparison of costs. He also asked for the author's opinion as to the time necessary for the maturation of a septic tank. In his own experience a biological filter might take up to two years before producing an effluent of the standard for which it was designed, particularly when underloaded.

39. Mr BRUCE agreed with Mr Hattersley's point that providing the design was right for these plants, settlement tanks, percolating filters and other established

systems worked extremely well, but there were situations where the conventional systems were not ideal.

40. Mr BRUCE agreed that it was very important to provide balancing wherever possible, and if balancing could be provided, a much greater efficiency of treatment could be achieved. The idea of putting balancing tanks between the settlement tank and the filter seemed to be a useful idea, but it might increase costs. On the other hand if flow was balanced properly, the size of the filter might be reduced by a factor of 2.

41. As far as the technical aspects were concerned, Mr BRUCE thought the 30:20 standard must come under severe scrutiny to see whether or not it was justified as a general standard, although given the right conditions most biological systems would achieve 30:20 as a matter of course, but perhaps not all the time.

42. Screening and grit removal were not generally employed, but on large systems they might be appropriate.

43. Following some further discussion with Mr HATTERSLEY, Mr BRUCE said the integral settlement zone was a practical proposition, and employed the Imhoff principle. It might not be the most effective system and a combination of separate settlement and Imhoff-type settlement might well be more effective. A direct comparison between different types of settlement had not been carried out. The idea of taking all the systems together and comparing them as had been done in the United States at the National Science Foundation (taking 12 different types of plant and operating them together) seemed to Mr BRUCE to be very valuable.

44. The effect of the speed of rotation of discs had been investigated by a number of people including a small investigation at the Stevenage Laboratory, but the effect was not particularly significant over the range 1-5 rev/min. The lower speed was to be preferred in terms of wear and energy requirements, and speeds of 1-2 rev/min would probably be used generally. Much higher speeds gave a very small improvement in performance in terms of nitrification, but were not worthwhile in terms of increased power requirement and wear cost.

45. Mr BRUCE said he had only mentioned in passing the possibility of waterwheel drive, and he did not think that system had been used to any significant extent. He was unable to say how long the film on the discs of the plant would survive without rotation but once the discs did stop there was immediate reduction in the efficiency of treatment, apart from the other effects resulting from drying out of unsubmerged film.

46. Concerning frost damage, Mr BRUCE said most plants were covered and indeed some were actually housed in buildings. He thought that providing there was a sewage flow through plant, then even during the night there would not be severe trouble from frost attack because the temperature of sewage was usually adequate to prevent freezing, providing the plants were covered and not subjected to strong cold winds.

47. In reply to Mr Hattersley's questioning the proposed loading of 6 g/m^2d, Mr BRUCE said it was difficult to know how conservative to be; he had received criticism at times about recommending such a low loading because it tended to make the size of plant required rather large. Mr BRUCE thought probably 6 g/m^2d was the upper limit for a 30:20 standard and it was up to the engineer to use his discretion, given all the evidence, with regard to the actual loading he employed.

48. In the Biobasket system the biomass came off in small pieces and worked through the packing. The individual pieces of packing were not movable and in fact movement was undesirable. Systems had been tried where the packing was movable and the abrasion of one piece on another was quite a serious problem; apart from rubbing off film, the medium would eventually wear out.

49. Mr BRUCE knew there was a lot of discussion about the time of maturation for a septic tank, but essentially it was a settlement tank with provision for sludge storage. If a septic tank was filled gradually it would produce an effluent which was not much inferior in quality to the effluent produced after six months. He found the remarks about filters taking up to two years to mature most surprising and thought there must have been something peculiar about that particular situation. The evidence was that given start-up during the spring or summer with the right loading and gradual increase of load, then a filter would usually produce an effluent of reasonably good quality within 6-8 weeks, with nitrification after perhaps another two or three weeks. Mr BRUCE referred Mr Hattersley to a paper by Wilkinson, Truesdale and Jones(9) which showed such a maturation period. However, Mr BRUCE was prepared to accept that with difficult

9. Truesdale, G.A., Wilkinson, R.W., and Jones, K. A comparison of the behaviour of various media in percolating filters. J. Inst. Pub Hlth. Engrs. 1961. 60 273 and J. Inst. Sew. Purif. 1962. 325.

sewages and a winter start-up it might take much longer for a filter to reach maturity.

50. Mr T.W. GRAY felt that the emphasis in the paper was obviously on small domestic sewage treatment plants, and reading the paper it appeared that this was the limit of the range of this type of equipment. However, his experience over thirteen years had ranged on plants from 30 persons up to 30 000 persons and it was in the larger plants that disc loadings could be extended beyond 6 g/m^2d. He agreed with the findings of the WPRL that 6 g/m^2d should be used on package plants but contested the figure when applied to larger schemes, where there was separate primary separation followed by multi-rows of discs, followed by secondary treatment.

51. Mr GRAY was interested to see the comment about overload factors and asked the author to comment on the work of Professor Pöpel who claimed a 400% overloading factor for periods of 2½-5 hours without deterioration in performance of the overall disc system. The work was quite extensive and there was a lot of data available on the subject. Mr GRAY said his organization always included some flow balancing in disc systems as they appreciated that it was essential. There were about 300 disc filter plants in France and probably over 700 plants in Continental Europe. Add to this the hundred in the U.K. and the total was 800 or more. It was essential to have a re-start mechanism in case of power failure. Otherwise if an imbalance was obtained, the torque produced could burn out the motor so it was essential to protect the electrical circuits. Regarding the effects of temperature Mr GRAY said some of this type of equipment was operating at about 4000 feet in the Alps where the temperature was pretty cold at night.

52. Someone had asked for prices and Mr GRAY gave some indications of cost. The small package plants offerred by his organization for some 30 persons cost about £5000 and for up to 200 p.e. cost £10 000, including the bucket feeder, the disc section and the secondary settling plant. 1000 p.e. would be provided with a disc system with four units each containing 138 two-metre diameter discs. The individual unit cost about £7000, and four about £25 000 for the biological stage alone.

53. Mr BRUCE had read Professor Pöpel's paper but did not feel he could comment on it in detail. He was prepared to believe that the increase in load did not have a dramatic effect on the performances of Professor Pöpel's plant, but suggested that no plant could withstand extreme shock loads. He thanked Mr Gray for pointing out possible disadvantages and the need for a re-start mechanism, although Mr BRUCE felt this would also apply to other plants relying on electrical power.

54. Mr M.W. ASKEW said Professor Pöpel had been very active im promoting the biodisc type of system in Germany in the mid 1960's and Mr ASKEW had seen his research installation as early as 1965, but in Germany his test apparatus was in fact referred to as "Professor Pöpel's prayer wheels"; it was suggested that the results achieved owed much to the enthusiasm of the research team.

55. The major disadvantage seemed to be the capital cost. He could not quote an example of an application to small scale sewage treatment, but he had looked at the potential application of this system to a number of things in the last 18 months. One in particular was in the treatment of fruit and vegetable processing waste on a comparatively small scale as it was only a research installation's effluent, with something like 80 kg BOD/day as a design loading. The potential capital costs of various systems were compared and the installed capital cost of the biodisc was over 60% higher than that of the option finally chosen, which was conventional high-rate bio-filtration followed by contact stabilization. Some manufacturers asked for the whole of the basin on which the discs were set up to be carefully constructed in concrete, with a clearance of about 10 cm, which made it more expensive. Mr ASKEW would like to see more performance data rather than research data before he would feel inclined to specify one of these systems. He believed the question of icing was important; a thin film of liquid was being dealt with which would easily freeze.

56. Mr ASKEW had done a certain amount of work on extended filtration some years ago. Although from the point of view of construction and operating convenience the system which the author mentioned was probably the most attractive, Mr ASKEW suggested it was not good in capital and operating cost terms. When feeding the system with macerated sewage (for the sake of only having one sludge outlet rather than two) the rate of loading to produce a given quality of effluent had to be so far reduced that overall it was more costly than using settled sewage. Maceration of

the solids tended to solubilise some BOD and increase the effective loading to the biological system.

57. Mr ASKEW said his organization had recently installed a submerged bed filter system to serve a population initially of 200, with the plant capable of accepting loads from a population of 400 within twelve months. They had looked at four alternative options and this was 25% lower than the price offerred by manufacturers of competitive systems. On submerged beds in the paper Mr Bruce had given a calculation which suggested that the appropriate loading would be 0.4-0.6 kg/m^3d to produce a 30:20 standard, and he questioned whether this was necessarily valid because it was essential to use a larger medium with a smaller specific surface because the medium would be agitated by the turbulence of the liquid generated by the air. It was also assumed that the treatment within a submerged bed filter was entirely attributable to the activity of the biological growths on the surfaces and owed nothing to the action within the bulk of the liquid itself (what might be considered as the activated sludge process), and Mr ASKEW said he would welcome the authors' comments on this.

58. Going back to the question of biodiscs Mr ASKEW said in the paper there was a suggestion from an American worker that a 30% reduction in loading might be necessary to achieve the same quality of effluent at 7°C as at 18°C. It suggested that in this temperature range the value of the Q_{10} factor, which was a means of describing the rate of reaction in a biological reactor under a fixed loading, was of the order of 0.5 whereas it was more likely to be 0.2.

59. Finally Mr ASKEW asked the authors to comment upon the operating energy requirements of the various systems they had considered.

60. Mr BRUCE said that experiments at Stevenage showed that temperature had quite a large effect and he was not at all surprised by the 30% reduction in loading necessary for just over a 10° drop; he would have expected possibly a 50% reduction. The temperature coefficient of 1.08 had been found to represent that sort of reduction in loading.

61. Regarding extended filtration, Mr BRUCE agreed about pre-settlement; basically the introduction of macerated crude sewage was not desirable from the operational point of view. However it could work in practice. If the real requirement was a sludge which was stable, then there was no alternative but to try and oxidize the crude solids. Mr BRUCE was interested that submerged bed systems seemed such a low capital cost, when his impression would be of high capital cost because of the complexities of aeration and a medium as well and it would be interesting to see how in time the system compared in capital cost. Sometimes early developments could be misleading.

62. Mr BRUCE replied to the point Mr Askew had raised about the medium. A small medium could be used, but it would be very expensive. The medium used for laboratory scale experiments was chopped up plastic tubing and the price was about £350 per cubic metre, and there was the risk of clogging as well. If a medium of high surface area could be obtained at a reasonably economic price then it would be a very efficient and intensive system.

63. Mr BRUCE did not know how the plants compared in terms of energy requirements except that a septic tank and soakaway or biological filter system was ideal from the point of view of non-consumption of energy.

64. Mr M. SANE asked whether there was any relationship between the BOD loading on the biodisc system and the hydraulic loading. Secondly, with the extended aeration activated sludge plants, what quantities of sludges could be expected from domestic type sewage, and what was the treatability of the sludge. Finally, what type of plant would the author recommend for small holiday resort areas, particularly for between 15 and 150 people located in inland areas (as opposed to coastal areas), where the effluent was discharging usually to quite high quality streams.

65. Mr BRUCE said the BOD load was the product of the hydraulic load and the BOD of the liquid; it could be dilute sewage at high flow, or strong sewage at low flow. Over a limited range of say 250 and 350 BOD, Mr BRUCE thought the design loadings suggested would apply, but very weak or very strong sewage would probably affect the appropriate BOD loading employed. In general the weaker the sewage the lower the BOD loading used to achieve a given quality of effluent.

66. With an extended aeration activated sludge plant, the volume of sludge produced depended on whether or not aerobic digestion was used and what degree of consolidation was achieved. Mr BRUCE

usually worked on the basis of about one gallon of surplus sludge per day per person, the range probably between 0.75 and 1.25 gallons, but it could be higher than that.

67. Mr BRUCE was not prepared to stick his neck out to recommend a particular type of plant for inland holiday resorts! There were so many factors including cost. In holiday camp situations the whole population arrived 'overnight'; there was no flow in the winter and spring and then suddenly at Whitsun or Easter there was a population of several hundred. How could the plant be matured and prepared for that situation? Several possibilities had been thought of including operation on synthetic sewage to mature the plant in advance. Mr BRUCE thought that activated sludge plants were more suitable in such circumstances because it was possible to import mixed liquor from a permanent works and the plant could be got into full operation very quickly.

68. Mr D.J. GRIFFIN had a few years ago served two small communities with a sewage treatment works which was designed to serve only one of these communities. The sewerage system and sewage treatment works had been built for one of the communities having a population of about 100 people, and had been operated for a few years. The local authority responsible for this works was asked to take over a virtually derelict works serving a population of about 120 people, which was about a mile distance from the existing plant. Various alternatives were looked at and Mr GRIFFIN's organization tried a novel idea of storing the sewage from this second community during the day in the sump of the pumping station and then using a suspended macerator pump to pump this to the existing works at night. This offerred considerable economies in capital expenditure and was adopted by the local authority concerned.

69. No monitoring of the situation prior to re-organization took place. However, very shortly after re-organization somebody mistakenly emptied 5 gallons of white spirit on to the filter. In May 1974, a few weeks after this had happened, some results were obtained:

Chlorides	59 mg/l
BOD	42 mg/l
Suspended solids	43 mg/l
Nitrates	Trace
Nitrites	2.4 mg/l

In October 1974 there was a final effluent sample:

Chlorides	24 mg/l
BOD	11 mg/l
Suspended solids	10 mg/l
Nitrates	12 mg/l
Nitrites	Trace

The plant in question consisted of a pyramidal settling tank, a shallow filter 4 feet deep with 1-inch slag media, a rectangular humus tank and at the time that the pumping main was put in, a Banks clarifier was added to the humus tank. Mr GRIFFIN felt this example might point the way to optimise on utilization of existing plant and might have a bearing on future thinking regarding the economics of balancing flows in sewerage systems.

70. Mr GRIFFIN said that for caravan and chalet sites and the like, maturation period at start-up was very important. He had heard of the system sometimes used to aid maturation of filters, of importing humus sludge from an existing works and putting it into the sedimentation tank with efficacious results. Mr GRIFFIN thought it was significant that all the plants referred to in the paper were dependent on a power supply but at isolated rural areas electricity supply was at its least reliable. Therefore he concurred completely with the authors in their suggestion that the long stop should always be provided in the form of tertiary treatment by land irrigation or other means.

71. Mr G.L. SYMES referred to a point mentioned earlier in the discussion about the possibility of using either comminuters or sedimentation before feeding plastic media. His experience was that it was fatal not to have primary sedimentation first. At one plant a man was employed full-time to stand on top of a tower trying to poke the solids down through it! Mr SYMES added that contact beds were not defunct as his Authority still had some.

72. Mr W. CAMPBELL did not agree that primary sedimentation was absolutely essential but agreed that comminution and maceration were normally unsatisfactory. Fine screens could be a suitable alternative depending on the nature of the substrate being handled.

73. He asked if the results quoted for extended filtration were those after the pea bed clarifier or effluent after settlement.

74. Mr CAMPBELL said he had carried out an experiment on a settled sewage with a media which was 135 m^2/m^3 surface area. He was

able to get around Royal Commission standard at 0.6 to 1 $kg/m^3/day$ BOD load. However it was on occasions difficult to produce Royal Commission Standard because of rather fine suspended solids coming out. The recirculation rate was two or three to one.

75. Mr BRUCE said the results given were for the pea bed clarifier, which was regarded as an integral part of the system.

76. Mr G.F.G. CLOUGH said energy was needed to treat sewage but did not always have to be provided from external sources. Anaerobic processes had a head start because the energy came from breaking down the substrate. Percolating filters if on a gravity head did not need any energy. The activated sludge systems needed most, particularly extended aeration systems. The high rate filter came half-way between the low-rate filter and the activated sludge system.

77. Mr CLOUGH said it would have been helpful if Mr Bruce had given the typical analysis on the effluent from a septic tank. He disagreed that a septic tank was only a settling tank as some anaerobic action took place. If it were only a settling tank it would need emptying much more frequently than in practice.

78. Mr CLOUGH thought that during the discussion there had been a certain amount of failure to distinguish precisely between Royal Commission Standard and an average 30:20 effluent. These were not the same thing. The Royal Commission said not exceeding 30:20, and without going into statistical detail, he suggested that something around 20:15 average was equivalent to Royal Commission.

79. Physico-chemical treatment would probably show to advantage for holiday camps requiring over-night start-up.

80. Mr BRUCE said it would be useful to harness the potential energy obtained from the anaerobic process and utilize it in the treatment but he did not think it was economic on a small scale. To spend as much energy in aerobic oxidizing of sludge was terribly wasteful.

81. Mr BRUCE still regarded the septic tank as a settlement tank with provision for sludge storage. There may be activity going on in the sludge itself, but septic-tank effluents were normally not very different from settled sewage except that suspended solids were lower in the former. Figures quoted by Nichol in a paper given recently to the IPHE showed BOD values from septic tanks in Scotland ranging between 250 and 300 mg/l. Anaerobic treatment of sewage was not very efficient; if a bottle of sewage was left for five days in the dark, there was little change in BOD.

82. Mr BRUCE endorsed Mr Clough's remarks about 30:20 standard, but if Mr Clough was seriously talking about 30:20 as the absolute standard then Mr BRUCE said an average of BOD 11-12 had to be aimed for, and this made a substantial difference in design considerations.

83. The physico-chemical treatment would of course be an instant method, ideal for holiday camps etc.

84. Mr P.D. LINE said that the energy consumption of the rotating disc process in small package plants was about 10 kilowatt hours/head per year.

85. Mr F.D. BALDWIN noticed the authors had tried as closely as possible to simulate field conditions in the experiments, and he wondered if they had considered abuse of the plant - the effects of infrequent desludging. Had excessive sludge levels been allowed to build up, and if so what sort of effect did this have on the performance characteristics of the plant? Was it the authors' opinion that central sludge treatment would be better in an area where there was a large scatter of small works producing sludges of different characters?

86. Mr BRUCE said they had tried one or two experiments on neglect, but it was difficult to simulate all that could happen in the field as one just did not have enough imagination! They left sludge for a while but to study neglect properly would take years to cover every situation. Leaving sludge for longer than a month was undesirable, but not dangerous.

87. Central sludge disposal was being practised, and Mr BRUCE thought it was recognized as being the best answer, although he did not know how costs compared. Some activated sludges which were well stabilized and non-offensive could be easily disposed of locally, but primary sludges must in general go to central sewage works. Although aerobic digestion plants were very expensive in terms of energy requirements they were much less effective than anaerobic digestion.

88. The CHAIRMAN had been left with a strong impression that even for the small

sewage plants for groups of houses or holiday camps it was quite impossible to generalise and produce a code of practice which could be used by say an architect. Every one of these cases must be considered on its merits even from the amount of land available, the proximation of dwelling houses etc. All these had to be taken into account, and one was left as always, no matter whether it was water works or sewage works, with the sludge problem. The CHAIRMAN said he had been reminded of something which he had tended to forget, that primary and secondary sludges were not the same thing and therefore whatever works were put in, it had to be borne in mind that whatever the sludge may be it had to be got rid of somehow. Some of the manufacturers' publications showed cesspool emptiers pumping sludge from the bottom of tanks, but there might well be no road anywhere near the site and this sort of thing had to be taken into account by engineers. The CHAIRMAN felt this was especially the case with private developers who built housing estates, who thought that when the sewage works had been built, it did not need any maintenance at all. They went off the site and the people living in the houses knew nothing about sewage treatment and were not concerned about looking after the works, and so the thing went to rack and ruin, ending with complaints in the council chambers about smell, flies etc.

89. Whatever any of these small plants contained, be it biodiscs, biological filtration or various methods of activated sludge, they all required maintenance and whatever manufacturers might say in their brochures, they still require maintenance. To have a plant for six months and not go near it, and expect it to operate satisfactorily, was just not on.

90. He thanked Mr Merkens who had so ably helped to produce the paper, and Mr Bruce for introducing it and dealing with all the questions.

D.G.M. ROBERTS & D.A.D. REEVE

a discussion: the place of consultants in the design of works for RWAs

CHAIRMAN: W.F. Lester, OBE, BSc, FRIC, FIWPC
President, Institute of Water Pollution Control

The CHAIRMAN said it was a pleasure to come as the President of the Institute of Water Pollution Control and see so many members of that Institute and of other kindred Institutes present at the 8th Public Health Engineering Conference at Loughborough University.

2. Mr D.G.M. ROBERTS thought it was an open secret that the present Secretary of State and his Conservative predecessor had written to all Water Authorities asking them to give a proportion of their work to consulting engineers, because it was in the national interest to maintain their export potential and they had to have a secure home base from which to mount their overseas operations. Members and senior staff of Water Authorities, however loyal they may be, were hard-headed realists and would also need good economic and operational reasons for acting in this way. Mr ROBERTS believed there were many reasons why it was in a Water Authority's own interests, let alone the country's, to employ consulting engineers for part at least of both their regular and their variable work loads.

3. In the post-war period the public health engineering sector had been one of the fields which successive Governments had used to regulate the amount of money going into the economy and Mr ROBERTS thought it would be uneconomic (and irresponsible) for Water Authorities to staff their own design teams to cope with the peaks. Consultants could only be used for "peak-lopping", however, if they were in existence, and they could only continue in existence if they were given a proportion of the base load work.

4. In the past, cost benefit studies for domestic public health projects had not been carried out to any great extent, but overseas these were the norm and, for example, the team for a study into the future water requirements of the Island of Mauritius recently carried out by Mr ROBERTS' firm consisted of 4 engineers and 2 economists. In the future the Finance Directors of Water Authorities were likely to require such studies for home projects, and as many consultants had had considerable experience of the very sophisticated techniques involved in such work they could readily incorporate them with engineering studies for U.K. projects.

5. On rush jobs, because of their greater flexibility and ability to recruit staff more easily, consultants could more readily respond to pressures and get the designs completed more quickly.

6. Through their more flexible salary structures consultants were better able to reward and encourage the bright young man and, therefore, were better able to make optimum utilization of their manpower resources. Also they were stimulated by competition and market forces and the need to cover their costs by the fees they earned. Although it was not possible to quote exact figures Mr ROBERTS believed consultants' design teams worked more efficiently and cheaply than the design staffs of bigger national and local government organizations and he felt it was right, when comparing costs of design work done by consultants with in-house costs, to include the total costs involved, including all administrative and office overheads, pensions etc. and also the real cost of the drop in productivity which could occur in slack times.

7. There are some problems or aspects of public health engineering which involve specialist techniques, and when such experience is not available in-house to an Authority, it made sense to go outside to a specialist with experience of that particular technique or problem.

8. When politically sensitive projects have to be studied, e.g. when a site has to be chosen for a sewage works or reservoir, the appointment of an independent and unbiased consultant to carry out impartial investigations and make recommendations (and even to be used as a scapegoat) was a valuable service which the profession could provide. Similarly a consultant could be retained as an expert witness at a Public Inquiry in support of an Authority's case.

9. Under I.C.E. conditions of contract the Engineer has a quasi-judicial function to perform, and there could be advantages if he were not also on the staff of the Employing Authority.

10. With the demise of the D.o.E. Engineering Inspectorate the country was losing a facility for transferring new ideas across the country. Consultants with country-wide practices could help in the introduction of new techniques from one Authority's area to another, while those with overseas practices were able to consider and apply techniques and processes developed overseas (e.g. in Germany and the United States).

11. Consultants frequently designed schemes and supervised their construction but then went off to another job and so did not have operational experience. Mr ROBERTS said this could be mitigated by more regular exchanges of personnel between Water Authorities and consultants, and he would like to see more of this in the future.

12. Mr ROBERTS said he had started by mentioning the export potential of consultants and because of the great importance to the nation of this aspect he would like to end by quoting some figures. British consulting engineering firms in the civil engineering field as a whole were currently responsible for some £6,000m of overseas projects, of which £387m were in the water supply field and £630m in the sewerage and sewage treatment field, a total of over £1,000m in the public health and water fields. If it took an average of four years to design and construct a project, that was some £250 million worth per year. With fees and R.E's salaries totalling some 10% about £25 million per year of foreign exchange was earned by consultants in these fields. In addition, there is a further advantage to British Industry because, when goods to BSS are specified, British manufacturers should have a competitive edge over their international competitors. There was, therefore, a very strong case for ensuring that British Public Health and Water Consultants should remain in business and be able to maintain their present leading position in the international field. For this, a secure and continuing home work load is essential.

13. Mr D.A.D. REEVE felt he ought to explain that his introduction following that of Mr Roberts was not framed as an answer to his; they had decided to make their introductions independently. He felt he should start with a few comments about how the Severn-Trent Water Authority would work. In the short term they were dealing with consultants on the old consultant/client relationship and he felt this was destined to change.

14. The work that had to be done in the Water Authorities fell into two categories. Firstly, as well as looking into the feasibility of schemes themselves, they would pay particular attention to feasibility studies on a very much broader basis. It was intended to proceed to carry out river basin or catchment studies. They would for example think of the River Derwent, part of the Trent basin, as an entity and try to work out a broad policy that would be applied to it. Subsequently, they would split this down into action programmes, all of which made sense and dovetailed together satisfactorily. They had made their first rather tentative start in this direction with the River Avon in Warwickshire where

there were particular problems. There was no question of this being a single-discipline study. It involved engineers of all persuasions, scientists, economists and all the sort of people that Mr Roberts had in his consultant's office. In order to do these studies properly masses of information was needed, most of which was derived internally. Mr REEVE thought that in nearly every case the promotion of these master plans would arise internally and would be done entirely, or very nearly entirely, within the Water Authority's own resources. This was because most of the basic information which was needed was available within Water Authorities in one form or another. There might well, therefore, be fewer opportunities in the future for consulting engineers to take part in feasibility studies of this type.

15. Much of the other work of the Water Authorities was being carried out at the moment by agent authorities. They were obliged to use District Councils for the sewerage function and in Severn-Trent at the moment 40% of the total budget was used for sewerage, and, therefore, 40% of the total capital work was done by agents over whom they had less control than they would have wished. The terms of the agency agreement had to be fixed on the basis of a model which the D.O.E. contrived, and there was no doubt that it showed signs that a fairly powerful local authority lobby was at work. To a large extent whether or not agent authorities used consulting engineers or their own design staffs was a matter for their decision. The agency agreement did not give any means by which Water Authorities could exercise control over this, but Mr REEVE felt that where it was suggested by an agent authority that the vast majority of the capital works should be designed by consulting engineers the Water Authority might be justified in suggesting that they should take over the consulting engineers as a direct employer.

16. Inside Water Authorities, unless Severn-Trent was an exception, they had not enough staff to carry out all the design that needed to be carried out without consulting engineers. Mr REEVE did not think it wise or sensible for Water Authorities to do all design work themselves; certainly there was no policy which would represent a movement towards this. Nevertheless, the Regional Water Authorities were bigger organizations than their predecessors and there were certain advantages of scale. Within Severn-Trent there were dispersed over the total region a fairly substantial number of rather small inherited design teams. If a particular piece of design could not be carried out within a division, then the obvious thing to do would be to see if a neighbouring division could be used as a consultant for the first division. Mr REEVE did not expect this to operate unless the cut back in capital availability continued. At present levels in Severn-Trent they were thinking of something like a 50-50 mix of in-house and consultant design and he thought this was a reasonable target at which to aim. The sort of work put out might change.

17. Mr REEVE had not consulted any of his colleague Directors of Operations for their present views, but their initial reaction varied from those that said it was their object to eliminate the use of consulting engineers at the earliest possible moment, through a substantial number who said they would do the base load of work in-house and would use consulting engineers to lop off the peaks, to those who said they wished to go on very largely with a mixture as before. Mr REEVE fell into the last group but in any event he did not see any reason by which this situation could be quickly changed.

18. Mr REEVE did not think that a thriving group of consulting engineers could operate if they were used only to top up the design during periods when there was an excess of money. He agreed with Mr Roberts that it was essential to have a fairly steady base load, though equally Mr REEVE considered it perfectly reasonable to ask consulting engineers to help out with peak loads if and when they arose. He believed the briefs would be very much more tightly drawn than they had been in the past, and briefs would be issued one at a time. He did not believe they were thinking of perpetual arrangements with any particular group of consultants. They would be looking for speed of reaction to the brief and would regard it as a strong merit for consultants to adhere to the programme they had set. They would be looking for realism in terms of the financial implications of any work that came out and for some means by which they could adhere to a sort of broad generality of approach without stultifying originality.

19. As a Director of Operations for a Water Authority, Mr REEVE could not do without consulting engineers and he did not want to do without them; he needed the injection of something that consulting engineers brought into the water field from time to time. He felt in time things would settle down to very much the same general degree of involvement as before, with less at the feasibility study end of the range and distinctly less freedom of action at the routine scheme end of the range of work.

20. Mr M. SANE wished to put across the social responsibility of the RWAs to consulting engineers and the community in general. At his last count of members of the A.C.E. there were some 120 consulting engineers engaged in the clean and dirty side of the water industry, employing something like 10 000 - 15 000 people partially or wholly in this field. These people had been engaged for a number of years serving some 1300 local authorities, and on the whole had done a reasonable job. With the advent of the Regional Water Authorities the whole future of these consultants has been placed in jeopardy. Amongst them there have been some who Mr SANE suggested were as capable as those existing members of the RWAs in the design and processing of water and wastewater facilities, but many, because of the recruitment procedures of the new organizations, have been unable to obtain positions with the RWAs. Therefore the possibility has to be faced that many of these people together with their design teams would be lost to the industry in the future unless they could be employed in worthwhile types of work. Many consultants in the past had looked overseas for work, but others had depended entirely on the old local authorities for their livelihood. As Mr Roberts has said, in order to keep overseas work consultants have to be concerned with a strong home market, and Mr SANE thought it necessary for them to be involved with the whole design concept of plants as well as new process technology to ensure credibility with overseas governments.

21. He also wished to take up Mr Roberts' comments on specialised activities of consulting engineers. The areas Mr SANE had in mind particularly were cost control, cost-benefit analysis, the running of contracts and the expenditure and control of money during the operation of those contracts. Here consulting engineers may have had a little more experience than the RWAs because of the opportunities they have had in the running of contracts in the past, and he hoped that some of this type of work would also come to the consulting engineers.

22. Mr REEVE was interested in the point about recruitment because he had been quite sad when the Water Authorities were being set up that he was not able to recruit from the staffs of consulting engineers. This was a Staff Commission decision and Mr REEVE thought many Water Authorities would be the poorer for this initially; with time he hoped to put it right. However, if too many people had been lost to Water Authorities, consulting engineers would be less well equipped to do the role they had in association with the Authorities.

23. Mr G.L. SYMES said there seemed to be two main difficulties in the employment of consultants by the RWAs. The first was that the capital allocations received at the moment were less than would have been liked. When the committee work was subtracted from the capital allocation, the base load left was only just enough for the design teams that were inherited. Therefore there did not appear to be a great deal of scope, until the Government gave more money, for very much more employment of consultants. There would be specialized work but not the bread-and-butter type of work for consultants.

24. Mr SYMES thought the other point was the great number of consultants. As had been stated there were 110 doing work in the dirty water field, and Mr SYMES said 37 of them were working for his Authority, having been inherited. He was sure Authorities had lists of consultants they would never give work to and some they were very happy with, but it was difficult to allocate work fairly to consultants.

25. Mr REEVE did not see the situation in Severn-Trent in quite the same way as Mr Symes did in the North-West. Although capital allocations were smaller than they would have wished, they were not that much smaller than they ought to be, and Mr REEVE had the feeling they were not doing too badly in terms of meeting the local authorities' real needs. However, they would fairly soon be issuing briefs to consulting engineers because Mr REEVE was worried that they were not keeping their pipeline of designs fully charged. Thus he thought that quite irrespective of whether more money was spent next year, there would be an increase in the amount of design work needed to be done in order to restore the status quo.

26. When it came to choosing consulting engineers, Mr REEVE hoped someone could tell him how to do it. He said he had a black list and also a list of people who worked well, but there were also certain geographical distributions that had some effect. He thought the Association of Consulting Engineers must itself know the difficulty a client was in when making a choice of consulting engineer.

27. Mr ROBERTS agreed that it might be difficult for Water Authorities to make up their minds whom to give work to, but he thought that in the immediate future they would go by their experience of the firms who had worked for them in the past, coupled with the need to find a particular specialist experience or resources for the particular job to be done. Mr ROBERTS hoped

consultants would not be picked on the basis of price. Some foreign countries tended to do this, particularly the wealthier oil countries. When loose job descriptions were drawn up some foreign consultants tended to quote very low prices, but clients lost in the long term because they were not getting the service which the job demanded.

28. Mr REEVE said he was interested in this. Earlier on, Mr Roberts had made a comment about the relative efficiency of Water Authorities and consulting engineers, and this was something that any employer must look at occasionally to see how he was carrying out his work in relation to the other methods available to him. Mr REEVE's previous Authority had made a fairly accurate assessment of the real costs of carrying out in-house design over many years and he was convinced that consulting engineers did not really get enough money from standard fees to do a decent job on some schemes. He would be horrified at any suggestion of operating on a basis of cut-rate fees.

29. Mr E.V. FINN was pleased and somewhat relieved to hear what Mr Reeve said about his Authority letting out something like 50% of the work, as he had heard that other Authorities had no intention of letting out anything like that percentage. Mr FINN could see the sense in Water Authorities doing their own feasibility studies, but he could also see the sense in Water Authorities using a consultant with a particular specialist knowledge to assist them with certain of their schemes. By so doing an Authority would obtain the experience of the consultant working in other parts of the industry or even other parts of the world.

30. Mr R.A.R. DRAKE said he thought conditions in the Thames Water Authority would be very similar to those in the Severn-Trent and that something like 50% of the work would go out. His establishment was precisely that of the GLC, and he was not allowed to have any more staff. The GLC had employed about ten consultants.

31. In the Metropolitan Public Health Division they used consultants' fees as a basis for estimating staff requirements. They felt they could do work as 'cheaply' as consultants. Undoubtedly sewage treatment works involved a lot more work than sewers and the consulting engineer was in a difficult position when he had to design sewage treatment works which were complex compared to sewerage which was simple. However, Mr DRAKE thought the main problem with consultants was their lack of operational experience, and he thought this could be overcome by making sure that the consultant's brief was detailed

32. As far as Mr Symes' remarks were concerned, Mr DRAKE felt it was rather short-sighted to stop design because money was stopped. His advice was to design as much as possible so that when the money was released, the designs would be ready.

33. Mr REEVE thought this was an interesting point because there was plenty of evidence that the Central Government used the Water Authorities to regulate public spending and he had little doubt that although expenditure was currently held below proper levels, in due course they would be asked to spend 10 or 20% more. Mr REEVE did not think he was able to say that they could do work more cheaply than consulting engineers, but he would say they could do work as cheaply. He would not comment about the final product, as everyone had their own views on this.

34. Mr REEVE said he tended to get worried about this question of operational experience. It was undoubtedly easier for Water Authorities to ensure that their design staffs had operational experience, but it was less easy now than it was before, and it was something that needed to be looked at carefully. Internal secondment was one of the ways in which they would seek to achieve it. External secondment with consulting engineers or contractors was useful but produced administrative difficulties.

35. Mr D.J. GRIFFIN said that speaking as a member of a partnership that operated to a fair extent overseas he would be interested to hear from Mr Reeve on a particular point regarding work in a country where there was very little public health engineering experience and expertise. Part of the brief on occasions was not only to carry out feasibility studies, to do detailed designs and to see that the plant was commissioned satisfactorily, but also to ensure that it operated satisfactorily for a stated period. It occurred to Mr GRIFFIN that there was a distinct opportunity for secondment of experienced men from RWAs to a consulting engineer to operate a new plant for water supply or sewage treatment.

36. Mr REEVE thought this would be of benefit, although he had the feeling that it would make more demands on flexibility and would develop a deeper degree of partnership than many were ready for. It was extremely difficult to move people from one place to another for relatively short periods on the scale that would be useful. He was not optimistic about this for at least two or three years.

37. Mr D.G. HALL said there seemed to be some general agreement that there was every need to proceed with design work in preparation for future construction. If the design work was being carried out in-house by the Water Authorities this presented no particular problem since it would be carried out by staff already on the establishment of the Authorities and would demand no particular financial allocation. If consultants were to be used during slack period in preparatory design work, then surely this meant the particular financial allocation would presumably be coming out of the money presently available for actual construction.

38. The second point Mr HALL made was that the established pattern for the work of the consulting engineer had been the report or feasibility study, the general design and then the supervision of the contract, and the full responsibility for the quality of work, the functioning of the designed project and the settlement of the final accounts. Over the years Mr HALL's organization had had experience of all sorts in the supervision of contract work. If the contracts were small ones in remote scattered rural areas it was difficult to obtain temporary staff of the right calibre to supervise such work. On the other hand for the site supervision of the bigger contracts they had built up a virtually permanent staff who were used to their designs, reactions, interpretations of general conditions of control, specifications etc, and this meant that if they were allowed to select their own supervisors, they could properly take full responsibility, and feel they were doing a full job as consulting engineers. Since re-organization there seemed to be a greater pressure for Authorities to second their own staff to the consultants for the supervision of contracts and whilst this sounded very good in principle, it led to very great problems as far as the consulting engineer was concerned. They had operated on this principle several times and found that it often became friction-ridden to have a member of the team on-site trying his best to serve two bosses. What was worse, if he was not carrying out the job satisfactorily, it was highly embarassing.

39. Mr REEVE agreed that if money was spent on design it was not available for works. Most people took the view that a reasonable proportion of the total capital ceiling be allocated between design and actual construction. This was particularly important in the case of agent authorities where RWAs had very little control over the staffs but had to pay design costs which were quite a substantial part of the total capital budget.

40. In the case of supervision of contracts or indeed interfering with the normal pattern of work with consulting engineers, Mr REEVE hoped he was not interpreted as suggesting that he saw consulting engineers relegated in general to the role of structural consultants or heating, lighting and ventilating people. If he employed a consultant, he felt that he wanted the whole man, not some emasculated shadow.

41. Mr REEVE did not quite understand the inference about the interference of site supervision. The only reason he could think of for doing this was if a Water Authority needed to place one of its junior members of staff on site for a period in order to satisfy the requirements of, for example, the Institution of Civil Engineers. Other than that if a consulting engineer had been given a brief then he ought to be allowed to get on with it. The consulting engineer's clients would on the whole be more discriminating than in the past and it might well be that they would be more interfering. Mr REEVE thought the main interference would be the compilation of the brief and seeing that the terms of the brief were being adhered to.

42. Mr B.A.O. HEWETT replied to an earlier query about the proportion of design work which Authorities intended to give to consultants. In the Southern Water Authority a great deal of discussion had taken place amongst the officers and members as to what proportion should be given, and it was eventually decided that 22½% would be put to consultants. Members had to justify to the electorate the increase in staff and the apparently high salaries being paid to well-qualified men in the new Authorities. To the layman it was difficult to understand why a consultant was necessary when there were highly paid engineers in these large new organizations. Thus there was a public relations job for the consulting engineer to convince the layman that he had a role to play. It seemed to Mr HEWETT that when discussing the role of the consultant there might possibly be a parallel with the medical profession, in which there was a GP and a medical consultant, the latter being a highly specialised doctor or surgeon who had been trained to a high level in one particular specialty. Many smaller engineering consultants had based their livelihood on the GP's role, which to a large extent would be taken over by the Water Authorities. Would Mr Roberts like to comment on whether he felt that as a result of this tendency, consultants should become much more specialised, like the medical consultant, to provide the expertise that Water Authorities

could not. Difficulties would arise with smaller firms of consultants who did not have the wide base load of work in other spheres of civil engineering, and could not afford to employ economists, statisticians and other specialists. He wondered if Mr Roberts felt that to overcome this problem there was some virtue in amalgamation of consulting firms following the pattern of the RWAs.

43. Mr ROBERTS agreed with Mr Hewett although it would only be possible to provide the special functions if consultants had some run-of-the-mill work as well. As a long-term development Mr ROBERTS thought that most of the bread-and-butter work would be done in-house by the Water Authorities but that some of the more interesting work could go out to the consultants because they could handle it quickly and it might be politically sensitive. Mr ROBERTS' practice had in the past worked for a large number of major Corporations who had substantial design teams, but nevertheless they had found it expedient to go to consultants and he thought Water Authorities would do this on some of their bigger projects. He thought the tendency would be for firms to work more as a consultant in the medical sense rather than as a GP, although he hoped that the GP aspect would not disappear altogether.

44. Amalgamation of consulting firms was difficult, but a number of firms had already amalgamated. Other firms had formed federations whilst still retaining their separate identities. There must now be a tendency for some of the smaller firms to join with larger firms, which would be a sad development in many ways because they had undoubtedly made a great contribution in the past.

45. Mr REEVE commented on the employment of consultants as a 'politically sensitive' matter. He felt this was a passing problem and was in part due to the great criticism that most Authorities had suffered from the Press, which made them very sensitive, particularly to labour bills and to the use of external consultants.

46. Mr A.P. MICHAELSON suggested that not enough attention had been given to the small or medium so called 'bread-and-butter' schemes, and Authorities were now having to correct difficulties in operation etc. on these works. It might be that the remuneration received by consultants on difficult sewage work schemes did not represent the amount of effort involved. He agreed with Mr Reeve that there would be tight briefs in the future so that consultants would know what was expected from them. Too often in the past they were given carte blanche and did not know what was expected of them. They did what they felt was intended but in many cases it was obviously not what the operator needed, nor perhaps what the river could accept in terms of effluent quality.

47. Mr Reeve had mentioned that there should be confidence in the consulting engineer. Mr MICHAELSON asked whether he would be confident enough to name the consulting engineer as the engineer responsible for the contract.

48. Mr MICHAELSON raised another point. Unfortunately many schemes in the pipeline were conceived by the previous local authorities and inherited by the North-West Water Authority. There was one previous local authority who at virtually the eleventh hour asked consultants to prepare schemes for all the rural villages within their area and handed these over to the new Water Authority. Many such schemes were not the ones that his Authority would now like to see go ahead, for example, a sub-regional scheme may produce a more acceptable solution.

49. Mr REEVE said his Authority had inherited a substantial number of contracts where the consulting engineer was named on the contract documents; and he thought this was not an unusual practice. He saw no reason why it should not go on, and indeed the adoption of the new conditions of contract made this even more necessary than before, as there was a closer relationship between the administration of the conditions and the site staff than there had been in the past.

50. Mr ROBERTS endorsed this. He felt it would be very unfortunate if there was any question of division of responsibility. If a consultant was employed he should be given a tight brief and then be allowed to produce the end product within that brief.

51. In reply to Mr Michaelson's comments about schemes inherited from the old local authorities, Mr REEVE said his Authority did not feel any moral obligation to honour this sort of ill conceived arrangement. He also had come across cases where a lot of last minute briefs were issued and loose consultant/client arrangements were hastily parcelled up.

52. Mr R. ADDISON said that at one time it was suggested in the Anglian Authority that they should aim at designing 75% of the base load in-house, but they started with a very modest engineering establishment.

There had been some difficulty in filling this establishment with engineers of the right calibre, and he did not think there was any possibility in the forseeable future of being able to design 75% of base load in-house.

53. Tighter and more detailed briefs, involving engineers and operation staff, fuller consultation during the course of the design and construction, and debriefing sessions on completion, involved the Authority staff to a greater extent than were the staff of the previous local authorities, and it would add an on-cost to the consultant's fee. Mr ADDISON said it was rather early to quote figures yet, but he felt the enormous on-costs which a local authority had to add to design salaries would not be so high in the future.

54. On the question of selecting consultants Mr ADDISON said his Authority had found that the better consultants had responded well to the tighter briefs and this had been a help in their selection of consultants.

55. Mr D.V. TRIMM, as an engineering contractor and one of the innocent victims of the war, was interested in the remarks about the consultant being the engineer and controlling the contract. Stability was needed, and he thought the wide variety of interpretations that arose in the conditions of contract caused problems. It would be helpful if Water Authorities developed a consistency of interpretation firmly controlled by the Authorities themselves.

56. Many new ideas and processes were promoted by engineering companies and his company would prefer to deal directly with an Authority rather than with an intermediate consultant.

57. Mr ROBERTS said that some Water Authorities were trying to establish their own code of practice as far as design parameters and procedures were concerned; on the whole this was helpful and desirable, although it could be taken too far as in practice no two cases were the same, and there would always be something different about any new works. Mr ROBERTS could understand Mr Trimm's point about new ideas, but he felt the consultant could play a part in assessing for virtues of new developments.

58. Mr REEVE thought the wide variations per megalitre capacity should be looked at. Some of the schemes going in now showed something like four to one variations in cost for things which were substantially the same. He was concerned as to how new systems of treatment would be tested out in field conditions. They cost more to design and would eat into the consultant's profit unless special arrangements were made. At a recent CIRIA meeting, there had been discussions as to the funding of extra costs arising from the adoption of ideas coming forward from organisations such as CIRIA and the Water Research Centre. It was impossible to break into new patterns of treatment and new systems without incurring extra design costs.

59. The CHAIRMAN thanked Mr Reeve and Mr Roberts for introducing the discussion subject and for dealing adequately with all the questions. He felt the subject had been constructively aired.