SLOW FILTRATION AS DISINFECTANT

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ABSTRACT

Slow sand filtration is the oldest water treatment system. Because of the lack of knowledge of its advantages and the emergence of rapid filtration, our countries have underestimated this system and relegated it to rural areas.

The behavior of the physical and biological mechanisms responsible for the efficiency of the slow filtration system is analyzed here to establish a difference with the rapid filter.

Through physical-chemical mechanisms, the filter accumulates sludge in the interstices of the filtration medium, and this sludge is returned to the environment (together with the microorganisms) during the washing process.

However, the slow filter destroys the microorganisms by physical and biological mechanisms. It is a clean technology which makes it possible to purify water without creating an additional source of environmental pollution.

1. Introduction

Slow sand filtration is the oldest water treatment system used by mankind. This system is very simple and effective because it is an exact copy of the purification process of nature itself when rainwater passes through the strata of the earth’s crust down to the aquifers or underground rivers.

The first known slow filtration plant was installed in Paisley, Scotland, in 1804. Since then, this type of system has been used uninterruptedly in Great Britain and the rest of Europe, mainly because it proved to be a very efficient way of removing pathogenic microorganisms.

The rapid filter was developed during the present century. Compared to the slow filter, it requires smaller areas to treat the same flow and, therefore, the initial cost is lower, but its operation is more complex and expensive. The slow filter was qualified as
obsolete by the new techniques because, since it is simpler than the most recent innovations, it was presumed to be inferior. Paradoxically, despite being the oldest treatment system in the world, it is one of the least understood, and one which has been the subject of the smallest amount of research into the behavior and efficiency of its process.

Recent research studies are now leading to renewed interest in the slow filter. They have expanded our knowledge of this naturally developed complex process which does not require the application of any chemical substance. However, such a system does require a good design, as well as appropriate operation and careful maintenance, so that the biological mechanism of the filter will not deteriorate and reduce the efficiency of microbiological removal.

2. The behavior of the slow filter (Huisman & Wood, 1974)

Biological filtration (or slow filtration) occurs when raw water circulates through a porous sand bed. During the process, the impurities contact the surface of the filter medium particles, and are retained. Chemical and biological degradation processes then take place, which reduce the settled matter to simpler forms. These are taken in solution or remain as inert material until they are withdrawn or cleansing takes place.

The processes taking place in a slow filter complement each other and act together, simultaneously, to improve the physical, chemical and bacteriological characteristics of the treated water.

The raw water that enters the unit, remains on the filter medium from three to twelve hours, depending on the filtration rate. During this period of time, the heaviest suspended particles settle and the lightest particles can agglutinate, thus facilitating their later removal. Algae grow during the daytime under the influence of sunlight, which absorb carbon dioxide, nitrates, phosphates, and other nutrients in the water to form cellular material and oxygen. This oxygen dissolves in water and reacts chemically with the organic impurities, making the impurities easier to assimilate for the microorganisms.

A layer mainly of organic origin is formed on the surface of the filter medium. This is known as schmutzdecke or “biofilm”. The water has to pass through this layer before reaching the filter medium. The schmutzdecke is mainly made up of algae and many other forms of life, such as plankton, diatoms, protozoa, rotifera, and bacteria. The intensive action of these microorganisms traps, digests and degrades the organic matter in the water. The dead algae and the live bacteria in the raw water are also consumed in this process. While nitrogenous compounds degrade, nitrogen oxygenates. Some color is removed and a considerable amount of suspended inert particles are removed by sifting.
Once the water passes through the schmutzdecke, it enters the filter bed and is forced to pass through it in a process that normally takes several hours. A physical sifting process takes place here, which is part of the total purification process. One of the most important properties of the filter layer is that of adherence, which is a phenomenon resulting from electric forces, chemical actions, and attraction of masses. To appreciate the magnitude and importance of this phenomenon, we need to visualize that one cubic meter of sand with the usual characteristics for slow filters has a grain area of almost 15 000 m$^2$. The water passing through the sand grains with a laminar flow (which constantly changes direction), facilitates the action of the centrifugal forces on the particles and the adherence of these particles to the surface of the sand grains.

An active settling process takes place in the pores or empty spaces of the filter medium (which constitute approximately 40% of the volume). This phenomenon is considerably enhanced by the action of electrostatic forces and mass attraction.

As a result of the phenomena mentioned above, the surface of the sand grains is covered with a layer, which is similar in composition to the schmutzdecke, with low algae and particle content, but with a high content of microorganisms, bacteria, bacteriophages, rotifera, and protozoa, all of which feed and absorb the impurities and residues of the others. This biological coating is very active down to a depth of 0.40 m in the filter medium. Different forms of life predominate at different depths. There is more biological activity near the surface of the filter layer, where conditions are optimal and food abounds.

Food consists mainly of particles of organic origin, carried by water. The organic coating maintains the suspended particles in the water until the organic matter is degraded and is assimilated by the cellular material, which in turn is assimilated by other organisms and converted into inorganic matter, such as water, carbon dioxide, nitrates, phosphates and salts that are subsequently carried away by the water.

The quantity of food diminishes at the end of the filter layer, originating another type of bacteria, which use the dissolved oxygen and solute nutrients found in water.

As a consequence of those processes, the raw water that enters the slow filter with suspended solids in a colloidal state and a wide variety of microorganisms and complex salts comes out virtually free of such impurities and with a low inorganic salt content. In the biological filtration process, not only have the harmful or dangerous organisms been eliminated, but also the nutrients in solution, which could facilitate subsequent bacteriological growth.

The effluent obtained usually has a low dissolved oxygen content and high carbon dioxide content, but both these characteristics can be improved with a later aeration process.
Since the performance of the slow filter depends mainly on the biological process, efficiency is low while the biological layer is still developing. It improves as filtration progresses. This process is known as the “ripening of the filter”.

3. Removal mechanisms

The transportation and adherence mechanisms that act on the particles carried by the water (Table 3.1) during the slow filtration removal process, are the same mechanisms that act in the rapid filtration process.

The main difference is the additional biological mechanism that acts in the slow filter. While in the rapid filter the microorganisms remain in the sludge retained on the filtration bed and are liberated again when they leave the filter with the wash water, in the slow filter, these microorganisms die as a result of the biological degradation process.

**Table 3.1. Particles found in water (AWWA, 1991)**

<table>
<thead>
<tr>
<th>Category</th>
<th>Group/Name</th>
<th>Size (microns)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mineral</td>
<td>Clay (colloidal)</td>
<td>0.001–1.0</td>
</tr>
<tr>
<td></td>
<td>Silicates</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Non-silicates: Fe, Ca, Al, Mg, etc.</td>
<td></td>
</tr>
<tr>
<td>Biological</td>
<td>Viruses</td>
<td>0.01–0.1</td>
</tr>
<tr>
<td></td>
<td>Bacteria</td>
<td>0.3–10</td>
</tr>
<tr>
<td></td>
<td>Cysts of Giardia lamblia</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Unicellular algae</td>
<td>30–50</td>
</tr>
<tr>
<td></td>
<td>Parasite eggs</td>
<td>10–50</td>
</tr>
<tr>
<td></td>
<td>Nematode eggs</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Cryptosporidium oocysts</td>
<td>4–5</td>
</tr>
<tr>
<td>Other particles</td>
<td>Small amorphous waste</td>
<td>1–5</td>
</tr>
<tr>
<td></td>
<td>Large amorphous waste</td>
<td>25–500</td>
</tr>
<tr>
<td></td>
<td>Organic colloids</td>
<td>--</td>
</tr>
</tbody>
</table>
3.1 Transportation mechanisms

This basically hydraulic removal stage illustrates the mechanisms through which the collision between particles and sand grains occurs. These mechanisms are primarily interception, settling, and diffusion. In order to understand them, we must first consider how the fluid behaves around a sand grain, considered as an obstruction to the water flow. Figure 3.1 shows how the flow model (which can be represented in terms of flow lines) is altered by the presence of a sand grain, shown as a sphere in the figure.

If a particle (represented by a black circle in the figure) is taken by the flow lines, it can collide with a sand grain, adhere to it and be removed.

a) **Sifting:** The sifting mechanism acts on the surface of the sand and only with those particles that are bigger than the sand interstices. The sifting is negative in terms of efficiency for the process because it rapidly causes the surface layer to become clogged, resulting in shorter filter runs.

The large solids, especially filamentous material such as the cladophorales algae, form a spongy layer over the bed that improves the sifting efficiency, acting as a prefilter above the sand bed, protecting it from fast clogging and allowing it to carry out its in-depth filtration function.

b) **Interception:** This is one of the ways in which particles may collide with the sand grains. Interception can occur only if the particle carried by the flow lines approaches the sand grain, so that it rubs its surface. The larger the particle, the more likely it will be that interception will occur (see Figure 3.1(a)).

c) **Settling:** The force of gravity acts on all particles, generating the vertical component of the resultant of the conduction rate, which can cause the particle to collide with the sand grain. Its influence is perceptible only with particles larger than $10 \mu m$ (Yao, 1971) (see Figure 3.1(b)).

d) **Diffusion:** This is the third transportation mechanism typically found in the slow filtration process. The thermal energy of the gases and liquids is expressed in
a disorderly movement of their molecules. When those molecules collide with a small particle, the latter also begins to move without control, in a series of short steps, often known as “disorderly walk”.

If the particle is carried by the flow lines, the diffusion can change its direction, moving from one flow lines to another, and it may eventually collide with a sand grain. In conclusion, the lower the filtration rate of the flow, the more steps the particle will take per unit of time. Therefore, the probability of collision increases as the interstitial filtration rate decreases. In addition, as the temperature rises, thermal energy also increases and, consequently, the number of steps per unit of time and the likelihood of collision increase, too. Diffusion is a very important mechanism with particles smaller than 1µm (Yao, 1971) (see Figure 3.1(b)).

e) Interstitial flow: The flow lines shown in Figure 3.1 have been idealized for a single sand grain. In a segment of filter bed with many sand grains, the flow lines have a more tortuous configuration, as indicated in Figure 3.2. By definition, the flow between any two lines of current is similar, and the space in which they run is called a cylindrical channel. These cylindrical channels have a winding configuration, forking and joining again at different points. This continuous change of direction of the flow creates a greater opportunity for collision, because particles and sand grains are continually crossing each other.

As indicated in figure 3.2, if a particle is carried by the interstitial flow, it will most probably collide against the sand grains during its movement. The possibility of colliding within any given section of its journey depends on the dimension of the sand grains, the interstitial filtration rate, and the temperature. The smaller the sand grains, the greater the probability of collision. The porosity of the medium is greater and, hence, there are more channels, that produce a greater number of bifurcations. In addition, the lower the interstitial filtration rate, the greater the possibility of colliding. As previously indicated, lower filtration rates give a greater opportunity for collision per unit of distance with the diffusion mechanism. However, as the interstitial filtration rate increases, there is a point beyond which the filtration rate has no influence even though it continues increasing. Finally, high temperatures intensify the diffusion mechanism, and also produce a greater likelihood of collision.

f) Collision probability: The whole analysis performed so far is closely related to the opportunity for a collision to take place between a particle and a sand grain, expressed by the coefficient (η). The number of collisions per displacement unit determines the potential for removal through filtration. The final removal depends on adherence taking place.

3.2 Adherence mechanism
Until adherence occurs, there can be no removal. The fraction of particles that adhere in relation to the number of collisions is, by definition, coefficient $\alpha$. Research studies suggest that the development of the biofilm provides the sand grains with an absorbent surface that favors adherence. Another assumption is that the extracellular enzymes coagulate the particles, thus making adherence possible. It is unknown in what situations the value of $\alpha$ increases or declines.

When the filter begins to function, and before the biological film is developed, coliform removal is close to zero, therefore $\alpha = 0$ (Bryck et al., 1987). After the biofilm has developed, the removal rate is in the order of 2 to 4 logarithms, coefficient $\alpha$ being close to 1.0. This indicates the importance of the biofilm in the efficiency of the slow filter. The microorganisms can die or be ingested by predators, before they reach an absorbent surface. Therefore, removal can be due to death or predatory action, as well as to adherence. However, after adherence, predatory action and death will inevitably occur.

The filter is considered “ripe” when the biofilm has reached its maximum development for the existing conditions. The maximum development limit of the biofilm has not yet been defined. More research is needed to obtain this important information.

![Figure 3.2. Flow lines within the filter bed](image)

However, research carried out by Bellamy et al. (1985), Bryck (1987) and Barrett (1989) have shown that the maximum development limit of the biological layer is related to the nutrient content of the raw water. Slow filters that treat water with a low nutrient content can be expected to present a removal of faecal coliforms in the order of 2 log after the ripening of the biological film has been produced (Bellamy et al., 1985). On the other hand, it is to be expected that removals in water rich in nutrients are obtained in the order of 3 log (Bellamy, 1985); in other cases removal efficiencies of up to 4 log are found. (Barrett, 1989).
4. Biological mechanism

As previously indicated, the total removal of particles in this process is due to the joint effect of the adherence mechanism and the biological mechanism.

At the beginning of the process, the water-borne predator or beneficial bacteria can multiply selectively, contributing to the formation of the filter’s biological film and using the organic matter deposit as a feeding source. These bacteria oxidize the organic matter to obtain the energy needed for their metabolism (disassimilation) and convert part of this matter into the material necessary for their growth (assimilation). Thus, the substances and dead organic matter are converted into living matter. The products of disassimilation are carried by the water to greater depths where they will be used by other organisms.

The bacteriological content is limited by the organic matter content in the raw water and is accompanied by a concomitant mortality phenomenon, when organic matter is liberated to be used by the bacteria of the deeper layers and so on. The degradable organic matter present in the raw water is thus gradually decomposed in water: carbon dioxide and relatively innocuous salts, such as sulfates, nitrates and phosphates (mineralization process), are discharged in the filter effluent.

The bacteriological activity described is more pronounced at the top of the filter bed and decreases gradually with the depth and availability of food. When the upper layers of the filter are cleaned, the bacteria are removed, and a new ripening period of the filter is necessary to restore the required bacteriological activity. Starting at a depth of 0.30 to 0.50 m, bacteriological activity decreases or ceases (depending on the filtration rate). Instead, biochemical reactions take place that convert the products of microbiological degradation (such as amino acids) into ammonia and the nitrites into nitrates (nitrification).

5. Relative role of schmutzdecke and sand in the efficiency of the filter

Most of the existing documentation on slow filtration gives the schmutzdecke all the credit for the microbiological efficiency of the filter.

Hazen (1913) reported concentrations in the order of $10^6$ bacteria/gram of layer in the filter surface and an exponential decrease with depth, to values of $10^5$ bacteria/gram 2 cm down. Collins et al (1989) informed that they had found $10^9$ bacteria/gram of dry layer in the filter surface, decreasing from $10^7$ to $10^5$ bacteria/gram at a depth of 30 to 45 cm.
Bellamy et al, in a study carried out in 1985 with a hydraulic rate of 0.12 m/h, indicate a removal of total coliform bacteria of three logarithmic levels when the layer was ripe. However, after the surface of the filter was scraped, the removal was of two logarithms, indicating that the schmutzdecke was not responsible for the whole efficiency of the filter, not even for the greater part of it.

6. **Factors that modify the efficiency of the slow filter**

Slow filtration maybe influenced by the combination of design, operational and environmental factors (see Table 5.1).

**Table 5.1. Variables of the process that affect the efficiency of the slow filtration**

<table>
<thead>
<tr>
<th>CLASSIFICATION</th>
<th>VARIABLES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design conditions</td>
<td>Filtration rate</td>
</tr>
<tr>
<td></td>
<td>Effective size of the sand (d_{10}) and uniformity coefficient (U.C.)</td>
</tr>
<tr>
<td></td>
<td>Loss of permitted load</td>
</tr>
<tr>
<td></td>
<td>Depth of the sand bed (maximum and minimum)</td>
</tr>
<tr>
<td>Operation parameters</td>
<td>Frequency of scrapes</td>
</tr>
<tr>
<td></td>
<td>Time during which the filter is not operating after a scrape</td>
</tr>
<tr>
<td></td>
<td>Minimum height of bed allowed</td>
</tr>
<tr>
<td></td>
<td>Filter ripening time</td>
</tr>
<tr>
<td></td>
<td>Flow variations</td>
</tr>
<tr>
<td></td>
<td>Age and type of schmutzdecke</td>
</tr>
<tr>
<td></td>
<td>Distance between ice layer and sand bed (in cold weather)</td>
</tr>
<tr>
<td>Environmental conditions of raw water</td>
<td>Water temperature</td>
</tr>
<tr>
<td></td>
<td>Raw water quality</td>
</tr>
<tr>
<td></td>
<td>Types of microorganisms present</td>
</tr>
<tr>
<td></td>
<td>Type and concentration of algae</td>
</tr>
<tr>
<td></td>
<td>Magnitude and type of turbidity</td>
</tr>
<tr>
<td></td>
<td>Concentration and type of organic components</td>
</tr>
<tr>
<td></td>
<td>Concentration and type of nutrients</td>
</tr>
</tbody>
</table>

**6.1 Design conditions**

The most important design factor in the filter efficiency is the surface rate or filtration rates. Bellamy (1985) demonstrated the influence of the filtration rate in bacteria and cyst removal. He found that when the other relations are well defined, the removal percentages are uniformly high, and that even with rates of 0.40 m/h, reasonable efficiencies are obtained (Table 5.2).

An important design factor is the simplicity of the technical solution selected for the design, bearing in mind the limited resources of the rural environment of the countries.
of the Region. Studies conducted (I. Hespanhol, 1960), (CEPIS/DIAPA Research No 1, 1980), demonstrated that slow filtration in the rural areas of our countries had failed from lack of simplicity. The technical solutions had been implemented with the technological characteristics of developed countries, which had all the appropriate human and economic resources, and materials, as well as a culture of operation for almost a century.

The appropriate technological solution developed by CEPIS eliminated all the elements that had been identified as vulnerable parts of the slow filter. It established very simple controls, basically only weirs, both to measure the flow and to control the minimum and maximum levels of the filter. The variable level was also left aside, since it is demonstrated that this does not affect the efficiency of the process. See figure 5.1.

**Table 5.2. Effect of the filtration rate on the average removal efficiency**

*(Bellamy, 1985)*

<table>
<thead>
<tr>
<th>Microorganisms</th>
<th>Number of analyses</th>
<th>Range of concentration in the raw water</th>
<th>Percentages of removal *</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Filter 1</td>
</tr>
<tr>
<td>Total coliforms</td>
<td>243</td>
<td>0–29,000 CFU/100 ml</td>
<td>99.96</td>
</tr>
<tr>
<td>Faecal coliforms</td>
<td>81</td>
<td>0–35,000 CFU/100 ml</td>
<td>99.84</td>
</tr>
<tr>
<td>Total bacteria count</td>
<td>351</td>
<td>10–(10⁹) CFU/100 ml</td>
<td>91.40</td>
</tr>
</tbody>
</table>

*Information obtained in pilot filters, 30.5 cm in diameter, operating continually during a year.

**Figure 5.1 Slow filter for rural areas (CEPIS, 1982)**

**6.2 Operation and maintenance conditions**

Proper operation and maintenance are decisive factors in the efficiency of the filter, mainly at the start-up stage or beginning of the operation of the new filter. During normal operation, the state of ripeness of the biological layer, the frequency of the
scrapes, the duration of each cleansing operation and the way the filter is refilled with sand are all important.

It must be taken into account at the start-up stage that new sand does not reduce the bacteriological contamination. Therefore, the initial effluent will have to be discarded, until an acceptable degree of efficiency has been verified. This was demonstrated by Bryck et al in new pilot filters, reporting an efficiency of faecal coliform removal of zero at the start-up stage; the same results were reported by Bellamy (1985). As previously analyzed, this is because the biological formation on the sand has not yet been developed. However, this process can be accelerated by placing ripe sand in the filter, which has been taken from other filters in operation.

Regarding the removal of Giardia cysts, results reported by Bellamy (1985) indicate efficiencies of up to 99.99% in new filters with filtration rates of 0.12 m/h, declining to 99.06% when increasing the filtration rate to 0.47 m/h (Table 5.3). Bryck (1987) identified five logarithmic removal levels immediately after the start-up of the filters. Fogel et al (1993) report efficiencies of Giardia cyst and Cryptosporidium removal in the order of 93% and 48% respectively. Research findings indicate that Cryptosporidium removal becomes difficult when the water is very cold or if the plant does not comply with design standards.

**Table 5.3. Removal of Giardia cysts with an effective size sand of 0.615 mm (Bellamy, 1985)**

<table>
<thead>
<tr>
<th>Filter</th>
<th>Test No.</th>
<th>Biological conditions of the filter</th>
<th>Filtration rate m/h</th>
<th>Concentration cysts influent</th>
<th>Concentration cysts effluent</th>
<th>Efficiency %</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>1</td>
<td>Ripe</td>
<td>0.12</td>
<td>3000</td>
<td>0</td>
<td>&gt;99.98</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Ripe</td>
<td>0.12</td>
<td>1456</td>
<td>0</td>
<td>&gt;99.92</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Ripe</td>
<td>0.12</td>
<td>1845</td>
<td>0</td>
<td>&gt;99.94</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>New</td>
<td>0.12</td>
<td>3227</td>
<td>0</td>
<td>&gt;99.99</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>New</td>
<td>0.12</td>
<td>2768</td>
<td>0</td>
<td>&gt;99.99</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>New</td>
<td>0.47</td>
<td>2768</td>
<td>26</td>
<td>&gt;99.06</td>
</tr>
</tbody>
</table>

The results of Table 5.3 show that the slow filter is always efficient when removing Giardia cysts and probably any other type of cysts of similar size, since the predominant removal mechanism in this case is sifting, so it does not matter whether the sand is ripe or not. Efficiency is maintained, even with sands of effective size in the order of 0.615 mm that surpass the range of 0.15 to 0.30 mm normally recommended.
On the other hand, many scientific studies have been carried out regarding the efficiency of bacteriological removal. These studies indicate that when the biological layer is removed, efficiency declines by at least a third and that it can be totally canceled out if the system is not being operated and maintained properly.

To diminish negative impact during the scraping of the filter, it is necessary to carry out this operation in one day, thus preventing the death of the beneficial microorganisms in the sand layer that will remain in the filter, and shortening the subsequent ripening period. When refilling the filter with sand, that is, when the layer has reached the minimum acceptable depth (up to 0.30 m according to recent research) and the sand’s thickness has to be restored to the design value, it will be very important to apply the entrenchment method, placing the semi-clogged sand from the bottom on the surface of the filter, over the new sand, to accelerate the ripening period.

5.3 Environmental conditions and raw water quality

The raw water conditions which most affect filter efficiency are temperature, the concentration of nutrients and toxic substances, and influents with high turbidity and color.

a) Temperature:

In extreme environmental conditions, efficiencies ranging from 0 to 90% have been detected (Huisman & Wood, 1974). The efficiency of faecal coliform bacteria removal can be reduced from 99% at 20ºC to 50% at 2ºC; if all other conditions remain stable. In filters operating with filtration rates of 0.3 m/h and temperatures of 4ºC, under good working conditions, it has not been possible to produce effluents with less than 50 CFU/100 ml. The old systems in London work with filtration rates of 0.20 m/h, obtaining filtrates with concentrations of faecal coliforms lower than 10 CFU/100 ml.

In Switzerland, the Netherlands and other developed countries with very low temperatures, the slow filters are roofed over to keep them warm and attenuate the effect of snow and frosts.

b) Concentration of nutrients:

The rate of development of the biological formation in the filter depends on the concentration of nutrients in the water, because this is the feeding source of the microorganisms. Experiments where an increased quantity of nutrients were introduced into a filter indicated that the formation of the biological layer was accelerated significantly, in comparison with another similar filter operating with the same quality of water.
In regions where low temperatures are associated with low nutrient concentrations in the influent, the filter layer can take several months to ripen and reach its maximum efficiency of bacteriological removal.

c) Concentration of algae:

Algae may enter the filter from the rivers, lakes, and dams that feed these systems. They are part of the schmutzdecke and, in adequate concentrations, their effect is beneficial for the operation of the filter. The algae maintain the biological balance by producing the oxygen that the predators require for their development and consuming the carbon dioxide that these predators exhale; at the same time they act as a prefilter on the surface of the sand.

However, under certain conditions particularly related to the availability of light and nutrients, such as the presence of phosphates and nitrates in the water, large growths of algae can occur. These blooms of algae can create serious problems of operation and treated water quality, such as the blocking or premature clogging of the filter bed, the production of odor and taste in the water, the increasing of the concentration of soluble organic and biodegradable substances in the water, and an increase in the difficulties relating to the precipitation of calcium carbonate and development of anoxic conditions. The filter run can be reduced to a sixth of its normal period by an exaggerated growth of algae, even in temperate climates such as in Great Britain. During their photosynthetic activity, the algae can reduce the water’s natural buffer capacity, and the pH can be raised considerably, even above 10 or 11. As a result, magnesium and calcium hydroxides can precipitate over the sand grains, affecting the efficiency of the process and the operating conditions of the filter.

The control of algae is difficult, but one solution is to control the nutrients in the source and control the effect of the light by covering the raw water reservoirs.

This problem is controlled in Europe by covering the filters with a roof. The lack of light does not greatly affect the process, and the reduction in algae makes it possible to operate with higher rates.

d) High concentrations of turbidity and color:

The ability of slow filters to reduce turbidity and high color is very limited. The raw water should not have an NTU of more than 10 to 20 over long periods. Peaks of 50 to 100 NTU for a few hours can be accepted. The problem is that they generate sludge on the surface of the filter, reducing the filter’s capacity for removal of the biological formation and dramatically reducing the duration of
the filter run. Because of the sludge formed, there are cases in which filters are scraped every two or three days. Besides affecting the quality of the water produced, this exaggeratedly increases operation and maintenance costs. Regarding a true color, the removal capacity of the slow filter is limited to 40 or 50 UC.

This aspect can be controlled using as many processes as necessary before the slow filter in order to adapt the inflow to the turbidity limits stipulated for the filter.

7. Conclusions

The slow filtration systems working in Europe, the United States, and Canada, where there is a well-developed operation and maintenance culture, report removal efficiencies of:

- Enterobacteria of 90 to 99%. The removal of faecal coliforms is affected by low temperatures, an increase in the filtration rates, the use of very coarse sand, very shallow beds, variation of the nutrient content, and the periodic removal of the biological layer.

- Protozoa cysts in the order of 99 to 99.99%, even before the filter ripens. Cryptosporidium cysts, 48%. Schistosoma cercarie, almost total removal.

Research studies developed in Latin America also indicate very good efficiencies of microorganism removal:

a) Studies conducted at the Azpitia plant, Peru (Pardon, 1985), in a system composed of a settler, a three-stage downflow prefilter and slow filters, report partial efficiencies of faecal coliform removal of 79.3% in the first stage of the prefilter, 51.4% in the second, 24.2% in the third, and 92.4% in the slow filter; that is, a total efficiency of 99.4%.

b) Studies were conducted in 1992 at the National University of Rosario, Argentina, under controlled conditions, in a system made up of a settler and a horizontal flow prefilter before the slow filter. This study assessed turbidity and faecal coliforms for six months, finding turbidity removal efficiencies of 60% in clear waters and up to 98% with high turbidity. The removal efficiency of faecal coliforms was 70%.

c) Studies conducted by Universidad del Valle in Colombia (Lloyd et al, 1992) in seven slow filtration systems also similar to the previous ones indicate that an effluent with less than 1 faecal coliform/100 ml is obtained, before disinfection. The studies demonstrate that when the waters are more contaminated, the
efficiencies are greater, obtaining faecal coliform reductions of 2.6 to 5.5 logarithmic levels. This is probably thanks to the greater number of nutrients in the raw water, which makes the process more efficient, as analyzed previously.

d) When the systems are well designed, and properly operated and maintained, the effluent of the slow filtration plants requires very low doses of chlorine as a last barrier; practically only to ensure that the water preserves its bacteriological quality until the time that it is consumed. It is a water with very low sanitary risk. The technology has existed for more than one century. Its adaptation by CEPIS to the conditions in our developing countries, has proven its great efficiency. The challenge is to develop an operational culture to obtain an effluent of uniform safe quality that can be consumed directly at no risk to the user.

Thus, slow filtration can validly be regarded as a microorganism removal process equivalent to disinfection.

8. REFERENCES


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