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REMOVAL OF IRON AND MANGANESE FROM GROUNDWATER,

WITH PARTICULAR REFERENCE TO DEVELOPING COUNTRIES.

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for Community Water Supply.

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INDEX.

	pag.
Chapter I Introduction	2
Chapter II Iron removal	4
- Oxidation and hydrolysis	
- Coagulation	
- Filtration of a colloidal Fe_2O_3 -suspension	
- Filtration of a flocculated Fe_2O_3 -suspension	
Chapter III Manganese removal	9
- Reactionmechanism	
- Initiation	
- Performance	
- Termination	
Chapter IV Dry filtration and subterraneous removal	12
- Introduction	
- Theory of dry filtration	
- Application of dry filters	
- Design of dry filters	
- Theory of subterraneous removal	
- Operation of Vyredox and Subterra	
Chapter V Fe and Mn in the distribution system	17
Chapter VI Treatment methods	19
- Introduction	
- Size of population	
- Electricity	
- Chemicals	
- Personnel	
- Removal methods	
Chapter VII A treatment plant for Borujwara	30
Chapter VIII A treatment plant for Abubshahar	36
References	43

CHAPTER I INTRODUCTION.

Iron and manganese in drinking water are objectionable for well-known reasons, they are: bitter taste, discoloration of rice, stains in laundry, turbidity, decreased milkproduction of cows, and serious problems in certain industries like dye-works, laundries, breweries, textile-industries, canneries, paper-mills, tanneries and photographic industries.

When suspended they occur as bivalent cations, or, exceptionally as a ferric-hydroxide colloidal suspension, stabilized by e.g. humic acids. In groundwater they dissolve from minerals containing iron and manganese (e.g. FeCO_3 , MnCO_3 , FeS , MnS). This dissolving is governed by certain conditions, among others, O_2 -content, alkalinity, redox-value, pH and sometimes acids reducing MnO_2 . The latter can often be found in swamp-areas.

The following list gives an indication of the range of actual iron and manganese contents and limits given by W.H.O. and V.E.W.I.N.

	High value	ACCEPTABLE		ALLOWABLE	
		W.H.O.	V.E.W.I.N.	W.H.O.	V.E.W.I.N.
Iron mg/l	30	0,3	0,05	1,0	0,1
Manganese mg/l	3	0,1	0,01	0,5	0,05

It may be noted that even higher contents have been recorded but they are exceptions like the manganese disaster in Breslau (1906) when $30 \text{ mg Mn}^{2+} / \text{l}$ was measured.

Whether removal of iron and manganese is a physico-chemical or biological proces is rather difficult to determine. There are theories, based on biological observations that lead to a mechanism of removal that would also be found if one had worked from physico-chemical assumptions.

Manganese removal can be fully understood as a chemical proces; however manganese-oxidizing bacteria probably play an important role. Deferrisation can proceed in a sterilized environment, but nitrification is most probably based in the action of the bacteria Nitrosomonas and Nitrobacter.

5

Alas the analogy cannot be pursued further due to the limited amount of literature available on biological removal of iron and manganese. This is one of the reasons I shall concentrate in this paper on removal by physico-chemical precipitation.

Deferrisation and manganese removal are two processes that usually go together. The reason for this is undoubtedly that most groundwaters are anaerobic and contain both iron and manganese. Furthermore, both iron and manganese occur as bivalent cations, their solubility characteristics are similar and both need oxidizing to enable precipitation.

As to the removal mechanisms there are distinct differences. Fe^{2+} can be oxidized and hydrolyzed at pH of 7 or higher and be flocculated at a pH of 8. The water can be clarified (e.g. flocculation and sedimentation) and subsequently filtered in in a conventional rapid filter.

In contrast, manganese removal occurs through oxidation in the filter after absorption to the filtering material. The rate of of oxidation is mainly dependent on the catalytic activity of the filter medium.

It appears that the removal of iron and manganese are two different processes; they can hardly proceed optimal in one single filter. This great difference in removal mechanism leads me to deal with them in separate chapters.

Dry-filtration and subterraneous deferrisation may be or become promising alternatives. They represent theoretical concepts which differ considerably from the ones discussed earlier, and they will be dealt with in a separate chapter.

One chapter will be dedicated to the problems caused by iron and manganese in distribution systems. Finally I shall go into the possibilities and difficulties of removal of Fe and Mn from groundwater in developing countries, completing the chapter with a summary of removal methods and their merits.

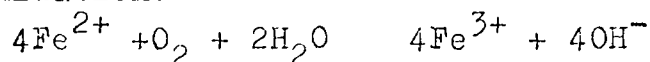
To illustrate the practical application of the list (and its shortcomings), I shall endeavour to design two treatment plants, one for a village of 1300 inhabitants (chapter VII) and one for a group of villages with together 13,000 inhabitants (chapter VIII).

CHAPTER II IRON REMOVAL

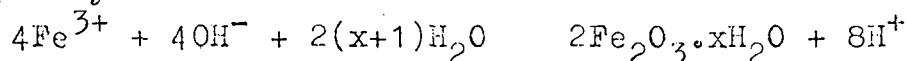
Oxidation and hydrolysis.

Disregarding special methods that will be discussed later, iron removal basically is oxidation, hydrolysis, flocculation and filtration. Oxidation can be achieved by aeration and by chemicals like chlorine, permanganate and ozone. I shall first concentrate on oxidation by aeration, a process widely used in the Netherlands.

Oxidation:



Hydrolysis:



These equations clearly demonstrate that if the water has insufficient buffering capacity, the pH would decline rapidly with corresponding decline of filtration-rate.

The pH is a very important factor in iron removal.

At a pH lower than 5, oxidation only proceeds slowly, at a pH of 7 or higher, the oxidation rate is high, provided sufficient buffering capacity is present.

The quantity of oxygen supplied by aeration, in fact, is of little interest to the oxidation rate. Theoretically, oxygen-saturated water (10 mg/l) can oxidize 70 mg/l of Fe^{2+} .

One should however always allow for the presence of ammonia in groundwater. 1 mg NH_4^+ can consume all the oxygen from the aerated water. Considerable amounts of nitrogen may even demand multiple aeration.

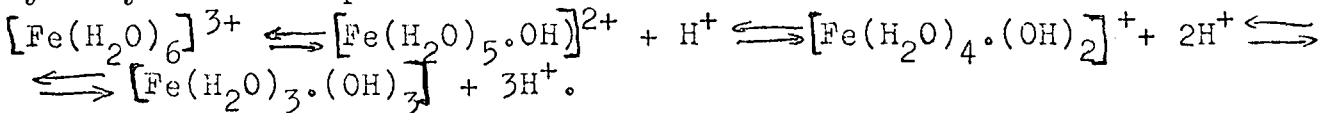
The oxidation of Fe^{2+} appears to be improved by previously formed ferri-hydroxide flocs or deposits. When dealing with dry-filtration we shall see the importance of the catalytic activity of precipitates. The catalytic influence is readily demonstrated when putting a new filterbed into use or a bed that has been backwashed. It will take some time for the oxidation rate to reach the desired level.

The effect of other ions in groundwater on the velocity of oxidation is that of a lower sensitivity to the residual Fe^{2+} concentration. The oxidation proceeds slower than would be expected from the reaction equation due to the presence of sulphate, phosphate, ammonia and bicarbonate.

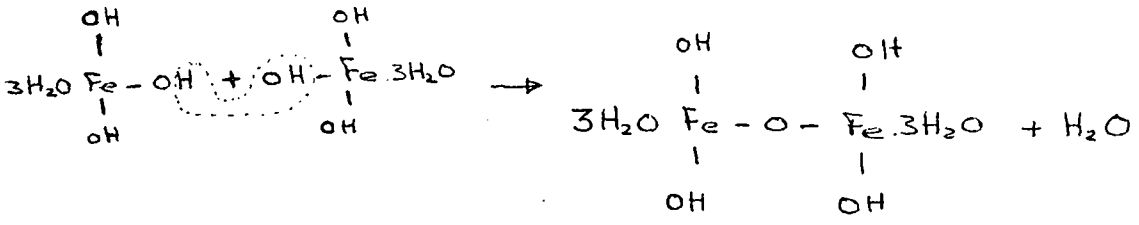
Coagulation

What makes a solution a colloidal solution ? As we shall see later on, this is an important question.

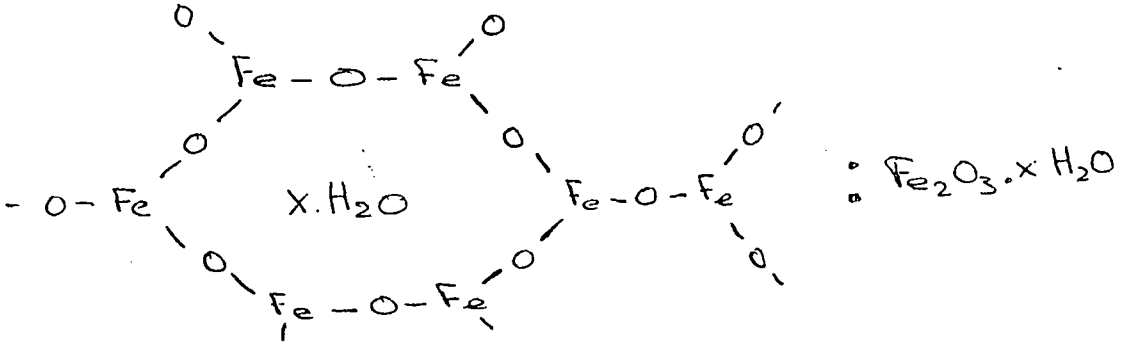
The hydrolysis of $Fe(H_2O)_6^{3+}$ can be regarded as a hydrolysis in steps:



Next, polymerisation takes place:



This polymerisation goes on:



The size of the colloidal particles formed usually is between 0,01 and 0,1 μm. If we consider a rapid filter with a particle size of the filtering material of 0,4 mm, and thus a pore diameter of 60 μm, it will be clear that mechanical straining is negligible.

Filtration of a colloidal solution (an other removal mechanism) is very well possible, but the efficiency is rather low. I shall discuss this kind of filtration later.

Flocculation after oxidation and hydrolysis is of vital importance in iron removal because coagulation determines whether a colloidal or a flocculated suspension is to be filtered. We have to understand the factors of influence on flocculation, with a view to control the process.

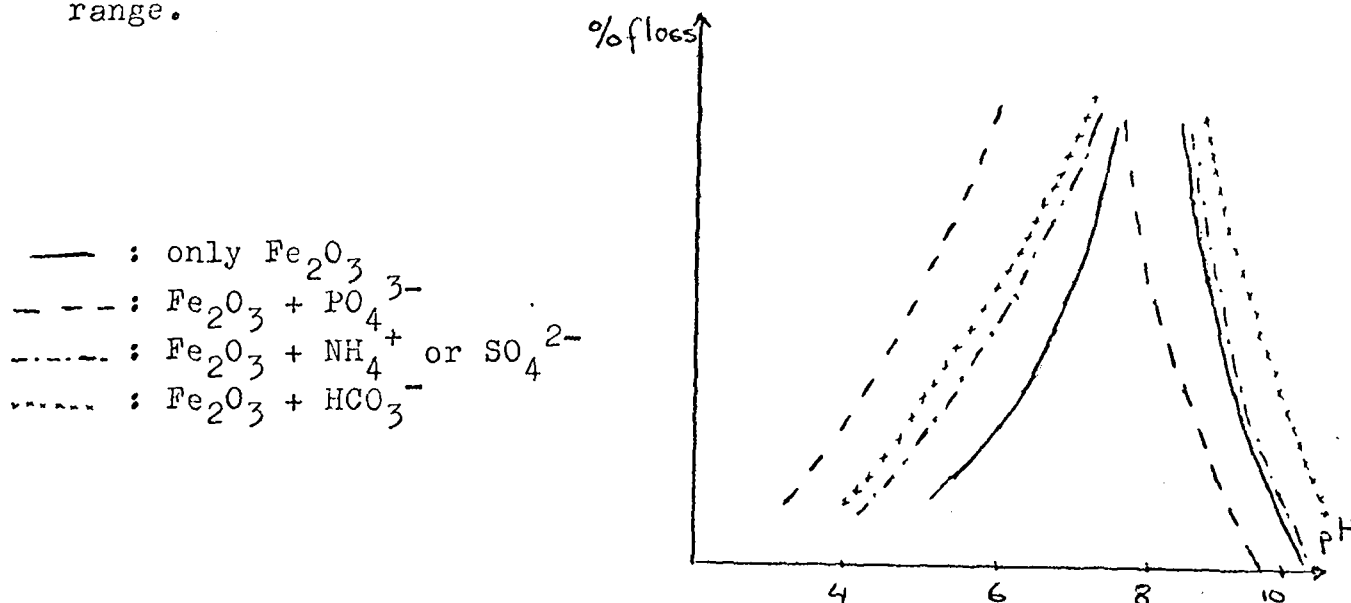
In a colloidal suspension between two particles 2 forces are present:

are interactive. An attraction caused by VanderWaals-forces and a repulsive due to similar surface charge of the colloids. As long as the repulsive force prevails, the solution will be stable, the particles will not coalesce and remain dispersed by the Brown movement. To achieve flocculation we must decrease the repulsive forces. This can be done by establishing a pH of 8. Experiments have demonstrated that the surface charge of colloidal iron is positive below $\text{pH} = 7,5$ and negative above $\text{pH} = 8,5$. $\text{pH} = 7,5 \dots\dots 8,5$ is the flocculation range of a ferri-hydroxide colloidal solution, the iso-electric point being about 8, which means that at $\text{pH} \approx 8$, the surface charge is zero and the repulsive forces are minimal. Then flocculation will occur readily.

Generally speaking we can state that a well flocculated suspension can be formed if the pH after oxidation and hydrolysis is about 8. Once again we find that iron removal is governed for a great deal by the pH.

The effect of other ions in groundwater on the flocculation range can be summarized as follows:

- phosphate shifts the whole range to lower pH-values
- ammonia and sulphate broaden the range to lower pH-values
- bicarbonate gives a general broadening of the flocculation range.



Laboratory investigation of the water to be treated constitutes an essential part of the overall investigation to find an appropriate means of deferrisation. The iso-electric point of Fe_2O_3 in a particular groundwater must be known for most methods.

Filtration of a colloidal Fe_2O_3 suspension.

This kind of filtration can only be achieved if the filtering material carries a surface-charge contrary to the charge of the colloids. However, after a short time the grain surface will be covered with colloids, and the effective charge of the "grains" will change. From then on, the other colloids will be repelled. Thorough backwashing will be required.

Actually the situation outlined above is rather undesirable and only interesting from a scientific point of view. In the framework of this paper it does not seem relevant to me.

Filtration of a flocculated Fe_2O_3 suspension.

The theoretical approach of deepbed filtration (the mechanism involved when filtering a flocculated Fe_2O_3 suspension) has made great progress in recent years thanks to the work of many investigators. The insight has greatly improved, but design from behind the desk still is not possible. Pilot plant research remains necessary to be able to work with the quality of filtering material available (grain size and grain size distribution), groundwater quality, filterrun, quality of effluent and so on.

Some indications may be given of parameters that have proved useful in designing rapid filters for removal of iron. These indications are merely rules of thumb and never are a substitute for a pilot plant.

- Filtering material: apart from usually not available burned dolomite and similar materials having catalytic activity, the most suitable material is sand. Whatever material is chosen for, it should be clean and durable, as much as possible free of clay and other impurities, the size may vary between 0,6 and 2 mm.

- Rate of filtration: conventional rate for removing impurities from surface water is about 5 m/h. When treating a well-developed Fe_2O_3 -floc the rate may be doubled so as to increase turbulence in the filterbed.

- Backwashing: due to the rather large size of the grains of the filtering material, achieving sandbed expansion may prove difficult. With grains of 2 mm diameter for instance, there is

likely to be no expansion during backwash. Backwashing of long duration will be required to obtain a clean filterbed.

CHAPTER III MANGANESE REMOVAL

Reactionmechanism.

While the pH plays a leading part in deferrisation, catalytic activity is essential in manganese removal. While oxidation of Fe^{2+} occurs spontaneously at pH 6,5 in water, the oxidation of Mn^{2+} requires a pH of 9 or 10. If desired, oxidation of Mn^{2+} may also occur at pH = 7, but then either chemicals are to be applied or use must be made of catalysis.

We can distinguish three manganese removal methods:

- 1) Manganese removal by catalytic activity
- 2) Use of lye, raising the pH to 9 - 10
- 3) Use of oxidants, potassiumpermanganate, chlorine and ozone have been applied.

ad 1) Oxygen can be used as oxidant (aerial oxygen), the pH between 7 and 8,5, it is an autocatalytic oxidation.

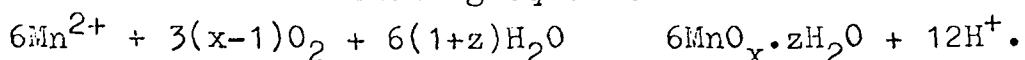
ad 2) By raising the pH to 10, the CO_3^{2-} -concentration will increase and CO_3^{2-} will precipitate as CaCO_3 (softening) and as MnCO_3 (rhodocrosite). Afterwards the pH must be corrected.

ad 3) KMnO_4 is a strong oxidant, the pH must be higher than 7, chlorine can be dosed when chlorination would take place anyhow for disinfection. Ozone oxidizes bivalent manganous ions to the septavalent permanganate, that transfers to tetravalent pyrolusite by filtration over activated carbon.

There is a fourth method, with ion-exchange. Application is found in industry for removing residual concentrations of manganese.

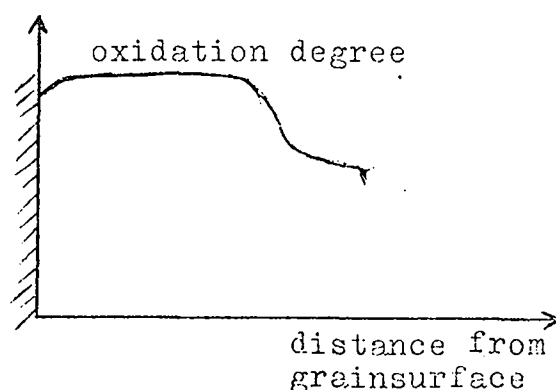
I shall now concentrate on the most interesting method that in many cases also is the most economical, namely manganese removal in a slightly alkaline environment with aerial oxygen as oxidant and autocatalysis as reactionaccelerator.

Considering Mn^{2+} -oxidation purely as a chemical process, we come to the following equation:



Now, the oxidationdegree x appears to be of vital importance for catalytic activity, the lower x (e.g. Mn_3O_4) the higher oxidation velocity.

Consequently we find that in the filterbed with good manganese removal performance the grains have a surface layer of Mn_3O_4 . This Mn_3O_4 however is thermo-dynamic unstable, it is urged to proceed oxidation to a higher oxidation level (e.g. MnO_2). We can distinguish two reactions, first the forming of manganese oxide with a low oxidation degree (Mn_3O_4) and next to it a continued oxidation of this Mn_3O_4 to MnO_2 . The point at issue now becomes to not let the second stage oxidation take place at the surface, but deeper in the layer surrounding the grain. Then the catalytic activity of the surface can be maintained by continuous new forming of Mn_3O_4 . One could imagine that the level of the oxidation degree may be related to the distance from the grain surface (see figure). The rule is: the lower the oxidation degree, the higher the catalytic activity.



Initiation.

To initiate manganese removal by catalytic activity, a layer of Mn_3O_4 should be formed as soon as possible. This can be done by using filter media that already show some catalytic activity (e.g. dolomite ores, magno and akdolite or manganese containing sands). Should this not be available, then initiation can be tried by covering the grains of the filtersand with a catalyser.

Sand usually does not have catalytic activity, but on the other hand it is a very suitable carrying medium. The grains can be covered by an active material by circulating a freshly prepared Fe_2O_3 colloidal suspension for some time at a $pH \approx 5,5$. The colloids have a positive charge and the grain surface is negative. The catalytic activity of the deposited Fe_2O_3 layer is far less than that of Mn_3O_4 , but it may be the beginning of manganese removal. After Fe_2O_3 -circulation, the pH is to be raised to 8,2 8,6 and the supply of Mn^{2+} must be as great as possible to stimulate the formation of Mn_3O_4 .

Performance.

The velocity of manganese removal appears to be almost independent of the oxygen supply in a bed with good performance. As long as the dissolved oxygen content remains between 1 and 20 mg/l, this content has no influence. Below 1,0 mg/l there is a chance that the oxygen concentration is insufficient for oxidation of all the manganese, above 20 mg/l continued oxidation will occur at the surface of the catalytic active layer, decreasing removal seriously.

Oxidation of manganous ion reduces the pH if no sufficient buffering capacity is available (e.g. of bicarbonate). We can generally state that both an increase of pH and HCO_3^- concentration have a stimulating influence on the oxidation velocity. Usually the desired pH lies between 7 and 8,5. A higher pH would cause oxidation in the homogenous waterphase, which is troublesome because a colloidal MnO_2 -suspension will be formed with the associated filtering difficulties. As to other ions: phosphate shows a light reduction of the manganese removal rate, other constituents have no appreciable influence.

Termination.

Termination of catalytic activity can in principle have two causes:

- 1) covering of Mn_3O_4 by other materials like MnCO_3 or FeO_3 colloids that managed to pass deferrisation. The latter reduces manganese removal capacity and raises the filterresistance due to the bulky condition of $\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}$.
- 2) Second stage oxidation of Mn_3O_4 at the surface of the active layer to MnO_2 . MnO_2 has considerably less catalytic effect on oxidation.

Second stage oxidation can be caused by stronger oxidants than aerial oxygen (more than say 10 mg/l), and finally by a pH higher than 9.

Experience has demonstrated that termination can also be caused by letting the filter stand dry for an extended time (so continuous operation is required), by backwashing too vigorously, or by backwashing with air.

CHAPTER IV DRY FILTRATION AND SUBTERRANEANOUS REMOVAL

Introduction.

Before dealing with other methods of iron and manganese removal in chapter VI, I shall first pay attention to two special methods of removal, dry filtration and subterraneanous removal. These two have specific characteristics that may stimulate their application more and more in future. I handle them separately because the theory on which they are based is different from the theories discussed so far.

Dry filtration resembles rapid filtration (in this context also referred to as wet filtration) . As to grain size, grain size distribution, filterdepth, filterrate and backwash mechanism the resemblance is even high. The characteristic difference is that rapid filters are submerged and dry filters are not. Together with water, air is drawn into the filterbed.

Theory of dry filtration.

Dry filtration was applied for the first time about a century ago, the theory of their function however dates from the fifties. Especially the names of Lerk, Linn and Boorsma must be mentioned here in this context.

Linn and Boorsma both took the view that iron and manganese removal is based on contact-catalysis and on the action of the electro-statical double-layer. Furthermore, Linn based his theory on the occurrence of turbulence. Boorsma replaced the latter view by the surface-action phenomenon. In the following all these concepts shall be discussed.

The theory of contact-catalysis implies that for good performance, the greater part of the molecules to be removed , must be contacted with the catalytic active surface layer of the sand-grains.

The theory on the electro-statical double-layer is important in cases where the reaction time is so short that no colloids may be formed that can pass the filterbed unimpeded. This means that the water should be contacted with air as short as possible before the bed or in the bed.

With laminary flow , only a small part of the molecules to be removed come close to the catalytic active surface layer. When the flow is turbulent , then more molecules approach

the grains. Turbulence can be increased by raising the filtration rate, but it does not disturb a laminary layer on the grain surface. Dry filtration means that water and air simultaneously pass the bed. With air in the pores, the water trickles down along the grains in extremely thin and turbulent layers. Research on this subject is being done at the Delft University of Technology.

The surface activity phenomenon was demonstrated by Lerk. It implies that a concentration increase occurs of ferri-hydroxide at the intermediate surface of air and water. This acts stimulating to oxidation (catalysis) and flocculation. The specific intermediate surface air-water has impressive dimensions in dry filters. This is the reason for applying filter material with a grain size as small as possible, but large enough to allow a reasonable filterrun and resistance of the clean bed.

Application of dry filters.

Dry filtration has two advantages compared to rapid filtration.

- 1) During the whole "detention time" the water is in contact with air, so depletion of oxygen can hardly occur.
- 2) The velocity of water in thin sheets along the grains can reach high values.

The first advantage is evident when the water requires much oxygen (for example when it contains ammonia). The second is important for all the catalytical and biological proceedings.

Sometimes an additional advantage of dry filtration is mentioned: the iron precipitate is more compact than iron deposits in rapid filters. It is dubious whether this is an advantage, because the length of filterrun is increased, but more vigorous backwashing is required. The necessity of vigorous backwashing renders dry filters less suitable for manganese removal as this may destroy the active layer. The catalytic active layer will be washed away by the energetic backwash.

Design of dry filters.

Air-supply: in the open, with filter rates low enough (less than 5 m/h), natural aeration generally is sufficient in open constructions for oxygen supply. Higher rates may cause clogging, noticeable by puddles on the bed. Of course this problem will present itself more readily when the last backwash is longer ago.

Above 5 m/h fans or compressors shall have to be applied in a closed structure. As to aeration one has to take care that the air will reach all parts of the bed.

It is essential that the water to be treated is aerated as short as possible before the bed in order to prevent premature oxidation due to prolonged reaction time. Negatively charged Fe_2O_3 colloids might occur, that pass the bed unhindered.

If sprayers are used for aeration, then cleaning must take place on a routine schedule to prevent clogging. Whether the iron and manganese deposits are of biological or physico-chemical origin is not completely understood. For design however it is not important to know, as both require a large specific surface. The electro-statical potential of broken material and the electro-kinetical potential of sharp material make these preferable, but simple clean sand with a grain size of about 1,0 mm too shows good results. Because of the backwash expansion of the bed, the uniformity coefficient of Allan Hazen should be at most 1,5. Blast-furnace slags and anthracite have also been applied, but one must always be aware of the possibility that worms and larvae find their way to the filtering material.

Due to depositions that cannot easily be washed away, (e.g. FeCO_3 and MnCO_3) the grains of the filtering material may grow in size during 2 - 3 years. Even the most vigorous backwash cannot remove these deposits and the filtering material shall have to be replaced. Furthermore, it means that the backwash rate will have to be flexible to be able to give the desired expansion, also after 2 - 3 years. In the design stage this must be born in mind.

The backwash usually is the same as for rapid filters. Differences are the additional air-wash (20 - 50 m/h), and the prolonged and more vigorous water backwash. Rule of thumb: rate 30 - 60 m/h, duration up to half an hour.

The air-wash makes clear that iron and manganese removal cannot both proceed well in one dry filter. Air-wash terminates the catalytic activity of the surface layer necessary for manganese removal. It might be taken into consideration to operate two separate dry filters for groundwater containing both iron and manganese. The first one could operate for iron removal

and be backwashed vigorously every 2 days, the second would remove manganese and backwashing would only have to occur rather quietly every 4 - 7 days.

Theory of subterraneous removal.

With conventional iron removal, adsorption follows oxidation, with dry filtration they occur almost simultaneously and with subterraneous deferrisation and manganese removal, adsorption is followed by oxidation. The principle has been applied in two processes, Vyredox and Subterra.

The principle is oxidation of iron and manganese in the aquifer, iron and manganese free water is extracted after injection of a smaller amount of oxygen saturated water.

The designers themselves give as explanation for the good performance the activity of aerobe iron and manganese oxidizing micro-organisms. They gather this from the adaptation time that elapses before optimal operation. Apart from the fact that there isn't very much known yet about these bacteria, the explanation is not very satisfying.

Van Beek and Vaessen give a more plausible explanation, based on physico-chemical data from literature.

By injecting oxygen-saturated water in an aquifer the anaerobe groundwater is forced back, leaving behind the constituents absorbed on the grains. Thereupon these constituents (a.o. Fe^{2+} and Mn^{2+}) are oxidized by the oxygen of the injected water and Fe_2O_3 and Mn_3O_4 (or Mn_2O_3 , MnO_2) is been formed on the grains.

These oxides on their turn have absorbing properties for the Fe^{2+} and Mn^{2+} that pass the "oxidized" part of the aquifer, when extraction is resumed.

All the Fe^{2+} and Mn^{2+} approaching the well will be retained until the absorption-sites are spent, then the iron and manganese will reach the well and be extracted.

Then the time has come to inject new oxygen-rich, degassed water into the well and the same proces is repeated.

We find that this explanation does not speak of adaptation period, rather of a breaking-in period.

Operation of Vyredox and Subterra.

A great advantage of the Vyredox system is that in principle every well can rather simply be made suitable for subterranean deferrisation. The cycle is started by injecting oxygen-rich, iron and manganese free, degassed water into the well and, if necessary, into some surrounding satellite-wells. Water free of iron and manganese may be withdrawn for some time, but after a few weeks (depending on operation conditions) the concentration of iron in the groundwater recovered surpasses a set limit. Extraction is then stopped and treated water is injected anew.

A possibility of management is injecting for 24 hours with such a pressure that iron free water can be recovered for one month.

CHAPTER V Fe AND Mn IN THE DISTRIBUTION SYSTEM.

Fe and Mn are sometimes mentioned as objectional in drinking water due to the possible precipitation and accumulation in the distribution system. Clogging can be the ultimate result. Usually the problem becomes manifest by red-brownish water leaving the tap. This is caused by the sloughing-off of previously formed iron and manganese deposits stirred up by high velocities, in particular during flow reversals. These deposits can have two origins:

- 1) the water itself as it is brought into the system.
- 2) corrosion of the distribution system.

The first source can be reduced in the purification plant by improved iron and manganese removal. It is rather difficult to give an indication of the concentrations at which no disturbances have to be expected. It depends on a variety of factors e.g. pH, O₂-content, alkalinity and velocity of flow. A very vague line can be drawn at 1 mg/l, but this is merely an indication with wide variation.

The second source too is dependent on many circumstances. The rate of solution of iron from the pipe surface is inversely proportional to the alkalinity, hardness and pH-value of the water and is directly proportional to the content of dissolved oxygen and carbon dioxide, the temperature, velocity of flow and the dissolved salt content, in particular chloride.

There are many other factors however that complicate the problem and are less well understood. For example, corrosion is stimulated by the activity of sulphur-reducing bacteria in dead ends of the system. The role of iron-oxidizing bacteria as *Crenothrix* and *Leptothrix* still is not completely understood. It is an established fact that chlorination of the water before it enters the system reduces corrosion considerably.

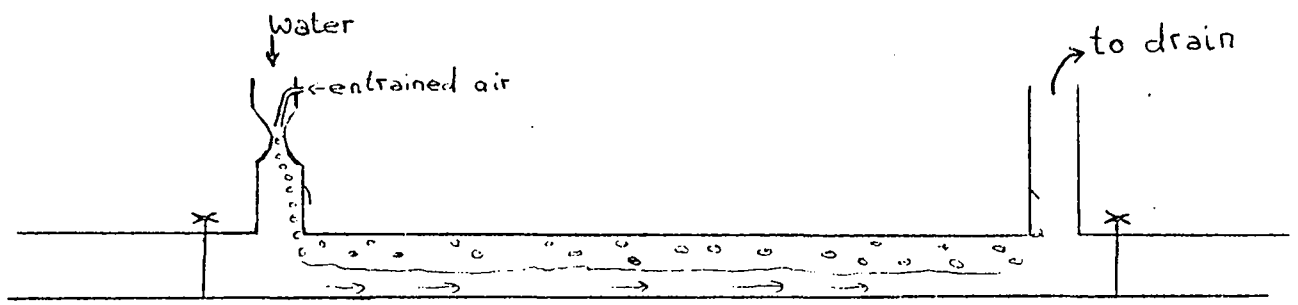
The factors of influence on corrosion give the direction of action to be taken to prevent the such.

- 1) Removal of dissolved oxygen, only applied industrially when water has to be heated.
- 2) Removal of free carbon dioxide, aeration (gasstripping) however is not sufficient, besides, it increases the oxygen content.
- 3) Abandoning the use of cast iron piping in favour of P.V.C.-tubes.
- 4) Chlorination reduces, as stated, biological activity.

5) Prevention by means of a coating of, for example, cement, sodium silicate and calcium carbonate.

Facing consumer complaints about red-brownish water, three actions may be taken, flushing, swabbing or mechanical cleaning.

Flushing is a well-known means to remove light deposits in dead ends. An attractive way to economize on the amount of water required is by entraining air into the pipe to be flushed. The water is thus forced to move along the bottom of the tube, increasing the velocity of flow.



It must however be born in mind that the cause of the complaints is fought, but the cause of accumulation is not. Should deposits only occur in dead ends, then consideration must be given to relining with a smaller diameter.

Swabbing and mechanical cleaning will prove necessary with heavily encrusted mains. Foam swabs, pigs and all kinds of scrapers have been developed and for further information I would prefer to refer to the manufacturers directions of use.

Finally a few general remarks:

It appears likely that nature of iron and manganese deposit is dependent on the characteristics, both chemical and biological of the source. Thus, in very general terms, the type of deposit in mains receiving a surface derived source is very different from that in a distribution system receiving treated groundwater. This accounts for the fact that manganese deposits are rarely found in systems receiving groundwater.

As a summary of this chapter we can state that red-brownish water can only partly be prevented by iron and manganese removal.

CHAPTER VI TREATMENT METHODS.

Introduction.

At the end of this chapter a survey is given of a number of iron and manganese removal methods. The advantage of a list is overview, the disadvantage is incompleteness. For sake of completeness, of every removal method a short explanation is added with a literature reference. Moreover, I shall first discuss the meaning of the headings of the columns.

In this chapter too, I shall try to define which methods are suitable for application in developing countries. This is a very important item, however as it involves a variety of decision criteria, I cannot deal with the subject extensively. Of course I cannot simply pass the subject, stating that the matter is too complex to deal with in the context of this paper. The selection criteria are not listed here as a whole, instead they are woven into the discussion of the headings. Adding to these contemplations a bit of my own philosophy on intermediate technology, we come to the heading of the last column. A warning must be added here concerning the survey. The list is part of this chapter and should not be used out of its context.

Size of population.

This is probably the most important selection criterion of a treatment method, the item that is first checked. It is in fact the basis of the other criteria. To make clear that this heading is meant in general terms, I shall give some examples: it is not probable that a village of 200 inhabitants can be regularly supplied with chemicals. Then there is the problem of payment of the chemicals. Generally it is better to try and construct an installation that can do without chemicals. Another example: if a facility requires skilled personnel, then that would only be feasible for a village of 5000 inhabitants or more. One can also take for granted that a village of less than 1000 will lack electricity and one can assume that there will be no money available for a large number of house-connections as these house-connections require a relatively high investment.

The number of house-connections is of vital importance as it constitutes a regular source of funds, while the collection of fee

for standpost facilities proves difficult.

Finally it must be mentioned that the size of the population that can be supplied of water free of iron and manganese also depends on the ingenuity of the designer to make use of local circumstances like topography and materials.

The superficiality of these examples demonstrates that the sizes of population given in the list should be regarded as an indication.

Electricity required?

First of all it must be stipulated that the question is an abbreviation of the question whether non-human energy is available for the iron and manganese removal part of the purifying plant. So by "electricity" I also understand energy derived from diesel-engins, wind-energy and so on.

Almost every treatment mentioned in the list can be run without electricity, if only enough pressure head is available. This can often be found in mountaneous areas with high-situated springs. In plains however one is more commonly faced with a well with waterlevel varying between a few meters and a few dozen meters below groundlevel. When the latter constitutes the water supply of a village of a few thousands of inhabitants, then non-human energy will be necessary anyhow to pump the quantity of water required.

Excluding diesel-engins and windmills as energy devices has a good reason. The number of reports describing the state of diesel-engins in developing countries all over the world as a failure one year after their installation is great. It is an established fact that maintenance, if any, is irrular to say the least. The use of diesel-engins can often provide an ideal solution in rural parts of developing countries if no maintenance were required. Alas this exactly is often lacking in these parts. Apart from maintenance, a diesel-engin needs fuel and here we have a second problem, as a constant flow of funds is required to keep the engins going.

As to windmills there is an analogy with diesel-engins concerning the maintenance. It requires less skills to take care of the windmill, but then again there is the statistical problem of the wind speeds required, making reservoirs necessary.

Chemicals required?

In my opinion, the overall approach should be that the use of chemicals must be avoided as far as possible. It should first be checked whether no alternatives are possible that require no chemicals.

Drawbacks of chemicals are: supply over usually large distances, the necessity of dosing-equipment, a reliable distribution system must be set up if not present, the chance of errors and accidents, trained personnel required and finally payment problems.

Now there are water qualities that make the use of chemicals inevitable, just imagine water containing organically bound iron and manganese, or water with stabilizing humic acids that maintains a suspension of iron colloids. These "difficult" waters can most of all be expected near (old) swamps. In case no other source is available, the use of chemicals is indicated.

One does often have the choice what chemicals will be applied. The availability and price depend strongly on the presence of certain industries and the infrastructure. The frequent use of lime and chlorine reported in literature gives the impression that they are readily available all over the world but I would like to refer to an investigation in the rural parts of India that showed that 90% of the dosing equipment was inoperative.

Personnel required?

Here the same problem arises as we had with electricity. We can simply state that whatever treatment method is chosen, maintenance shall always be necessary, be it only routine work of a few hours per week.

I find it rather difficult to define to what extent one could trust on self-help for maintenance. Some authors claim that maintenance based on self-help is an illusion, others argue that it depends among other things on circumstances, on the land and community. The latter opinion seems most agreeable to me; if a community is motivated and responsibility for its water supplies then simple maintenance should be possible on a volunteer basis.

Are we however dealing with a more or less labourintensive

treatment method, then we can hardly get away without a permanent staff, certainly not when pumps and chemicals are applied. That brings us upon the next question: how well trained should the staff be ?

This seems more readily answerable. If one uses locally available materials to build an easy operable plant, then simple maintenance could be performed by one of the artisans that helped building the facility. Should there however be pumps running, then an engineer should at least be available on short terms.

We find that the answer yes or no to the question whether personnel is required poses other questions. Thus it seems wise to state the following: "no" does not mean that maintenance isn't necessary, it means that no permanent staff is required and that occasional maintenance can be performed by the local population. "Yes" means that at least one person is engaged to be present at working hours and to do all the maintenance. He must be instructed how to act at irregularities.

A last remark: under personnel should be understood the personnel required for the iron and manganese removal part of the purifying plant, so administration personnel for example is not included.

best method	contaminant(s) removed	size of population	operability & maintenance	chemicals required?	electricity required?	operating costs?	initial investment	operating expenses	applicability
iron precipitation	Fe, gases	< 100	no	no	no	possible	low	low	rural areas of developing countries
iron precipitation filtration	Fe, gases, Mn	not relevant	depends on quantity	no	no	possible	low	low	rural areas of developing countries
iron-copper precipitation filtration	org. bound Fe, Mn, gases	> 5000	possible	yes	yes	yes	moderate	moderate	large rural communities
iron precipitation filtration	org. bound Fe, Mn, gases	> 1000	possible	yes	yes	yes	moderate	moderate	large rural communities
iron-chemical oxidation filtration	org. bound Fe, Mn, gases	> 5000	possible	yes	yes	yes	moderate	rather high	large rural communities
ionizing activated carbon filtration	"difficult" groundwater	> 50.000	yes	yes	yes	yes	high	high	urban areas of industrialized countries
iron precipitation filtration	org. bound Fe, NH ₄ ⁺ , gases	not relevant	possible	no	yes	yes	moderate	low	universal
iron precipitation filtration	org. bound Fe, Mn, NH ₄ ⁺ , gases	not relevant	yes	no	depends on quantity	yes	moderate	low	universal
iron precipitation filtration	org. bound Mn, little Fe, gases	> 5000	yes	yes	yes	yes	high	moderate	large rural communities of developed countries
iron-chemical oxidation filtration	"difficult" groundwater	> 5000	yes	yes	yes	yes	high	moderate	large rural communities or urban areas of developing countries
iron-zeolite ion-exchange	little Fe and Mn	> 50.000	yes	yes	possible	possible	high	high	industrial
iron-zeolite ion-exchange filtration	much Fe and Mn, gases, org. acids	> 50.000	yes	yes	possible	yes	high	moderate	urban parts of industrialized countries
ion-exchange softening	see comment	> 10.000	yes	yes	possible	possible	high	low	industrial
iron-zeolite ion-exchange filtration	Fe, Mn	> 10.000	yes	no	no	yes	high	low	developed countries

1) Aeration, sedimentation.

This is the most essential part of deferrisation. The plant can be as simple and as extensive as possible or necessary, according to available funds or quantity desired.

Aeration can be achieved by gravity (e.g. cascades, discs), by spraying or by aspired air (venturi-aeration), dependent on what is available or required.

When planning a sedimentation tank, a detention time of 3 - 4 hours can be held as sufficient when no further treatment follows. Only aeration and sedimentation however is not very effective, it should be regarded as merely a part of the treatment method. Removal of manganese can only occur to very small extent if a catalytic active layer is formed on the means of aeration e.g. tower cascades.

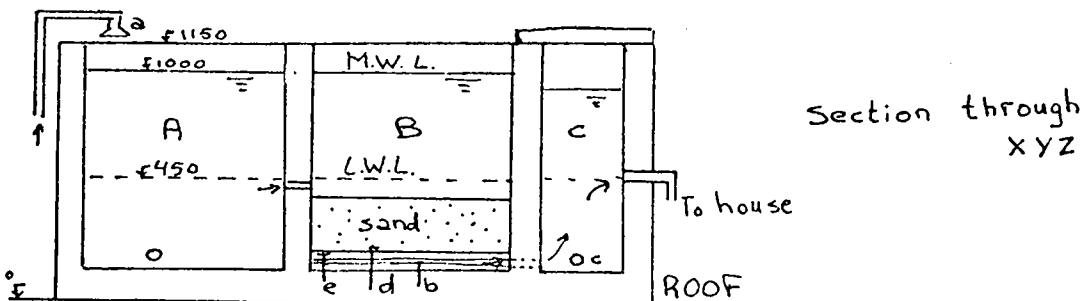
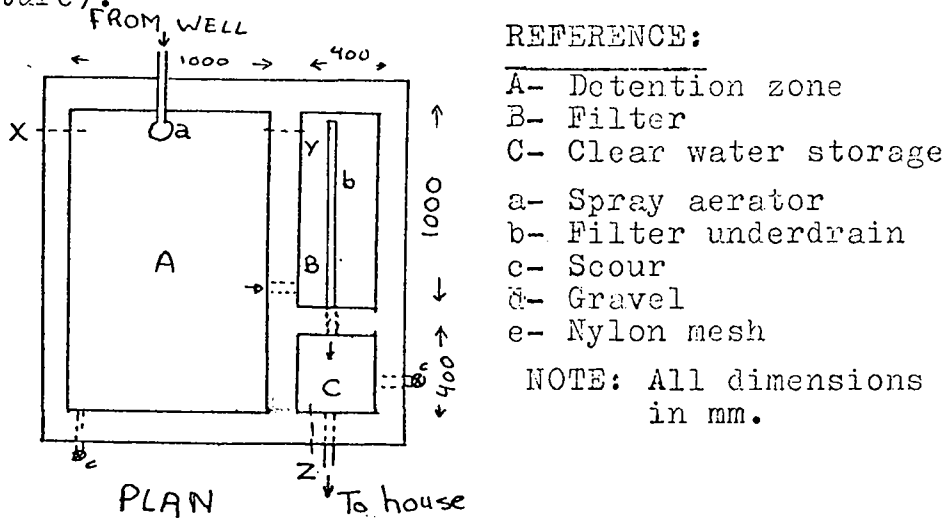
No good result at all is to be anticipated when the iron is organically bound. Furthermore, the pH after aeration must be ± 8 for else no settleable flocs will be formed.

Lit.: Cox.

2) Aeration, sedimentation, filtration.

This is a great improvement compared to the method mentioned above. Here too we can expand at will. A small installation is the roof-tank, a very compact plant for small communities.

(see picture)



Water for hundreds of thousands in the same sequence aeration-sedimentation-filtration is produced by the Waterleidingbedrijf Midden Nederland in Linschoten and at the Eastbourn Waterworks Company.

The water to be treated may now also contain manganese; it can take some time before removal gets started, it can also be initiated.

As filtering material a variety of materials is available. Most commonly applied is sand (grain size 0,6 2,0 mm) or coal of the same dimensions or anthracite. In many countries research is done to the suitability of locally available materials. In very special cases they may be useful, but in most cases, simple sand is the best solution.

As to the filtering rate, when large quantities (say more than 100 persons) are required, then the filter must be operated as a rapid filter, allowing for a number of extra appendages and backwash facilities. When treating small quantities, a slow sand filter may be taken into consideration, allowing for a larger area, but facilitating maintenance, cleaning and costs.

Lit.: Cox, George, Practical Solutions.

3) Aeration, pH-correction, sedimentation, filtration.

Iron and manganese that are not too strongly bound to organic constituents can be removed by this procedure. Even humic acids that stabilize a solution of colloidal iron lose their dispersing effect.

Here we can clearly see the difference between iron and manganese removal. Iron needs a pH of 8 - 8,5 for flocculation (iso-electric point) while manganese needs a pH of 9 - 10 for oxidation if removal does not get started in the filterbed. For the pH-correction, well-known agents are lime, sodiumhydroxide or sodiumcarbonate. The drawbacks of applying chemicals have been discussed previously.

Lit.: Cox.

4) Aeration, flocculation, sedimentation, filtration.

By using coagulants a higher efficiency can be achieved.

The dosing has to be followed by flash-mixing and a flocculation phase to enable a settleable floc to be formed.

As coagulants can be used soluble Al^{3+} and Fe^{3+} combinations and poly-electrolytes, in some countries clay and calcium carbonate are applied. An interesting development is the adding of wood-ash to iron-containing laterite runoff. So far, it has only proved suitable for a limited removal to 1 mg Fe/l, but further research might be able to give better results. Adding ash also raises the pH to such values that manganese oxidation should be possible.

Lit.: Cox, Egbuniwe.

5) Aeration, chemical oxidation, filtration.

Organically bound iron and manganese can be oxidized by strong oxidants like chlorine and potassiumpermanganate if aeration alone is insufficient. Especially the latter is rather expensive and not always available, while chlorine is more easily obtainable in many countries as it also is used as disinfectant.

Originally the method is meant to remove manganese, but iron too is oxidized as we have seen in chapter II.

Lit.: Greene, Cox.

6) Ozonizing, activated carbon filtration.

Properly speaking, this method is essentially the same as the previous. Groundwater is contacted with ozone with a dose of 1,5 mg O_3 /l at most, contact-time 5 minutes, followed by an intermediate contact tank where the excess ozone is liberated. The ozone oxidizes the iron and the manganese (to permanganate) before the water is filtered through activated carbon filters. The activated carbon absorbs the iron and reduces MnO_4^- to MnO_2 . The latter is a redox reaction, simultaneously the activated carbon is oxidized to carbondioxide.

In Dusseldorf the method is practised for the treatment of bank-infiltrated water of the River Rhine. Here a double layer activated carbon filter was installed, the first for iron and manganese removal, filterrun 2 - 5 days, the second to eliminate taste and odour problems. This second layer can be backwashed separately from the first and this is only done every 4 - 8 weeks. It goes without saying that an oxidizing agent as strong as ozone is capable of oxidizing almost every constituent in groundwater. As disadvantages must be mentioned the highly qualified personnel required and the great capital investment.

Lit.: Greene.

7) Dry filtration.

This is an exceptional method to remove organically bound iron and manganese without the use of chemicals. Especially suitable if ammonia prevails in the groundwater. Because of the relatively high frequency of vigorous backwashing, dry filtration is only applicable for deferrisation and nitrification.

Lit.: Greene, Sybrandi.

8) Dry filtration, rapid filtration.

Not only a better result can be obtained concerning iron removal, but also water containing organic constituents can be treated. Moreover, manganese is removed to a large extent, this however is dependent on redox-value and the form in which manganese is present.

A small scale application of this method is the Richardson and Cruddas Package Plant. Should a larger installation be required then the same firm can deliver a procedure according to the same principle.

The small scale design supplies up to 100 l/h, the big one can serve 500 - 1000 persons.

Lit.: Alagarsamy, Sybrandi, Greene.

9) Contact-filtration, rapid filtration.

Oxygen (air) is entrained by a venturi-aerator, a small pressure head is sufficient (\pm 50 cm). Usually upward flow at rates up to 10 m/h is preferred, but a lower rate may be used. Superior results are claimed for pyrolusite as filtering material which is a manganese oxide. This filtration is usually followed by rapid filtration. The treatment is suitable for water containing manganese and little iron or ammonia. Disadvantage is that a closed structure is required to prevent entrance of air. Provision must be made for rapid draining of the bed so as to wash away the excess oxides from the grains and for the use of a hose stream for periodic cleansing.

Lit.: Cox.

10) Dry filtration, permanganate dosing, rapid filtration.

With the treatment: aeration (spraying), dry filtration, aeration, KMnO_4 -dosing and rapid filtration even the most "difficult"

groundwater can be handled. Even strong organically bound Fe and Mn can be oxidized, yet relatively small amounts of permanganate are necessary as the dry filtration has already done all the possible oxidizing and removing. The system has been applied in St. Jansklooster.

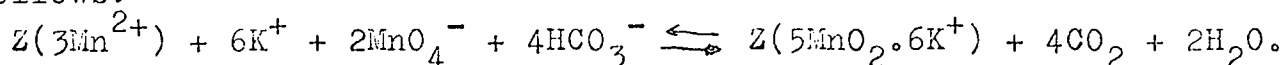
Lit.: Greene.

11) Ion-exchange by manganese zeolite.

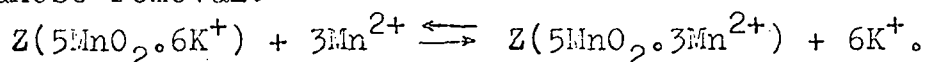
Manganese zeolite is an ion-exchanging material that is made by treating glauconite (a hydrated combination of silicates with Na^+ , K^+ and Fe^{2+}), with a Mn^{2+} -salt, thus exchanging the monovalent cations with mangabous ions.

Final treatment with permanganate as oxidant produces the manganese greensand.

If we refer to the zeolite as Z, then the preparation goes as follows:



Manganese removal:



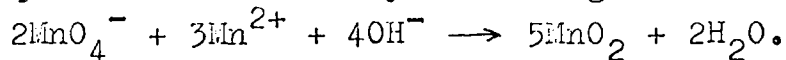
Regeneration proceeds by the first equation. This regeneration can take place periodically; in the U.S.A., continuous dosing of a slight excess KMnO_4 is practised. Bearing the price of KMnO_4 in mind, only water with smaller quantities than 15 mg/l of Fe or Mn can be treated this way.

Lit.: Greene, Kleyn.

12) Sludge-blanket filtration.

This method enables reduction of the demand of MnO_4^- .

After aeration, pH-correction (to 7,8) and a contact-time of about 30 minutes, KMnO_4 is dosed, about 10% of what would be required theoretically according to the reaction:



The water is then led through an upward flow conical sedimentation tank with a detention time of $2\frac{1}{2}$ hours. Here a catalytic active sludge-blanket is formed that also retains what has not been oxidized. The treatment is finished with rapid filtration. It is an elegant method but it makes rather stringent demands as to pilot-plant research and to management. Only suitable for larger quantities of iron and manganese for else the detention time would be too long to enable a blanket to be formed.

Lit.: Greene.

13) Softening by ion-exchange.

Actually removal of Fe and Mn is a side-effect of this industrially applicable method. The water to be treated this way has to satisfy a few conditions:

- anaerobic water;
 - Fe and Mn must be bivalent;
 - less than 10 mg/l of Fe and Mn;
 - hardness must be 34 times as large as the content of Fe and Mn.
- Regeneration is simple with NaCl-solution.

Lit.: Cox.

14) Subterraneous precipitation.

Seems ideal for water containing most of all Fe^{2+} and Mn^{2+} ; if beside these constituents also gases occur, then after subterraneous deferrisation and manganese removal, gas-stripping will have to take place.

It still is a rather new method with a few items that have not yet been examined as far as I know, like the suitability for organically bound Fe and Mn.

Lit: Hallberg, Beek.

CHAPTER VII A TREATMENT PLANT FOR BORUJWARA.

Borujwara is a small village in Maharashtra (India) with a present population of 670 inhabitants and an expected population of 1300 inhabitants. The estimate for the waterconsumption is 70 l.c.d. and the capacity of the plant will have to be $5,75 \text{ m}^3/\text{h}$, using a peakfactor of 1,5 .

Fictive data: - iron content 4 mg/l

- manganese content 1 mg/l, both loosely organically bound.

Here and now a warning is to be given concerning the use of the survey of chapter VI. The list gives the impression that one could simply select the correct removal method by examining the list and the own data. Th following will make clear that one has to be cautious.

According to the list, the alternatives are:

- 4) aeration, flocculation, sedimentation, filtration.
- 7) dry filtration.
- 8) dry filtration, wet filtration.

We can state that dry filtration and wet filtration will give the best results, that flocculation (process 4) will be insufficient as we are dealing with organically bound iron an manganese and that dry filtration alone might give insufficient removal of manganese. Nevertheless I would like to propose dry filtration, the more so as it represents a cheap and simple solution that should be able to find a wide field of application in developing countries.

We know by now that dry filtration can only be applied in a continuous process. Capacity $5,75 \text{ m}^3/\text{h}$; supposing a filtration rate of 4 m/h, then natural aeration can be sufficient for oxygen-supply. The surface area of the filter is $5,75/4 = 1,44 \text{ m}^2$. The depth being 1,5 m, the volume of the sand will be $2,16 \text{ m}^3$. With the assumption that the porosity is 40%, the total volume of the pores is 864 liters.

Supposing that clogging will occur when 10% of the top half of the filter pores is filled, we find a volume of 43,2 liters to be filled before backwashing is required.

Deposits taking 20 l/kg Fe give a possibility of storing 2 kg of iron deposits. Capacity $5,75 \text{ m}^3/\text{h}$, contents $4 \text{ g Fe}/\text{m}^3$; hence maximal deposition of 23 g/h. The lenght of filterrun thus is approximately 4 days.

Grain size clean sand : 1,2 mm }
 Pore volume: 0,4 } backwash rate 30 m³/m².h
 Temperature: 20 °C }
 Expansion sand bed: 10% }

Length of backwash is 15 minutes, so we need 12 to 13 m³ of backwashwater.

Dividing the dry filter into 2 equal filters with a surface area of 0,75 m² each, halves the quantity of backwashwater required each time. This dividing is attractive anyhow for reasons of management, flexibility of operation and possibility of repairs. So we need 6 m³ of backwashwater in 15 minutes, meaning a pump with a capacity of 24 m³/h, or a reservoir of 6 m³. This reservoir must then be filled every two days for backwashing one of the two filters. For reasons of reliability and cost, a reservoir seems the most attractive alternative.

With a view to the population size, a peak in the water demand is to be expected, so a reservoir is to be built anyhow. It will then be depending on the local topography whether a separate reservoir for backwashwater is to be built or that the water can be drawn from the municipal reservoir. Should a separate reservoir be built, then we should try to further decrease the amount of water required.

This can be achieved by:

- 1) Closing the effluent gate directly before backwashing. The filter is filled with untreated water before backwash starts. This may give a reduction of 1 m³ of reservoir-volume.
- 2) Extra agitation during backwash by means of rakes. The length of filtration may be shortened to 10 minutes this way. It remains to be seen whether such a reservoir at a height of 3 meters above the backwash troughs can be filled by handpower. If not, then a small diesel-engine with low capacity will have to be installed.

As to the functioning of the filter, the following can be said:

- 1) Iron removal should not give any trouble.
- 2) Manganese removal might cause some troubles because the violent backwash may rub off the catalytic active deposits of Mn₃O₄ on the sandgrains. However, we know that manganese removal can also be initiated by iron deposits. With a view to the rather small amount of manganese in the groundwater (1,0 mg/l)

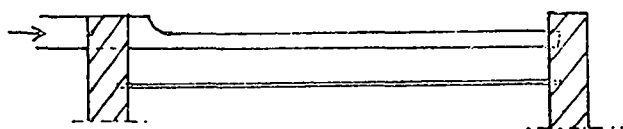
compared to the W.H.O. standard of allowable content (0,5 mg/l), we may expect that manganese removal (notwithstanding the low efficiency) will satisfy that standard.

To ameliorate the efficiency it could be considered to agitate with rakes in the top half of the filter, where we may expect to find iron deposits, leaving the lower half of the filter less disturbed, allowing for manganese removal. Whether this agitating is very beneficial is dubious, but it may be tried.

We shall now discuss the separate elements of the dry filter.

1) Aeration. As stated above, with a filtration rate of $4 \text{ m}^3/\text{m}^2 \cdot \text{h}$, natural aeration is sufficient. The water must however be divided equally over the filter surface. A simple cascade consisting of horizontal trays should satisfy this demand. For a good and equal division of the water, these trays must be placed perfectly horizontal.

The supply can consist of a tube reaching over the filter with the top half sawn off to allow the water to trickle down. The tube can be made of P.V.C.

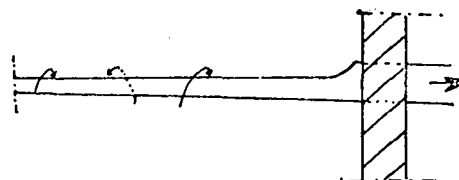


To establish a draught through the filter, the filter will have to have some ventilation holes underneath the drainage system. Simple holes however would have to be plugged during backwash, I prefer to make a few ventilation

tubes either reaching as high as the backwashwater reservoir or fitted with valves to be closed during backwash.

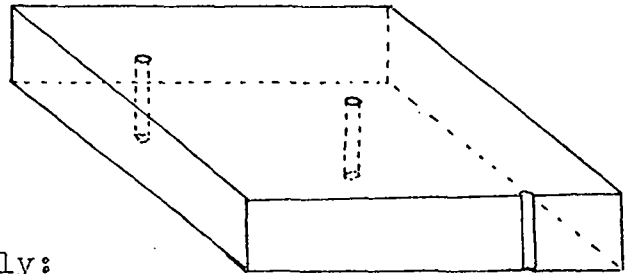
2) Washwater troughs.

In order to maintain a vertical flow as much as possible, preference should be given to two washwater troughs. These tubes must be sawn open in such a way that the top side (the discharge level) is horizontal and the bottom side has a slight slope to ensure rapid flow to waste. A diameter of 5 cm is sufficient.



3) The sand. I choose sand with an average grain size of 1,2 mm. With this diameter expansion of 10% can be achieved and still result in a length of filterrun of 2 days. The specific surface (important in dry filtration) is sufficient. The Allan Hazen coefficient of uniformity should at most be 1,5 and preferably less than 1,3 to prevent stratification after backwash.

4) The underdrainage system. Dependent on the available materials and know-how, this can consist of a variety of constructions. The whole filterbox can be made of reinforced concrete in which case the false bottom may simply be constructed by leaving some openings in the hardening concrete with small pieces of P.V.C. tube. If these openings have a diameter of 1 cm, then per m^2 of false bottom 50 holes must be left open to ensure a good dispersion of the backwashwater.



Above this false bottom, subsequently:

15 cm gravel	$\phi = 16 \dots 23$ mm
10 cm fine gravel	$\phi = 5,6 \dots 8$ mm
15 cm coarse sand	$\phi = 2 \dots 2,8$ mm

Underneath the false bottom a space of 20 cm for supply of washwater, for discharge of effluent and for ventilation openings.

5) Filterbox. This can be made of reinforced concrete or masonry with corner clasps. Rectangular, inside dimensions 85 x 85 cm.

Total height: bottom space	:	20 cm
false bottom	:	10 cm
underdrainage	:	40 cm
filter sand	:	150 cm
expansion 10%	:	15 cm
freeboard under discharge:		25 cm
freeboard above discharge:		<u>40 cm</u>
		300 cm

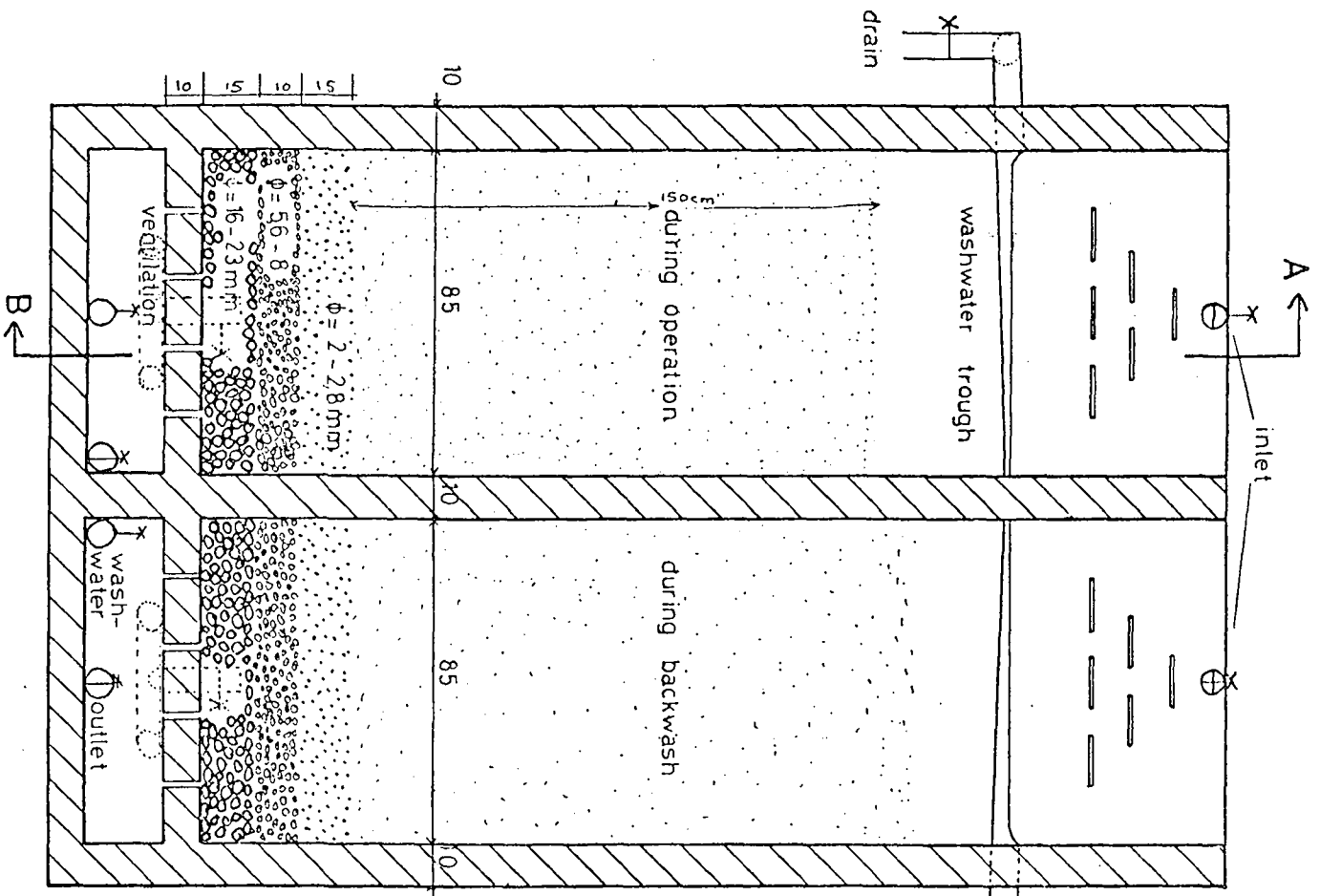
When made of reinforced concrete, the wall must be 10 cm thick.

6) Backwash facilities.

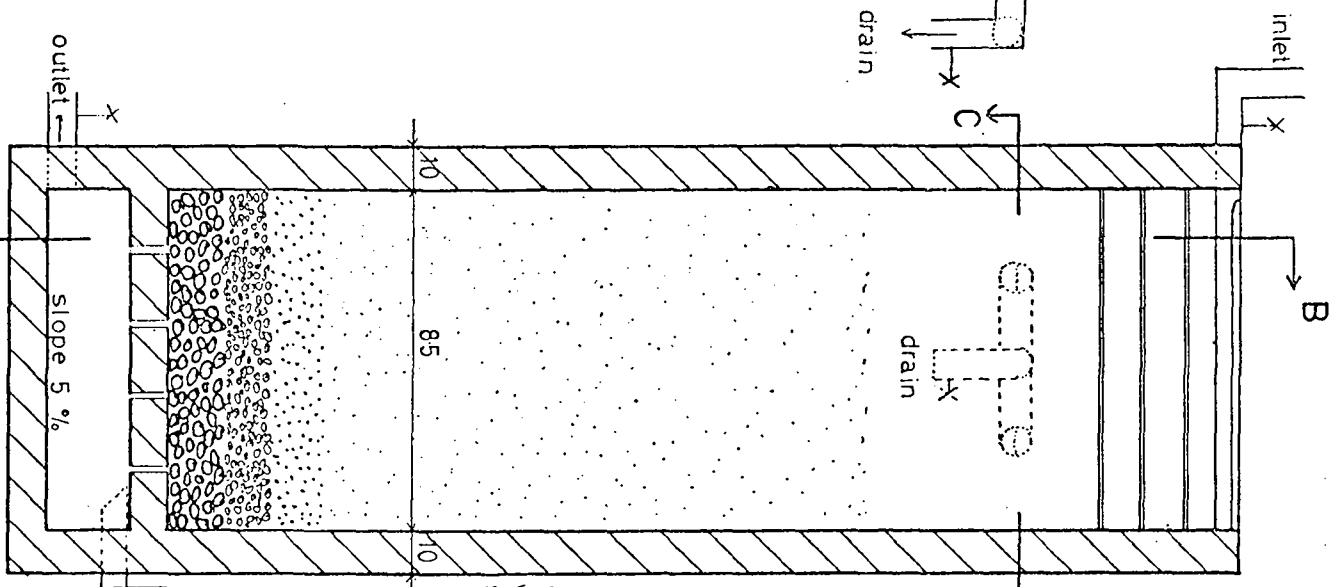
Total resistance during backwash consists of

- height of filtersand = 1,50 m
 - resistance underdrainage \approx 0,50 m
 - resistance pipelines \approx 0,50 m
- 2,50 m

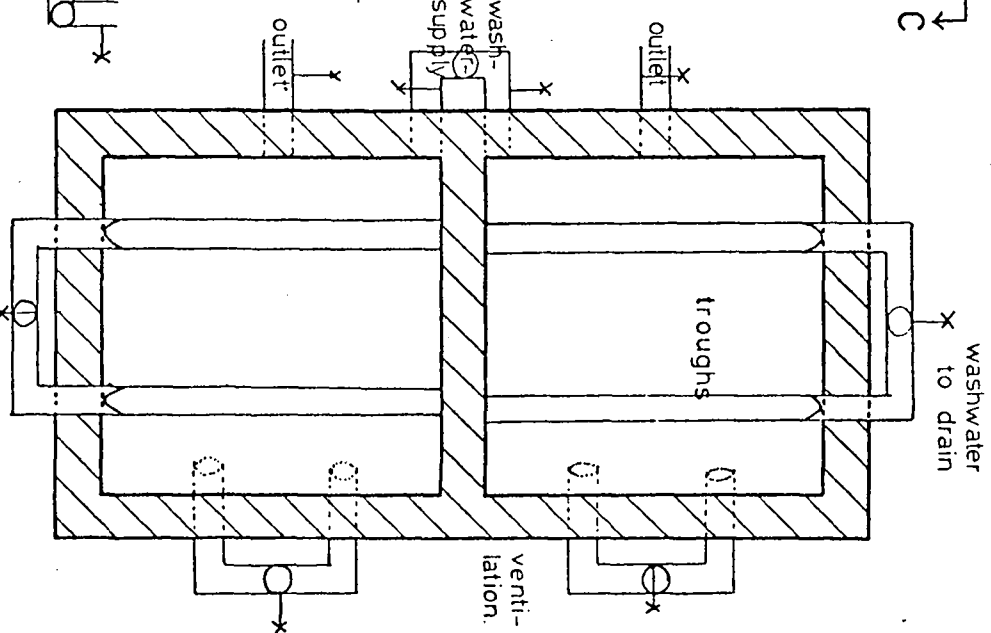
One should however allow for an increase or decrease of the resistance caused by the filter sand, as the grains will augment their size due to deposits that aren't sufficiently washed away. Dependent on the specific weight of the deposits, the resistance may increase or decrease. It seems judicious to allow for a margin of 0,5 m. Hence, we must situate the backwashwater reservoir at an altitude of 3 m above the washwater troughs.



Section B-B



Section A-A



Section C-C

DRY FILTER
 capacity : $5,75 \text{ m}^3/\text{h}$

all tubes diameter : 5 cm
 dimensions in cm.

CHAPTER VIII A TREATMENT FOR ABUBSHAHAR.

Abubshahar is a group of villages in Hayana (India) with a present population of 9000 inhabitants and an expected population of 13.000 inhabitants. Water consumption is estimated at 45 l.p.d., the capacity of the plant will have to be $30 \text{ m}^3/\text{h}$.

Fictive data are: Iron content 4 mg/l

Manganese content 1 mg/l.

Both are loosely organically bound.

Treatment alternatives according to the list of chapter VI are:

- 3) Aeration, pH-correction, sedimentation, filtration.
- 4) Aeration, flocculation, sedimentation, filtration.
- 5) Aeration, chemical oxidation, sedimentation, filtration.
- 8) Dry filtration, wet filtration.
- 10) Dry filtration, chemical oxidation, filtration.
- 14) Subterraneous oxidation.

All these methods have their pros and cons, which shall be discussed shortly in order to make a rational choice.

3) pH-correction is appropriate to increase flocculation-properties of the particles, it may however be expected that the oxidation will be insufficient as the iron and manganese are organically bound, meaning that this method in this case could merely be an additional treatment.

4) Here, the same drawback is valid, furthermore, it makes stringent demands on the quality of the flocculating agent so as to prevent deteriorating of the (for the rest) excellent quality of groundwater.

5) May be considered.

6) May be considered.

10) Excellent treatment, but the groundwater quality we are dealing with now does not warrant the rather large expenses. The water isn't "difficult" enough.

14) This method is up to now only known as ready made from the manufacturer. There remain many questions unanswered, making a design behind the desk a rather hazardous operation.

Remaining alternatives are thus chemical oxidation and dry filtration followed by wet filtration. The principles of dry filtration have been discussed in the preceding chapter,

reason for me to give attention to chemical oxidation. By which I do not mean to say that this method is preferable under the circumstances. The circumstances include the results of laboratory investigation on the groundwater. Especially for chemical oxidation, laboratory investigation is of utmost importance.

For the chemical oxidation of iron and manganese, three agents are widely applied, namely chlorine, permanganate-ion and ozone. The latter requires a prohibitive capital investment and very well trained personnel, so it may be considered as unsuitable. Permanganate-solutions or grains are rather expensive and only available in rather prosperous countries. Furthermore, permanganate-solutions have to be freshly made every day and be kept in dark containers of glass to prevent weakening. All together, chlorine seems most suitable to me as chemical oxidant.

My proposition of the separate elements of the treatment are as follows:

- 1) Dosing of lye.
- 2) Aeration by cascades.
- 3) Dosing of chloride of lime.
- 4) Hydraulic flash-mix.
- 5) Reaction-time of 10 minutes in a hydraulically mixed tank.
- 6) Sedimentation and filtration in one.

These elements will be discussed underneath with their merits.

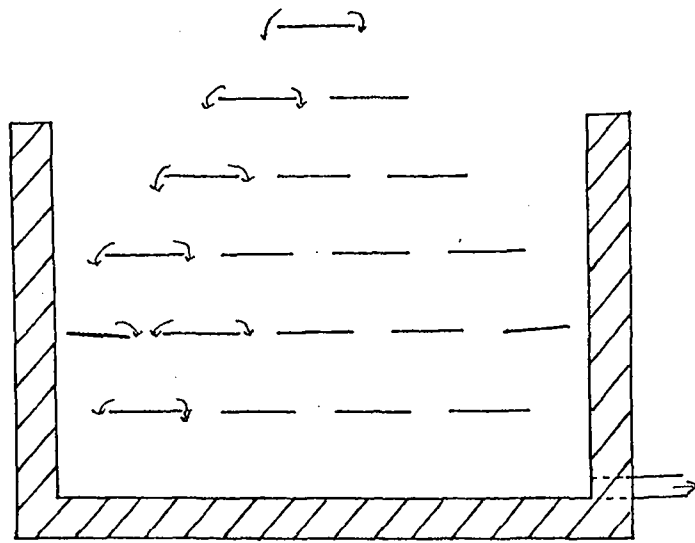
1) Dosing of lye. Any kind of lye can be used. It is meant to raise the pH to about 8 in order to reduce the reaction-time of the following chlorine dosing, and to reach the iso-electric point of iron-flocs. It is dosed before the cascades to make the use of the turbulence in the cascades as mixer.

2) By aeration one can save on the amount of chloride of lime because it will then only be necessary for that part of the iron and manganese that is organically bound.

Laboratory research shall have to determine which part of the iron and manganese can be oxidized by aeration and how much will then be necessary to oxidize the rest with chlorine.

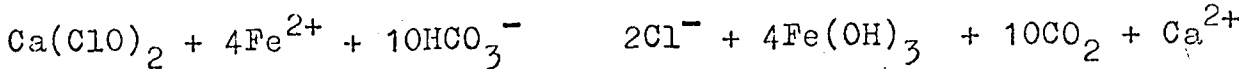
To economize on the amount of lye to be used, it seems attractive to reduce the amount of CO_2 as much as possible, thus raising the pH. Cascades however have low efficiency in

CO₂-stripping so it is unlikely that aeration by cascades would ever render lye superfluous. The minor efficiency of cascades can be improved by using trays instead of pails and by arranging the trays at short distance from one another (say 15 - 20 cm).



3) I prefer chloride of lime dosing as it is the form most widely applied in rural areas, making it more likely to be obtainable. It does have some advantages compared to chlorine gas. It requires rather large volumes (in our case no problem). The stabilizers applied to prevent weakening (giving a high pH !) may cause clogging in dosing equipment due to CaCO₃-deposits. By applying dosing equipment with simple maintenance a regular cleaning is possible and the latter drawback too is overcome.

To determine the dose required we must do some assumptions that otherwise would have come from the laboratory. We assume that after aeration 2 mg Fe²⁺/l and 0,5 mg Mn²⁺/l are left to be oxidized.



2 mg Fe²⁺/l require 1,4 mg Ca(ClO)₂.



0,5 mg Mn²⁺/l requires another 0,7 mg Ca(ClO)₂/l.

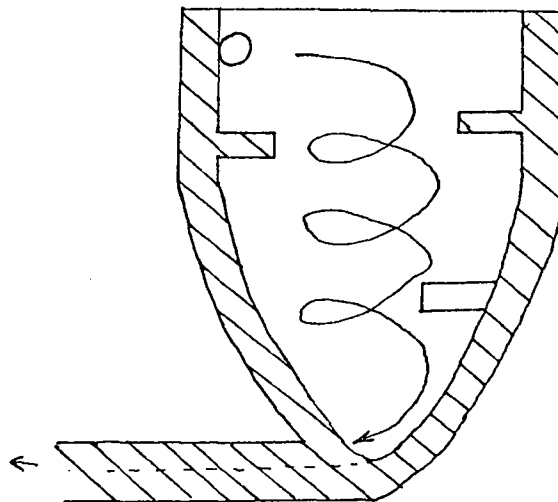
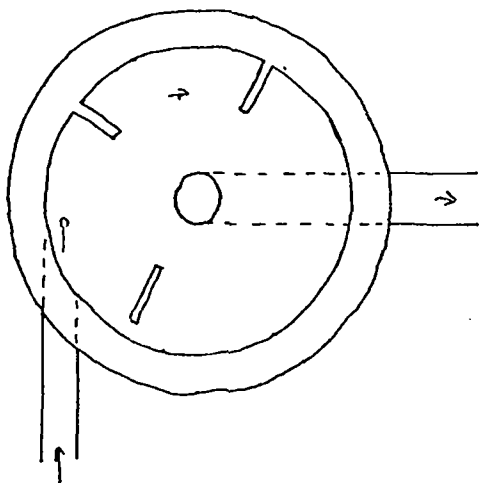
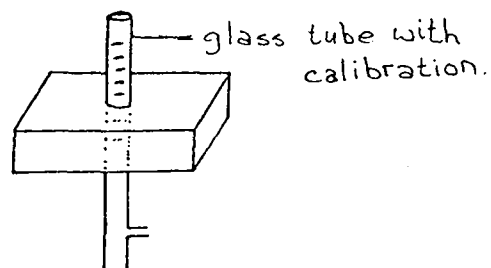
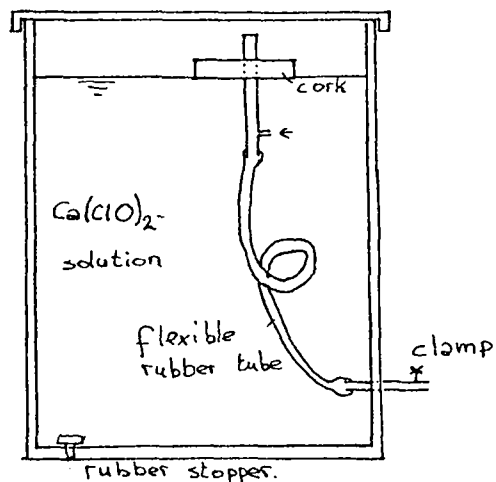
We need about 2,1 mg Ca(ClO)₂/l for oxidation. Although we are treating bacteriologically safe groundwater, a small amount of excess chlorine would not be harmful bearing the quality of the average rural distribution system in mind. Moreover, the slight excess could prevent the growth of iron and manganese oxidizing bacteria in the pipelines. Summarizing, a dose of 3 mg Ca(ClO)₂/l seems judicious.

For the dosing use can be made of a variety of equipment ranging from a coconut shell chlorinator to a hydro-ejector with rotameter. The cost of the equipment should not be too heavily pounded on, the first selection criterion being reliability.

Therefore I choose for a system that can be made and maintained by local craftsmen. It is a combination of Practical Solutions 360.01 and 360.13. The vertical tube in the cork is adjustable in height, regulating the dose.

4) Hydraulic flash mix. This element is of vital importance for a good and fast dispersion of the chlorine throughout the body of water. All mechanical mixers have the drawback that they are driven by engines and all engines require maintenance from trained personnel. Hydraulic mixers don't have this disadvantage. Furthermore, they give equally good or better results, if only they are properly designed. Some extra attention during the construction saves a lot of headache caused by breakdowns of mechanical mixers.

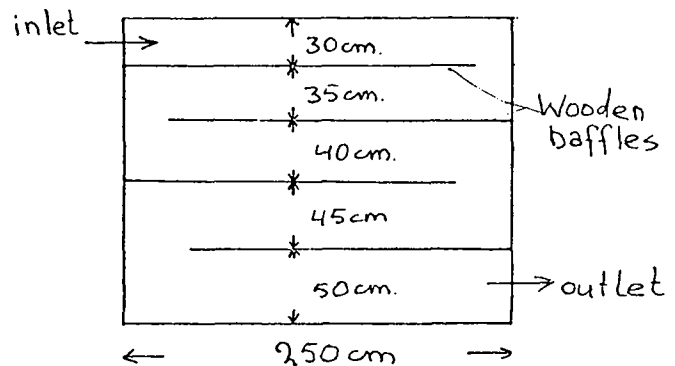
A round tank with a tangential entrance of the water and a few small baffles should give sufficient mixing.



5) For the reaction time of chloride of lime with the iron and manganese, we must know the pH of the water immediately after dosing. The reaction-time required is strongly related to the pH. Supposing a pH of 8 (laboratory !) with some buffering capacity, a reaction-time of about 10 minutes should be sufficient.

With a flow of $30 \text{ m}^3/\text{h}$, we need a tank with a volume of 5 m^3 . Choosing a depth of 1,0 meter, we obtain a surface area of 5 m^2 .

I propose a bassin of 2 x 2,5 m, with baffles arranged as in the picture.



6) Designing a sedimentation tank for a flow as small as $30 \text{ m}^3/\text{h}$ and a minimal depth of say 2 meters is a rather awkward affair, the more so as we should prefer 2 tanks. Combining sedimentation and filtration in a rapid filter with a thick layer of supernatant water (1,5 m) and a normal filtration rate ($6 \text{ m}^3/\text{m}^2 \cdot \text{h}$), the result will be a rather short detention time (15 min.) but presumably enough to allow the flocs to reach dimensions retainable by the filter.

This way we can pass a separate sedimentation tank with a probably small efficiency, we have no cleaning problems and fluctuations in the supply are more easily worked out. Flow: $30 \text{ m}^3/\text{h}$; filtration rate $6 \text{ m}^3/\text{m}^2 \cdot \text{h}$, hence surface area 5 m^2 , to be divided into two filters with a surface area of $2,5 \text{ m}^2$ each.

A sand layer of 1 meter, grain size 0,8 mm. Larger grains can very well be applied if a larger filtration rate is desired. In this case a small grain size is chosen for reasons of cleaning with small amounts of backwash water. Grain size distribution should according to the uniformity index of Allan Hazen be less than 1,5.

Porosity 0,4

Grain size 0,8 mm

Temperature 20°C

Sand bed expansion 30%

backwash rate $40 \text{ m}^3/\text{m}^2 \cdot \text{h}$.

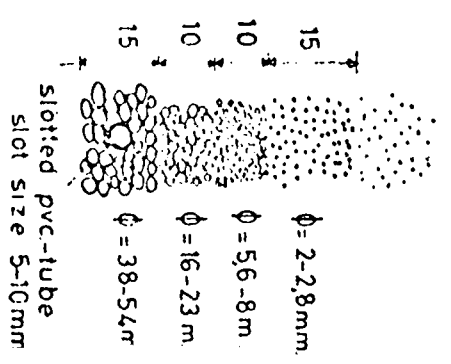
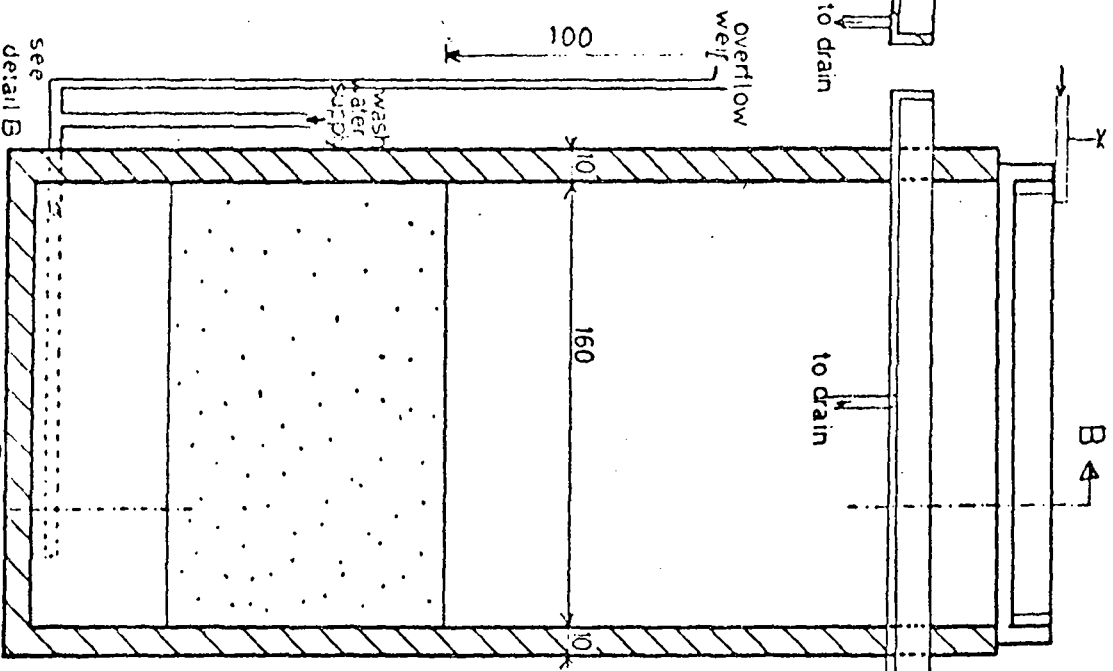
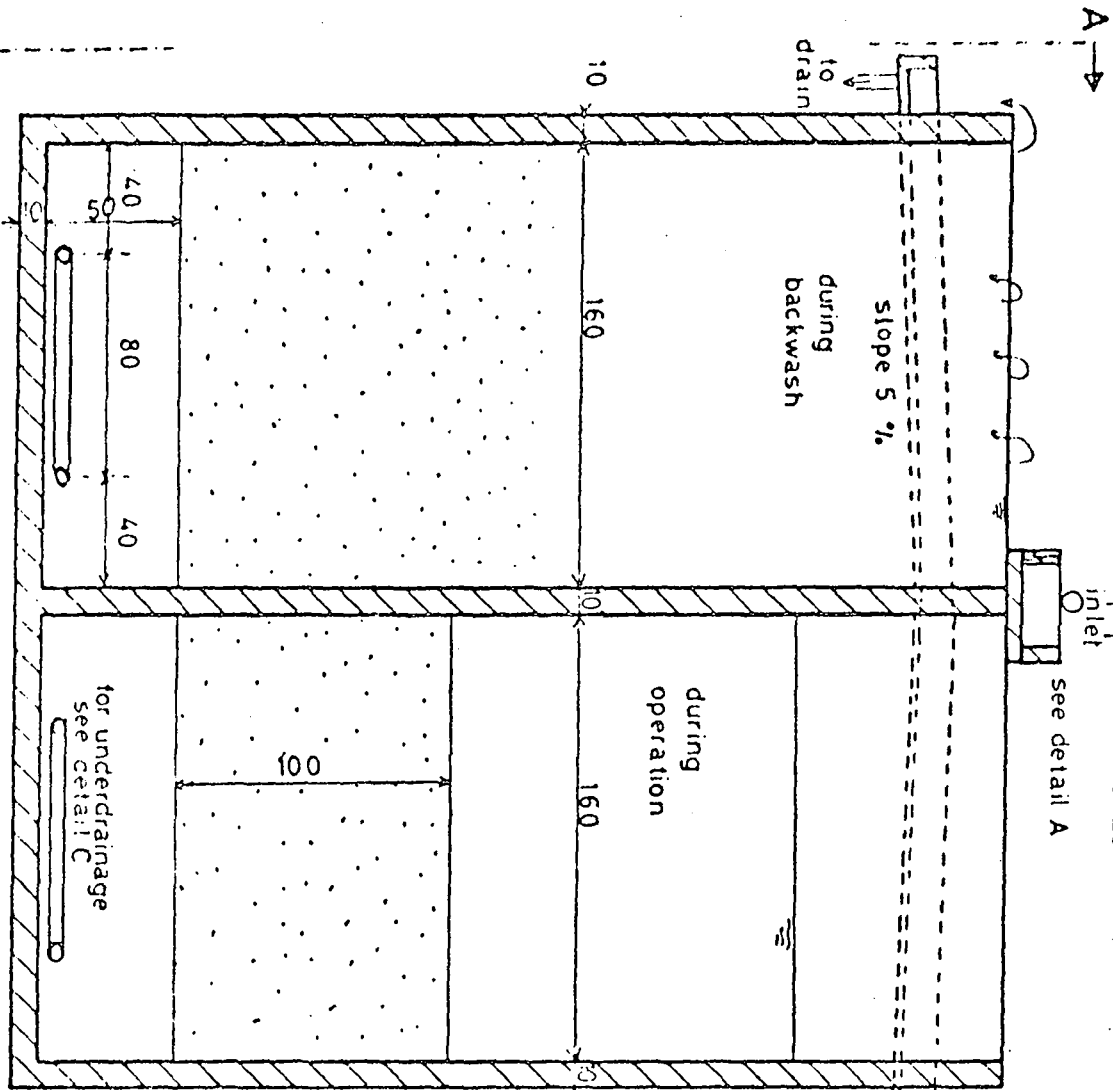
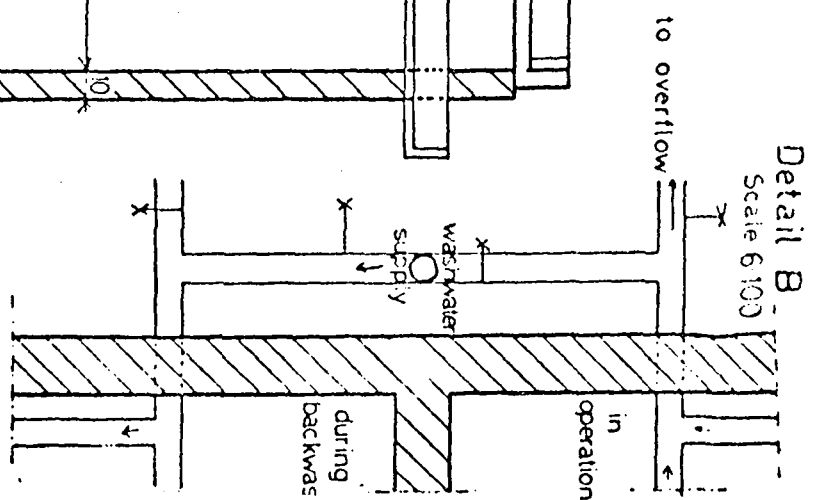
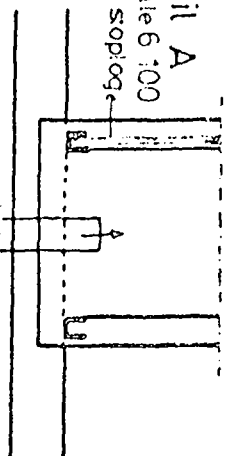
Surface area $2,5 \text{ m}^2$, backwash time 5 minutes, hence we need

a reservoir for backwash water with a volume of 8,5 m³.
Furthermore there is not much to say about the filter, except that I prefer the system of declining rates, as it is one of the systems that does not require much filter equipment like floaters and valves.

I have designed a filter applying as much as possible the same materials in order to reduce the amount of spare parts. Further information can be found in the picture on the next page.

Detail A
Scale 6/100

RAPID FILTER
Capacity 30 m³/h
filter rate 6m³/m²h



All tubes diameter 5cm
dimensions in c.m.

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