SLOW SAND FILTRATION PROJECT

FIRST MEETING OF PROJECT PARTICIPATING INSTITUTIONS


BACKGROUND DOCUMENT 1 - 9

PRELIMINARY LIST OF REFERENCES ON

SLOW SAND FILTRATION

and

RELATED SIMPLE PRE-TREATMENT METHODS

2nd revision

NOVEMBER 1976
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PREFACE

This list of references is the preliminary outcome of a literature survey on slow sand filtration and related simple pre-treatment methods, carried out by the IRC. For this survey use has been made of various documentation centres and libraries. Next to this, many institutions and experts working in the field have been approached by means of a mailing survey. As per November 1976 about 300 references were obtained, that seem to be pertinent to the subject. The material has been reviewed and annotated. The keywords used for this annotation are given in the thesaurus added to this list.

The references on this list are only partially provided with keywords. These selected references (marked: ★ ★ ★) are considered particularly relevant to the application and practice of slow sand filtration in rural areas of developing countries. Most of these references are published in English.

After a second review of these references the material will be compiled in a selected annotated bibliography, that will be published and made available on a larger scale.
Keyword list:

Algae
Biological Action
Chemical Action
Clogging
Description Plant
Design
Extra Treatment
Filter Material
Filtration Rate
General Description
Low Cost and Simple Methods
Low Temperature
Maintenance
Management
Manual
Operation
Performance
Physical Action
Pre-Treatment
Public Health
Raw Water Quality
Shading
Socio-Economic Impact
Theory
Training
Tropics
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tr>
<td>Ber. a. d. Dort. St.</td>
<td>Berichte aus der Dortmunder Stadtwerke A g</td>
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<tr>
<td>EWTJ</td>
<td>Effluent and Water Treatment Journal</td>
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<td>GWA</td>
<td>Gas-Wasser-Abwasser</td>
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<td>GWF</td>
<td>Das Gas- und Wasserfach</td>
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<td>JANWA</td>
<td>Journal American Water Works Association</td>
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<td>JIWE</td>
<td>Journal of the Institution of Water Engineers</td>
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<td>JIWWA</td>
<td>Journal of the Indian Water Works Association</td>
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<td>JNEWWA</td>
<td>Journal New England Water Works Association</td>
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<tr>
<td>Proc. SWTE</td>
<td>Proceeding Society of Water Treatment and Examination</td>
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SLOW SAND FILTRATION PROJECT

FIRST MEETING OF PROJECT PARTICIPATING INSTITUTIONS


BACKGROUND DOCUMENT I - 10

Filtration of water and waste water
Slow Sand Filtration

by

Prof. K.J. Ives

Copy from:
C.R.C. Critical Reviews on Environmental Control
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SLOW SAND FILTRATION

In water treatment, slow sand filtration takes first place historically, as it was developed in the early 19th century for clarifying river waters. When slow sand filtration proved to be an effective barrier against the transmission of disease by water in the middle and late 19th century its popularity for the treatment of municipal water supplies reached its peak. The advent of chemical coagulation with rapid filtration and the almost universal adoption of chlorine for disinfection of water caused a decline in the application of slow sand filtration. However, today many cities in northern Europe still use slow sand filtration, principally London where a new works is being commissioned with an output of about $0.5 \times 10^6$ m$^3$/day, and where total slow sand filter capacity is about $2 \times 10^6$ m$^3$/day.

Both Van de Vloed in the I.W.S.A. 1955 London Congress Report and Ridley in the S.W.T.E. 1967 Symposium referred to the historical precedence and development of slow sand filtration, and Ridley was drawing upon his experience in London’s Metropolitan Water Board. The Community Water Supply Unit of the World Health Organization issued a document in 1970 entitled Biological or Slow Sand Filtration by Huisman, which is intended to promote consideration of slow sand filtration, particularly in developing countries where simplicity is required, and land and labor are cheap.

Mode of Operation

Van de Vloed attributed the first complete explanation of the purification processes in slow sand filters to Kemna in 1899. Technologically the filters are easily described, and Ridley (S.W.T.E. 1967 Symposium) gave filtration rates of about 0.05 m/h for slow sand filters acting alone, and about 0.15 m/h where some preliminary treatment (coarse rapid filtration or microstraining) was applied. Van de Vloed pointed out that this rate must not be applied immediately to a clean filter but that it should be slowly stepped up from about 0.02 m/h. This stepping-up should take at least a day, sometimes several days (depending on the biological activity, which depends on the season), which neither author mentioned. The sand size was given as 0.25 to 0.35 mm Hazen effective size, the size for which 10% of the sand by weight is finer, corresponding approximately to the median size by number. This weight-number relationship is rarely appreciated by those quoting Hazen effective sizes, yet they do not seem to query the concept of a ten-percentile being representative or effective. This, and the significance of the uniformity coefficient, a measure of the size distribution, given as 1.5 to 2 by Van de Vloed, have been explained more fully by Fair, Geyer, and Okun in their textbook, Water and Wastewater Engineering. The sand is usually about 1 m thick, supported on graded gravel about 0.2 m thick, with about 1.0 to 1.5 m of water over the...
sand surface. Rate of flow is controlled by valves and head losses is indicated; a maximum of about 1.5 m water gauge is allowed before the filter is cleaned. These cleanings normally occur about every two to three months, although this period may drop to as little as two weeks in exceptional conditions.

This mechanical description of the filter does not do justice to the real mode of operation of the filter which is biological and biochemical. Van de Vloed laid great stress on the large surface area presented to the water by the fine sand grains, and the great amount of energy available at this interface. Unfortunately, adsorption, ion-exchange, electrostatic fields, and catalysis were concepts presented by him with no clear definitions or demarcations and a confused picture of this surface energy was the result. He was more explicit concerning the biological factors which were involved, and defined the "autotrophe zone" as being the uppermost layers of the sand inhabited principally by actively photosynthesizing algae. This zone is only a few millimeters deep and provides some oxygen for other microorganisms which oxidize organic matter. Below this is the "heterotrophe zone", colonized mainly by aerobic bacteria which convert organic material in the water to carbon dioxide, water, and simple inorganic salts.

In the S.W.T.E. 1967 Symposium, Ridley detailed the stages of succession of algae growing in the slow sand filter. He stated that small unicellular green algae were usually the first to appear in the water over the filter bed. After about five days diatoms or other algae in the inflow seeded the sand surface, or they may have been left behind from the previous filter run. After the first ten days larger filamentous algae could proliferate, including the well-known "blanket-weed" (Cladophora). Van de Vloed pointed out, however, that this autotrophic zone of algae is not strictly necessary to the function of the slow sand filters, because covered filters in cold climates can work satisfactorily. Also, it may be added, there are small slow sand filters in Scotland in which the flow is upward and the biologically active zone is at the base of the sand. Naturally, such filters are covered to protect the filtrate.

In addition to the advantage of the autotrophe zone in providing oxygen, Ridley described the disadvantages. These were related to the clogging which could occur, particularly with diatoms, by the algal cells themselves and by gelatinous matrices (palmelloid stages) produced by certain algae. Sometimes the filamentous matted algae could be overproductive photosynthetically, with the accumulated oxygen bubbles causing the mat to float up from the sand, carrying much of the top layers of sand with it. This increased the permeability very markedly, giving a rapid fall in head loss and possibly an increase in filter rate. The result was a poor filtrate, and collapse of the mat at night, back on to the surface, could seal it very effectively. Ridley also remarked that living or dead algae are excellent substrates for bacterial growth, which could produce taste, odor, or decomposition compounds in the filtered water. Furthermore, certain algae could produce polyphenols which could produce chlorophenolic tastes in the finally treated water.

Huisman, in his document prepared for the World Health Organization, presented a clear summary of the mode of action of a slow sand filter. He described the purification that begins while the water is above the sand (having a few hours' retention). Here, larger particles start to settle, smaller ones coalesce, and planktonic algae are photosynthesizing. On the surface of the sand is the organic layer known as the "schmutzdecke", which is slimy and gelatinous, comprising filamentous algae, diatoms, and bacteria. Large particles of mineral and organic matter, living and dead algae, parasites, and a proportion of other impurities are left behind, trapped in the sticky mass, where they are digested and broken down. Below the thin schmutzdecke, which is only about a centimeter thick, the water passes down through the bulk of the sand, taking one to two hours to pass through. Some straining takes place; most particles are much smaller than the pores, but settle to sand surfaces by gravity, diffusional, or hydrodynamic forces. (These forces in filter pores are discussed more fully under Rapid Filtration). Consequently, the sand grains become coated with a sticky layer of organic matter containing bacteria, bacteriophages, and some predatory microorganisms such as protozoa and rotifera. Organic matter is broken down and converted into cell material, and inoffensive inorganic materials are carried away in the now mineralized filtrate. This activity of the filter declines with depth. In his I.W.S.A. 1955 London Congress Report, Van de Vloed showed some interesting photographs of the schmutzdecke and coated sand grains.
Both Van de Vloed and Ridley in their papers, and Huisman in his document, stressed the fact that slow sand filters are unsuitable for highly turbid waters. Huisman stated that the best results were obtained when the average turbidity was 10 mg/l or less, although short peaks of 100 to 200 mg/l could be accepted. This matches well the London Metropolitan Water Board situation where reservoir waters have turbidities usually below 10 mg/l but which can suffer from high concentrations of algal cells, up to about $10^7$/l, during short intensive algal blooms, as reported by Ridley. Because of these peaks, preliminary treatments may be desirable. These have been described by Ridley as algicidal treatment of the reservoir water (usually with copper sulfate), and primary rapid sand filtration or microstraining. Huisman advised against prechlorination or copper sulfate treatment before slow sand filtration, perhaps on the grounds that residuals of chlorine or copper could affect the biological activity in the filter. If the reservoir where the treatment takes place is reasonably remote from the filters, such toxic residuals are unlikely to be significant. Regarding direct prechlorination of slow sand filters Baumann et al. reported favorably using residual chlorine doses averaging 8.8 mg/l, but it appeared that this oxidized the organic and living matter on the sand surface.

There has been general agreement, and certainly Huisman commented on it, that coagulation treatment (with alum, for example) before slow sand filtration is undesirable. This is because the alum floc will rapidly seal the sand surface, and occlude the schmutzdecke, with a consequent rapid rise in head loss, and deterioration in biological purification. In certain circumstances described by Ives pH changes in the filter, together with low pH caused by alum dosing, could precipitate aluminum hydroxide in the lower layers of the filter, which gave rise to great difficulty with regard to cleaning.

When taste or odors have arisen in the source water (river or reservoir) it has been found useful to add powdered activated carbon to the slow sand filter inlets. The powdered carbon has settled on the sand surface, where contact with the water passing through has provided absorption of the offensive compounds. Although this may shorten the filter run and reduce photosynthesis in the schmutzdecke, it has the advantage that all the carbon can be readily removed at the next filter cleaning.

Filter Cleaning

If a pressure profile is drawn through the depth of a slow sand filter, as shown in Figure 3, it will be seen that nearly all the head loss occurs in the

![Pressure profile through a slow sand filter.](image)
top 1 to 2 cm, corresponding to the location of the schmutzdecke. Consequently, the removal of this top layer will restore the permeability of the sand. As the sand is completely mixed, in spite of not being uniform in size (Hazen uniformity coefficient > 1.0), the freshly exposed layer can develop a new biological film and act similarly to the layer just removed. Consequently, each cleaning, by scraping, can carry away the dirty sand, and the filter restored to working, without replacement of the layer which has been removed. This, of course, cannot go on indefinitely, and after about 15 cleanings, each removing about 2 cm, the bed thickness has to be restored to its original level by resanding.

This scraping of the surface, referred to by Van de Vloed in the I.W.S.A. 1955 London Congress Report, was carried out by hand skimming with shovels until the advent of light tractors fitted with skimming blades in the early 1950's. These machines reduced labor costs, but mechanical maintenance was necessary, and it was thought that some dirty sand might be churned into the lower layers by the tracks of the vehicles. However, no such adverse effects have been reported.

Whether removed manually or mechanically, the sand has to be cleaned and stored externally to the filters. It is too valuable to discard. External sandwashing was not described either by Van de Vloed or by Ridley in his paper to the S.W.T.E. 1967 Symposium. However, it has been described in the textbook by Fair, Geyer, and Okun as a simple hydraulic countercurrent cleaning process. In this, sand and dirt are separated by water jetting through a pipe into a chamber where the sand settles but the dirt is carried upwards by a flow of water. Several such jetting tubes and separator chambers are usually connected in series. The clean sand is finally jetted into an open sand storage bin.

Another innovation about 1960 was the in situ sandwasher, which was the subject of a paper by Burman and Lewin. In this device, which spans the filter, supported on the walls, there is no need to draw down the water over the filter to expose the sand surface. Water jet lances are lowered into the sand about 15 cm, while the sand is covered by a caisson about 30 cm wide running the full width of the bed. Dirty water is pumped from the caisson while clean water from the jet liquidizes and cleans the sand locally. When the 30 cm strip is clean, the caisson and jets are transferred to the adjacent 30 cm, which is then cleaned, and so on, along the entire length of the bed. (See Figure 4.) In this way no sand is removed and no resanding is necessary. The time that the filter is out of service is only one day, instead of the usual three. Burman and Lewin claimed that the hydraulic grading of the sand in the cleaned zone (i.e., fine sand on the top) prevented silt penetration into the bed, with no noticeable change in head loss. Rifley, however, remarked that such a machine has proved difficult.
to operate efficiently whenever algal growths were present. Part of this he attributed to the eutrophic nature of London's water and part to the fact that large numbers of physiologically active algae, particularly diatoms, remained in the supernatant water after the cleaning process. In effect this seeded the sand surface and reproduction of the algae concerned proceeded very rapidly, with concomitant shortened runs. In the skimming process the sand surface is dried out by draining down the filter. Any algae remaining after cleaning have had to survive this adverse desiccation, so they are slow to become active again. A similar machine has been installed at Antwerp Waterworks, and a scraper mounted on a spanning bridge is used at Amsterdam.

Ridley gave some costs for operating slow sand filters at different works in the London area. Presumably these were predominantly cleaning costs, although the filters were supervised during operation. They do not include maintenance, replacement, and repair charges, and probably do not include energy charges attributable to the head losses. His values for 1963-64 are given in Table 1. The reason why the slow sand filtration alone cost more was that it operated at only about one third of the rate of filtration as the water received no prior treatment. These figures can be compared with those estimated by Ives [36] for 1954 (i.e., ten years before), which included all capital charges suitably amortized, according to British practice at that time, and energy charges. His values were:

- Microstraining plus slow sand filtration: 0.24 U.S. cents/m$^3$
- Rapid plus slow sand filtration: 0.30 U.S. cents/m$^3$

In the discussion of the I. W. E. 1971 Symposium, Ridley stated that a properly operated slow sand filter could produce filtrates of excellent quality (turbidity less than 0.1 mg/l Fullers Earth scale) for less than 0.22 U.S. cents/m$^3$, which was markedly less than 0.80 m$^3$ quoted by Miller for rapid filtration. In the same discussion Mugele gave the total cost of filtration (mainly rapid plus slow sand filtration) for the Metropolitan Water Board, including station overheads, for the year 1969-1970, as 0.248 m$^3$ and compared this with an average figure for coagulation plus rapid filtration works of 0.6 m$^3$ quoted by Burley and Mawer. [37] These comments were challenged by Miller, who pointed out that the Metropolitan Water Board, as the largest water authority in Britain, benefited from economy of scale with large installations. Furthermore, the storage reservoirs which retained the Thames water for several weeks produced a marked improvement in the water quality for most of the year. This benefit should be costed into the slow sand filtration figures, as the other costs referred to works without this pretreatment advantage.

**New Developments**

As an appendix to his I.W.S.A. 1955 London Congress Report, Van de Vloed listed replies from national rapporteurs who described the situation with regard to sand filtration in their own countries. From this, the decline in use of slow sand filtration was evident, and one might have forecast its early demise. This, however, has not been the case and in addition to the innovations in cleaning which have been already mentioned, a number of developments have been recently discussed. Certainly, Huisman's 1970 document for the World Health Organization [31] indicated a number of topics which could be developed or be the subject of research. Among these was the intermittent draining down of the filter during its run to slow down algal development on the schmutzdecke, particularly in tropical areas. Another suggestion was the use of a layer of activated carbon in the filter to improve color and odor removal. He mentioned particular current problems which might be solved by suitable research: over-development of blanket weed (Cladophora) on the

<table>
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<th>Process Type</th>
<th>U.S. cents/m$^3$</th>
</tr>
</thead>
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<tr>
<td>Slow sand filtration</td>
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</tr>
<tr>
<td>Rapid plus slow sand filtration</td>
<td>0.16</td>
</tr>
<tr>
<td>Microstraining plus slow sand filtration</td>
<td>0.10</td>
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</table>

(Ridley, S.W.T.E. 1967 Symposium on Filtration)
surface; the growth of certain organisms, for example Nais worms in the underdrains; and production of hydrogen sulfide due to warm weather anaerobiosis in the sand layers which reduced sulfates in the water; some of these might be ameliorated by prechlorination.

In the S.W.T.E. 1967 Symposium, Ridley noted that artificial turbulence could retard rates of reproduction of algae and that this might be applied to the supernatant water of slow sand filters. He also mentioned, in passing, the advantage of partially-shading a slow sand filter from sunlight, although he did point out that many algae require a relatively small amount of light for carbon assimilation in excess of respiratory requirements. Ridley also described an experimental compromise between rapid and slow filtration in which 0.74 m of sand 0.3 to 0.4 mm effective size, highly uniform, has been used at flow rates of 2.4 to 2.9 m/h. Filtrate turbidities have been unsatisfactory, but further development of the idea might be possible. This appears to be too optimistic and naive an approach considering the different mechanisms involved in rapid filtration (physical) and slow filtration (biochemical). If some means of flocculating the very fine particles of turbid matter were used, possibly cationic polymers, and a rapid chemical oxidation/mineralization could be achieved (for example, with ozone) then such a compromise might work effectively. Ridley also gave favorable mention to the report by Lynch et al. who coated a freshly cleaned slow filter with diatomite at 0.5 kg/m². Ridley felt that such a layer should be more porous than a layer of living algae and that it warranted further investigation. If this were to be successful it could be argued that the water is therefore amenable to diatomite filtration with a more compact, mechanically controlled plant.

Not much development has taken place in mathematical theory of slow sand filtration, although it may be remarked that the source paper of modern rapid filter theory, written by Iwasaki in 1937, was an attempt to describe slow sand filtration in mathematical terms. Earlier work by Hazen (see Fair, Geyer, and Okun) had been concerned with the hydraulic resistance of a clean sand bed and the effects of water temperature changes. Iwasaki dealt with the clogging effect and efficiency of removal, but his equations were more applicable to physical removal mechanisms as found in rapid filters. Neither Van de Vloed’s report nor Ridley’s paper made any reference to mathematical modeling in slow sand filtration. In 1970 Folkman and Wachs published a paper on the filtration of Chlorella through dune sand. Their rates of flow were between 0.04 and 0.25 m/h corresponding to slow sand filtration rates, through 3 m depth of dune sand. The size analysis of this sand was not given, but permeabilities were quoted of about 30 m/day. A normal slow sand filter operating at 20°C has a permeability of about 50 m/day, so the dune sand was somewhat finer (or less porous) than slow sand filters. Therefore the experiments of Folkman and Wachs approximated to slow sand filtration, although they never said so. They found that rapid filter theory, modified to allow for an exponential head loss rise with time in the surface layer, adequately described their results. The exponential rise in head loss was probably due to growth of Chlorella in the logarithmic phase, during the long periods of operation (up to 300 h). It may be that these results, suitably interpreted, could form the basis of a mathematical theory of slow sand filtration, utilizing growth kinetic equations for the microorganisms involved.

The last word on slow sand filtration should go to Ridley, because he expressed the sentiments of Van de Vloed and Huisman concerning the great hygienic value of the process: “Whatever the trends, it must be accepted that... .advantages... .must not be achieved by any reduction in hygienic quality standards. The problem is one where the requirements of toxicologists and bacteriologists are of first priority but where co-ordinated research could solve many of the recurrent difficulties.”
SLOW SAND FILTRATION PROJECT

FIRST MEETING OF PROJECT PARTICIPATING INSTITUTIONS


BACKGROUND DOCUMENT I - 12

The Removal of Viruses

by Slow Sand Filtration

by

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THE REMOVAL OF VIRUSES BY

SLOW SAND FILTRATION

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Research Report from Thames Water Authority
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In context of the Slow Sand Filtration Project
THE REMOVAL OF VIRUSES BY SLOW
SAND FILTRATION

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ABSTRACT

The ability of slow sand filters to remove enteroviruses from contaminated reservoir water has been assessed using experimental filters and attenuated poliovirus type 1. The effects of flow rate, depth of sand, temperature, filter maturity and cleaning on this process have been examined. The filters were found to be highly effective in removing viruses at up to 2.5 times the normal flow rate of 4.8 m per day and at temperatures as low as 5°C. The removal of bacteriophage T7 and naturally occurring bacteria by filtration have also been studied. When compared with poliovirus bacteria were less and bacteriophages were more efficiently removed.

INTRODUCTION

Five sixths of London's water supply is derived from sources which are known to be contaminated with enteroviruses. This water, from the Rivers Thames and Lee, is treated by a process of reservoir storage followed either by rapid sand filtration or by microstraining, and slow sand filtration. The water is finally disinfected with chlorine before being passed into supply. The most important elements of this process are reservoir storage and slow sand filtration. The rapid sand filters or microstrainers play a relatively minor role, and are included in order to increase the filter working period before cleaning is required; chlorination is properly regarded as a final safeguard.

Slow sand filters have been used in the treatment of London's water for almost 150 years and at the present time the area employed covers 72 hectares. A large amount of experience in their operation has been accumulated. They have beneficial effects on the colour, turbidity, taste and bacterial content as well as removing traces of many organic chemicals.
The fact that they are highly efficient at removing bacteria has been used as a basis for controlling filter operation. The filters are routinely monitored and any that give unsatisfactory results, for example recently cleaned or resanded beds, are run to waste or have their flow rate adjusted until water of a suitable quality is produced.

The Thames Water Authority is undertaking a continuing programme of research into many aspects of slow sand filtration. The steady increase in demand for water has led to proposals to make the filters more productive by increasing the flow rate and so avoiding the need for additional works on valuable land. The chemical, bacteriological and biological implications of these proposals are being studied along with engineering and management considerations such as head loss and cleaning requirements.

Recently, knowledge of the distribution and importance of enteroviruses in contaminated water has rapidly increased, and there have also been major advances in virological techniques involving tissue culture methods, new cell lines, virus concentration techniques and the development of attenuated strains of viruses. The stage has now been reached where, although it is not yet possible to monitor individual filters, it is feasible to examine established methods of water treatment and to evaluate their effects on viruses.

Viruses were first isolated from the River Thames in 1963 (Poynter, 1966) and since 1965 the virus levels at the river intakes have been regularly monitored. They have been repeatedly demonstrated in the raw water at counts of up to 100 plaque forming units (PFU) per litre, and although none had been found in the stored water at the start of this research, improved methods have recently demonstrated their presence at up to 2 PFU per litre under normal winter conditions.

It was felt that not all the viruses present were being isolated and under conditions of a virus epidemic or in emergencies, such as flooding, a large increase in numbers was possible. It was also reasoned that as virus particles were much smaller than bacteria (poliovirus 28 nm diameter, E. coli 2.5 x 1.0 μm,) they might well penetrate a sand filter more easily. In view of the almost complete lack of knowledge in this respect, it was decided that the effect of slow sand filtration on viruses in water should be investigated.
It is possible to carry out research into many aspects of slow sand filtration on full scale beds or large experimental filters, using the normal stored water supply. However, the natural levels of virus in the stored water were too low to detect by the methods available and it was therefore necessary to add virus in order to measure the efficiency of the filters. To do this on a full scale bed was impracticable. Such a bed may be 0.5 hectares in area and produce 2,500 m$^3$ per day. There was also the problem of the large scale experimental use of a potential human pathogen in close association with the public water supply. It was therefore decided to confine the investigation to two small experimental filters at Kempton Park works. These filters were isolated from the main part of the works, and could be supplied independently. The filtrate could be collected and disinfected if required.

Over four years a comprehensive picture of filter behaviour under a wide variety of conditions has been built up. Soon after the investigations started it became apparent that the most adverse natural conditions under which the filters would operate would occur in cold weather, and investigations were concentrated on the winter period. During this time, all the winters were relatively mild and it was not possible to observe the filters under severe conditions.

**MATERIALS AND METHODS**

**The Experimental Filters**

The filters were housed in an unheated building, and were designed to resemble full scale filters. They were made of perspex cylinders 0.09 m$^2$ in area and 3 m high, the upper part being detachable to permit cleaning. Each filter was fitted with a flow meter and valve and a manometer to record the head loss. Inside, a perforated base was covered with 150 mm of gravel overlaid with up to 600 mm of filter sand. The water column, at least 1.5 m deep, was exposed to diffuse daylight but the sand was otherwise in darkness. The filters were supplied with stored water from the Thames valley reservoirs via Staines Aqueduct.

Water inoculated with poliovirus was supplied in two ways. In the first experiments the virus was added to a large tank of water and, after mixing, this was pumped to the top of the filters and the overflow returned to the tank. The use of this method was discontinued because the natural rate of virus inactivation during warm weather was such that a constant level of virus could not be maintained. In the alternative approach the...
aqueduct water was fed to the filters via a ball valve and small quantities of concentrated virus suspension were continuously metered into the water via a mixing chamber situated between the valve and the filters. The concentrated virus was maintained in an aseptic state by adding a small amount of chloroform. This method gave more consistent results than the earlier arrangement.

The quantities of virus added to the water varied between 100 and 2,000 PFU per ml but was normally in the range of 400 - 600 PFU per ml. This inoculum was the minimum required to enable virus to be measured in the unconcentrated filtrate, thus avoiding inaccuracies due to the concentration process. The concentrated samples were intended for use when the unconcentrated samples were found to be too dilute. This however was not always possible, and to avoid the necessity of adding excessive amounts of virus during periods when the filters were highly effective the concentrated samples were used.

The filters were cleaned when the head loss was about 0.5 m. The filter was drained, the upper part of the cylinder dismantled and the surface layer of dirt and sand, approximately 25 mm deep, was removed and replaced with clean sand. The upper section was then replaced and the filter backfilled until water could be added from the top without disturbing the sand surface. The process took about three hours. The surface layer of sand was replaced at each cleaning in order to avoid any problems that would be incurred by a sand bed of varying depths. In full scale filters the sand is usually replaced when the initial 600 mm of sand has been reduced to about 300 mm.

**Sampling Procedures**

Samples were collected daily from the top of the water column, 50 mm above the sand surface and also from the filtrate. In the case of samples for poliovirus titration 4 ml aliquots were added to 1 ml of 5 x concentrated cell growth medium and stored at -30°C, and with samples for bacteriophage titration 9 ml aliquots were added to 1 ml of 10 x concentrated phage dilution medium together with 0.5 ml of chloroform, and stored at 4°C. Additional 1 litre samples of the filtrates were concentrated by one of the following methods: in the early experiments the alginate membrane technique was used (Pöynter et al 1975), but from 1972 onwards membrane adsorption was adopted (Windle Taylor, 1973).
The latter method was modified slightly for use with bacteriophages, the pH of the sample was adjusted to 7.0 instead of 4.5 thus preventing inactivation of the phage by low pH.

Bacteriology

The samples were regularly examined by routine bacteriological methods (Report 1969) consisting of a membrane count of coliforms and E. coli at 35° and 44°C, and agar plate counts at 22° and 37°C. The filters were used for experimental purposes only when judged to be operating normally by accepted bacteriological standards (Burman, 1962).

Poliovirus

The LSc 2ab strain of poliovirus 1 was used throughout the experiments. It is relatively safe to handle, plaques well in the laboratory, is a typical enterovirus and is one of the smallest of the enteric viruses; it is also one of the viruses common in the raw water. In any large community a poliovirus immunisation programme, which may be taking place more or less continuously, means that this type of virus is usually present in sewage contaminated water.

The virus was plaque purified and cultured initially on secondary Cynomolgous Monkey kidney cells (Wellcome Reagents Ltd.), and later on the Vero line of monkey kidney cells (MacFarlane et al. 1969). The infected cultures were frozen and thawed three times to disrupt the cells and liberate the virus but no further steps were taken to disperse the virus clumps as it was considered that naturally occurring viruses contaminating the raw water may well be aggregated. Poliovirus stocks were stored at -30°C.

Virus Assay

The poliovirus was assayed by means of a plaque technique similar to that of Hsiung et al (1955). The early experiments used secondary cynomolgous cells but later the Vero cell line was employed. Cell monolayers grown in 4 oz medical-flat bottles were inoculated with 0.5 ml of the virus sample using four replicates for each sample assayed.

Bacteriophage

The experimental filters were employed to evaluate the use of a bacteriophage in the place of enteroviruses in this type of study. The phage MS2 was originally chosen because it resembles poliovirus in size and shape and is also, like polio, an RNA virus. Both bacteriophage and host (E. coli F+ NCIB 948) were obtained from the National Collection of Industrial Bacteria. However, some recent electron micrograph studies reveal that the phage was wrongly identified and was in fact...
a T-phage, probably T7 (Ayres 1974). It is not therefore directly comparable with poliovirus but we retained it because of its excellent survival in water and good plaqueing characteristics.

Media  Double strength lawn agar contained in grams per litre:
Bacto-tryptone 20, Difco yeast extract 10, glucose 2 and NaCl 10. The pH was adjusted to 7.2 with N NaOH and 20 g/1 Difco Special Noble agar was added. After autoclaving and cooling to 45°C, 10 ml each of sterile solutions of 0.5 M CaCl$_2$ and 0.5 M MgSO$_4$ were added.

Dilution medium consisted of NaCl 0.3 g, Difco peptone 1 g and 10 ml of Tris HC1 buffer (1 M) at pH 7.8 plus 1 ml of 0.5 M MgSO$_4$ solution per litre.

Assay  An overnight culture of the host bacterium was grown in tryptose soya broth (Oxoid) on a shaker at 37°C. The phage was titrated by a plaque technique modified to incorporate a large volume of inoculum. 2.5 ml of the sample, diluted if necessary, was placed in 90 mm petri dish, taking care to avoid pipetting any of the chloroform. To this was added 0.1 ml of the host culture and 2.5 ml of double strength lawn agar at a temperature of 45°C. The suspension was mixed well, allowed to cool, and incubated overnight at 37°C in an inverted position. Three replicates of each sample were prepared.

Storage  All T7 stocks and samples were stored at 4°C in the presence of chloroform.

RESULTS AND DISCUSSION

The most important conclusion reached is that slow sand filters are very efficient at removing enteroviruses from water. The following factors have been shown to influence this removal. All the examples given are the average daily results obtained over at least one week.

Temperature  This is the one factor affecting filter efficiency which cannot be easily controlled on a large scale. Low temperatures cause a marked reduction in filter efficiency. For example, a filter operating at a standard rate of 4.8 m/d at a temperature of 11 - 12°C reduced virus by 99.999 per cent. At 6°C the reduction was 99.8 per cent, approximately a hundredfold difference. Conversely high temperatures promote virus removal. On occasions in warm weather less than 1 in 10$^6$ of viruses was applied to the top of a filter running at 4.8 m/d has been detectable in.
<table>
<thead>
<tr>
<th>Year</th>
<th>Temp. Range °C</th>
<th>Filter No.</th>
<th>Flow Rate metres/d</th>
<th>Poliovirus 1</th>
<th>Bacteriophage</th>
<th>E. coli</th>
<th>Coliform Bacteria</th>
<th>37°C Colony Count</th>
<th>22°C Colony Count</th>
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<td>12</td>
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**TABLE 1 - The percentage reduction in viruses and bacteria for 1974 averaged over quarterly periods.**
the filtrate. The effects of temperature are illustrated in Table 1 where, for example, the control filter at temperatures between 5 and 8°C reduced viruses by an average of 99.68 per cent and at 18 - 16°C by 99.997 per cent.

**Filtration Rate**

Increased rates of filtration lead to less efficient removal of viruses and bacteria. When the results (Table 1) of filter No. 1 running at 12.0 and 9.6 m/d are compared with the control at 4.8 m/d an approximate tenfold difference in the reduction of virus is apparent. The results in Table 2 however show that satisfactory results with both bacteria and viruses can be obtained at high flow rates and at temperatures as low as 5°C. At lower temperatures and in heavily contaminated water lower flow rates may be advisable.

These results indicate that under average weather conditions there is no virological objection to higher flow rates.

The effects of sudden increases in the rate of flow was tested by abruptly doubling the rate of the control filter which had been running at 4.8 m/d for a year, to 9.6 m/d and comparing the results with the high rate filter which was already running at 9.6 m/d. The results (Table 3) show the averages for the week before, and the three weeks after, the increase. Immediately following the increase the quality of the filtrate was slightly lower than the high rate filter but it rapidly improved so that there was no difference after three weeks. This result shows that mature filters respond quickly to variations in flow rate and do not need lengthy maturation at a new flow rate.

**Cleaning**

A typical effect of cleaning a filter is shown in Table 4. Cleaning does not have a marked influence on the experimental filters and when averaged over a week the results are negligible. This is in marked contrast to observations on a full scale filter. It is likely that the effects of cleaning are influenced more by the length of time the filter is drained than by the removal of the surface layer. The experimental filters can be easily and rapidly cleaned and be running normally in a few hours whereas a full scale bed may take days. An accidental blockage in the water supply led to the drainage of the filters for about 24 hours. This event may more accurately illustrate the effect of cleaning a large bed. (Table 4) The percentage reduction of the virus fell from a weekly average of 99.59 and 99.99 before draining to 95.88 and 99.86 afterwards.
The percentage reduction of viruses and bacteria averaged over three weeks at a temperature of 5 - 6°C. The experimental filter (No. 1) was running at 9.6 and 12.0 m/d and the control (No. 2) at 4.8 m/d.

<table>
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<td>Flow Rate m/d</td>
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<td>Poliovirus 1</td>
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</table>

Filter Maturity

The maturity of a filter has been known to have a significant bearing on the efficiency with which bacteria are removed in full scale installations. This was also found with viruses. Accidental damage during the summer of 1972 caused filter number 1 to be taken out of use for repairs. The filter was refilled with clean sand from the sand store and put back into use at a rate of 4.8 m/d in early October. When virus inoculation was started in January, 1973, a difference in performance between the two filters was noticed, the old filter (number 2) being approximately ten times more efficient than the new one (Table 4). These effects were parallel in both the bacteriological and virological results. The difference remained for two months over a temperature range of 5 - 7°C and flow rates up to 7.2 m/d, and survived two cleaning processes. Eventually as the temperature started to rise, and following further cleaning, the filters became similar in performance.

It seems likely that the warmer conditions accelerated the maturation of the filter.
TABLE 3 - The weekly average percent reduction in viruses and bacteria by slow sand filter.

<table>
<thead>
<tr>
<th>Date</th>
<th>Temp. Range °C</th>
<th>Filter No.</th>
<th>Flow Rate metres/d</th>
<th>Percentage Reduction</th>
<th>37°C Colony Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>19-25 Nov</td>
<td>11-11</td>
<td>1</td>
<td>9.6</td>
<td>99.30</td>
<td>99.87</td>
</tr>
<tr>
<td>26-30 Nov</td>
<td>10-11</td>
<td>1</td>
<td>9.6</td>
<td>99.60</td>
<td>99.85</td>
</tr>
<tr>
<td>1-9 Dec</td>
<td>10-9</td>
<td>2</td>
<td>9.6</td>
<td>99.50</td>
<td>99.42</td>
</tr>
<tr>
<td>10-16 Dec</td>
<td>10-9</td>
<td>1</td>
<td>9.6</td>
<td>99.82</td>
<td>99.95</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>9.6</td>
<td>99.91</td>
<td>99.99</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Filter No. 1 was running constantly at 9.6 m/d.

The flow rate of filter No. 2 was doubled from 4.8 to 9.6 m/d.
The weekly average reductions in virus numbers by immature (No. 1) and mature (No. 2) slow sand filters during spring 1973.

<table>
<thead>
<tr>
<th>Date</th>
<th>Temp. °C</th>
<th>Flow Rate m/d</th>
<th>Percentage Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Poliovirus Filter No. 1</td>
</tr>
<tr>
<td>22/1</td>
<td>6 - 6</td>
<td>4.8</td>
<td>99.76</td>
</tr>
<tr>
<td>29/1</td>
<td>5 - 6</td>
<td>4.8</td>
<td>99.74</td>
</tr>
<tr>
<td>5/2</td>
<td></td>
<td></td>
<td>Filters cleaned</td>
</tr>
<tr>
<td>6/2</td>
<td>5 - 5</td>
<td>4.8</td>
<td>99.59</td>
</tr>
<tr>
<td>26/2</td>
<td></td>
<td></td>
<td>Filters drained for 24 hours</td>
</tr>
<tr>
<td>27/2</td>
<td>5 - 5</td>
<td>4.8</td>
<td>95.88</td>
</tr>
<tr>
<td>5/3</td>
<td>5 - 5</td>
<td>4.8</td>
<td>99.65</td>
</tr>
<tr>
<td>12/3</td>
<td>5 - 6</td>
<td>6.0</td>
<td>99.78</td>
</tr>
<tr>
<td>28/3</td>
<td></td>
<td></td>
<td>Filters cleaned</td>
</tr>
<tr>
<td>2/4</td>
<td>7 - 7</td>
<td>7.2</td>
<td>99.96</td>
</tr>
</tbody>
</table>

Depth of Sand: In full scale filters the sand depth varies between 600 and 300 mm. The results from experimental filters containing sand at these two depths are given in Table 5 where the percentage reduction in poliovirus at flow rates varying from 2.4 to 7.2 m/d are shown. These results were obtained when the temperature and biological activity in the water were varying rapidly, however, it can be seen that the depth of sand has an important effect on filter performance. For example, at a flow rate of 4.7 m/d the viruses were reduced by an average of 99.998 per cent in the deep filter but only by 99.940 per cent in the shallow one. The ratio of
The weekly average reduction of poliovirus 1 by slow sand filters containing 300 and 600 mm of sand.

<table>
<thead>
<tr>
<th>1971 Date</th>
<th>23rd Nov.</th>
<th>30th Nov.</th>
<th>7th Dec.</th>
<th>14th Dec.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage reduction:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Filter No. 1 (Sand depth 600 mm)</td>
<td>99.98</td>
<td>99.999</td>
<td>98.87</td>
<td>99.69</td>
</tr>
<tr>
<td>Filter No. 2 (Sand depth 300 mm)</td>
<td>99.940</td>
<td>99.997</td>
<td>92.59</td>
<td>96.46</td>
</tr>
<tr>
<td>Ratio 1/2</td>
<td>25</td>
<td>58</td>
<td>34</td>
<td>11.3</td>
</tr>
<tr>
<td>Biological Activity *</td>
<td>6.7</td>
<td>4.5</td>
<td>15.0</td>
<td>9.0</td>
</tr>
<tr>
<td>Temperature °C</td>
<td>9.0</td>
<td>9.0</td>
<td>8.0</td>
<td>7.0</td>
</tr>
<tr>
<td>Flow rate m/d</td>
<td>4.8</td>
<td>2.4</td>
<td>7.2</td>
<td>4.8</td>
</tr>
</tbody>
</table>

* Biological activity was measured by the number of days taken for virus numbers to decline naturally by one log.

The concentration of virus in the two filtrates was 1:25. These results suggest that the loss of efficiency due to increased flow rates could be partly rectified by increasing the sand depth.

The effects of temperature and flow rate given above were obtained on filters containing 600 mm of sand. Due allowance should therefore be made when these results are related to full scale beds in which, under present management practice, the sand depth may vary.

Virus Losses in Aqueduct Water When attenuated poliovirus was added to aqueduct water a marked decline in virus numbers was recorded. It was most noticeable at higher temperatures but was also apparent in cold weather, and varied considerably at different times of the year. The results in Table 5 show the extent of this effect in the tanks of inoculated water.
during the autumn of 1971. In these examples the rate of decline varies between 1 log in 4.5 days and 1 log in 15 days. These values are typical of those found in stored water (Poynter 1966). Most of this loss has been attributed to biological activity in the water because this effect was considerably reduced by passing samples of the water through a sterilising membrane before adding the virus. This phenomenon has been investigated by Poynter (1966), who concluded that it was due to protozoa in the water.

Estimates of the amount of virus inactivated in the water above the filter sand are consistent with the levels of biological inactivation in the stored water. This loss, which may be up to ten per cent of the total, is limited by the short retention time of the filter, approximately 7.5 hours when the filter is operating at 4.8 m/d. It is possible that further inactivation may take place within 50 mm of the sand surface i.e. below the lowest point at which the water was sampled. These observations, however, indicate that most of the virus is removed by the sand bed.

**Bacteria and Viruses Compared**

A comparison of the bacteriological and virological data obtained from the filters at the same time shows that the two sets of results run in parallel (Tables 1, 2 and 3). The percentage reduction for E. coli is slightly less than for poliovirus, for example, in Table 3, filter number 1 reduced poliovirus by 99.30 and E. coli by 95.1 per cent and filter number 2, 99.86 and 99.2 per cent respectively. This result is unexpected because although both are incapable of multiplying in a filter, E. coli is much larger than poliovirus. The other measurements of bacterial content namely the coliform bacteria and 37\° and 22\°C colony counts produced similar results, although the removal of the 37\° organisms was lower than the others. This similarity of the results obtained for both the bacteria and poliovirus was consistent over a wide variety of temperatures and flow rates. If this relationship can be confirmed on a full scale working filter it will be very useful because it implies that the normal bacteriological control of slow sand filtration can be assumed to apply to entero-viruses thus obviating any need for further virological controls.

Obviously caution should be exercised when extrapolating from the above results derived from small experimental filters to full scale beds. Where however it has been possible to compare the experimental results with those obtained from a full scale bed, for example, the high rate beds...
at Ashford Common (Windle Taylor, 1973), good agreement has been obtained, suggesting that the virological results are also applicable to the large filters.

**Coliphage T7 as an Indicator in Filtration Studies**

When compared with enteroviruses the advantages of using a bacterial virus are many. The latter can be easily and cheaply cultured and titrated and the results are quickly available. When titrating poliovirus a cell monolayer may take four days to grow before inoculation and the result may not be available for a further six days. With T7 phage however, the host bacteria can be cultured overnight and a reliable count obtained six hours after inoculation. The culture of cells for virological work needs care and can be expensive, but many phages can be used in a routine bacteriological laboratory. In addition bacterial viruses are non-pathogenic to humans and can safely be used in waterworks. They can also be grown in very large numbers and can therefore be used on a larger scale than enteroviruses.

Examples of the results obtained from the simultaneous inoculation of the filters with poliovirus 1 and coliphage T7 are shown in Tables 1, 2 and 4. The period of inoculation covered a wide variety of temperatures and flow rates. The early results showed great promise (Table 4), those obtained with the two viruses being practically identical, but in later results (Tables 1 and 2), probably due to changed conditions, the phage showed a consistently greater reduction. Both viruses faithfully reflected variations due to flow rate and temperature but the reduction in phage numbers was always more marked than that of poliovirus. It was therefore concluded that coliphage T7 is an unreliable indicator of the enterovirus removing ability of a slow sand filter. The possibility still exists that other bacteriophages may give better results.

**Mechanisms of Virus Removal**

The reduction in efficiency at low temperatures, the adverse effects of drainage, and the phenomenon of maturation are all consistent with the view that the removal of bacteria and viruses by slow sand filtration is essentially a biological process. The potential of these processes has already been illustrated by the inactivation of viruses in stored water.

Possible physical mechanisms by which sand filters could remove very small particles have been examined by Ives et al (1969) and Cookson et al (1970). These processes are important but, experiments with small sand
filters have demonstrated that viruses were not removed by clean 'sterile' sand when operated at normal flow rates (4.8 m/d), (Windle Taylor, 1970).

Investigations into the microbiology of slow sand filters by Lloyd (1972) has demonstrated the presence of large numbers of bacteria consuming organisms, both attached to the sand grains and in the interstitial spaces. A possible concept of a slow sand filter is that it consists of a very large surface area populated and grazed by bacteria ingesting organisms which are fed by other bacteria, small particles and chemicals dissolved in the filtering water. The sand merely acts as a substrate for the biological activity. The process of maturation may be simply a measure of the time taken for this situation to become established. The physical mechanisms such as gravity, diffusion and adsorption are important in bringing the particles into contact with this surface.

It is likely that for any given set of conditions the efficiency of filtration is proportional to the length of time the water is in contact with this large surface. This period can be increased by slower filtration or greater sand depth. The effects of temperature are probably related to the activity of the various organisms. It is unlikely that the sand is uniformly populated throughout its depth. Food supply and possibly oxygen diminish at lower levels leading to a more restricted fauna. However an increase in the population density of organisms at these lower levels may be brought about by increasing the flow rates and therefore the food supply.

CONCLUSIONS

Several conclusions can be drawn. Most important perhaps is that slow sand filtration is a highly efficient means of removing enteroviruses from contaminated reservoir water. Factors adversely effecting this removal were: low temperature, high flow rates, reduced sand depth, and filter immaturity. The adverse effects of cleaning are probably due to prolonged drainage and exposure of the sand bed.

Another important conclusion is that, despite their marked differences, viruses and bacteria respond in much the same way to the cleansing mechanisms of a sand filter. Polioviruses were removed with an efficiency similar to but slightly greater than that of bacteria. The similarity between the response of bacteriological and virological results to the above factors suggests that normal bacteriological methods can be used to indicate the enterovirus removing ability of a slow sand filter. However, the bacterial
virus T7 was considered an unreliable indicator in this respect.

From a virological point of view it would appear that high flow rates could safely be used especially in warmer weather.

In many respects slow sand filtration is ideally suited to the treatment of water in the developing countries. The process is highly efficient in removing bacteria, viruses and chemicals and is capable of producing water of the highest quality. The filters are very reliable, easily controlled, use cheap materials and are not dependent on sophisticated machinery and imported chemicals. Their main disadvantages, in requiring a relatively large area of land, being fairly labour intensive, and having reduced efficiency at low temperatures would not apply in many of these countries.

ACKNOWLEDGEMENT

The authors wish to thank Mr. Hugh Fish, Director of Scientific Services, Thames Water Authority, for his help and encouragement during the preparation of this paper.
REFERENCES

AYRES, P. (1974) Personal communication


SLOW SAND FILTRATION PROJECT

FIRST MEETING OF PROJECT PARTICIPATING INSTITUTIONS


BACKGROUND DOCUMENT I - 13

Slow Sand Filtration

Copies from:

44th and 45th Report of the Metropolitan Water Board, London
Experimental Studies of Slow Sand Filtration

In the 43rd Report (page 61) it was indicated that shading techniques were being developed for reducing the quantities of algae which develop as "local growths" in the supernatant water, and on the sand surface, of slow sand filters.

The particular algae involved include a range of Chlorophyta and diatoms with high rates of growth and reproduction during midsummer. The most troublesome are of two types, the large filamentous forms such as Cladophora (see 41st Report, page 91, Plate VI), Enteromorpha, Hydrodictyon, and Melosira, together with a variety of small unicellular Chlorophyta and Cryptophyta. Pennate diatoms such as Nitzschia and Synedra may also be prolific.
It will be appreciated that none of the above algae develop to bloom proportions in storage reservoirs and, therefore, they occur only as minor constituents of the algal species passing on to a slow sand filter. Despite their inability to develop in the lacustrine conditions of a storage reservoir, the environmental features of a slow sand filter basin favour their rapid growth and reproduction (43rd Report, page 63).

The successional patterns of these midsummer algae are well known, and a typical sequence would be unicellular Chlorophyta, followed by pennate diatoms, then some filamentous diatoms, and ultimately the filamentous Chlorophyta (Ridley, 1967). The potential problems include penetration of the sand column by the smallest algae, clogging of the sand interstices by larger species, and matted layering of algae at the sand-water interface.

Thus, a situation frequently arises at times of peak demand when, despite efficient reduction of algal blooms in the storage reservoirs, the quantity or quality aspects of slow sand filtration are affected by an inability to control the rates of primary production in the filter basin.

The amount of light received by algae is critical, and when the filter shading trials were planned the main objective was to restrict development of excessive crops of specific algae. This was shown to be practicable in June 1970 by using a black polythene covering, floated on the water surface, to shade about 20 per cent of the 0.3 ha area.

It will be seen in the coloured photographs facing this page that the unshaded area has been colonized to a much greater extent than the shaded area.

Examination of representative sections of the sand surface at the end of a filter run lasting several weeks showed interesting flora-fauna differences.

<table>
<thead>
<tr>
<th>Melosira spp</th>
<th>Dense masses</th>
<th>Unshaded area</th>
<th>Shaded area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorophyll-a (μg/cm²)</td>
<td>125</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Organic matter (as per cent. dry weight)</td>
<td>9.7</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>Chironomid larvae (number/cm²)</td>
<td>11</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

These effects of shading are of important economic significance because in 1969 the Board were operating 174 slow sand filters, covering an area of 64 ha. By 1972, a further 32 filters will be in service at the new Coppermills works.

Routine bacteriological results from the shaded bed and the adjacent control bed and all other beds were compared for the two periods of the experiment, 15th May–7th June 1970 and 17th June–15th July 1970. The results are set out in Table XXVIII. When bed 4 was cleaned samples of sand were obtained after cleaning from the top 100 mm from the shaded and unshaded areas and the results are set out in Table XXIX.

During the first period coliform counts were negative throughout on both beds and thus lower than all other beds. Colony counts were lower on the shaded bed than on all other beds. During the second period when the beds were reversed the coliform and E. coli counts and colony count were higher on the shaded than on the unshaded bed, but the E. coli counts were lower on the shaded bed than on all other beds. With this small number of samples little significance can be attached to these differences, but this investigation is being extended.

All the bacteriological results for the sand from the shaded and unshaded areas were of the same orders of magnitude and indicated no significant difference in performance.
TABLE XXVIII
Bacterial content of filtrates from shaded and unshaded beds

<table>
<thead>
<tr>
<th></th>
<th>Coliform count per 100 ml</th>
<th>E. coli count per 100 ml</th>
<th>Colony count per ml</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minimum</td>
<td>Mean</td>
<td>Maximum</td>
</tr>
<tr>
<td>15th May-7th June, 1970</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shaded bed 4 (11 samples)</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Unshaded bed 6 (4 samples)</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>All other beds (25 samples)</td>
<td>0</td>
<td>0.4</td>
<td>4</td>
</tr>
<tr>
<td>17th June-15th July, 1970</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shaded bed 6 (13 samples)</td>
<td>0</td>
<td>20</td>
<td>190</td>
</tr>
<tr>
<td>Unshaded bed 4 (12 samples)</td>
<td>0</td>
<td>0.1</td>
<td>1</td>
</tr>
<tr>
<td>All other beds (39 samples)</td>
<td>0</td>
<td>4</td>
<td>84</td>
</tr>
</tbody>
</table>

TABLE XXIX
Bacterial content of sand from shaded and unshaded areas of bed 4. Top 100 mm after cleaning, 11th June, 1970

<table>
<thead>
<tr>
<th></th>
<th>Shaded area</th>
<th>Unshaded area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coliforms per 100 ml</td>
<td>650</td>
<td>500</td>
</tr>
<tr>
<td>E.coli per 100 ml</td>
<td>110</td>
<td>350</td>
</tr>
<tr>
<td>37°C Colony count per ml</td>
<td>800,000</td>
<td>560,000</td>
</tr>
<tr>
<td>22°C Colony count per ml</td>
<td>8,800,000</td>
<td>4,000,000</td>
</tr>
<tr>
<td>37°C Spore count per ml</td>
<td>172,000</td>
<td>110,000</td>
</tr>
<tr>
<td>Yellow spores per ml</td>
<td>44,000</td>
<td>16,000</td>
</tr>
</tbody>
</table>

The cost of materials and installation for a removable plastic cover for shading about 80 per cent of the filter area is about £300. Maintenance costs are negligible, but it remains to be seen whether the plastic material should be replaced by a more robust covering. At the present time, a slow sand filter requires cleaning, on average, 7 times a year; if shading reduces the frequency of cleaning, capital costs could soon be recovered. The economics are interesting, and the system could lead to maintenance of optimum rates of filtration for much longer periods than are now possible.

In effect, shading merely retards or inhibits primary production, and in a complex ecosystem such as the slow sand filter the effects on the biota are far reaching. For example, reduced quantities of algae will be available for the invertebrate fauna which graze directly on algal cells or on algal debris. This group includes Protozoa, Hydrozoa, Platyhelminthes, Rotifera, Nematoda, Annelida, Crustacea, Insecta and Arachnida.

It will be necessary, therefore, to adjust the ratio of shaded to unshaded area at different times of the year to ensure adequate quantities of viable algae which will produce oxygen for the respiratory needs of these invertebrates as well as for the bacterial-fungal associations which also play important roles. Excessive shading could, of course, lead to anaerobic conditions within the filter, deterioration in bacteriological efficiency, and unacceptable smell and taste in filtrates. Care must be taken to submerge the plastic material below the water surface to prevent water birds from alighting and further fouling the water.
Slow Sand Filtration

One of the major research activities since 1971 (and which is still continuing) is a fundamental study, carried out in close conjunction with the Chief Engineer's Department, of the Board's most important treatment process, namely slow sand filtration. The purpose of this work is to determine whether increased filtration rates can be obtained without any deterioration in filtrate quality or possibly combined with improved filtrate quality, either from existing filtration stations or from modified filtration stations or with fundamental design changes which could be incorporated only in new filtration stations.
Much of this work has been carried out on a pair of miniature slow sand filters at Walton previously described in the 38th Report, page 37, as well as on full scale beds and laboratory scale filters. The most important operational factors studied have been, increased filtration rates, sand grading, bed shading, prefiltration ammoniation and with prefiltration ozonation only just started. The effect of these operational changes on the chemical, biological, bacteriological and virucological quality of the water has been studied. In order to understand the effects of these operational changes some studies on the ecology of the normal filter bed microflora and fauna have been initiated.

Filter Bed Shading

Initial investigation of filter bed shading was described in the 44th Report, page 83. Although shading successfully inhibited algal growth this did not result in significantly increased filter runs but it saved the labour involved in removal of large masses of filamentous algae at certain seasons. The experimental black polythene sheeting used for shading was not suitable for permanent installation. In terms of both heat retention and filtrate quality, any benefits are unlikely to justify the capital cost involved in providing durable covers suitable for the present system of filter cleaning. There was also some difficulty in removing and replacing the covers and greater opportunity for bird pollution of the water. The present experiments are being phased out of the research programme to allow greater efforts on high rate filtration.

Increased Filtration Rates

Increased filtration rates have been operated on the two Walton experimental filters at rates up to 15 m/day using one bed as a control. Following the initial success with these filters the full scale bed number 45 at Hampton was operated at fast rates. The results of these fast filtrations are presented in Tables VI and VII.

Results have been summarized as averages per filter run or group of filter runs. With regard to Hampton bed 45 the bacteriological results on the first day after cleaning have been omitted as these are not included in the control bed which was cleaned at different times nor in the general well which was also used as a control.

Trials at Walton showed that the experimental filters could be run at rates up to 12 m/day (Table VI) without any deterioration in the chemical and bacteriological parameters including the additional microbiological parameters that were investigated. Without a detailed statistical analysis there appears to be no significant difference in any of these results. Even at 15 m/day the only parameter indicating what may be a significant difference is ammonical nitrogen; most other parameters are better on the fast filter than on the control. Similar results were obtained when the trials were extended to bed 45 at Hampton (0.5 ha), again at rates of up to 12 m/day (Table VII). This suggests that results from the pilot-scale filters at Walton can be extrapolated to full-size secondary beds, and that existing rates of filtration could be increased considerably. Coliform and E. coli counts were higher on run 11 on Hampton bed 45 but still lower than the control. Ammonia and albuminoid nitrogen were slightly higher than controls; all other results were lower or about equal. The sand depth was at the lowest limit normally used, namely 0.3 m, and the bed was re-sanded after run No. 11. It may be necessary to re-consider the minimum bed depth for these very fast filtration rates.

During 1972, and based upon experience at Walton experimental filters, the normal practice of starting a new bed at about 1 m/day on day 1, and increasing to about 5 m/day by day 5, was gradually modified at Hampton, on bed 45 only, so that the filter was working at 1-3 m/day
on day 1; 6-12 m/day on day 2; 12 m/day consistently from day 3 onwards. This change of procedure caused no apparent deterioration in the physical, chemical, biological or bacteriological quality of the filtrate. The results suggest that newly cleaned beds could be returned to service in summer at rates much higher than previously thought possible. The initial experiments covered a period when the stored water quality was extremely good and water temperatures were optimum, but these satisfactory results continued into the winter period when stored water quality was poorer.

The accumulation and distribution of silt and organic debris in the sand columns were studied. There appears to be no noticeable difference between a high-rate and a low-rate column, using the standard "silt test" method which is used by local filter foremen to determine the need for trenching a bed. A more precise method for determining column penetration and accumulation is being developed as part of the research programme.

There was however a cumulative difference in head-loss between the fast rate and control beds at Walton such that the fast rate bed started with a higher head-loss after cleaning than the control bed thus reducing the length of filter runs and necessitating deep cleaning of the sand after a few months at fast rates. As however this initial head-loss occurred on the fast rate bed as soon as the rate was increased above that on the control bed this may be a phenomenon related solely to the hydraulics of the bed in relation to filtration rate.

The special hydraulic situation at Hampton bed 45 allows filtration consistently at rates of up to 12 m/day to be maintained for long periods because head-losses can be allowed to rise to about 3 m. This is not practicable at most of the other secondary beds in the Thames Valley where the present design limits the maximum head-loss to about 1-2 m. If these types of bed were filtering at 12 m/day the filter run could frequently be less than a week, and this would pose an impossible situation in terms of management.

**Sand Grading**

The whole of the sand in the Walton east filter was replaced with builder's grade sand after washing through the sand hoppers, before commencing run No. 10. The results (see Table VI) compared with the control filter were still highly satisfactory although some parameters showed some falling off in quality as is to be expected in an immature bed. Similar sand was put into the control bed before commencing run No. 11 following which the cast filter gave better results for some parameters presumably due to its greater maturity. This sand is very much cheaper than the closely specified grade normally used by the Board and these preliminary results indicate that a possible considerable saving in cost of sand could be achieved. Coarser sand can also have an effect on silt penetration and mechanical cleaning processes all of which need to be investigated.

**Conclusions and Future Action**

For long-term high-rate filtration, an essential requirement is for a head-loss capability of about 3 m, or a large increase in labour and equipment for more frequent cleaning.

In the immediate future, short periods of higher-rate filtration (up to a maximum of 12 m/day) at certain existing filters appear to be acceptable from the water quality aspects, and in some circumstances beneficial to the general quality of a works output. However, the long-term implications of consistently high-rate filtration are at present obscure and require further investigation.
**TABLE VI**

Effects of increased filtration rates on Walton experimental filters

Average results per run

<table>
<thead>
<tr>
<th>Run number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
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<th>10</th>
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</thead>
<tbody>
<tr>
<td>Date</td>
<td>17th Apr. to 15th May 1971</td>
<td>20th May to 16th June</td>
<td>16th June to 16th August</td>
<td>16th August to 17th September</td>
<td>21st September to 11th October</td>
<td>13th October to 8th Nov.</td>
<td>1st January to 27th March 1972</td>
<td>7th April to 22nd May</td>
<td>25th May to 10th July</td>
<td>4th August to 31st October</td>
<td>2nd Nov. to 4th December</td>
</tr>
<tr>
<td>Length of run</td>
<td>20 days</td>
<td>25 days</td>
<td>30 days</td>
<td>20 days</td>
<td>27 days</td>
<td>87 days</td>
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<td>46 days</td>
<td>88 days</td>
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</tr>
<tr>
<td>Ftiltration rate m/day</td>
<td>East Filter: Control Filter</td>
<td>East Filter: Control Filter</td>
<td>East Filter: Control Filter</td>
<td>East Filter: Control Filter</td>
<td>East Filter: Control Filter</td>
<td>East Filter: Control Filter</td>
<td>East Filter: Control Filter</td>
<td>East Filter: Control Filter</td>
<td>East Filter: Control Filter</td>
<td>East Filter: Control Filter</td>
<td>East Filter: Control Filter</td>
</tr>
<tr>
<td>37°C Colony count/ml</td>
<td>5.4</td>
<td>5.4</td>
<td>5.4</td>
<td>5.4</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>12</td>
<td>12</td>
<td>12</td>
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<tr>
<td>22°C Colony count/ml</td>
<td>660</td>
<td>335</td>
<td>340</td>
<td>495</td>
<td>1,105</td>
<td>174</td>
<td>50</td>
<td>94</td>
<td>81</td>
<td>114</td>
<td>90</td>
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<td>Caliform count/100 ml</td>
<td>6</td>
<td>3</td>
<td>2</td>
<td>1</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
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<td>1</td>
</tr>
<tr>
<td>E. coli/100 ml</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Colour-Dragg units</td>
<td>24</td>
<td>23</td>
<td>21</td>
<td>21</td>
<td>27</td>
<td>26</td>
<td>19</td>
<td>17</td>
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<td>Turbidity, units</td>
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<td>0.1</td>
<td>0.1</td>
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</tr>
<tr>
<td>Ammonia N mg/l</td>
<td>0.016</td>
<td>0.012</td>
<td>0.008</td>
<td>0.010</td>
<td>0.007</td>
<td>0.006</td>
<td>0.015</td>
<td>0.011</td>
<td>0.005</td>
<td>0.007</td>
<td>0.009</td>
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<td>Albuminoid N mg/l</td>
<td>0.113</td>
<td>0.091</td>
<td>0.098</td>
<td>0.093</td>
<td>0.083</td>
<td>0.081</td>
<td>0.003</td>
<td>0.007</td>
<td>0.015</td>
<td>0.010</td>
<td>0.012</td>
</tr>
<tr>
<td>Fungi/100 ml</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
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</tr>
<tr>
<td>Yeasts/100 ml</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
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</tr>
<tr>
<td>Streptomyces/100 ml</td>
<td>58</td>
<td>48</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
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<td>Micro-organisms/100 ml</td>
<td>450</td>
<td>420</td>
<td>420</td>
<td>420</td>
<td>420</td>
<td>420</td>
<td>420</td>
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<td>420</td>
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<tr>
<td>Fluorescent pseudomonad/100 ml</td>
<td>71</td>
<td>71</td>
<td>71</td>
<td>71</td>
<td>71</td>
<td>71</td>
<td>71</td>
<td>71</td>
<td>71</td>
<td>71</td>
<td>71</td>
</tr>
<tr>
<td>Clostridia/100 ml</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Run number 10. Builder's grade sand used in east filter.
Run number 11. Builder's grade sand used in both filters.
Run number 12. Results to 4th December only as ozonation was started on 5th December and run continued until 31st December, i.e. 59 days.
TABLE VII

Effects of increased filtration rates on Hampton bed 45

Average results per run

<table>
<thead>
<tr>
<th>Run number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
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</thead>
<tbody>
<tr>
<td>Date</td>
<td>1st Sept. to 13th Sept. 1971</td>
<td>17th Sept. to 15th Nov.</td>
<td>25th Nov. to 14th Feb. 1972</td>
<td>16th Feb. to 14th April</td>
<td>20th April to 4th June</td>
<td>8th June to 2nd July</td>
<td>6th July to 28th August</td>
<td>2nd August to 27th Sept.</td>
<td>31st August to 9th Nov.</td>
<td>1st October to 14th Nov. 1973</td>
<td></td>
</tr>
<tr>
<td>Length of run (days)</td>
<td>13</td>
<td>60</td>
<td>57</td>
<td>46</td>
<td>25</td>
<td>23</td>
<td>27</td>
<td>28</td>
<td>39</td>
<td>61</td>
<td></td>
</tr>
<tr>
<td>Max. Filtration rate m/day</td>
<td>6.4</td>
<td>5.4</td>
<td>6.0</td>
<td>6.0</td>
<td>6.0</td>
<td>7.2</td>
<td>12.0</td>
<td>11.4</td>
<td>12.0</td>
<td>11.4</td>
<td></td>
</tr>
<tr>
<td>37°C Colony count/ml</td>
<td>6</td>
<td>16</td>
<td>13</td>
<td>9</td>
<td>7</td>
<td>10</td>
<td>10</td>
<td>13</td>
<td>11</td>
<td>9</td>
<td>44</td>
</tr>
<tr>
<td>22°C Colony count/ml</td>
<td>48</td>
<td>78</td>
<td>120</td>
<td>90</td>
<td>47</td>
<td>105</td>
<td>32</td>
<td>45</td>
<td>44</td>
<td>66</td>
<td>22</td>
</tr>
<tr>
<td>Coliform count/100 ml</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>E. coli/100 ml</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Colour-Burgess units</td>
<td>20</td>
<td>17</td>
<td>17</td>
<td>16</td>
<td>20</td>
<td>20</td>
<td>26</td>
<td>25</td>
<td>20</td>
<td>19</td>
<td>19</td>
</tr>
<tr>
<td>Turbidity units</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.1</td>
<td>0.0</td>
</tr>
<tr>
<td>Ammonia N mg/l</td>
<td>0.003</td>
<td>0.009</td>
<td>0.011</td>
<td>0.004</td>
<td>0.004</td>
<td>0.004</td>
<td>0.017</td>
<td>0.009</td>
<td>0.025</td>
<td>0.015</td>
<td>0.023</td>
</tr>
<tr>
<td>Albuminoid N mg/l</td>
<td>0.086</td>
<td>0.080</td>
<td>0.089</td>
<td>0.087</td>
<td>0.095</td>
<td>0.096</td>
<td>0.101</td>
<td>0.098</td>
<td>0.102</td>
<td>0.077</td>
<td>0.084</td>
</tr>
</tbody>
</table>
It is proposed to include in this further work, better quantitative methods for assessing accumulation and distribution of silt, organic debris, and invertebrates in secondary sand columns. Alternative methods for cleaning slow sand filters are being considered. These include \textit{in situ} "backwashing" systems similar to those in use for primary filters, and mechanical devices for skimming sand surfaces whilst the bed is still full of water. Mathematical models of the slow sand filtration process are being developed and manipulated to assess the effects of various operational procedures, e.g. high-rate filtration, depth of skim, stored water quality, length of filter run, etc., in relation to filtrate quality. The reliability of the model will improve as the relevant data are accumulated.
SLOW SAND FILTRATION PROJECT

FIRST MEETING OF PROJECT PARTICIPATING INSTITUTIONS


BACKGROUND DOCUMENT I - 14

Guidelines for Waterworks Technical Management

- Slow Sand Filters -

by

Japan Water Works Association

1975
3.7 SLOW SAND FILTER

3.7.1. Characteristics of Slow Sand Filter

Slow sand filtration is a method in which activities of microorganisms are utilized for water filtration, that is, by help of the viscosious film formed by algae, bacteria and other eumycetes proliferating on the surface and inside of the sand layer, suspended substances like turbid matter and pathogens, and dissolved substances like ammonia, manganese and odor-generating matter are removed or decomposed physically, chemically and/or biologically. Therefore, in slow sand filtration, it is necessary to produce such conditions as contribute to the life of these microorganisms or in other words, to curb such conditions as threaten to hinder their living and growth.

It has been maintained that in a situation where the average turbidity per year is less than 10 degrees, less than 3 ppm of BOD and less than 5,000 (100 ml MPN) of B. coli, slow filtration has noticeable advantages over rapid filtration as follows:

a. Maintenance and control is easier
b. Water quality is more stabilized
c. More economical for the said reasons and
d. Remarkable effect in deodorizing water.

In slow filtration, attention should be paid to the following:

1) Filtration of turbid water

Turbidity of water is a most important condition in the choice of slow sand filtration as is stated in the water facilities criteria. Even if a turbid water (of upwards of 30 deg. turbidity) should be filtered, so long as it is temporarily, turbidity will be seldom perceived in the filtered water, but when such water is filtered continuously, the filter will get clogged and filtration obstructed. Sometimes, heavy clogging comes of a sudden after several months elapsed. This phenomenon will be explained as follows:

The viscosity particles and turbidity substances penetrate into the depth of the sand layer, accumulate and when the raw water recovers its normality and with revival of filtering film, normal filtration resumes, the exuberant growth of bacteria fed by the turbidity substances left in the sand layer because of insufficient scraping, clogs the filter. Once the situation comes to this there is no hope of recovery, no matter how strenuously sand-scraping is carried on. In case the filtering layer becomes soiled like this, Naïs (species of earthworm) frequently proliferates and finds their way into the filtrated water.

Thus, the lesson to be learned here is:

a. The slow sand filter should be fed by as little turbid water as possible.
b. Usually, turbidity should stay below 10 deg., and when the turbidity of raw water exceeds 30 deg., it must be reduced to lower than 10 deg. by means of coagulo-sedimentation.

2) Filtration of water abundant in plankton algae
In slow sand filtration, in principle, chemical sedimentation is not employed, so that, if the raw water contains a high percentage of Plankton Algae, these tend to clog the filtering layer. This will not only multiply the number of sand scrapings to several times, but increase the number of idle filters accordingly, thereby supplying of water suffering from shortage of filtered water.

To get rid of clogging of filter by Plankton Algae, it is recommended to remove these in the reservoir or if it is impossible, to remove them at the first stage of the double-stage filtration process or by coagulo-sedimentation. (cf. 3.11 8, 3.11, Treatment of Plankton Algae)

3) Treatment of algae in filters

Variety of organisms proliferate in the slow filter, so special considerations will be needed when the source of supply depends on underground water or subsurface water. In this kind of filter, there will be exuberant growth of filamentous algae like Melosira Spirogyra, Mougeotia, etc., which cover the filtering film or appear as if a blanket were spread. These algae will help filtration while alive, but have, at the same time, the negative effect of marling the appearance of filter basin or causing filtering interruption. When dead, they often-clog the filter or add unpleasant smell to the filtrate.

The growth of these algae can be checked by use of chlorine or copper chloride, but treatment by chemicals may also kill the film-forming organisms and deter filtration, so, in principle, use of chemicals should be avoided. However, in case chemical treatment must be applied, sufficient care is necessary about its dosage and dosing frequency. Sometimes, underground water creatures propagate underside of the filter layer and collecting gallery, or Nais proliferate in the sand layer; they may appear in the filtered water and invite complaints from users. These creatures are, most of them, of tenacious chlorine resistance and difficult of treatment; therefore, the filter beds must always be kept clean and safe from their proliferation. When the growth of nereids is seen in the filter, treatment by slaked lime at the time of sand scraping of the filter is recommended.

4) Turbid raw water and filtration effect

Slow sand filtration is a highly hygienic and safe process of purifying water because it can produce a quality water even when the raw water is more or less turbid. However, when the turbidity advances and exceeds a certain limit filtering function will come to a complete standstill and become useless.

The reason for this filter failure is that with progress of turbidity, the algae of the filter film will begin to perish and instead such Protozoa as are found in sewage will grow prolific, thus in addition to scarcity of the algae furnishing oxygen, large quantities of oxygen is consumed for oxidation of organic matters and ammonia, so the oxygen of the sand layer begins to run out. At a further stage, iron and manganese in the sand layer will dissolve into the water and frequently color the filtered water. The limits of turbidity when the slow sand filter can normally function will be BOD, 3 ppm, dissolved oxygen, 5 ppm, ammonia nitrogen 0.5 ppm, B. coli 5,000/100 ml (approx. ratios).

3.7.2. Operation of Filter Basin

1) Water level of filter basin should be kept mostly up to the designed level, at least upwards of 90 cm above the sand surface.

2) Filtering rate, according to the quality of raw water, should be within the designed max. rate. Also, what should be kept in mind is that changing the filtration rate suddenly will have had effect upon the filtration efficiency; 10 ~ 20 % increase in the rate of filtration will have no significant influence upon it, but sudden 50 % rise will impair the filtration effect extremely.

3) Outlet level of the filter basin should not be lower than the sand layer surface so that no negative water head be produced in the filter layer to reduce filtering efficiency.

4) Filtration head loss is an index of the filter conditions, which claims constant checking; sudden rise or fall of it means an accident in the filter film or in the bed, so instant stop of operation and check and repairs are needed.
5) Duration of filtration days, so long as the quality of filtrate is good and the necessary quality secured, will be so much the better as it is longer. But since filtration rate, raw water quality and condition of the filter bed will exert an influence upon it, extremely short or long duration calls for our survey.

6) Head loss, quantity of the filtrate and water level of the distribution reservoir must be periodically observed, recorded and utilized for delivery control. In addition, for the same purpose, operation diary should be prepared and kept in which days of filtration duration headloss at a definite hour of the day, filtration rate, etc. are to be entered.

7) Filtration controlling device and headloss gauge must be so arranged as to be able to grasp the flow and headloss correctly. For checking, repairing and adjustment of these instruments, the idle hours of the filter as in scraping and replenishing of sand should be employed. Further, by use of such hours, inspection, repairs or repainting of the fitting pipes, valves and other accessories would be conveniently made.

3.7.3. Maintenance of Filter Beds

1) No act of stirring the filter film with such tools as rake and rod should be allowed for fear of the film being damaged and partial filtration ensuing. Also watch out for up-floating of the film due to the growth of algae and damage by fishes, shells and earthworms. In case the film has actually been damaged or is feared to be, thicker than usual scraping of the sand layer must be done as early as possible.

2) The conditions of the beds must be always checked and making use of the aforesaid idle hours of the filter, subsidence, sludge accumulation inside the filter and growth of microorganism should be periodically inspected. On detecting these faults, proper steps mentioned earlier should be taken as early as practicable. The materials or samples for filter layer survey can be taken by thrusting the sand-collector into the sand layer.

3) When the water level at the outlet has dropped to the sand layer surface of the basin, scraping of the sand must be conducted. However, the head loss of the basin, when the water level at the outlet comes down near the surface height of the sand layer, tends to increase suddenly and several basins get clogged simultaneously, causing shortage of the filtered water; thus early scraping will be needed to avoid such situation.

4) At each scraping time, depth of the remaining sand layer is measured, and when the depth has lowered to around 40 cm, sand must be replenished; as regards sand replenishment, the number of filters to be sand-replenished per year should be determined on the basis of the remaining sand depth of each filter, and replenishing must be performed in turn during the months when water demand is comparatively low. (cf. Note 2)

5) As regards sand-replenishment, use of sand insufficiently washed will affect filtration effect, so the work of sand-washing must be done with minute care. (cf. Note 3)

6) In the cold district, scraping and replenishing of sand in the filter must be carried out before

1. For sand collector, a brass pipe of 1mm in thickness to be used (pipe of too thin wall or of plate brass rolled is not usable because the lower end will open at penetration)

2. Pipe diameter should be so designed as its area equals 1cm²: too large or too small dia. is not adequate.

3. By using the spatula shown on the right samples can be taken every 2cm depth.

Figure—3.10 Sand collector for slow sand filter (unit, cm)
3. MANAGEMENT OF PURIFICATION FACILITIES

Table—3.5 Conditions of Filter (Slow System)

<table>
<thead>
<tr>
<th>No. of Filter Basin</th>
<th>Conditions at definite hour of the day</th>
<th>Average</th>
<th>Conditions consolidated</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

coming of the cold season. When they must be done in the cold months, care must be taken lest the sand layer should be frozen.

7) For uncovered filters in the cold district, on freezing of the water surface, ambient ice-cutting is necessary in order to check the rise of ice pressure.

Note 1. Sand-scraping
(1) Sand-scraping is generally conducted in the following order:
   - (a) suspension of inlet and outlet operations
   - (b) cleaning of sidewalls of filter-basin
   - (c) draining on and under the sand surface
   - (d) scraping of the sand surface
   - (e) carrying-out of the scraped sand
   - (f) levelling of the sand surface
   - (g) returning of the filtrate
   - (h) introducing of the raw water
   - (i) draining of initial filtrate
   - (j) starting of operation

(2) On draining of the sand surface, the sludge and organisms sticking on the filter walls should be swept off by long-stemmed brush or bamboo-broom.

(3) Draining of the sand surface should be done at the drain, while draining of the bottom, at the drain of the outlet by degrees after the above work has completed. Sudden and abrupt draining might damage the filter layer, draining under the sand surface would be adequate when done around 20 cm under the surface.
Table 3.6 Conditions of Slow Filter

<table>
<thead>
<tr>
<th>No. of filter basin</th>
<th>Remarks</th>
<th>Scrapping completed at</th>
<th>T. M.</th>
<th>T. M.</th>
<th>Filtrete drained at</th>
<th>T. M./Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Height of water at mouth</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B. Filtration rate</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C. Quantity of filtrate</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D. Bed level</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E. Height of water at mouth</td>
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<td></td>
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<td></td>
<td></td>
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<td>F. Water level after filter</td>
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<td>G. Water level</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>H. Height of sand</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I. Quantity of filtrate</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>J. Name of examiner</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. MANAGEMENT OF TURFICATION FACILITIES
(4) For scraping, the sand surface of about 1 cm in thickness will be scraped off by use of such tool as “joren” or a kind of scoop (sketch—3.11) evenly and uniformly; for this purpose, number and direction of scraping ridges must be changed from time to time; ridge intervals of 2.0 ~ 2.5 m will suit the purpose, and the scraped sand will be carried out by use of basket, carrier bicycle, conveyor, etc.

(5) In scraping, workmen must not tread direct upon the sand surface; nor the wheels run on the surface; treading board should be used instead. (see sketch—3.12) After the scraped sand has been carried away, the surface must be levelled by use of wooden leveller.

(6) Prior to introduction of raw water, the filtrated water must be sent back from the outlet for the purpose of deaeration of the sand layer and surface protection, at the rate of less than 2m/d, and water to be introduced into the filter up to the height of 10 ~ 20 cm above the sand surface.

(7) Raw water must be led in gradually after the sending back of the filtrate and up to the specified level. For preventing the turbulence and scouring of the sand layer, concrete slabs or bricks must be spread at the inlet for raw water.

(8) Draining of initial filtrated water must be continued within the limits of 3-m/d. with gradual raise of filtration rate the filtrate to be discharged, until filtering effect is perceived.

(9) Resumed filtration function is to be confirmed through the process of quality tests on the filtered water. However, when time intervals from the initial filtration to this confirmation is determined on the basis of the quality of raw water, filtering function may be regarded as
resumed after that period elapsed. The items for water quality test in this case should at least include: turbidity, color, bacteria and B. coli.

Note 2. Sand-replenishing

(1) Sand-replenishing should be conducted in the following order:
   (a) draining on and under the sand surface
   (b) scraping of the sand surface
   (c) replenishing of sand and relocating of the old sand
   (d) levelling of the sand surface
   (e) draining of the initial filtrate
   (f) starting of operation

(2) Cleaning of the filter walls should be conducted in a manner similar to that in scraping, only with closer attention.

(3) Draining under the sand surface should be extended to the bottom of the collecting gallery.

(4) In replenishing sand, the amount or depth of the sand to be removed will better be determined by examining vertical pervasion of the sludge in the sand layer.

(5) In replenishing sand, see that the old sand will not be thrust into the lower layer by force of the new sand; for this purpose, first scrape the old sand up to the coarse sand layer at proper width, then introduce the clean sand over which the old sand must be relocated. This process will be repeated until the whole bed is renewed. During the work, sheeting will serve to prevent the old sand from mixing with the new. (see sketch 3.13)

(6) Sending-back of the filtered water, introduction of the raw water, draining of the initial filtrate and starting of operation will be done in a manner similar to that in the case of scraping of sand; draining of the filtrate, as it will take time before the normal function is resumed, should be done at nearly 50% of the specified filtration rate, with strict water analyses conducted the while.
(7) When entry into the filter is necessary for sand-replenishing, scraping or repairing purposes, wear clean footwear and take care that the filter bed will not be soiled. Pollution by wildlife must be also watched.

Note 3 Sand-washing
(1) The washed, clean sand should be in conformity with the standards specified in the "Standards for waterworks facilities" edited by the Japan Waterworks Association.
(2) In case there is shortage of quantity and pressure in the water used with the sand-washer, sand-cleaning effect will decrease because of reduced washing efficiency. Also there is fear of the sand flowing away when the water quantity and pressure are too great. Though the optimum quantity and pressure will vary dependent upon the type and capacity of individual sand-washer, the average figures are:
Amount of water required, approx. 10 times the amount of soiled sand
Clean sand produced, approx. 70 ~ 80% of the amount of soiled sand
(3) The washed, clean sand should be stored in a chamber for this special use, safe from contamination and flying, located convenient for transport of sand and equipped with perfect drainage at the bottom.
(4) The soiled sand should be placed on a concrete floor separated from the clean sand and be washed before getting dry. Also, the settling chamber for the sludge from sand-washing and drain pipe system should advisably be dredged periodically.
(5) The sand-washer must be equipped with metal net of about 6 mm mesh for removing gravels or wood chips often mixed with the soiled sand.
(6) Since the nozzle, jet pipe and metal net of the washer are liable to damage, spares should be stocked for ready replacement.

3.8 PIPE SYSTEM AT FILTER PLANT

3.8.1 Piping in the premises of filter plant
1) In the premises of filter plant, there are many kinds of pipe systems of specific character and functions. In the case of urgent operation, a single mishandling of any of these systems might invite nonoperation or no service of water. In preparation for such need, always confirm the location of each valve and the direction of their movement, and on the occasion of accidents like pipe bursting, etc., be ready to take adequate action as occasions require, by use of well-arranged detailed diagrams of piping systems of the plant. For this purpose, such diagrams should be kept in a place easy of reference.
2) When using a bypass, the dead water must be released from the drain pipe on the way before use of it.
3) The drain pipe must be so used as to collect no mud, sludge or rubbish that will make flow impossible; especially the sludge drain pipe must be occasionally cleaned by pressure water and for in-plant draining, catch basin and/or draining pump should be provided as occasion requires.
4) Valves and valve room must be kept in good order; valve controller and joint rod must be responsive to ready use.

3.9 CLEAR WATER RESERVOIR

3.9.1 Management of a clear water reservoir
1) In conveying clear water to the service reservoir, a clear water reservoir is operated as follows. Namely, a clear water reservoir where the purified water is stored operates as a buffer basin. In addition, filtration velocity is prevented from changing rapidly and filtrating operation will
3) Ventilating hole, man-hole, control gallery, control room and water inspection hole of clear water reservoir should be locked and be protected against pollution caused by rainfall, dust and small animals like rodents.

4) The water gauge, remote system water gauge, alarm devices and automatic operation devices should be checked for their correct functions.

3.9.2. Cleaning and disinfection of the clear water reservoir

1) In case of a newly-constructed clear water reservoir, or of repaired one, the inside of the reservoir should be first cleaned and then washed with clean water and finally should be filled with clear water containing approx. 10 ppm of free chlorine. If the residual chlorine in the water exceeds 5 ppm after the water is left for 24 hours, the water will be left for another several days for dissolution of the alkali in the water. The existence of offensive smell will also be checked. If the residual chlorine is below 5 ppm, disinfection should be repeated.

After this procedure, the water is drained and the clear water reservoir is filled with clean water. In case the residual chlorine seems to decrease only a little and the offensive smell is not recognized after lapse of 24 hours, the water may be distributed. On the contrary, when the residual chlorine decreases remarkably or the offensive smell is still recognized, disinfection should be repeated.

2) In case deposits cling to the inside walls of clear water reservoir or sediments accumulate in it.

<table>
<thead>
<tr>
<th>Table—3.7 Density of chlorine gas in the air and symptom of intoxication</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Degree of Poisoning</strong></td>
</tr>
<tr>
<td>---</td>
</tr>
</tbody>
</table>
| Slight | • Tears run out  
• Coughs come out  
• Sneeze and snivel | 2 ~ 5 | 2 to 3 hours by working  
15 min. and resting 15 min. alternately |
| A little Serious | • Difficulty in breathing and seeing things  
• Ache in the chest | 5 ~ 30 | Working almost impossible |
| Serious | • Impossibility of breathing  
• Losing physical senses  
• One's life jeopardized after 30 to 60 min. | 30 ~ 60 | Working impossible |
| | • Fatal dose | 1000 | |

* Allowable concentration of Cl₂ gas is below 1 ppm.

with the inside polluted, the clear water reservoir should be washed and cleaned after emptying the basin. In case of cleaning and repairing a clear water reservoir, these works should be performed based on 1).

Note: Poisoning by Chlorine Gas

When engaged in washing with the water containing chlorine in a clear water reservoir or a service reservoir which is almost sealed up, the workman will be often affected by chlorine gas in the eye and nose, some people showing a slight symptoms of intoxication or poisoning.
SLOW SAND FILTRATION PROJECT

FIRST MEETING OF PROJECT PARTICIPATING INSTITUTIONS


BACKGROUND DOCUMENT I - 16

Design of Water Treatment Plants

Part III
(Slow Sand Filters)

by

Dr. A.G. Bhole

Copy from:
Journal of the Indian Water Works Association
VII, 1975, no. 4, p. 249
Design of Water Treatment Plants

Part-III

Dr. A. G. Bhole*, MIWWA, B.Sc., B.E. (Hons.), B.A. (Eco), M.E., Ph.D., M.I.E.

This part deals with the subject of slow sand filtration, chlorination and clear water reservoir. Part I of this series which was published in Journal of JWIIA, Volume VII, No. 2 (April-June 1975) dealt with the problems connected with the design of aerator, measuring weir, flash mixer, clarifier, chemical house etc. Part II of the series which was published in Journal of JWIIA, Vol. VII, No. 3, (July-Sept. 1975) dealt with various aspects of design of rapid sand filter.

25. FILTRATION (SLOW SAND FILTERS)

The slow sand filters are used as an alternative to rapid sand filters or in combination with rapid sand filters.

26. DESIGN OF SLOW SAND FILTER

The design of slow sand filter is governed by many factors, the important among them being:

i) The quality of raw water

ii) The nature and efficiency of pre-treatment, if provided.

iii) The characteristics of filter media,

iv) The hydraulic loading of filter,

v) The method and interval of cleaning,

vi) The required quality of filtered effluent.

Limitations: The quality of raw water affects the performance of the slow sand filters which are capable of coping with turbidities of 100-200 mg/l for a few days, 50 mg/l is the maximum that should be permitted for longer period. Best purification occurs when the average turbidity is 10 mg/l or less (expressed as SiO₂). Hence, the river water can be treated with slow sand filters only when the raw water turbidity is brought down in the range of 50 mg/l to 10 mg/l by means of flocculation, sedimentation process, or in addition to this 'roughing' filtration.

The number of filter units is given by the formula:

\[ N = \frac{1}{4} \sqrt{Q} \]

where \( N \) = the number of filter units which is never less than 2,

\( Q \) = m³/h,

\[ N = \frac{1}{4} \sqrt{320} \]

\[ = 4.5, \text{say 5} \]

Provide one more unit as a standby

Total number of beds = 6

and area of each unit = \[ \frac{1280}{5} \]

= 256 m²

say 260 m²

This is in accordance with the range of area prescribed by Huisman¹. According to him the minimum workable size is usually considered to be 100 m² while twice this area is to be preferred. A maxi-
The designed filter hence is safe. If the length to width ratio is 2:1, then length of each unit is 23 m and width 11.5 m.

28. DEPTH OF WATER IN FILTER BED

The depth of water is determined according to the maximum resistance anticipated. In practice, the depth varies between 1.0 m and 1.5 m. Exceptionally the depth is as high as 2.0 m, but rarely more than 2.0 m.

Let the depth of water in the present design be 1.25 m.

29. FILTER BED

The most suitable medium for filter bed is sand. Its coefficient of uniformity varies between 3 and 1.5. Let the coefficient of uniformity be 2.

The effective diameter usually lies in the range of 0.15 mm to 0.35 mm. Let the effective diameter in the present case be 0.20 mm.

The bed should be composed of hard, durable and preferably rounded sand grain and should be free from clay, loam and organic matter. The sand should not contain more than 2% of calcium and magnesium, calculated as carbonate.

The depth of sand bed varies between 1.2 to 1.4 m. It may be somewhat less if the raw water is reasonably clear and the filter runs are consequently longer than average. Let the depth of sand bed be 1.3 m.

30. UNDER-DRAINAGE SYSTEM

It serves two-fold purposes. One, of supporting the filter medium and other of providing an unobstructed passage-way for the treated water to leave the underside of the filter.

There is a tendency to use drainage systems other than pipes, these days, except for the smaller filters. One of the simplest arrangements is done by using standard bricks to support the medium and to provide drainage space. Normally, the dimensions of the bricks are 5 x 11 x 22 cm. So each channel would drain a strip of 23 cm width (Fig. 1).

One of the important criteria about the under-drain system design is that the system should not usually exceed 10% of the resistance of the filter bed when at its lowest (i.e., when the sand is clean and the bed is at its minimum thickness after repeated scappings) so that the variation over the area of the filter may be kept within the acceptable limit.

A layer of gravel between the under-drainage system proper and the filter bed itself helps in two ways. It prevents the filtering medium from entering and choking the drainage water ways and ensures a uniform abstraction of the filtered water when a limited number of drains are provided.

The supporting gravel system is built up of various layers, ranging from fine at the top to coarse at the bottom. Each layer is composed of carefully graded grains (i.e., the 10% and 90% passing diameters should differ by a factor of not more than \( \sqrt{2} = 1.41 \)).

The design criteria for the gravel bed is as follows:

(a) The grains of the bottom layer of gravel should have an effective diameter of at least twice the size of the openings into the drainage system (e.g., the spacings between bricks or between open-jointed pipes).

(b) Each successive layer should be graded so that its smaller \( d_{10} \) particle...
Design of Water Treatment Plants Part-III

diameters are not more than four times smaller than those of the layer immediately below.

c. The uppermost layer of gravel must be selected with a $d_{10}$ value more than four times greater than the $d_{30}$ value of the coarsest filtration sand and less than four times greater than the $d_{10}$ value of the finest filtration sand taken from natural deposits which will vary in grain size from one spot to another.

In the present design, let the sand medium have the following values.

$\begin{align*}
    d_{10} \text{ of sand medium} &= 0.22 \text{ mm} \\
    d_{30} &= 0.30 \text{ mm}
\end{align*}$

The uppermost layer of the supporting gravel should have a $d_{10}$ value between $0.22 \times 4$, approximately $0.90$ mm, and $0.30 \times 4 = 1.2$ mm.

The uppermost gravel layer with a $d_{10}$ value of $1.0$ mm and a $d_{30}$ value of $1.4$ mm ($d_{10} \times \sqrt{2}$) would therefore be suitable. The layer immediately below could have equivalent values of $4.0$ mm and $5.6$ mm and the 3rd layer $16$ mm and $23$ mm respectively. Normally, the joints in the under-drainage system are $8$ mm or less in width. Hence, these three layers will suffice.

When it is too difficult or expensive to grade the gravel within the layer to the recommended ratio of $1: \sqrt{2}$, the requirement may be relaxed to a factor of $1:2$, but in this case the layers should have their $d_{10}$ values restricted to three times that of the layer above. With this criterion, the gravel bed will have following gradation:

$\begin{align*}
    \text{Top-most layer} \quad &1 \text{ mm to } 2.0 \text{ mm} \\
    \text{Second layer} \quad &3 \text{ mm to } 6.0 \text{ mm} \\
    \text{Third layer} \quad &9 \text{ mm to } 18 \text{ mm} \\
    \text{Bottom layer, } &27 \text{ mm to } 54 \text{ mm}
\end{align*}$

The normal depth of each layer is $6$ cm. The depth may be about $15$ cm even.

Normally, the total depth of gravel bed is $30$ cm. The gravel has high permeability and hence the resistance to downward flow is negligible.

If the first system of gravel layers is adopted, then size of gravel and layer thickness would be as shown in Table 1.

<table>
<thead>
<tr>
<th>31. FILTER BOX</th>
</tr>
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<tbody>
<tr>
<td>Most filter boxes are today built with vertical or near vertical walls of a depth sufficient to accommodate the various parts mentioned earlier. The internal depth of the box would be the sum of the following depths —</td>
</tr>
<tr>
<td>Free board above water level — $0.25 \text{ m}$</td>
</tr>
<tr>
<td>Water depth above filter — $1.25 \text{ m}$</td>
</tr>
<tr>
<td>Gravel support — $0.30 \text{ m}$</td>
</tr>
<tr>
<td>Brick filter bottom — $0.16 \text{ m}$</td>
</tr>
<tr>
<td><strong>Total:</strong> $3.26 \text{ m}$</td>
</tr>
</tbody>
</table>

Filter box should be water tight, not merely to prevent loss of treatment water, but to prevent ingress of ground water, which might contaminate the treated effluent. In this regard, additional precaution would be to ensure that the floor of the box is above the highest water table.

“Short circuiting” or the downward percolation of water along the inner wall face without passing through the filter bed, endangers the purity of the effluent, and structural precautions must be taken against it. One of the following methods can be adopted to prevent the same:

(a) Construction of sloping walls, since the sand tends to settle tightly against them.

(b) In case of vertical walls, built-in grooves of $6 \times 8$ cm along the bottom por-

| TABLE 1: DETAILS OF GRAVEL BED |
|----------------|-----------------|-----------------|
| Position of Gravel layer | Size of gravel | Thickness of layer |
| Top layer | 1 to 1.4 mm | 8 cm |
| Middle layer | 4 to 5.6 mm | 10 cm |
| Bottom layer | 16 to 23 mm | 12 cm |

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tion of the internal surface of wall or artificial roughening of the internal surface.

(c) A slight outward batter to the internal surface to obtain the advantages of sloping walls.

A precaution, once in common use, was to keep the under-drainage some distance from the base of the walls, but this method increases the effective filtering area and is rarely adopted now a days. Above and below the area of contact with the sand-bed, all concrete surfaces should be as dense and smooth as possible to reduce fouling by slimes and other aquatic growths.

Problems like thermal expansion and contraction, shrinkage of concrete, uplift of floors and unequal settlement become more difficult as the area of the structure increases. Hence, to ensure water tightness, it may be preferable to plan for a larger number of filters of smaller size.

32. CONTROLS

Controls required in the slow-sand filters are mentioned below:

a) Raw water delivery: When individual pumps are provided for each filter, the quantity of water to be supplied may be controlled at the pump outlet. A more usual case is a common set of pumps supplying a number of filters or the raw water flow by gravity from a single reservoir with a Regulating valve to maintain the supernatant water at a constant level (Valve A in Fig. 2).

The entrance of raw water into the supernatant water reservoir has to be so arranged that the sand bed below is not disturbed by turbulence. One such arrangement is a drainage trough which is constructed under the inlet to absorb the vertical force of the incoming water at the start of filling operations, before a sufficient layer of water has accumulated to protect the filter surface.

b) Scum outlet: A trough is preferred for this purpose and in large filters several troughs should be constructed on different sides of the filter box so that whichever way the wind is blowing, the scum can be removed simply by increasing the rate of inflow very slightly and allowing the supernatant water to spill over the lip of the trough. Valve need not be provided on the trough drain, which is led

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FIG. 2. DIAGRAM OF A SLOW FILTER, SHOWING CONTROL VALVES
(from "slow sand filtration" by L. Huisman and W.T. Wood.)

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to waste. The troughs also act as overflow arrangement for supernatant water.

c) Supernatant water drain: In order to expose the sand surface for cleaning, it is necessary to remove the supernatant once in one to three months (i.e. the interval between the scrapping of sand bed). A separate drain and emptying through (B in Fig. 2) is therefore provided through which the supernatant water may be discharged to waste or returned to raw water pumps. Provision of adjustable sill along the part of the trough's length is useful to match the lip of the trough to the new level of sand bed after each cleaning.

d) Bed drainage: This is necessary to lower the level of water within the bed by a further 10 cm or more so that the Schmutzdecke and the top layer is relatively dry and easy to handle. A valve D (Fig. 2) is provided to carry this drainage to waste.

e) Effluent Control Valve: This is the most important control in the filter operation. This is shown at E in Fig. 2 immediately downstream of the flow meter. The valve has to be adjusted as the bed resistance increases throughout the length of the filter run to control the rate of filtration.

f) Effluent weir: It is a fixed weir with an adjustable crest plate as shown in Fig. 2. A telescopic outlet with a float above it to get a constant head is also an alternative arrangement. The effluent control valve can be omitted when such a constant head arrangement is possible.

The weir serves three fold purposes. It prevents negative heads developing in the bed. It aerates the effluent thus raising its oxygen content, and helps to release dissolved gases such as carbon dioxide. Lastly, it makes the operation of the filter independent of water-level fluctuations in the clear water reservoir.

A by-pass valve (G in Fig. 2) should be provided to enable the downstream side of the weir which can be emptied through valve F which is also capable of draining the chamber upstream of the weir.

g) Adduction Line: The outlet valve (J in Fig. 2) and pipes leading to the clear water reservoir should be of a size that is in accordance with normal hydraulic principles, taking into account losses from friction and turbulence. It is a good practice to install pipework capable of carrying, say 50% more than the load immediately anticipated, since this adds little to the initial cost, but could save large sums later.

h) Diversion of filtered water: During the ripening period of a new or a recently cleaned filter, it is necessary to divert the effluent to waste or return it to the raw water reservoir until the bacterial action of the bed has become established and the effluent quality is satisfactory. The valve H (Fig. 2) is provided for this purpose.

i) Back filling: After cleaning the filter bed, filtered water is introduced from the bottom of the bed to drive out the air bubbles from the medium as the water level inside the sand rises. The filtered water is admitted through the valve C (Fig. 2).

33. DESIGN OF CHLORINE HOUSE AND CHLORINATOR

The Chlorine House should have minimum four rooms, three in one row and one in front of the central room. The central room can be used to house the chlorinator, while one of the side rooms can be used to store the filled-in cylinders and the other side room to store the empty ones.

The room meant for storing the chlorine cylinders or containers should be accessible to truck and hence should have a ramp at one side. The room should be fire resistant and should have at least two exits. All exit doors should open out. Normally natural ventilation and means for cross ventilation should be such that permits change of complete air in the room in about 10 to 15 minutes. Provision of ventilator at the bottom, one opposite to the other, is quite effective. The room should be cool and protected against external heat sources. The room should be vented to the upper atmosphere and equipped with positive means of exhaust either near the floor level, or at the centre of the room or opposite entrance, capable of a complete air change within 2 to 4 minutes at the time of emergency. A combination of fresh air inlet system and
exhaust system consisting of fans that force the fresh air into the room through openings near the ceiling and exhaust fans that expel any chlorine-contaminated air near floor level, is the most satisfactory ventilation system. The system should be completely independent of any other ventilation system.

Chlorinator: It is an instrument designed to fulfill the following criteria:

(i) To regulate the flow of gas from the chlorine container.
(ii) To regulate the desired rate of flow within the range of the machine.
(iii) To indicate the flow rate of gas being fed, and
(iv) To provide means of properly mixing the chlorine gas either with the main body of water or part of it.

The chlorinator normally consists of the following parts:

a) Chlorine cylinder or chlorine tank supplied with its main valve and filled with liquid chlorine under pressure.

b) Fusible plug, a safety device provided over all the cylinders or big containers. The plug is designed to melt in a temperature range of 70°C to 77°C to prevent a build-up of hydrostatic pressure resulting from thermal expansion due to sudden rise of temperature.

c) Pressure reducing valves to bring down the pressure of the gas. One of the two valves is meant for coarse adjustment while the other for fine adjustment.

d) Pressure gauges, two in number, one to read the high pressure, in the cylinder and other to read the low pressure at which the gas is metered.

e) Measurement device, through an orifice, of low pressure feeding gas with manometer containing indicator liquid like carbon tetrachloride or concentrated sulphuric acid.

f) Non-return valve through which chlorine must bubble through concentrated H₂SO₄ or pass through calcium chloride to absorb moisture and to facilitate prevention of moisture getting into the machine.

g) A china-clay tower of 2 m height and 30 to 45 cm diameter filled with 10 cm ceramic balls or of any other inert material with an arrangement to pass the chlorine gas from bottom through the column to the top and part volume of water from top to bottom to ensure uniform and homogeneous mixing of gas with water.

h) Pipes, valves, containers and other equipment (through which dry chlorine passes) should be air-tight, so that chlorine gas does not come in contact with moisture, since the mixture is very corrosive. A flexible arrangement should be provided on the discharge line from the chlorine cylinder, and the piping should slope upward from the chlorine source especially when discharging in liquid state. Long piping has to be avoided. Hard rubber, PVC or polyethylene pipes should be used for low pressures, while materials such as silver, platinum or hastelloy C should be used for high pressures. The room in front of the central room (where the chlorinator is installed) should contain equipments such as gas mask, a set of spanners etc. to meet the emergency.

Number of Cylinders:

Let the dosage rate of chlorine to disinfect water be 2 ppm.

\[
\text{Chlorine requirement per hr.} = 320 \times 10^3 \times 2 \times 10^{-6} = 0.64 \text{ kg.}
\]

\[
\text{Chlorine requirement per day} = 0.64 \times 24 = 15.36 \text{ kg.}
\]

This is less than 16 Kg/day. Hence a cylinder of 50 kg. should be used. If the requirement of chlorine is more than 16 Kg/day then the excessive drop in temperature in the cylinder will prevent evaporation. If more than 16 Kg/day of chlorine needs to be fed, an additional cylinder for each additional 16 Kg. or part thereof should be attached to the apparatus(2).

34. UNDERGROUND RESERVOIR FOR STORAGE OF CLEAR WATER

While designing the underground reservoir, following aspects have to be considered:

a) Capacity of the reservoir: This depends upon the capacity of the pumps and their pumping hours. Capacity of the reservoir would be least when the pumping is done 24 hours and vice versa. According to Na'irajan(3), “The total capacity of clear water reservoirs should be adequate for storage of treated water, especially during low supply periods at night, 254
Design of Water Treatment Plants Part III

when reservoirs become full. Instances are reported, where in water from the filters have backed up into the inspecting galleries and reducing the rate of filtration. The remedy lies in having additional clear water reservoir within the plant or that the final water should be automatically pumped to the balancing reservoirs in the town.

The underground reservoir at Calicut and Lucknow have capacity of about 2.5 hr storage. The storage capacity of reservoirs at Kanhan Water Works is of about 30 minutes storage.

If the pumps work for 24 hrs, then the capacity of the reservoir can be between 30 minutes to one hour storage.

b) Compartments — A reservoir normally should have two compartments to facilitate periodical cleaning, inspection and repairs. Incidentally this helps in building up levels in the reservoir when required and reducing the number of expansion joints in R.C.C reservoirs.

c) Scour-valves — There should be sufficient number of scour valves to facilitate cleaning, normally one of 300 mm dia, for each compartment has to be provided in the sump. The scourd water should be led to a natural water way or a sewer.

d) Inlets and Outlets — Outlets are provided in a sump about 15 cm lower than the general floor level. A dwarf honey-combed brick wall is provided around the sump to prevent the danger of unwary workers slipping into the open ends of the outlets during cleaning. The inlet is located at a diametrically opposite end of outlet to minimise short circuiting. The inlet has a vertical bend at the end with a bell mouth to reduce the impact of falling water on the floor and side walls. The buoyancy of inlet arm can be prevented by means of cement concrete anchor blocks.

e) Recorder — A vertical stilling chamber of 90 cm dia, with suitable openings at the bottom is provided to house a float type of recorder. There is a corresponding opening in the roof slab in each compartment to connect the float with the recorder. The stilling chamber is in a relatively undisturbed portion of the reservoir, away from the outlet and is constructed of brick masonry.

f) Overflow — The overflow is provided for each compartment and is in the form of a weir or a pipe of larger diameter than the inlet with its invert at full supply level. The roof is not designed to take up-lift.

g) Free board — A free board of about 60 cm is provided above the over flow arrangement.

h) Stair case — It is needed for entering a reservoir. It should be made of non-corrodable material. The staircases has to be sufficiently wide for admitting men and materials during repairs.

i) Ventilators — They are normally C. I. pipes 15 cm dia, with their ends facing downwards, fitted with a wire-mesh. The spacing of the ventilators is suitably arranged.

j) Roof slab — The roof slab should be perfectly water tight and should slope outside so that rain water does not accumulate on the slab.

k) Manhole — 50 cm dia, circular manholes are sufficient for lighting and ventilation and to permit men and material in the reservoir at the time of repairs.

l) Drains — Peripheral drains are required to carry away leakage and rain water.

35. DESIGN OF THE UNDERGROUND RESERVOIR FOR ITS CAPACITY

Assuming that the pumps are working all the 24 hours, capacity of the reservoir can be equal to 1 hr storage.

:. If ultimate capacity of the plant is taken into account then capacity of the reservoir would be equal to 640 m². Let depth of the reservoir be 2 m.

:. Area of the reservoir = 320 m²

:. Provide 4 compartments each of the area 8 x 10 m.

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SLOW SAND FILTRATION PROJECT

FIRST MEETING OF PROJECT PARTICIPATING INSTITUTIONS


BACKGROUND DOCUMENT I - 17

In Defense of Slow Sand Filters

by

S.V. Belsare

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In Defence of Slow Sand Filters

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SYNOPSIS

Slow Sand Filters are by themselves very efficient in producing water of a high bacterial purity, due to various processes that take place in the filter media, as described in the article. On the other hand, Rapid Sand Filters, are not so effective and have to rely on disinfection for complete bacterial purity of water. In rural areas, one cannot rely upon effective disinfection for want of skilled supervision and of simple tests for available chlorine in bleaching powder normally used and of chlorine residual in the effluent. The author, therefore, pleads that slow sand filters, with their added advantages of simple construction and operation may be given a fair trial especially in rural areas.

1. INTRODUCTION

Present trend in the design of filters is towards increasing filtration rates. Filters designed at the rate of 80 gals/sft/hr are obsolete and filters designed at the rate of 100 gals/sft/hr are being considered outdated. Current practice is to design filters at 150 to 200 gals/sft/hr. This increasing rate has come as a very timely solution to designers and engineers who are confronted with the problem of augmentation of existing plant capacities but where there is shortage of funds or other difficulties. When adopting such high rates of filtration the basic duty to be performed by filters is considered to be reduction in turbidity load. Given an influent turbidity of 20 ppm the filters are expected to bring it down to 1 ppm or less. The work of the filter is expected to end here, disinfection being relied upon for complete bacterial purity.

In contrast to these high rates the slow sand filter works at a tremendously low rate i.e. 4 gals/sft/hr. or say 0.2m/hr. It requires 25 times as much space as an ordinary rapid sand filter and consumes twenty-five times more media; involves construction of massive retaining walls. It is said to be less efficient and to develop anaerobic conditions. However, with all these drawbacks I would consider slow sand filter, the really proper and correct treatment of water for complete bacterial purity for the following reasons.

As against rapid sand filter, the slow sand filter works on the water in numerous ways and treats it completely. The different mechanisms which act on water are (A) transport (B) attachment and (C) purification. These alter the very character of influent water and release an altogether different water in quality which is much safer and wholesome and may or may not need disinfection.

In view of the complete biological transformation of water quality by these mechanisms acting in a filter media in the slow sand filters, it is the process which can be said to really treat water whereas other types can be called to filter water only. The process is thus rightly called Biological Filtration.

2. MECHANISMS ACTING IN A FILTER MEDIA

The three mechanisms are briefly described below:

(A) Transport Mechanisms:

This is the principal process in which the particles are brought into contact with sand grains and actions of (i) Straining (ii) Sedimentation (iii) Inertial or centrifugal forces (iv) Diffusion (v) Mass
Straining: It is the process by which particles greater than the interstices between sand grains are prevented from passing further. It has been observed that for a perfectly spherical sand grain, the smallest size of the particle arrested is about 1/7 of the diameter of the sand grains. Thus in a slow sand filter with a grain size of 150 \( \mu \) (0.15 mm) the smallest size of particles arrested would be 150/7 = 20 \( \mu \) or 0.020 mm. Thus it would be clear that an average colloid with a size of 1 \( \mu \) or bacteria with its maximum length of 15 \( \mu \) cannot be arrested in the filter by this process and these will have to pass through the bed unless intercepted otherwise.

Sedimentation: This process works on the assumption that the whole media act as numerous sedimentation basins. In one cum of filter sand with 38% porosity and the average size of sand grain of 0.25 mm, the total surface area of all sand grains is about 15000 m\(^2\). Allowing for all the area which is facing downwards or which is in contact between sand grains and also which is liable for scour the net surface area available is about 1000 m\(^2\). Treating this area as though it were of a single sedimentation basin, the surface loading with a filtration rate of 0.2 m/hr in a slow sand filter will be extremely small. The sedimentation efficiency which depends on the surface loading will be quite high. The minimum size of particles which can thus be removed is 9 \( \mu \), as compared to 1 \( \mu \), the size of a colloid, which thus cannot be intercepted.

It will thus be evident that even with the smaller sizes of sand the straining and sedimentation are able to arrest particles 4 \( \mu \) and larger. The colloids and bacteria, which are finer, will have to pass down unless intercepted otherwise. If coarse sand is used as in rapid sand filters the interception is still inferior.

Inertial and Centrifugal forces: The inertial and centrifugal forces act upon particles with a specific gravity higher than that of water causing them to leave the flow line and come in contact with sand grains.

Diffusion (Brownian Movement): Diffusion brings suspended particles into contact with containing surfaces. It acts independently of the filtration rate throughout the depth of filter bed even if the water is not flowing.

Mass Attraction: This force is universal and contributes to both the transport and attachment mechanisms. The force is very weak and decreases with the sixth power of distance. It however supplements inertial and centrifugal forces.

Electrostatic and Electrokinetic attractive forces: These are described under attachment mechanism, below.

Attachment Mechanism: The main forces that hold particles in place once they have made contact with the sand grain surface are (i) Electro-static attraction (ii) Mass attraction and (iii) Adherence. A combination of these forces is frequently referred to as Adsorption.

Electrostatic Attraction: Clean quartz sand grains have generally a negative charge and they are therefore, able to attract positively charged particles of colloidal matter such as crystals of carbonate, floculi of iron and aluminium hydroxide as well as cations of iron and manganese. The colloidal particles of organic origin including bacteria have a negative charge and are consequently repelled. Therefore, in initial stage filter is not effective in removal of these impurities.

During ripening process positively charged particles accumulate on the sand grains and thereafter start attracting negatively charged particles and colloids of organic origin and also nitrate and phosphate radicals. This process continues till oversaturation occurs and charges are reversed. The continuing reversal of charges goes on throughout the period of filter run.

Although clean sand has a negative charge the sand obtained from river bed
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has picked up some positive charge and therefore this bed ripens early.

(ii) Mass Attraction: This is already described under 'A' above.

(iii) Adherence: During ripening period, particles of organic origin will be arrested and deposited on the filter surface and on the individual grains in the upper part of the bed. These deposits quickly become the breeding ground for bacteria and other micro-organisms which produce a slimy material known as Zoogloea which consists of active bacteria, their waste and dead cells and partly assimilated organic materials. The Zoogloea forms a sticky gelatinous film on the surfaces of the schmutzdecke and sand grains to which particles from water tend to adhere when brought close to by one of the transport mechanisms. The particles consisting of organic matter are assimilated to become part of the Zoogloea film while inert matter is held until eventually removed by sand bed cleaning operations.

(C) Purification Processes:

The various biological purification processes whereby the trapped impurities within the filter bed are broken down and rendered innocuous are inter-dependent and can be described in combination.

Within the Zoogloea film the bacteria multiply selectively using the organic matter from raw water as their food. Part of the matter is used for their metabolism. Thus the dead organic matter is converted into living matter. The dissimilation products are carried away by water to be used again at lower depths. The growth in the bacterial population is accompanied by an equal dying off. This in turn liberates organic matter to be used by bacteria at lower depth. In this way the whole of the degradable organic matter present in raw water is gradually broken down and converted into water, CO₂ and relatively innocuous salts, such as sulphates, nitrates and phosphates, to be discharged into filter effluent.

Different types of bacteria are found at different depths in the filter bed.

Sudden changes in the filtration rate upsets this equilibrium and hence it is desirable to operate this plant continuously without interruption. It is also desirable to maintain uniform raw water quality as far as possible, as bacteria are developed conforming to the quality of water.

Three conditions are necessary for satisfactory biochemical oxidation of organic matter. These are (i) Sufficient reaction time (ii) adequate amount of oxygen and (iii) temperature above a minimum level. The first condition is fully satisfied by keeping filtration rate low as in a slow sand filter. As regards second condition aeration of raw water may become necessary if dissolved oxygen contents are low. As regards effect of temperature it has been observed that the reduction in permanganate consumption brought about by slow sand filtration is directly related to temperature.

Bacteria including E.coli contained in the raw water are brought in contact with sand grains by the above processes. The unfavourable environments in the filter bed, such as temperature below 30°C, the filter bed not containing enough organic matter of animal origin to meet their nutritional needs and the predating organisms developed on the bed feeding on them, reduce their number drastically. Even though statistical data is not available it is observed that the micro-organism in the filter bed act as poison to E.coli bacteria. More so in the case of pathogenic bacteria.

3. EFFECTS OF ALGAE ON FILTERS

Practically all surface waters abound in algae. As autotrophic organisms algae need sunlight for their photosynthetic process and are therefore likely to be absent in covered filters or where the sunlight is obstructed by turbidity. The property of algae most significant to water purification is its ability to build cell material from simple material such as water, CO₂, nitrates and phosphates.
In cold climates when temperature falls down algae die as their living conditions become less favourable. This results in liberation of organic matter, consumption of oxygen and production of CO₂ generating anaerobic conditions. If mortality of algae is suddenly increased by sudden changes in raw water quality or drop in temperature, such degradable organic matter is liberated necessitating filter being taken out of service.

The following advantages of algae, however, outnumber their disadvantages.

(i) They use organic matter in the raw water to build up cell material.

(ii) Even though equivalent material is released when they die the material is more easily degradable than the original. An uncovered slow sand filter consumes about 10 times more oxygen than a covered filter and it adds to conversion of unassailable organic matter into easily degradable one.

(iii) The filamentous species of algae help in forming of Zooglocal film for trapping and proliferation of plankton, diatoms and other forms of life which consume bacteria. The proliferation of algae will be bound by the quality of raw water. Sufficient light, nutrients and suitable temperature encourage their growth. A clear water with low turbidity and containing such mineral constituents and Co₃ nitrate and phosphates provides favourable conditions.

(iv) Under tropical conditions periods of blooming and dying are less pronounced and filter cleaning is normally required after definite time interval and is also less troublesome. Due to oxidation the overall effect is reduction in organic load in the effluent and obtaining a hygienically more safe water.

4. CONSTRUCTION DETAILS

As compared to other types of filters slow sand filters are very simple in construction as described below:

Filter box of the required size is to be constructed with impervious sides and floor. The floor is provided with a central channel towards which the floor slopes from both sides. The channel is of adequate size capable of discharging the total flow at the gradient provided in the channel. The major components deciding the depth of the filter box are:

(a) Supernatent water
(b) Sand medium
(c) Under drainage system

(a) Supernatent Water: The height of water above the sand bed serves two purposes. Firstly it allows sedimentation to take place on the sand bed thus achieving part purification and secondly it offers the necessary pressure for the water to overcome the loss of head which is minimum when the filter is just started and maximum at the end of the filter run. Even though filters could be run with varying head it is customary to work the filters with a constant head by throttling the outlet valve initially and gradually opening it as the head loss in sand increases. The maximum head allowed is about 1 to 1.2m and hence the height of supernatent water is kept at 1 to 1.2m. In order that the sand media is not allowed to go dry the outlet weir is kept about 8cm. above the sand bed.

(b) Sand Media: Fine sand with an eff. size between 0.15 & 0.35mm and uniformity coefficient between 2 and 3 is used. A very uniform size of sand is not required as the filter is not required to be back washed. The sand should be free from clay, loam and other organic matter and calcareous material. The total depth of sand required is as under:

Immediately below the filter skin lies the purifying zone which is about 0.3m to 0.4m. The greater depth is required for coarser sand.
under no circumstances can be kept less than 0.7m.

(c) At the time of every cleaning operations 1 to 2 cm. of material is removed and assuming 5 such operations during the year a total of 10 cm. will be removed during one year. During a period of 5 years after which resanding may normally be done, a depth of 0.5m. will be needed.

Thus a total depth of 1.2m. is required to be provided in the slow filter.

An additional 30cm. will be needed for the coarse sand and gravel to act as supporting media. This should be provided in layers of 8 to 10cm. each. The sizes should be provided upwards from 0.35 cm.

(d) Under drainage system: This should be above the central drain with the flow sloping from both sides. The filter should normally be covered with standard bricks laid over one another with a gap for entrance of filtered water. The design should be such that filtered water is collected uniformly all over the filter area and the loss of head is negligible say 0.01m.

5. CONCLUSIONS

(i) The process of biological filtration is more suited to countries in the tropical zones where warm temperatures and abundant sunlight encourage growth of algae which are beneficial to water treatment.

(ii) The other advantages of slow sand filters are oft repeated such as simplicity in construction and operation, requiring no skilled supervision.

(iii) It is however to be added that slow sand filters should be preferred not merely because of their simplicity in construction and operation but because of their superior bacterial treatment to water. Normally, it is said that disinfection should take care of bacteriological improvement of water and filters should aim at reducing the turbidity. However, in small towns and villages, for sterilisation, we have to depend upon bleaching powder, strength of which goes down with storage. There is no proper and foolproof way of knowing the strength of the powder and also of the residual chlorine in water. Under such uncertain situations, which are particularly present in rural conditions, the filtration process itself has to be a complete treatment without much further reliance on sterilisation and slow sand filters offer the alternative.

(iv) The addition of coagulants such as alum increase the acidity and reduce pH value of water which renders it corrosive. Slow sand filters do not need such addition of chemicals to water and hence leave the water more or less in the same pH range as original.

(v) Many of the objections to the slow sand filters are taken because the filter is not properly constructed or maintained. One of the possible reasons for improper functioning of the filter is the lack of care in filling sand. Slow sand filter requires fine sand with eff. size 0.15 to 0.30 mm. and uniformity coeff. between 2 and 3. Fine quartz sand normally available in the Central Indian rivers is ideally suitable for these filters. However, it has to be ensured that the sand is free from calcareous material, silt and clay particles. It is not known whether proper and careful search for the sand was made before filling the filters which are giving trouble. As the quantity of sand required is huge, some laxity may have occurred in the collection of this very important media. Secondly periodical re-grading including replacement of large part of sand has to be carried out. This essential requirement must not be neglected.

(vi) It is, therefore, the earnest plea of the author that slow sand filters should be given a fair trial in this country for small water supply projects as its operation is simple, and the warm climate in India is more suited to its working. In this connection, it is pertinent to point out that a small slow sand filter of 0.6 MGD capacity built at Umri near Nagpur is giving excellent service.