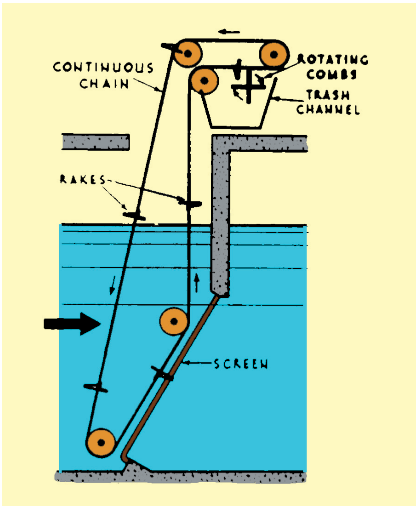
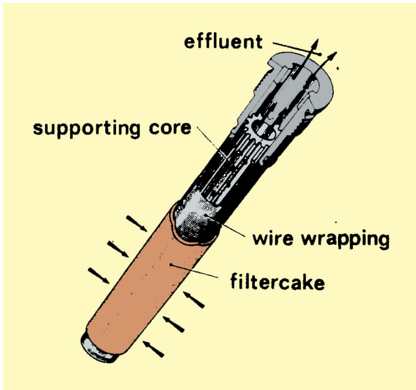
CT 4470

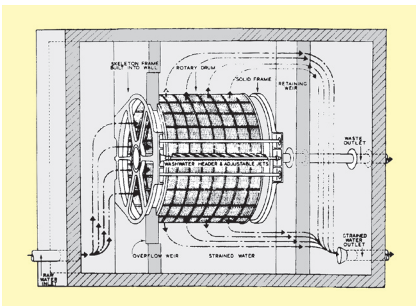
Mechanical filtration

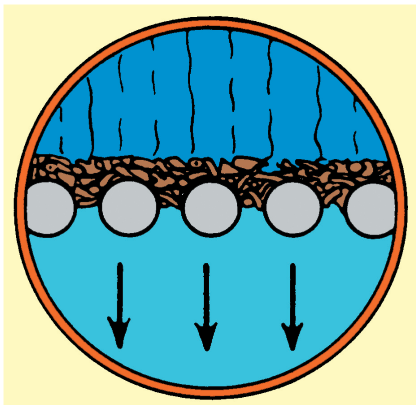
September 2004

Prof.dr.ir. L. Huisman









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Mechanical filtration

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(formerly published in combination with “Sedimentation and flotation”)

1st edition 1973

2nd edition 1982 (reprinted September 2004)

MECHANICAL FILTRATION

Contents

1. Definitions and terms

Mechanical filtration is the process whereby the water to be treated is passed through a porous membrane, consisting of closely spaced bars or gratings, perforated plates, woven wirecloth or fabric, etc, retaining the floating and suspended particles that are larger in size than the openings in this screening device. With time an accumulation of strained-out material occurs, by which the effective openings in the membrane are reduced and also smaller particles can be retained. This process may be enhanced by adding to the raw water inert fibrous or powdered material, so-called filter aid, capable of forming a mat of intertwined threads or a granular layer which now does the actual work, the porous membrane itself only serving to support this layer of filtering material. Under all circumstances, however, the thickness of this filtering layer is small and its action entirely mechanical.

Mechanical filtration may serve different purposes. In the field of water and waste water engineering the most important ones are

a. protection of the treatment plant by removal of the grosser floating and suspended impurities which otherwise might clog pipelines and channels, damage pumps and other mechanical equipment or interfere with the satisfactory operation of the various unit operations;

b. clarification of the passing liquid by removal of more finely divided particulate matter. Mechanical filtration alone is seldom able to give the desired amount of purification, but it may be of invaluable help to lighten the load on subsequent treatment processes, to reduce the volume of the sludge zone in settling tanks, to prevent a rapid clogging of slow sand filtres, etc.

Next to this, mechanical filtration is used extensively for the dewatering of sludge in water and waste water treatment plants.

When during operation retained material accumulates on the porous membrane, the openings decrease in size and combined area, increasing the resistance against the passage of water. After some time this resistance becomes so high that cleaning of the filter is necessary. With regard to the way this cleaning is effected, three types of mechanical filters may be distinguished, screens, strainers and pre-coat filters. Screens may further be subdivided in fixed screens, cleaned in situ and movable screens which are stationary during operation but are lifted from the water for the purpose of cleaning. Strainers are in continuous motion, but only part of the fabric is submerged in the water, available for operation, while the other part is above the surface for cleaning. Pre-coat filters finally may be stationary or moving with cleaning at intervals or continuously by washing away the coating of filter aid and retained impurities.

2. Screens

Fixed screens are commonly constructed from parallel bars (fig.1) rectangular in cross-section, about 10 mm thick and 50 mm wide. They are not meant to purify the water, only to prevent chokage and damage of the subsequent installation. As a consequence, the size of the openings between the bars is not smaller than strictly necessary with regard to their function of equipment protection. According to the size of these openings, bar screens may further be subdivided in

a. coarse screens or racks, clear openings 50 - 150 mm, to prevent logs and timber, dead dogs and cats, etc, from entering the plant;
b. medium-size screens, openings 20 - 50 mm, to keep back those grosser impurities which even in larger plants might clog pipelines, injure pumps and other mechanical equipment;
c. fine screens, openings 5 - 20 mm, for the protection of plants with limited capacity, where small diameter pipelines and small sized pumpbowls must be used.

The approach velocity of the water in the channel upstreams of the screen may not be smaller than 0.3 - 0.5 m/sec to prevent settling out of suspended matter, while the passing velocity of the water in the openings between the bars may not be larger than 0.7 - 1 m/sec to prevent that soft, deformable matter is forced through the screen openings. The ratio between these two velocities depends primarily on the size of the openings compared to the width of the bars, but may further be decreased by setting the bars at a smaller angle (α in fig 4) with the horizontal. When clean, the resistance of a

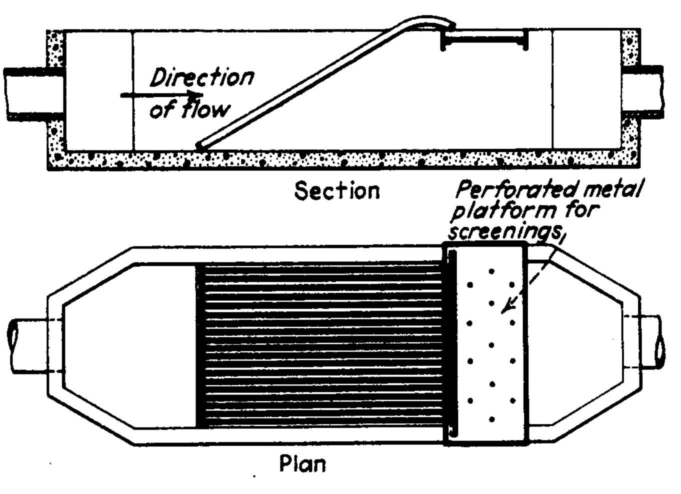


Fig. 1 Fixed bar screen

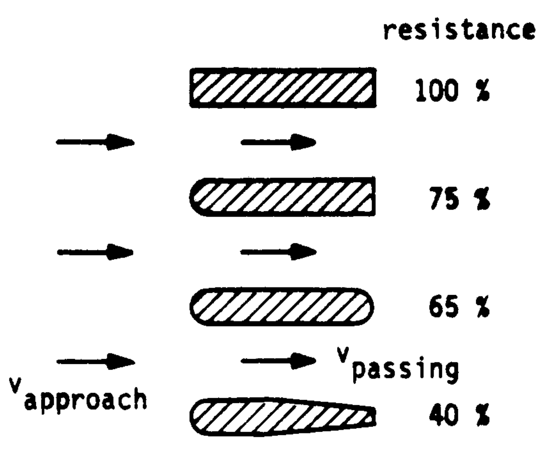


Fig. 2 Streamlining of bars

bar screen is small, a few centimetres only. This resistance may be reduced by streamlining the cross-section of the bars (fig. 2), but generally this is not worth the cost involved. The shape of the bars in fig. 3 has the additional advantage that the openings are self-cleaning and clogging is less. Due to this clogging, the resistance will increase sharply, from H_o for a clean screen with a percentage open area p_o to

$$H = \left(\frac{p_o}{p}\right)^2 H_o$$

when the percentage open area is reduced to p. This head loss will produce a large load on the bars (fig. 4), asking for sufficient

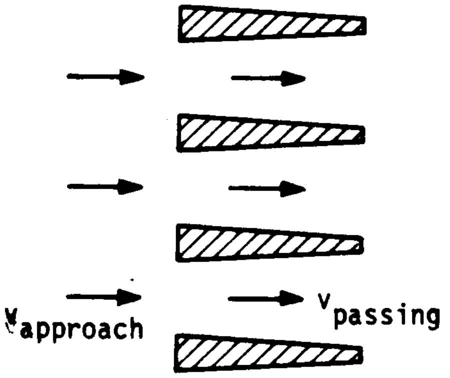


Fig. 3 Bar screen with self-cleaning openings.

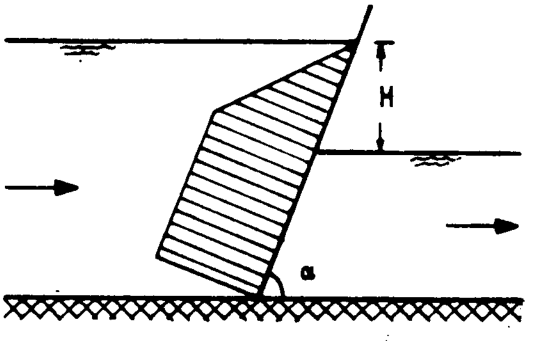


Fig. 4 Hydraulic loading of a bar screen.

structural strength, which in the course of time may even decrease by corrosion. By regular cleaning this hydraulic load must be limited, keeping the maximum value of H below 0.5 m for instance. With regard to unforeseen circumstances, however, it is good practice to base the structural design of the bars on a resistance of 1 to 2 m, depending on local circumstances. Sometimes the maximum resistance is limited by providing the screen with a bye-pass, receiving the water from a side weir with rack (fig. 5).

In water supply practice, bar screens are set at the inlet of surface water from rivers or lakes. Due to their velocity of flow, rivers may carry a high suspended load. The intake works, however, are constructed in such a way that only a minimum amount

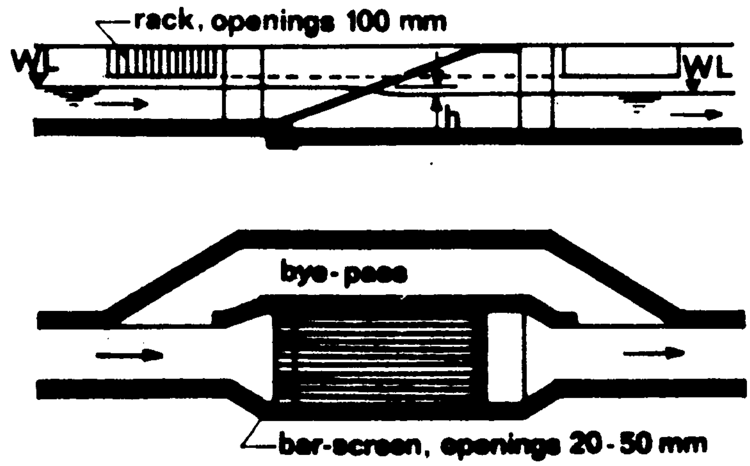


Fig. 5 Bar screen with bye-pass.

of impurities is entrained by the water abstracted. In fig. 6 the entrance velocity is less than 0.1 - 0.2 m/sec, the bottom preferably more than 0.5 m above the river bed, while floating matter is kept back with a dip or floating boom. As a consequence only little material is retained by the screen, allowing this screen to be set at a steep angle, 60° - 75° with the horizontal and making hand cleaning with rakes (fig. 7) a perfectly sound solution. The entry of fishes can be prevented with electrical shock devices (fig. 8), while in cold climates heating arrangements, steam jets or electric wiring, are necessary to prevent a blocking of the

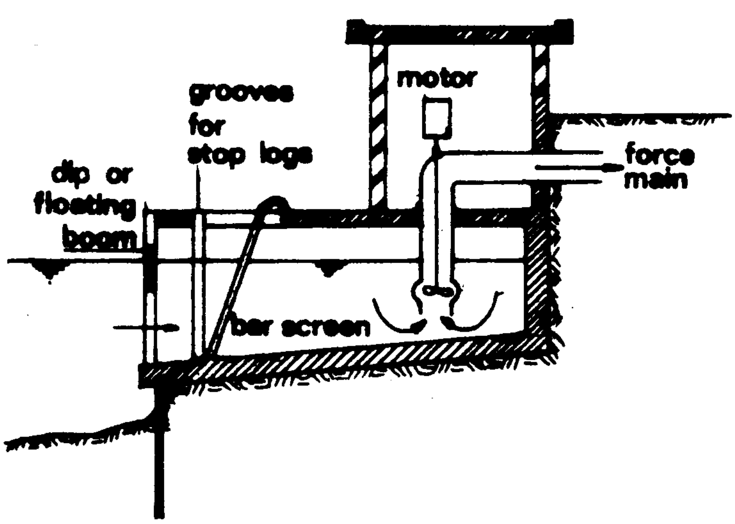


Fig. 6 River water intake with pumping station

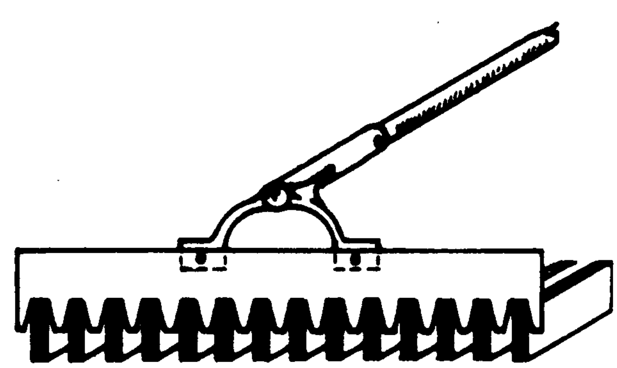


Fig. 7 Rake for manual cleaning of bar screens

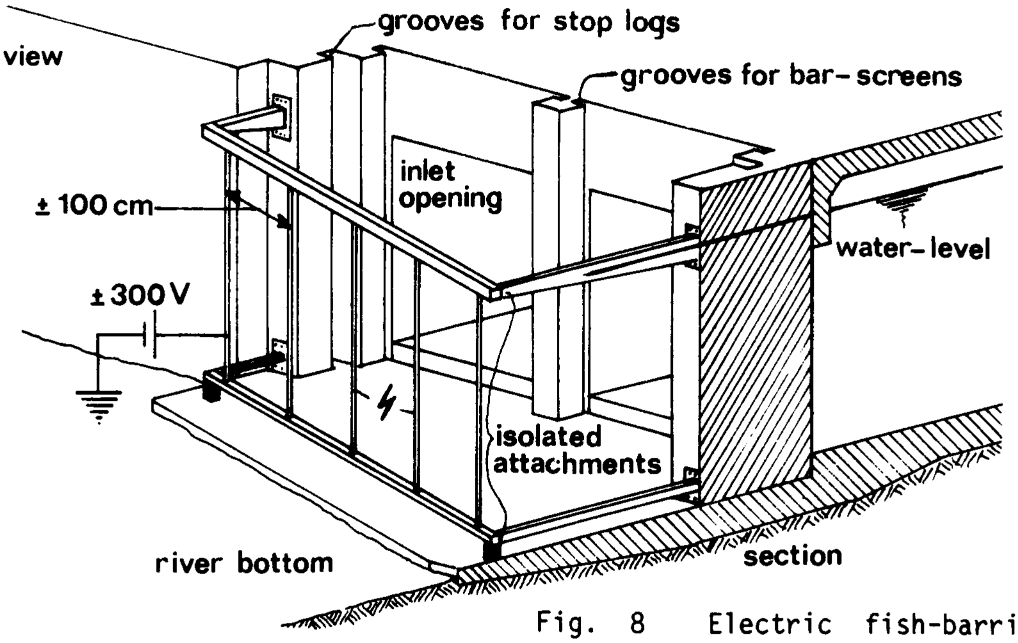


Fig. 8 Electric fish-barrier.

screen by anchor or frazil ice. Disposal of the rakings is commonly not a problem. The amount is small, their nature not offensive, often allowing a downstream return to the river. In smaller plants, intake works as described above are too elaborate and only the inlet to the pump needs a strainer (fig. 9). When this strainer is not accessible for cleaning and blocking cannot be excluded completely, a hydraulic backwash of the strainer may give an attractive solution (fig 10). Similar constructions may be used for abstracting water from lakes where by the absence of flow grosser suspended impurities will not be present. Even when screening is completely superfluous, a rack is required for protection of the operating personnel. Commonly such racks are made of circular bars, for instance with a diameter of 20 mm and openings of 100 - 150 mm. Wire-mesh screens are cheaper and less deformable, but they tend to retain more material as for instance leaves in autumn. Lifting them above water, however, is

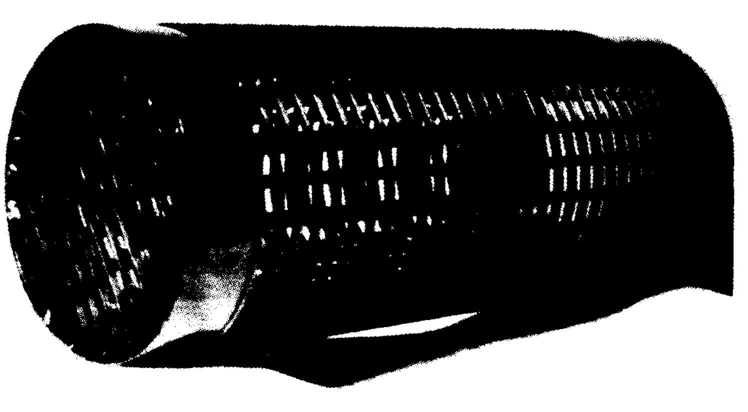


Fig. 9 Pump strainer

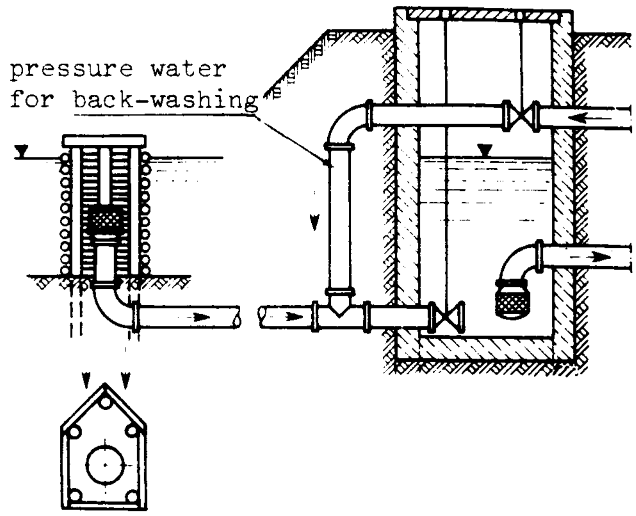


Fig. 10 Riverwater intake with a hydraulically back-washed screen.

easy after which they can be cleaned with a jet of pressure water. Very conscientious engineers construct such movable screens in duplicate, so that one is always in the water for operation while the other is above water for cleaning.

In waste water treatment plants, bar screens for equipment protection are set before the pumps and when no pumping is required before the primary settling tank or grit chamber when present. Compared with river water, the amount of floating and suspended matter is much larger, while furthermore no selection can be made and all this material must be processed. As a consequence, large amounts of screenings must be expected, for municipal sewage roughly

size openings	5	10	20	50	mm
screenings	15	10	5	2	$\times 10^{-3}$ m^3/capita /year.

A plant handling the domestic sewage from 100.000 people will have a maximum hydraulic capacity of about 0.6 m^3/sec, asking for a screen area of 1 - 1.5 m^2 on to which an amount of 1 - 3 m^3 of suspended matter will be retained each day. This amount is so large, that hand cleaning with long-tined rakes is only possible when the screens are set with a small angle, down to 20° or 25°, with the horizontal. Such a flat position has the added advantage that the flowing water pushes the retained material to the top of the screen, facilitating cleaning, while the damming effect of a partially blocked screen raises the upstream water level, by which the wetted screen area will increase appreciably. With regard to the origin and putrescibility of the screenings, manual cleaning is an unpleasant task to say the least. In sewage treatment plants bar screens are therefore mostly cleaned mechanically. In developed countries with a high cost of labor, mechanical cleaning will also be more economical, moreover because the screens can be set at a steeper angle, 60° to 75° with the horizontal, reducing space requirements.

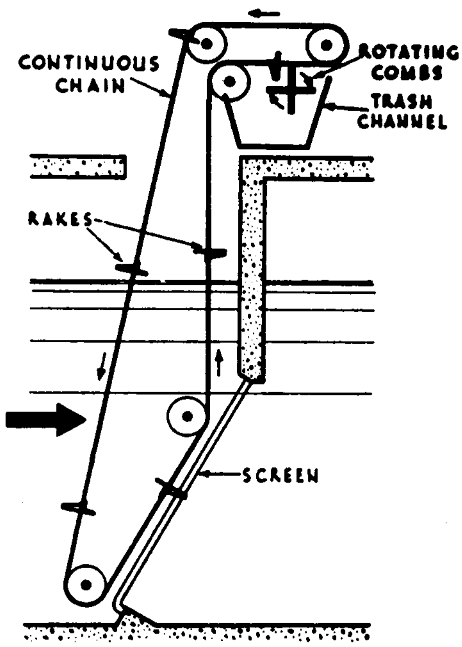


Fig. 11 Diagram of a mechanically raking screen.

The principle of cleaning bar screens mechanically is shown in fig. 11, but as regards the actual construction innumerous proprietary designs are available of which fig. 12 and 13 only show a few examples.

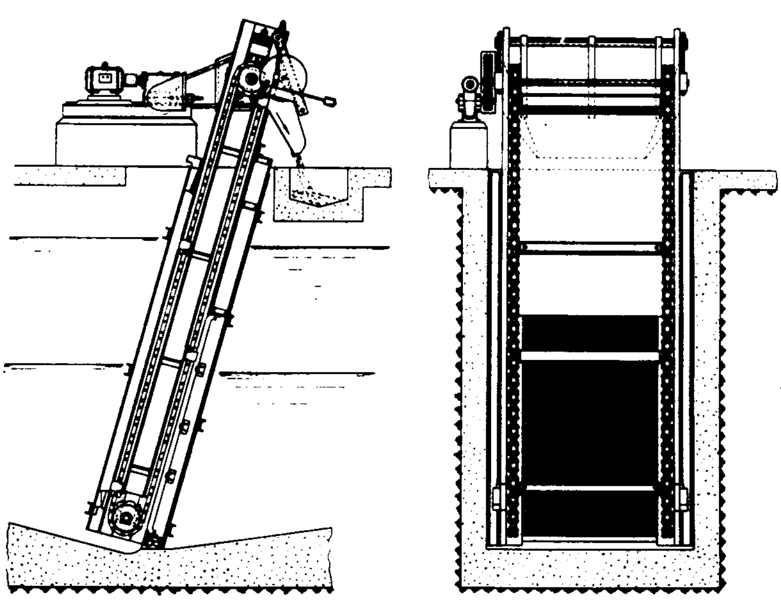


Fig. 12 Mechanical rakes mounted on an end-less chain (Passavant).

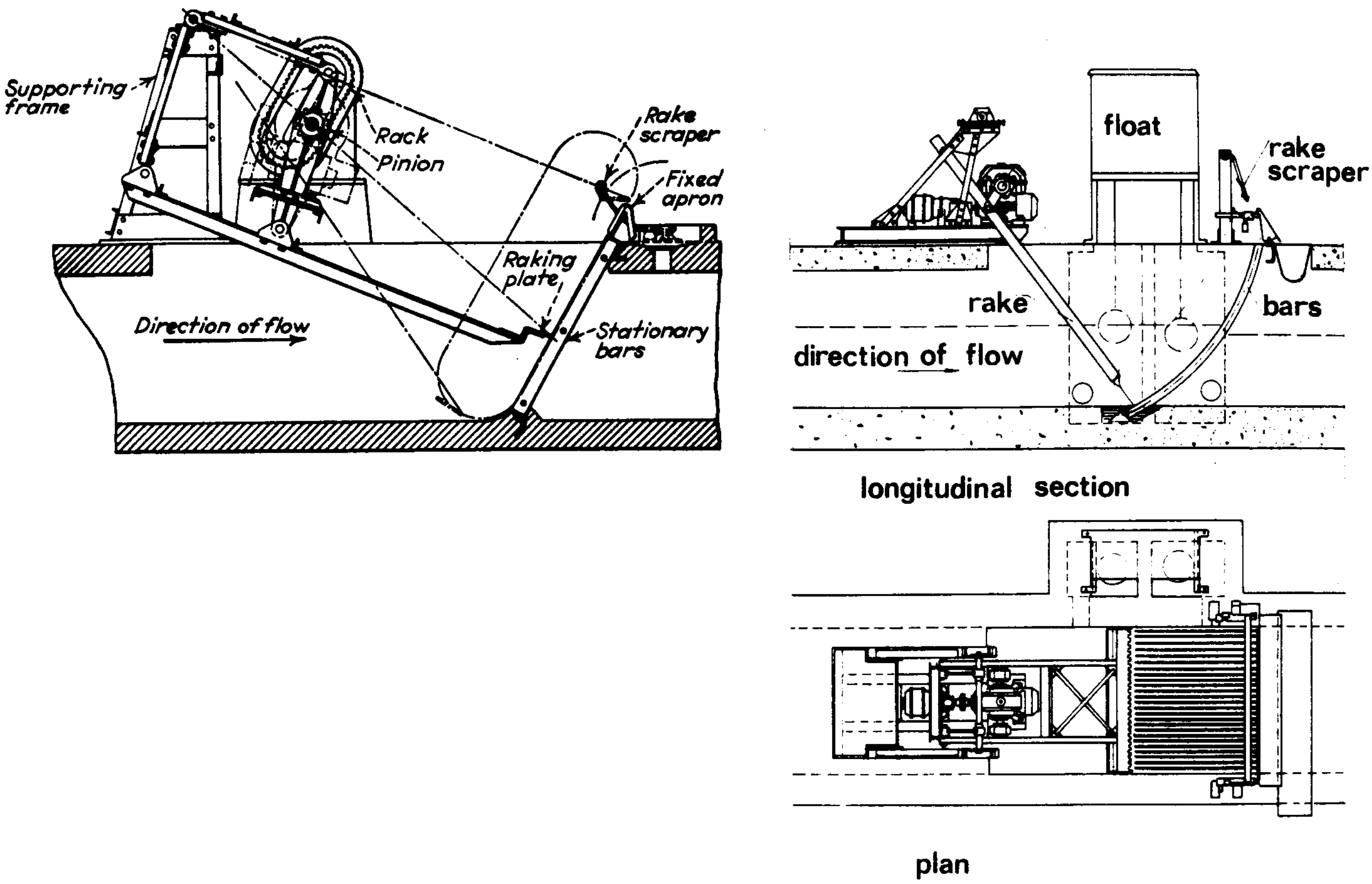


Fig. 13 Dorrco bar screens.

The common feature is the presence of rakes which periodically sweep the entire screen area, removing the retained material, in this way keeping the hydraulic head loss down to values of about 0.1 m and preventing surges of high flow after a strongly clogged screen is cleaned and restored to its original capacity. The rakes can be operated by a timing device or by a float on the upstream water level measuring the amount of ponding. Preferably both controls are installed, working independent of each other, to prevent damage when one of them fails. A remaining difficulty concerns the amount and nature of the retained materials. Disposal may be effected by burying, burning, addition to digester tanks or municipal refuse, but again this work is unpleasant and labor intensive. Keeping in mind the purpose of equipment protection, a solution may also be obtained by grinding the screenings and returning the pulverized material to the sewage for subsequent treatment in settling tanks. The shredder

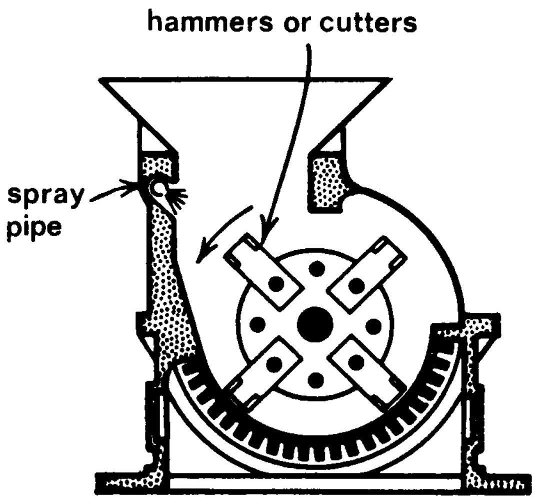


Fig. 14 Shredder.

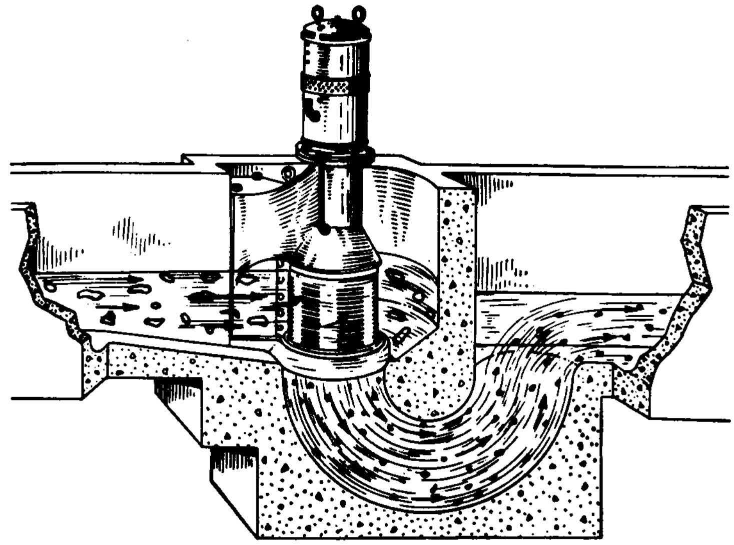


Fig. 15 Comminutor.

of fig. 14 is set above the water level, making it difficult to prevent nuisance from odors or moisture. A more elegant and straightforward solution is to pass the whole flow of raw sewage through comminuting devices (fig. 15), which desintegrate the grosser impurities without removal from the water. The screenings remain submerged, reducing flies, odors and unsightliness. With regard to the small clearance between moving and stationary parts, comminutors are preferably set behind the grit chamber, after the hard and sharp grit particles have been removed from the liquid. In both cases, however, racks remain necessary, but they keep back only minute amount of materials, mostly of an inoffensive nature.

In the beginning of this section it was stated that bar screens are only used for equipment protection. In exceptional cases, however, mechanically raked fine screens are used for purification purposes. In drinking water practice they may be applied to remove suspended particles of the same density as water ahead of settling banks. Where sewage is discharged without treatment, fine screens may still be desired to keep back coarse floating objects, which otherwise would render receiving waters unsightly or cause objectionable shore-line conditions. In terms of surface water pollution, however, their effect is negligeable, being a few percent only. In both cases much better results can be obtained with strainers, having much smaller openings. To prevent freezing in winter time and with sewage to prevent nuisance of flies, odors, etc, fine screens must be installed in a screen house.

3. Strainers

Strainers are moving screens with part of the porous membrane below water for operation and the other part above water for cleaning. The membrane travels at an appropriate speed of for instance $(50)10^{-3}$ m/sec, so that blocking of the openings by the arrested solids is only partial and the hydraulic resistance against the passage of water fairly low. After leaving the water, the membrane is liberated from the retained impurities by cleaning arrangements, after which it re-enters the water in a clean condition. This continuous cleaning allows the use of fine openings, even with heavily contaminated water. Common constructions are

parallel bars with openings of 2-5 mm;
perforated metal plates with slots 1-2 mm wide;
fine meshed wire cloth with openings 0.2-1 mm.

The larger openings can be cleaned with rakes or brushes, but for the finer openings jets of water, steam or air must be applied. With regard to their more delicate construction, strainers are usually housed, which in cold climates is even a necessity to prevent freezing in winter time. Strainers are easily damaged by corrosion and great attention must consequently be given to the selection of suitable materials or coatings.

Strainers are commonly bought as complete units from firms specializing in this field. This has resulted in an enormous variety of proprietary constructions of which fig. 16 and 17 shows perfo-

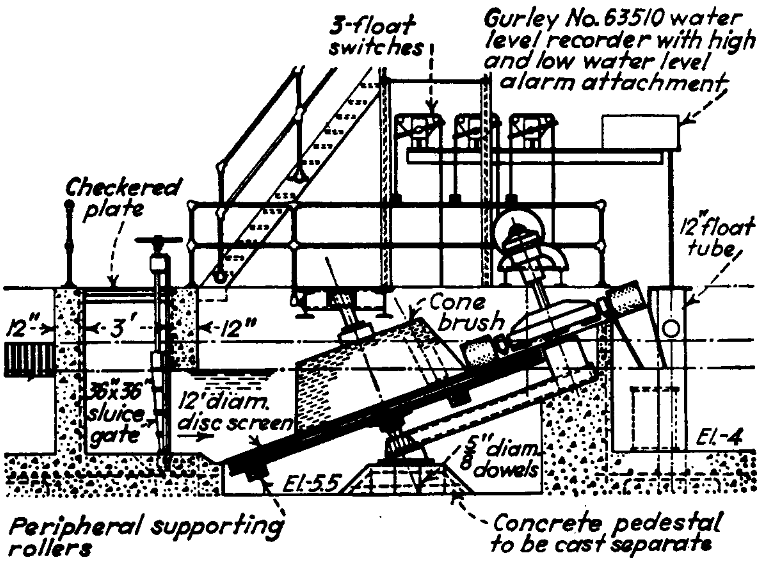


Fig. 16 Riensch-Wurl disk screen.

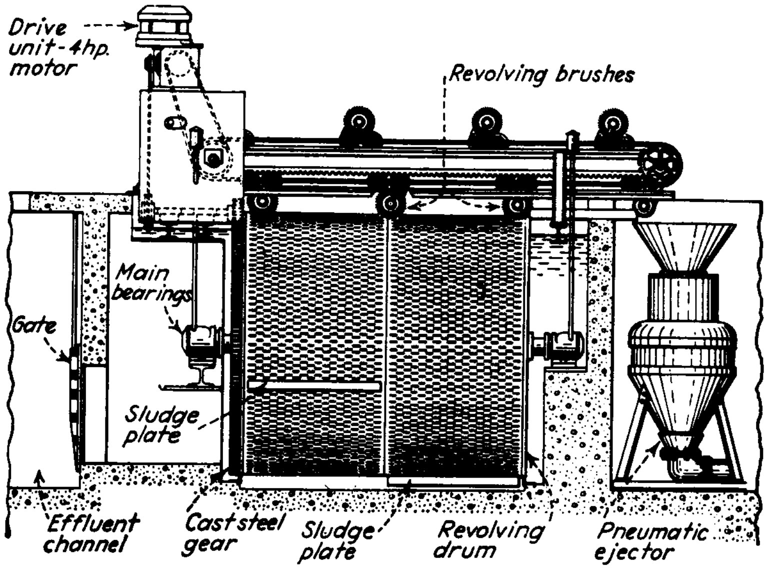


Fig. 17 Link-Belt drum screen.

rated plate strainers cleaned with brushes and fig. 18 to 22 wire mesh strainers cleaned with wash-water jets. Travelling band strainers are very popular, but the installation of fig. 19 has the disadvantage that inadequate back-washing results in retained impurities being carried into the downstream side of the screen. In this respect, the construction of fig. 23 is better suited. As an added advantage, the wire gauze is now stretched over curved frames, increasing the area of contact with the water and the capacity per unit width. Especially with fine openings, a failure of the washwater supply will result in a rapid clogging, increasing the resistance against the passage of water. To prevent damage of the fabric by this hydraulic loading, relief weirs must be present or the strainers installed in duplicate (fig. 24).

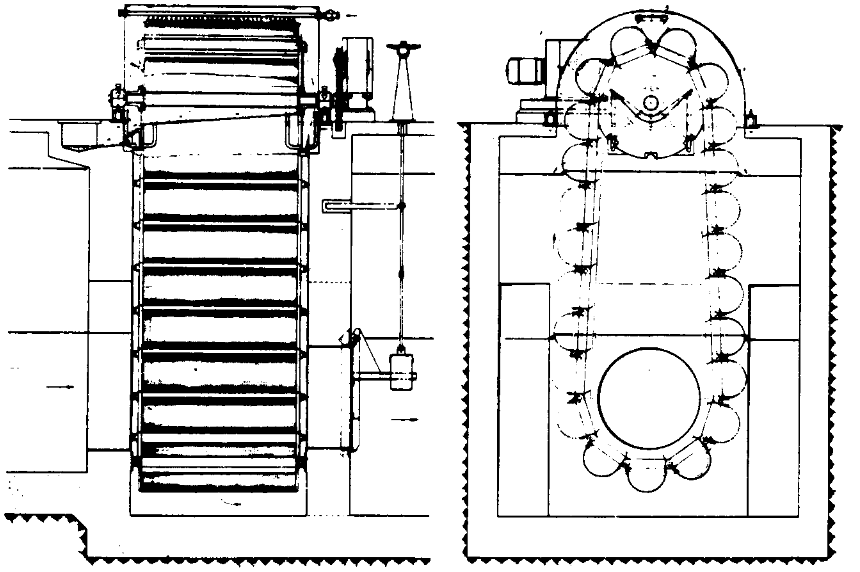


Fig. 23 Travelling band strainer.

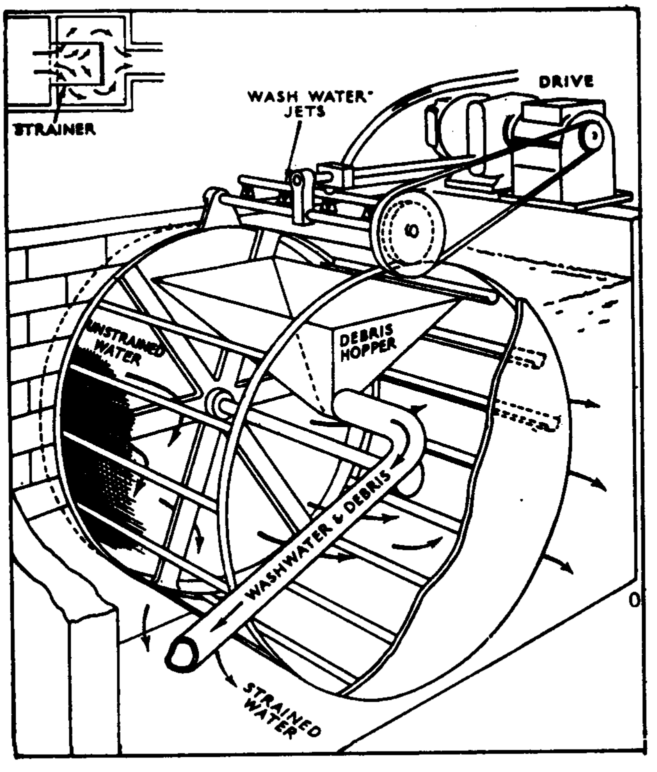


Fig. 18 Rotary drum strainer

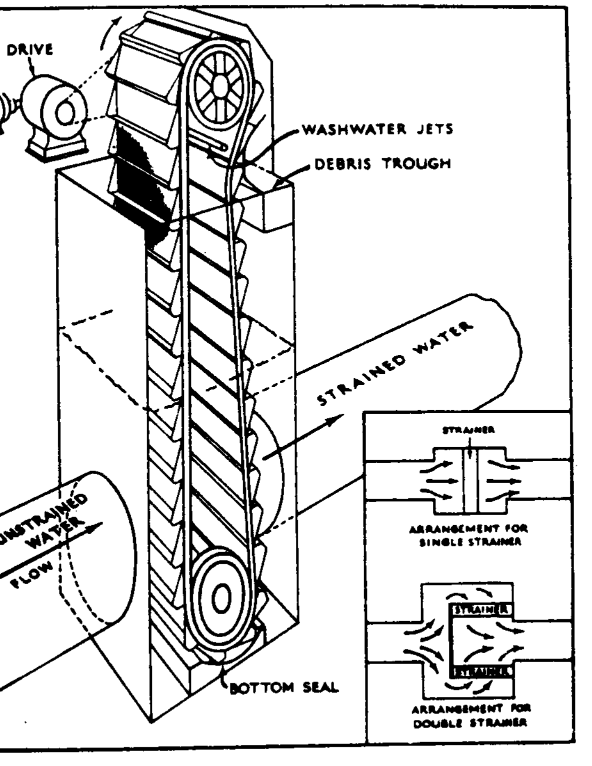


Fig. 19 Travelling band strainer

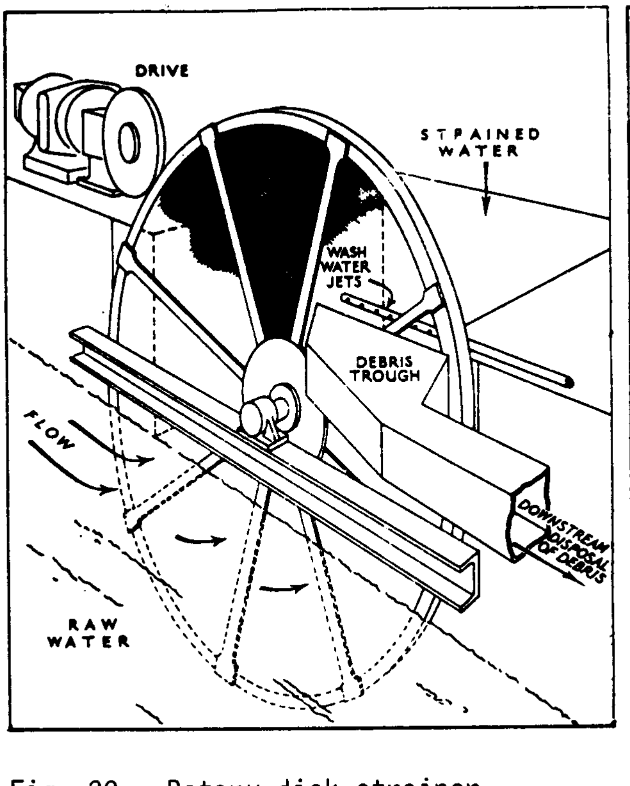


Fig. 20 Rotary disk strainer

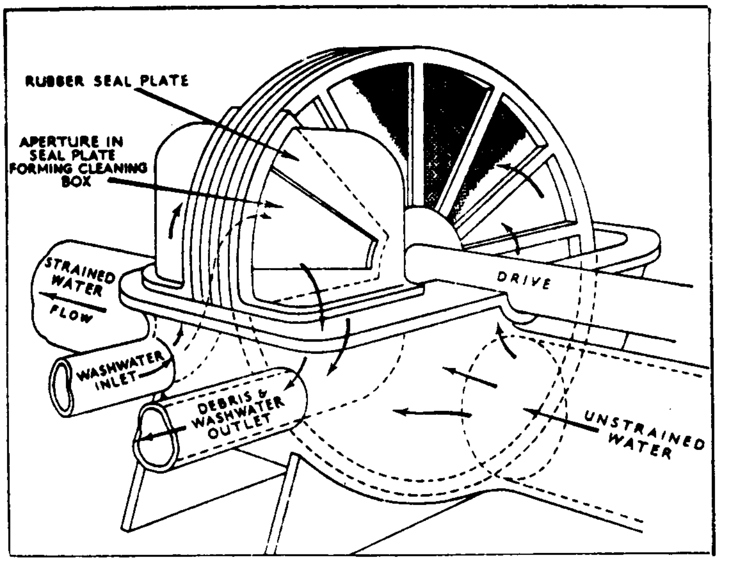


Fig. 21 Pressure strainer

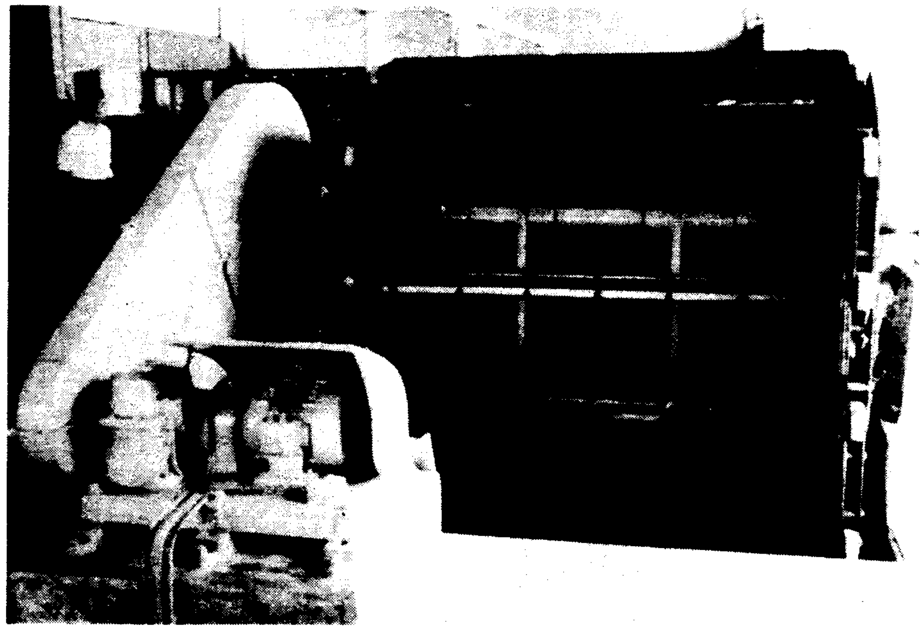


Fig. 22 Travelling-band strainer at the Skudai treatment plant for Singapore.

In water supply practice, strainers may be used directly after the intake screens, to assure that subsequent treatment processes such as sedimentation and filtration may proceed unhindered. In terms of real purification, their effect is small and hardly worth the cost involved, but they do have value in nuisance prevention in assuring a smooth operation of the plant. Disposal of the retained material is usually not a problem. The washings are collected in a launder and are led back to the river at a point well below the intake. In waste water treatment, strainers are sometimes used in stead of primary settling tanks. This gives an appreciable saving in the cost of construction, but on the other hand the efficiency in removing suspended solids is much smaller, 10 to a maximum of 20% in stead of 50% and more. The most elegant disposal of the retained material is now by pumping it to the digester tanks. In exceptional cases strainers are used as sole treatment of waste water, to prevent a visible contamination of the receiving water, the formation of sludge banks and septic conditions. With the larger amount and the putrescibility of the strainings, disposal is a difficult problem. Common solutions are burying, incineration or addition to the municipal refuse.

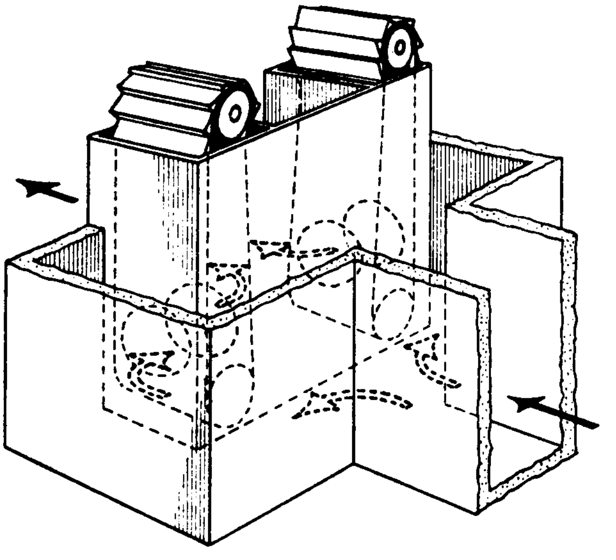


Fig. 24 Travelling-band strainers in duplicate.

4. Principles of micro-straining

Micro-strainers are hydraulically cleaned rotary drum strainers (fig. 25), covered with a finely woven metallic fabric. This fabric

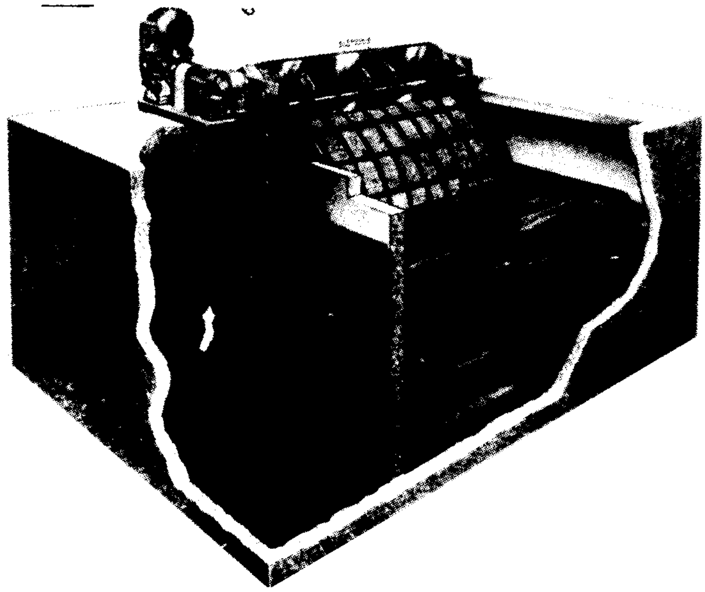
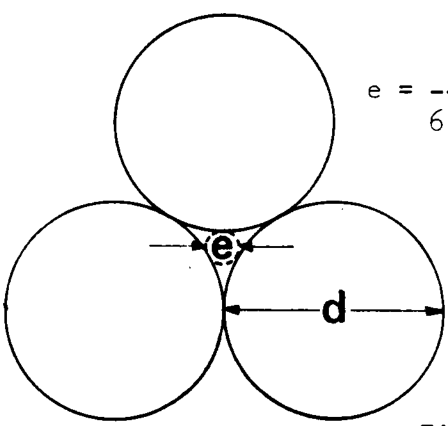


Fig. 25 Perspective drawing of a micro-strainer.

has extremely small openings, 0.02-0.06 mm, that is to say smaller as the interstices between the grains in a rapid or slow sand filterbed (fig. 26). The fabric moreover is woven in such a way that viewed normally no open area is shown (fig. 27), promoting the formation of a matt of retained material (fig. 28). In this way the openings are further reduced, enabling micro-strainers to keep back solids of sizes still smaller than the minute apertures of the fabric. The remaining openings are so small indeed, that with fixed screens and even the clearest of raw waters, they would become blocked in a matter of minutes, whilst with ordinary good quality water containing larger amounts of suspended matter, their useful life would be reckoned in seconds. Micro-strainers must therefore be



$$e = \frac{d}{6.46}$$

	d	e	
rapid filters	0.6	0.093	mm
slow filters	0.2	0.031	mm

Fig. 26 Openings between the grains of a filterbed

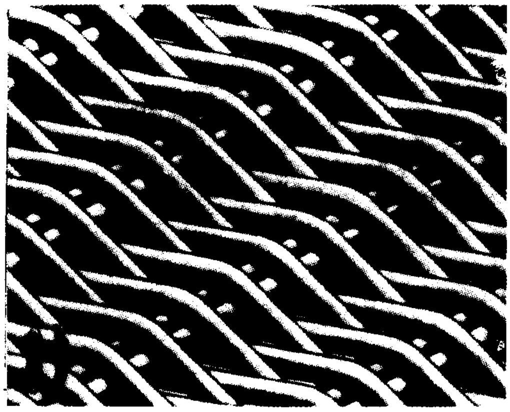


Fig. 27 Micro-straining fabric

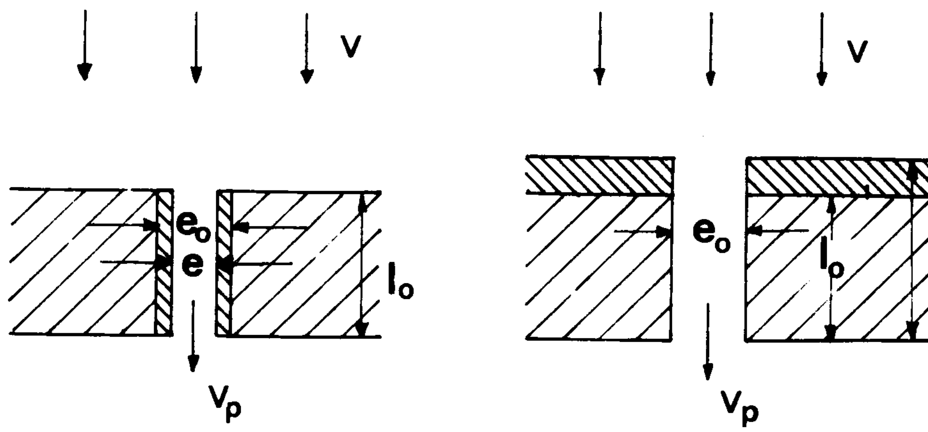
Fig. 28 Matt of microscopic plankton organisms on micro-straining fabric

build as automatic selfcleaning machines, which run continuously, eliminating solids from the water flowing through them and disposing of these solids at the same time.

With the continuous back-washing, the capacity of a micro-strainer not only depends on the area and construction of the micro-mesh fabric, the clogging properties of the raw water and the maximum allowable flow resistance, but also on the area of fabric cleaned in unit time. To draw up a relationship between the six factors involved, various models may be visualized. In fig. 29a it is assumed that the clean fabric has n pores of length l_o and diameter e_o per area A, while clogging reduces this diameter uniformly to e. According to Poiseuille's law for the laminar flow of water through capillary tubes, the flow resistance than equals

$$H = \frac{32\nu}{g} l_o \frac{v_p}{e^2}$$

with ν as kinematic viscosity of the water, g as gravity constant and v_p as actual velocity of the water inside the pores. With v_o as constant capacity per unit area



a. deposition in the pores b. deposition on the surface

Fig. 29 Models for clogging of micro-straining fabric.

$$v_p = \frac{v_o A}{n \frac{\pi}{4} e^2}$$, substituted

$$H = \frac{128\nu}{\pi g} \frac{A}{n} l_o \frac{v_o}{e^4}$$

The resistance of the clean fabric thus becomes

$$H_o = \frac{128\nu}{\pi g} \frac{A}{n} l_o \frac{v_o}{e_o^4} = \alpha v_o$$

and after clogging

$$H = H_o \left(\frac{e_o}{e}\right)^4$$

With c_a as gravimetric and $\gamma_a c_a$ as volumetric concentration of suspended matter retained by the micro-mesh fabric, the reduction in pore size from e_o to e in time t is determined by

$$v_o c_a \gamma_a tA = n\, l_o \frac{\pi}{4} (e_o^2 - e^2)$$

from which follows

$$1-\left(\frac{e}{e_o}\right)^2 = \frac{v_o c_a \gamma_a tA}{n l_o \frac{\pi}{4} e_o^2} = \beta_a v_o t \qquad \text{or}$$

$$\left(\frac{e}{e_o}\right)^4 = (1 - \beta_a v_o t)^2 \qquad \text{and} \qquad \frac{H}{H_o} = \frac{1}{(1 - \beta_a v_o t)^2}$$

In fig. 29b another model is shown with the retained material being deposited on the membrane, increasing uniformily the length of the pores from l_o to l, but leaving their diameter unchanged at e_o. According to the formulas given above, the increase in flow resistance is now determined by

$$H = \alpha v_o \qquad\qquad H = H_o \frac{l}{l_o}$$

$$v_o c_b \gamma_b t A = (A - n \tfrac{\pi}{4} e_o^2)(l - l_o)$$

from which follows

$$\frac{l}{l_o} - 1 = \frac{v_o c_b \gamma_b t A}{l_o(A - n \frac{\pi}{4} e_o^2)} = \beta_b v_o t \qquad \text{and}$$

$$\frac{H}{H_o} = 1 + \beta_b v_o t$$

In reality, however, the two models will occur simultaneously. The increase in resistance is now due to both phenomena, in formula

$$\frac{H}{H_o} = \frac{1 + \beta_b v_o t}{(1 - \beta_a v_o t)^2}$$

Taking the logarithme gives

$$\ln \frac{H}{H_o} = \ln (1 + \beta_b v_o t) - 2 \ln (1 - \beta_a v_o t)$$

For small values of t this may be approximated by

$$\ln \frac{H}{H_o} = \beta_b v_o t + 2\beta_a v_o t = \beta v_o t \qquad \text{and}$$

$$\frac{H}{H_o} = e^{\beta v_o t}$$

that is to say an exponential increase of flow resistance with time. For larger values of t, this will not be completely true. The difference, however, will be small as according to the first model the resistance rises more rapidly and according to the second model more slowly with time than corresponds with an exponential increase.

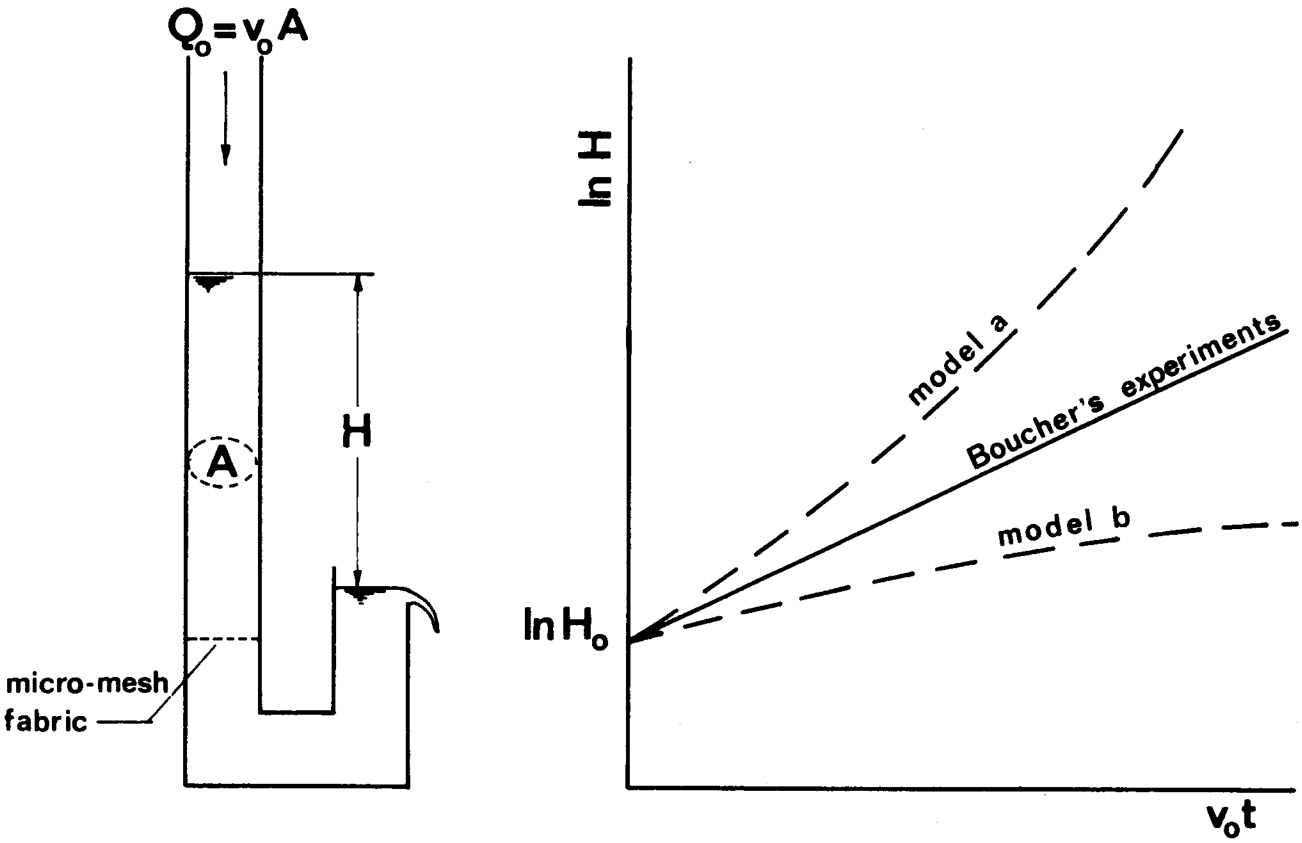


Fig. 30 Experimental determination of filtrability according to Boucher.

The straining law derived above has been checked experimentally by Boucher, measuring the resistance of the micro-mesh fabric as function of the volume of water passed. As shown schematically in fig. 30, the fabric to be applied is percolated at a constant rate v_o. The resistance H is plotted on logarithmic scale against the time t on linear scale giving for most types of water indeed a straight-line relationship with as formula

$$\ln H = \ln H_o + \beta v_o t \qquad \text{or}$$

$$\frac{H}{H_o} = e^{\beta v_o t}$$

In this formula the initial resistance H_o depends on the construction of the fabric

$$H_o = \alpha v_o$$

and on the viscosity of the water, that is on the temperature

$$\frac{\alpha_1}{\alpha_2} = \frac{\nu_1}{\nu_2} \simeq \frac{0.7 + 0.03\ \tau_1}{0.7 + 0.03\ \tau_2}$$

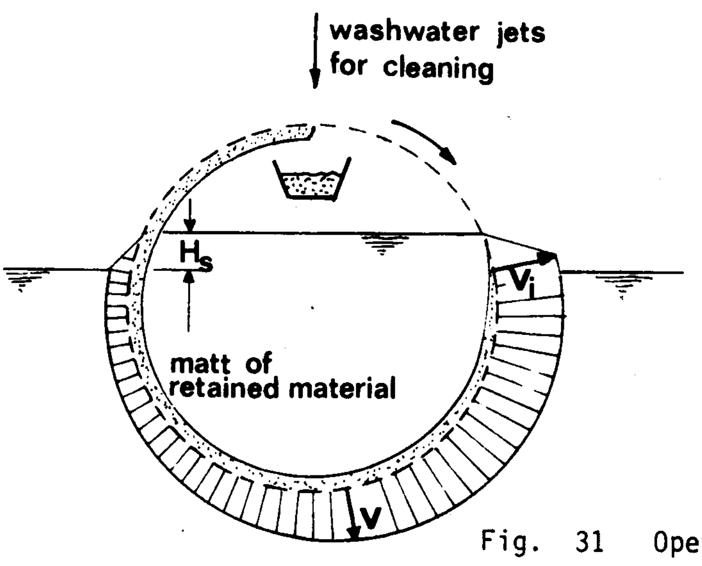
with τ as temperature in degrees centigrade. The value of β is a function of the clogging properties of the raw water in combination with the micro-mesh fabric to be used. It may show great seasonal fluctuations and for an adequate design, it is therefore essential to measure the value of β during at least a full year. Boucher's formula in the meanwhile does not correspond completely with the operating conditions of a micro-strainer. Here the straining medium passes into the water in a clean state, is submerged progressively over the whole of its working area as the drum rotates and emerges from the water in a partly blocked condition. With a constant head loss H_s, this means a decrease in straining rate with the time of submergence (fig. 31). Keeping in mind the laminar flow conditions and the proportionality between resistance and the total amount of water passed, Boucher's law may now be written as

$$\frac{v}{v_i} = e^{-\beta \int v dt} \quad \text{with } v_i = \frac{H_s}{\alpha} \text{ as initial rate of straining.}$$

Differentiating this formula to t gives

$$\frac{1}{v_i}\frac{dv}{dt} = -e^{-\beta \int v dt}\beta v = -\beta\frac{v^2}{v_i} \qquad \text{or}$$

$$\frac{dv}{v^2} = -\beta dt$$



fabric area A
wetted fabric area pA
time of revolution T

Fig. 31 Operating conditions of a micro-strainer

Integration between the limits $t = 0$, $v = v_i$ and $t = t$, $v = v$ yields

$$-\frac{1}{v} + \frac{1}{v_i} = -\beta t \quad \text{or } v = \frac{v_i}{1 + \beta v_i t}$$

With the notations of fig. 31, the average straining rate will equal

$$v_a = \frac{1}{pT}\int_o^{pT} v\,dt = \frac{v_i}{pT}\int_o^{pT} \frac{dt}{1 + \beta v_i t}$$

$$v_a = \frac{1}{\beta pT} \ln (1 + \beta v_i pT) \qquad \text{With}$$

$v_i = \frac{H_s}{\alpha}$ the capacity of the micro-strainer thus becomes

$$Q = v_a pA = \frac{A}{\beta T} \ln \left(1 + \beta \frac{H_s}{\alpha} pT\right)$$

in which the constants α and β have to be determined each time anew. In practice the straining rate v_a varies from values as low as $(2 - 3)10^{-3}$ m/sec with rather contaminated water such as a humus laden effluent from a sewage treatment plant, up to about $(25)10^{-3}$ m/sec with good quality water from impounding reservoirs. This straining rate can be raised in different ways

a. by selection of a coarser fabric with larger openings, decreasing the value of α and β. At the same time, however, the effiency of the micro-straining process is lowered and more suspended matter will pass into the effluent;

b. by the abstraction of a less turbid water, lowering the value of β;

c. by shortening the time of revolution T, augmenting the circumferential speed from a low value of 0.05 or 0.1 m/sec to a high of 0.5 m/sec;

d. by increasing the allowable flow resistance H_s from normally applied values of 0.1 - 0.15 m to a maximum value of 0.25 m. In many cases, however, such an increase will result in a break-through of the fabric supported mat of retained material - indicated in the diagram of fig. 30 by a sudden fall-off from the straight-line relationship - again lowering effluent quality.

The straining capacity can also be increased by choosing a larger drum area. With a diameter D and width B, the gross area of the drum equals πDB and varies in practice from

minimum D = 0.75 m, B = 0.5 m , $\pi DB = 1.2\ m^2$
maximum D = 3 m, B = 3 m , $\pi DB = 28\ m^2$

The net area of the fabric is about 10% smaller, while with 60 - 65% submergence the value of p is about 0.6. Best results are obtained when the size of the drum, respectively the number of drums in larger installations, is chosen such as to ensure that under normal circumstances satisfactory operation is obtained at low to average speeds and with a normal head loss. This leaves the possibility of increasing drum speeds and allowing a larger head loss for periods of deteriorating raw water quality.

5. Construction, operation and application of micro-strainers

As described in the preceding section, a micro-strainer is a revolving drum strainer - operating under open gravity conditions in a rectangular tank, usually made of reinforced concrete, occasionally of steel. Microstrainers were develloped by the firm of Glenfield and Kennedy Ltd, Hydraulic Engineers in Kilmarnock, Scotland. Their construction is shown schematically in fig. 32, where in principle two parts can be distinguished

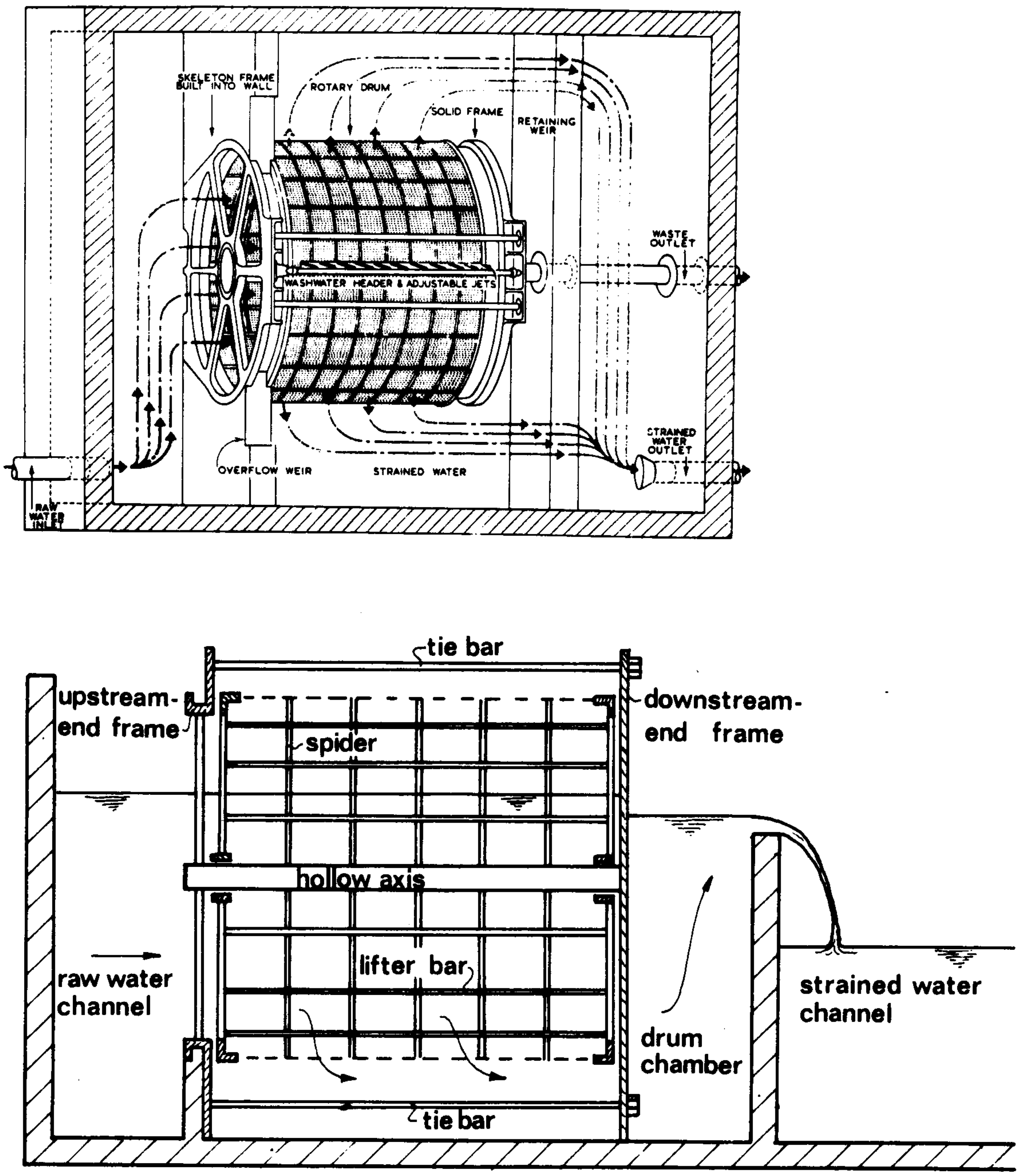


Fig. 32 Schematic construction of micro-strainers

a. a stationary part, consisting of the upstream and downstream endframes, interconnected by a hollow axle and 4 tie bars. The upstream endframe is fitted with a spoked wheel, providing large segmental openings and is built into the concrete or other division wall between the raw water channel and the drum chamber. The downstream endframe is blanked off by plating and the water pressure acting upon it is transmitted by the tie bars to the upstream endframe and the division wall;

b. a rotating part, consisting of two open endframes, supported on the hollow axle by ball and roller bearings and interconnected by lifter bars, stiffened with circumferential strips and spiders when necessary. In this way a cage is constructed (fig. 33) over which the micro-mesh fabric is stretched and fastened down by metal strips. The running clearence between the stationary and rotating parts is closed by adjustable felt-lined sealing bands, spring loaded to resist the differential head of water across the drum.

The actual work of the micro-strainer is done by the micro-mesh fabric, which must satisfy the contradictory requirements of providing on one hand fine openings, capable of matting and on the other hand an as large mechanical strength as possible. The original

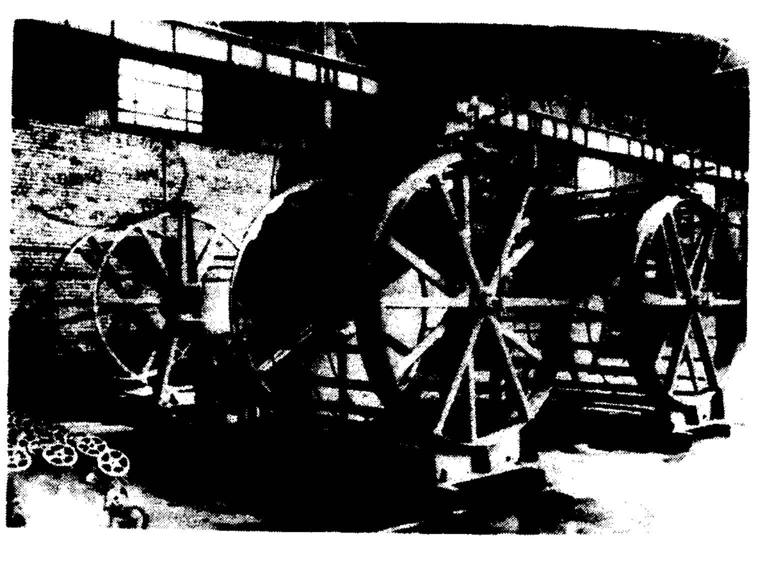


Fig. 33 Micro-strainer body.

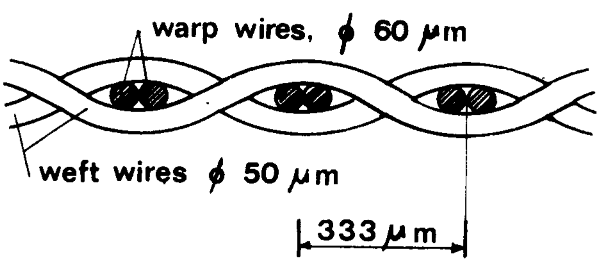
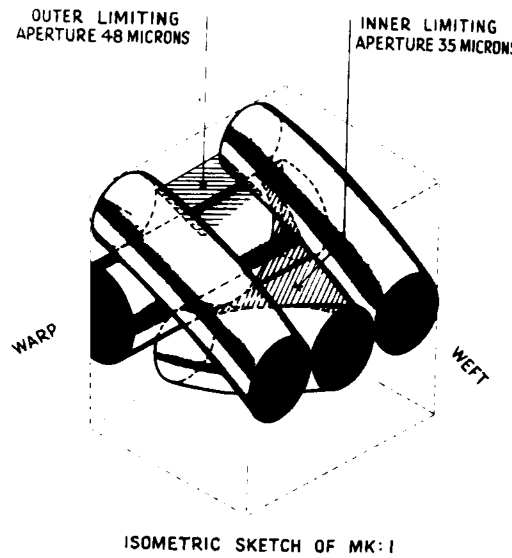


Fig. 34 Construction of Mark I micro-mesh fabric.



construction (mark I fabric) is shown in fig. 34 and consists of stainless steel wires with diameters of 50 and 60 μm, woven in special manner with 3 pairs of warp wires and 20 weft wires per mm, giving per mm² 135 openings with an inner limiting aperture of 35 μm. Nowadays 3 types of fabric are available

mark	0	I	II
size of opening in μm	23	35	60
number of openings per mm²	231	135	92
percentage open area	35.0	40.6	57.6

Notwithstanding the particular way of weaving, the micro-mesh fabric is still quite delicate. For additional mechanical support it is therefore sandwiched between square woven coarse mesh stainless steel wire cloth, pinned together by stainless steel screws, nuts and washers and fastened to the drum cage by longitudinal and circumferential straps (fig. 35). Stainless steel in the meanwhile has water repel-

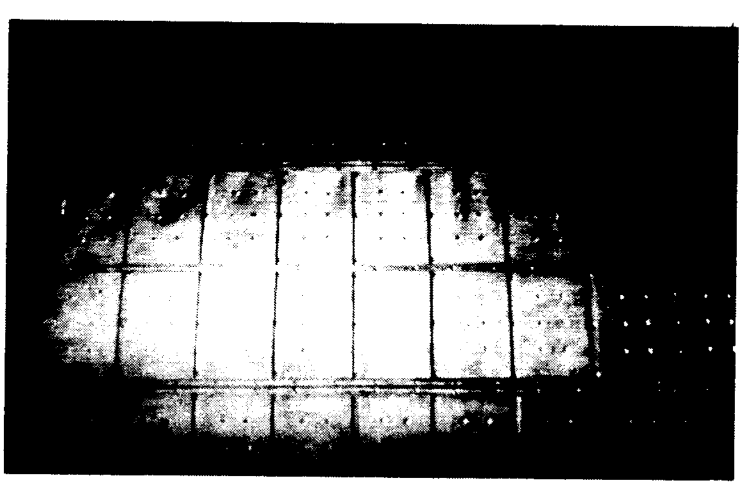


Fig. 35 View on micro-mesh fabric.

lent properties. To prevent entrainment of air by the backing fabric with the air blanking off large areas of the drum, seriously reducing the capacity, this fabric must be made from dull wires with openings of at least 2 - 2.5 mm or other materials such as monel metal must be used for its construction. In case clogging of the sandwich by filamentous algae is anticipated, the inner supporting fabric can be left out.

During operation the raw water enters the drum axially through the open frame at the upstream end, turns 90° and passes the micromesh fabric radially from inside to outside the drum. The strained water leaves the drum chamber over a fixed weir, the level of which is chosen such that the drum is submerged for about 60% of its diameter The drum is rotated by an electric motor, through worm-and-spur reduction gearing and speed-change gearbox, terminating in a pinion which meshes with a large spur-ring bolted to one side of the drum. Speeds measured on the drum periphery vary between 0.05 and 0.5 m/sec, higher as the diameter is larger. The number of revolutions is between 0.5 and 5 per minute, for which an electric input of 1 kW is always sufficient.

During operation the micro-strainer is cleaned continuously, using a row of wash-water jets over the full width of the drum (fig. 36). The wash-water nozzles are adjustable and self-cleaning and

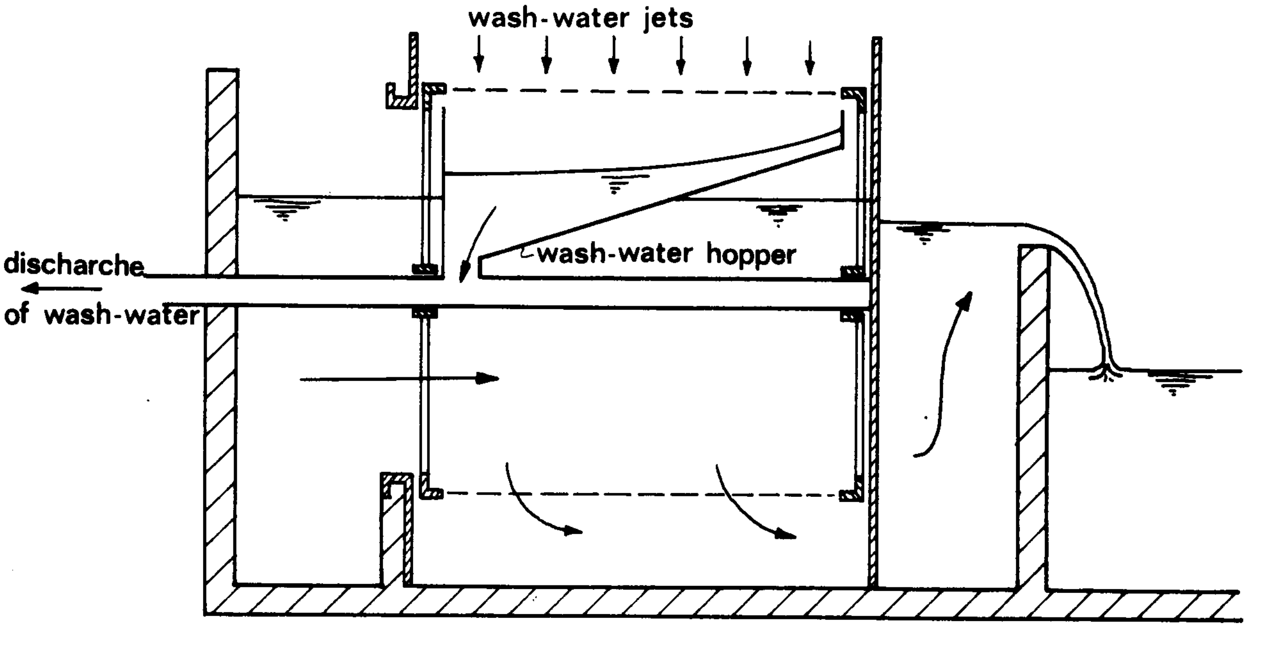


Fig. 36 Continuous hydraulic cleaning of micro-strainers.

designed for producing a thin continuous vane of water (fig. 37 left), which strikes vertically downward through the fabric, thus washing away the retained material from the inside of the drum into the waste water hopper and away through the hollow axle (fig. 36 and 37 right). Solids which do not adhere to the fabric are picked up by longitudinal bars inside the drum and are again deposited into the waste hopper. Preferably filtered and chlorinated water should be used for back-washing, with a jet pressure of 3 to 7 m watercolumn, depending on local circumstances and in an amount of 0.5 - 1.5% of the volume of water strained. This low-pressure back-washing in the meanwhile is only possible by the presence of the outer backing fabric

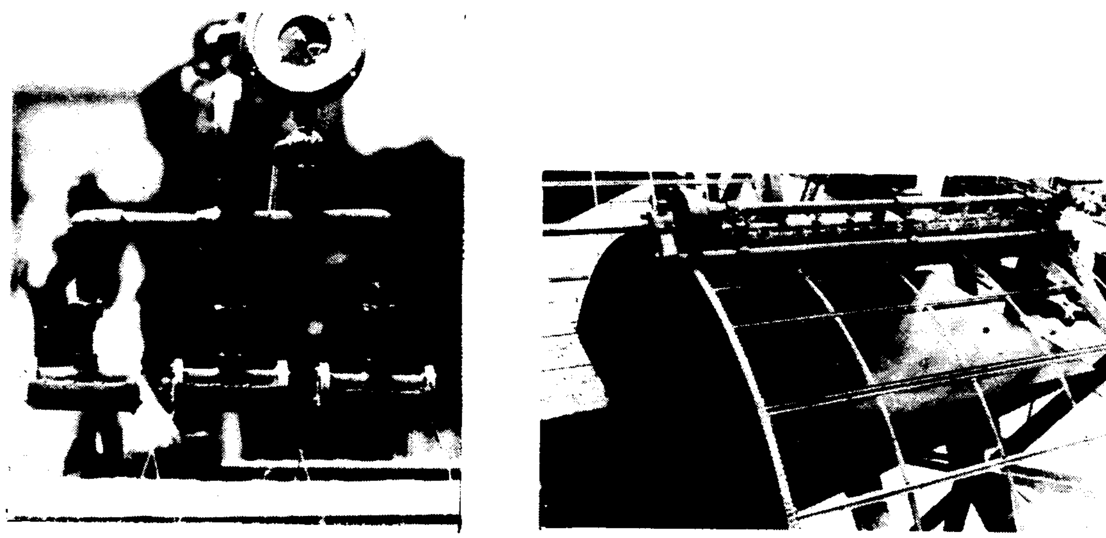


Fig. 37 Wash-water jets and waste-water hopper.

described above, which assures that the micro-mesh fabric below the wash-water nozzles is immersed in a nappe of retained water, in this way breaking down the surface tension which would otherwise deflect the wash-water jets sideways, preventing them from penetrating and cleaning the micro-mesh fabric. To keep the wash-water from splashing over the machine, the wash-water jets are covered by a plastic shield (fig. 38). In case the wash-water supply fails or the drum stops, a continuous clogging of the micro-mesh fabric will occur. Excess differential pressures which might damage the fabric can be avoided by providing the division wall between raw water inlet and the drum chamber with a weir (fig. 32), in this way limiting the upstream water level. Bacterial slimes are difficult to remove by back-washing alone and when they occur a blinding of the fabric and reduced flow capacity will result. Bacterial slimes can be destroyed by washing the strainer drum with a strong chlorine solution at intervals of one to a few weeks, but their occurence can also be prevented by equipping the micro-strainer with high-intensity ultra-violet lights (fig. 39).

From the description given above, it will finally be clear that corrosion is a serious danger to micro-strainers. The selection of suitable high-quality materials in conformity with the best water engineering practice is therefore of the utmost importance.

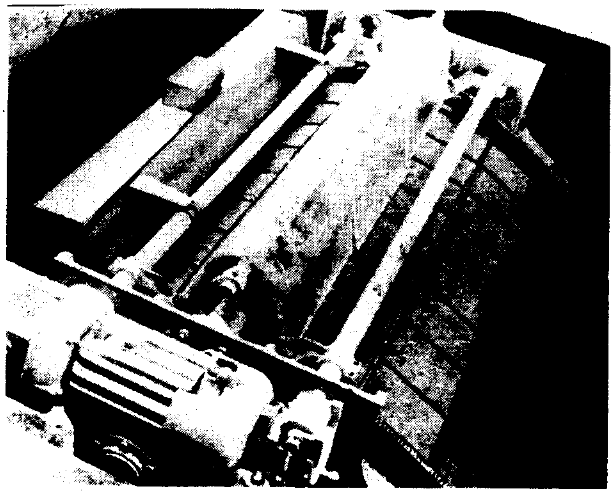


Fig. 38 Plastic shield covering wash-water jets to prevent splashing.

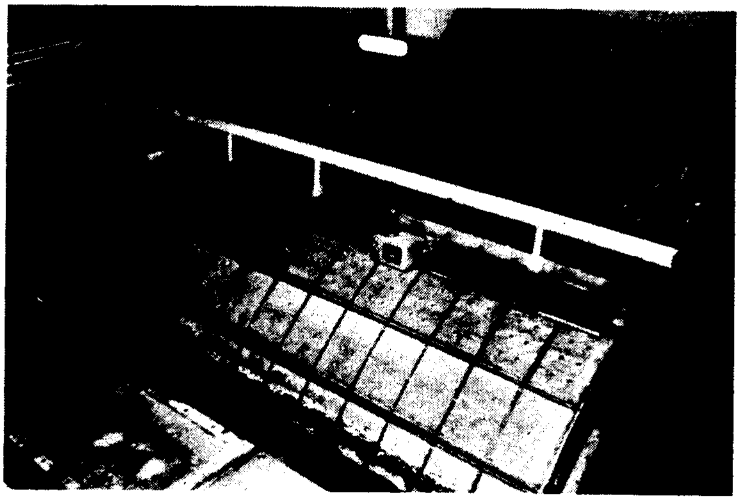


Fig. 39 Ultra-violet light radiation to control bacterial growth.

Micro-strainers were develloped thirty years ago as treatment preceding slow sand filters, to increase their capacity and/or length of filterrun. In this respect micro-strainers compete with rapid or primary filters, giving a solution much cheaper in cost of construction and operation, while also space requirements and head-losses are appreciably reduced. On the other hand, however, their action is entirely mechanical, removing particulate suspended matter such as sand, silt and algae, but there is no change in the chemical characteristics of the water. Micro-strainers are unable to remove colloïdal matter and color, ammonia and dissolved organic impurities, nor is there any marked decrease in the number of bacteria. With regard to the speed of clogging and the ensuing flow resistance, they are unfit for the treatment of heavily silted river waters.

In public water supply practice of to-day, micro-strainers are still used to lighten the load on subsequent slow filters and next to this on subsequent rapid filters, in particular when the raw water is heavily loaded by algae. These algae may also greatly disturb the process of coagulation, flocculation and sedimentation and again here preceding micro-strainers may be used to advantage. To remove the carry-over of coagulant flocs from settling tanks, micro-strainers are not well suited. When the flocstrength is large, the clogging of the fabric will be too rapid and when the floc strength is small, the efficiency too low, the coagulated matter flowing like water through even minute apertures in the fabric. In exceptional cases, the raw water is still so fair and unsullied that it can be distributed as drinking water without filtration. For safety's sake such waters must be sterilized, while micro-straining is now sufficient to keep back the little amount of debris and a sparse population of living organisms. For many industrial processes a first quality drinking water is not required and there micro-straining can be used even when the raw water contains color and colloïds. The same applies when micro-strainers are used to provide primary filtration prior to infiltration through natural sand formations in the process of artificial recharge.

Also in the field of sewage and industrial waste treatment, micro-straining may be of great value. With regard to the rapid clogging of the extremely fine openings, however, it may only be used as a primary treatment when the water to be handled is not more than lightly contaminated, as often is the case with industrial effluents. Here it may even be the sole process to which the water is subjected. With more contaminated trade wastes, micro-straining can be used for polishing the water, after a primary treatment by other means. The same holds true for the treatment of municipal sewage, where micro-strainers are used after the secondary settling tanks following trickling filters or the activated sludge process, to lower the suspended solids content and the bio-chemical oxygen demand of the effluent, in this way reducing the contamination of the receiving waters.

6. Principles of pre-coat filtration

As elaborated in the preceding sections, the efficiency of micro-straining is greatly enhanced by the building-up of a matt of retained material on the fabric. This also means, however, that especially with larger mesh-sizes and cleaner water, better results could be obtained by pre-coating the micro-fabric with inert powdered or fibrous material. In this way the actual work of clarification is done by the pre-coat, acting as a filter, while the fabric now only serves to retain and support the pre-coating materials. With moving strainers, this pre-coat would be washed away and lost after every revolution, increasing the cost of operation and interfering with the disposal of wash water. In some cases this is not objectionable, for instance not when asbestic or cellulose fibres are recovered from the wash-water and re-used, but in many other instances a more satisfactory solution is obtained with stationnary filters. These stationnary pre-coat filters operate in the same way as a conventional slow sand filter, but the filtering material is finer and the filtration rates are higher, both factors resulting in a much more rapid clogging. After reaching the maximum allowable head loss, the filter media into which is embedded the suspended matter removed during filtration is again discharged to waste and the supporting medium re-precoated to ready it for further work.

The rapid clogging of stationnary pre-coat filters could be retarted and the length of the filtering cycle greatly increased by adding during filtration a small continuous dose of filtering material (filter aid) to the raw water, in addition to the initial coating of the filter elements. With this body-feeding as it is called, the suspended solids in the raw water do not penetrate the pre-coat, reducing its porosity and permeability, but together with the filter aid they build up a cake of adequate porosity and permeability (fig. 40). The

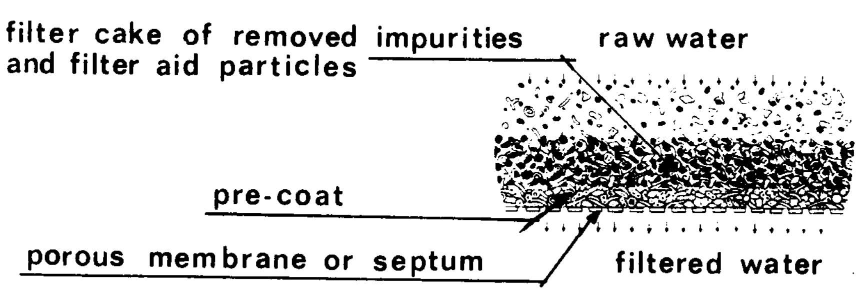


Fig. 40 Pre-coat filtration with body-feed.

increase in resistance now results from a growing cake thickness with time, again necessitating a periodic cleaning, but the lengths of filterrun are much longer, allowing the use of a more turbid raw water. The construction of a pre-coat filter with body-feed is shown schematically in fig. 41. At the beginning of the filterrun, the pre-coat is formed on a porous membrane or septum, supported in one way or another, while during filtration the cake of filter-aid particles and retained solids is built up. After reaching the maximum allowable thickness and resistance, both pre-coat as filter cake are washed away and the process begins anew.

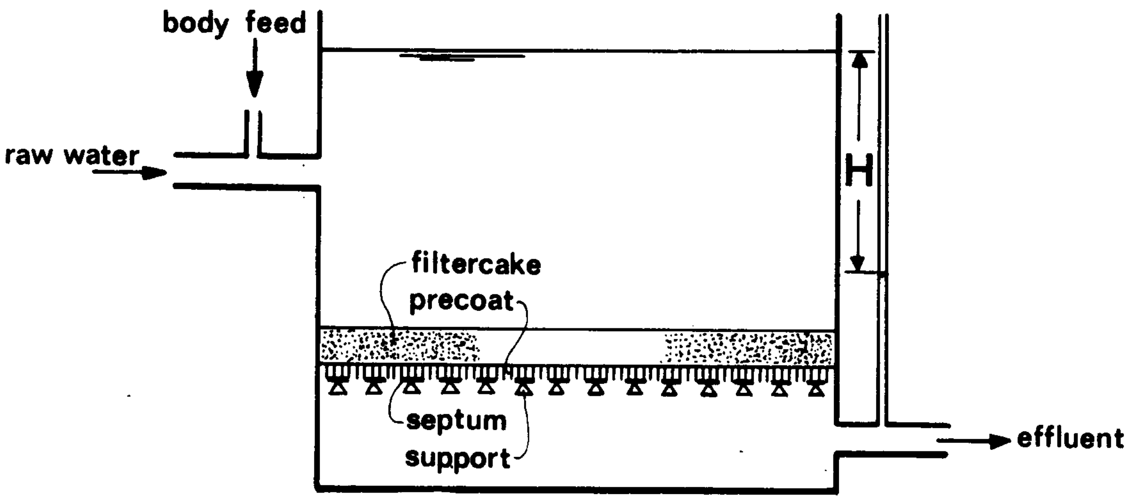


Fig. 41 Schematic diagram of pre-coat filter with body feed.

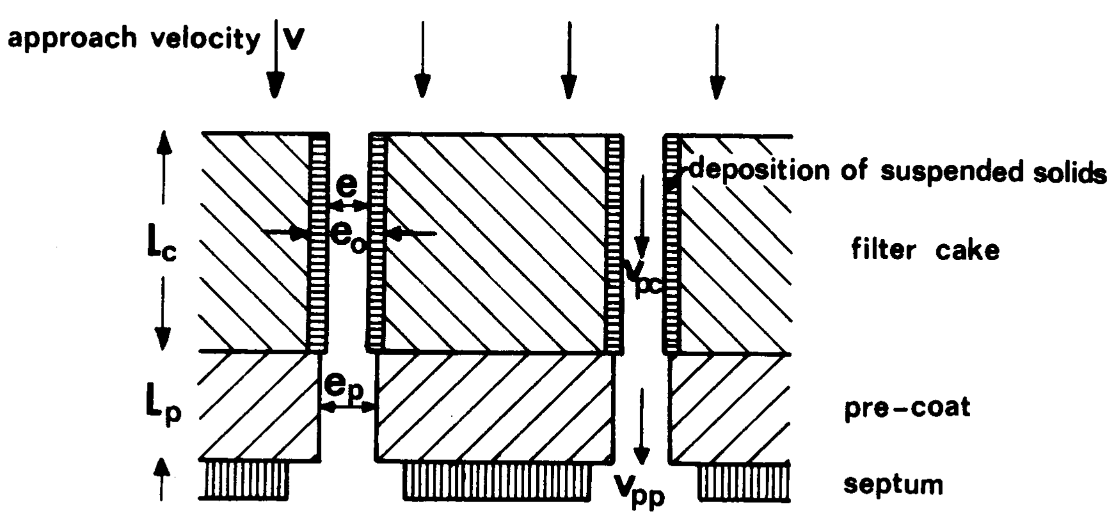


Fig. 42 Model for clogging of a pre-coat filter with body feed.

To derive a mathematical formulation of the filtration process described above, the model of fig. 42 will be considered. Three parts may be distinguished here, the septum, the pre-coat and the filter cake, each with its own resistance against the passage of water. For the septum this resistance is due to losses of friction and turbulence. The latter losses are proportional to the square of the velocity, but with the low rates and small openings commonly applied the friction losses follow the linear resistance law of laminar flow. Together

$$H_s = av + bv^2$$

with a and b depending on the construction of the septum. Next to this, the factor a will vary with the viscosity, that is with the temperature of the water. With H_s small, usually not more than 0.05 m watercolumn (including the resistance of the septum support), this variation may safely be left out of consideration.

The pre-coat is built up of filter-aid material to which sometimes other substances as for instance asbestos fibres are added to speed up its formation . In fig. 42 it is assumed that this coat has n openings of length l_p and diameter e_p per area A and that no clogging occurs. Poiseuille's law for laminar flow in capillary tubes now gives as resistance

$$H_p = \frac{32\nu}{g} l_p \frac{v_{pp}}{e_p^2}$$

with ν as kinematic viscosity of the water, g as gravity constant and v_{pp} as actual velocity of the water inside the pores. With v as approach velocity (capacity per unit area)

$$vA = v_{pp} \, n \, \frac{\pi}{4} e_p^2 \qquad \text{or}$$

$$H_p = \frac{128\nu}{\pi g} \frac{A}{n} l_p \frac{v}{e_p^4} = \frac{v \, l_p}{k_p}$$

with k_p as coefficient of permeability depending on the structure of the pre-coat, that is on the material applied, and on the viscosity of the water.

In case the filter cake is built up with clear water and no clogging occurs, its resistance is similar to that of the pre-coat

$$H_c = \frac{v\, l_c}{k_c}$$

The thickness l_c, however, is not constant but increases as filtration goes on. With c_a as gravimetric concentration of the filter aid material added continuously to the incoming water and $\gamma_a c_a$ as its volumetric concentration when building up the filter cake, fig. 42 gives as account for this material

$$v\gamma_a c_a tA = l_c (A - n \tfrac{\pi}{4} e_o^2) \qquad \text{or}$$

$$l_c = v\gamma_a c_a t \frac{A}{A - n \frac{\pi}{4} e_o^2} = v\gamma_a c_a t \frac{1 + \alpha}{\alpha}$$

with α as a positive number. Substituted

$$H_c = \frac{1 + \alpha}{\alpha} \frac{v^2 t\, \gamma_a c_a}{k_c}$$

When filtering turbid water, clogging of the filter cake will occur, reducing the diameter of its pores from e_o to e and increasing the resistance to

$$H_c' = H_c \left(\frac{e_o}{e}\right)^4$$

With c_s as gravimetric and $\gamma_s c_s$ as volumetric concentration of suspended matter retained by the filter cake

$$v\gamma_s c_s\, t\, A = l_c\, n \tfrac{\pi}{4} (e_o^2 - e^2)$$

from which follows

$$\frac{e^2}{e_o^2} = 1 - \frac{v\, \gamma_s c_s\, tA}{l_c\, n \frac{\pi}{4} e_o^2}$$

or with the value of l_c calculated above

$$\frac{e^2}{e_o^2} = 1 - \frac{A - n\frac{\pi}{4}e_o^2}{n\frac{\pi}{4}e_o^2}\frac{\gamma_s c_s}{\gamma_a c_a} = 1 - \alpha\frac{\gamma_s c_s}{\gamma_a c_a}$$

Substituted

$$H_c' = \frac{H_c}{\left(1 - \alpha\frac{\gamma_s c_s}{\gamma_a c_a}\right)^2}$$

and with the value of H_c

$$H_c' = \frac{1 + \alpha}{\alpha}\frac{v^2 t}{k_c}\frac{\gamma_a c_a}{\left(1 - \alpha\frac{\gamma_s c_s}{\gamma_a c_a}\right)^2}$$

For a better understanding of this formula, the ratio

$$n = \frac{\gamma_a c_a}{\gamma_s c_s}$$

may be introduced. Substituted

$$H_c' = \frac{1 + \alpha}{\alpha}\frac{v^2 t}{k_c}\gamma_s c_s\frac{n^3}{(n - \alpha)^2}$$

That is to say a resistance which increases linearly with time and which is proportional to the first power of the suspended solids content c_s and to the second power of the filtration rate v. The influence of the ratio n between body feed and suspended solids content is more difficult to evaluate. Differentiation of H_c' to n yields

$$\frac{\delta H_c'}{\delta n} = \frac{1 + \alpha}{\alpha}\frac{v^2 t}{k_c}\gamma_s c_s\left\{\frac{3n^2}{(n - \alpha)^2} - \frac{2n^3}{(n - \alpha)^3}\right\}$$

$$\frac{\delta H_c'}{\delta n} = H\frac{n - 3\alpha}{n(n - \alpha)}$$

According to this formula , an increasing body feed will lower the resistance as long as

$$\alpha < n < 3\alpha$$

which operating conditions should therefore be preferred when possible.

With the many unknown factors in the meanwhile, the calculation given above is of theoretical value only. In practice another approach is commonly used, writing the flow resistances as

$$H_p = \frac{C_a v}{K_p}, \qquad H'_c = \frac{c_a v^2 t}{K_c}$$

with C_a as the mass of the filter aid in the pre-coat in grams/m^2, c_a as the body feed rate in grams/m^3 and K_p and K_c in gram/m^2/sec as constants to be determined by experiment. The constant K_p only depends on the pre-coat material, having for instance values of 15 - 50 gram/m^2/sec for diatomaceous earth , depending on the grade applied. Next to this, the value of K_c varies with the amount and nature of the suspended solids to be removed. With diatomite filtration of aerated, iron containing water, this relation will roughly equal

$$K_c = (0.001 - 0.003)\left(\frac{c_a}{c_s}\right)^{1.8-2.2}$$

with the constants depending on the grade of diatomaceous earth to be applied. In this case the resistance of the filter cake equals

$$H'_c = (300 - 1000)\,\frac{c_s^{\,1.8-2.2}}{c_a^{\,0.8-1.2}}\,v^2 t$$

that is to say a smaller resistance as the body feed rate is higher!

7. Construction, operation and application of diatomite filters

In pre-coat filtration, the essential part is the filter element, consisting of a supporting member over which the septum is stretched. The actual work of clarification, however, is carried out by deposits of filtering material on this septum, sub-divided in the pre-coat formed prior to filtration and the filter cake build up during filtration (fig. 41). As filtration goes on, the thickness and flow resistance of the filter cake increase continuously untill the maximum allowable head loss is reached. Pre-coat and filter cake with the retained solids from the raw water are then sloughed off and the septum cleaned by back-washing.

Pre-coat filtration may be carried out with various materials, such as Perlite, cellulose powders, cellulose and asbestos fibres, etc, but in the field of public water supplies diatomaceous earth is almost used exclusively.

This natural material consists of the silicious remains of diatoms (fig. 43) and can be found in many places all over the world. After

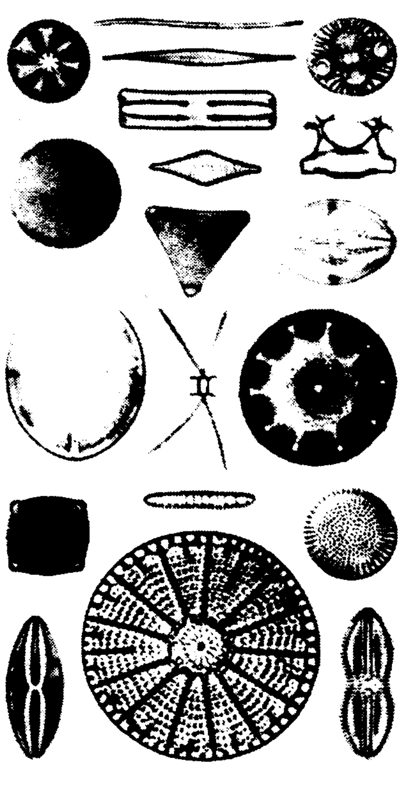


Fig. 43 Silicious skeletons in diatomeceous earth.

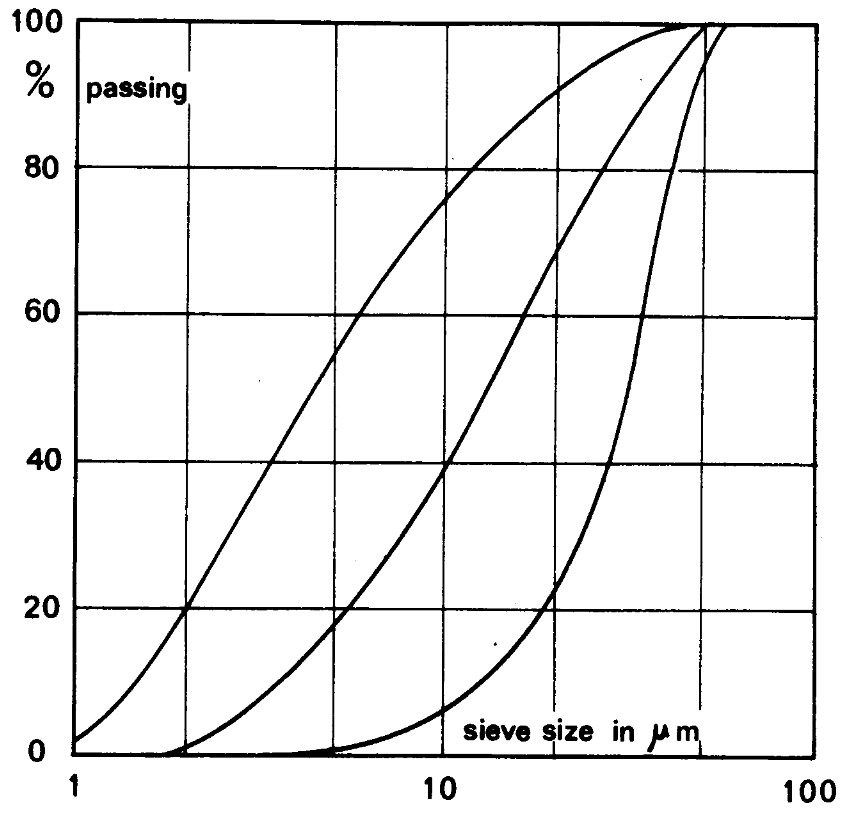


Fig. 44 Diatomite grades.

excavation it is dried, grinded, sometimes calcined and then separated by screening into the various diatomite grades commercially available (fig. 44). Which grade must be used in a particular case, depends on local circumstances, on the amount and nature of the suspended impurities to be removed and on the desired clarity of the effluent. With a fine grade an exceptional clear water can be obtained, but with coarser grains the length of filterrun will be larger, also allowing the use of a more turbid raw water. Due to its composition of about 90% SiO_2, 4% Al_2O_3 and other oxydes for the remaining part, diatomite is chemically inert. The true mass density amounts to 2600 kg/m^3, but with a pore space of for instance 93%, the apparent mass density is only 180 kg/m^3.

The septum for supporting the diatomite can be made in different ways, from finely woven wire cloth or synthetic fabrics, from closely spaced wire wrappings and from porous materials such as sintered metal or aluminium oxyde grains. Under all circumstances it must be resistant against corrosion and not liable to fouling, requirements which are best fullfilled by stainless steel fabrics of parallel wires with long narrow openings and a width of 125 μm or less. These openings are still so large that in many cases all the diatomite is able to pass, requiring bridging (fig. 45) to build up the pre-coat. This

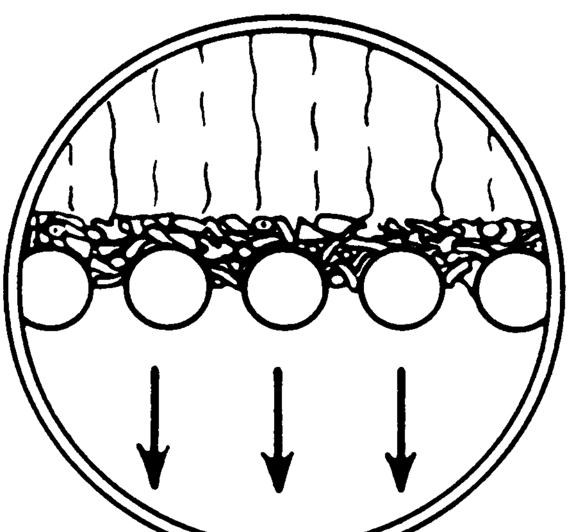


Fig. 45 Bridging to built up the pre-coat.

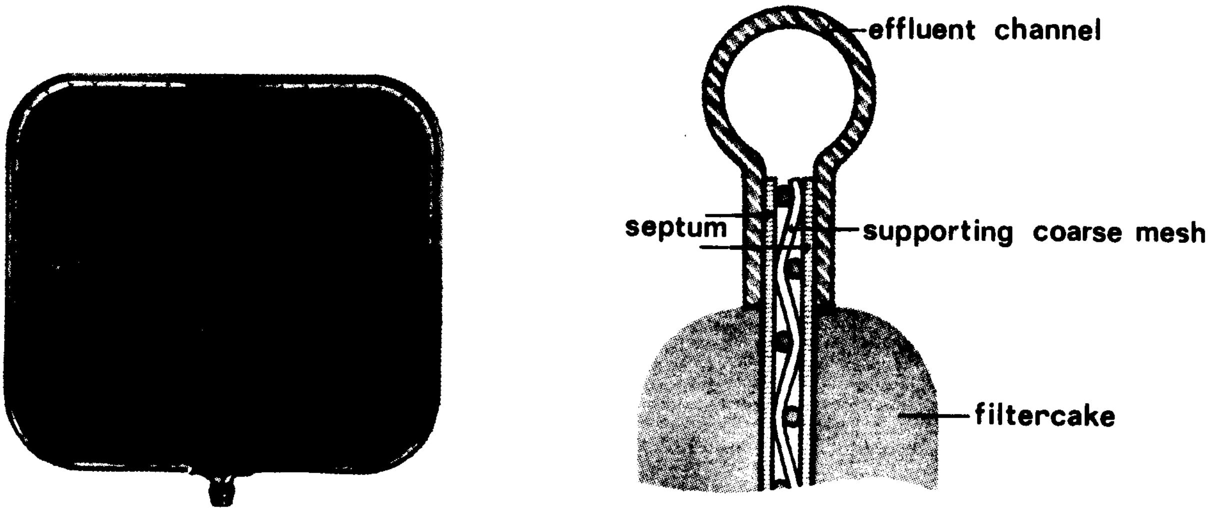


Fig. 46 Filtering leaf.

process takes much time, but it can be accelerated by the addition of coarser diatomite grains or asbestos fibres to the pre-coat material. Commonly the pre-coat contains 500-700 grams of diatomite per m^2 of septum, giving a thickness of about 3 mm, a coefficient of permeability roughly equal to $(0.1)10^{-3}$ m/sec and with a normal filter rate of $(1)10^{-3}$ m/sec, a flow resistance of a few cm's water column only.

The member supporting the septum must be rigid and sufficiently strong to prevent disturbing the filter cake when during filtration its weight and flow resistance increases. The actual construction of the supporting member depends on the shape of the filter elements to be applied. Leaves as shown in fig. 46 are rarely used in public water supply practice and here the cylinders of fig. 47 are more

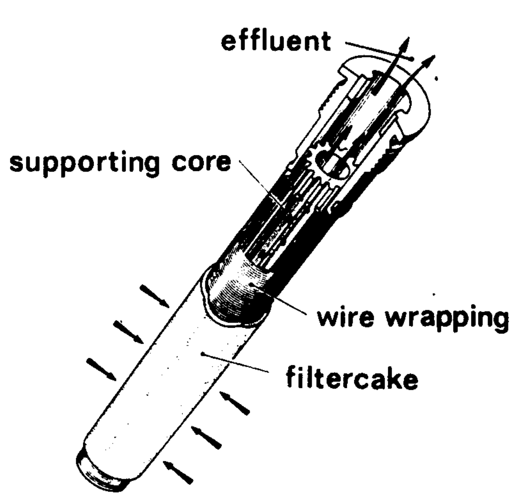


Fig. 47 Filtering candle.

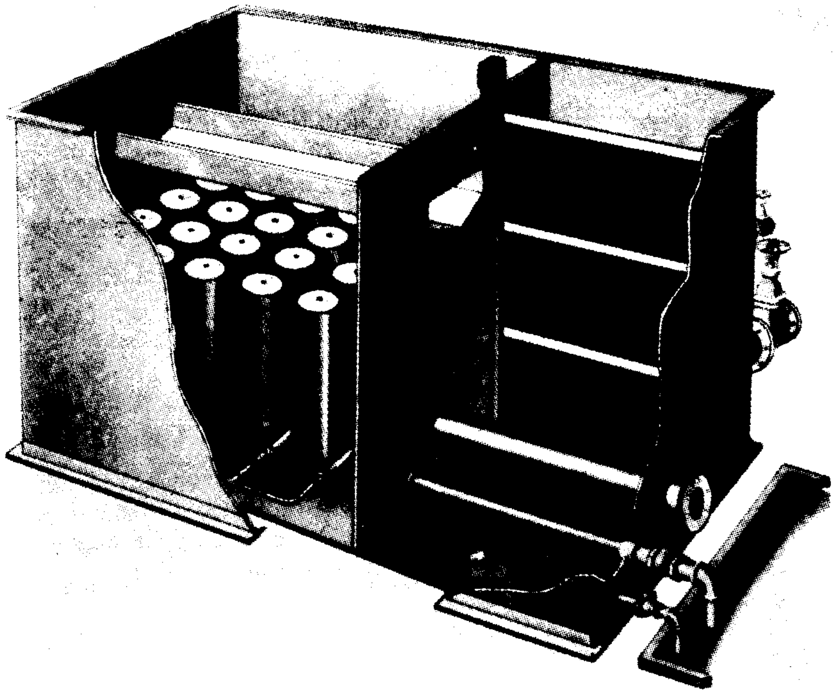


Fig. 48 Gravity filters operated by suction.

popular. Essentially they consist of a hollow, fluted and perforated core, often made of ceramics, wound with stainless steel wire as septum, providing continuous openings of any desired width. Next to the requirements of structural strength and corrosion resistance, the core must have good drainage characteristics, keeping the hydraulic resistance including the septum below 0.05 m.

With gravity filtration, the filtering elements are contained in a box, made of concrete or steel. With regard to the high losses of head accompanying continued filtration, such open filters are often operated by suction. If this is indeed necessary, a better solution can be obtained by accommodating the filtering elements in a watertight steel shell and forcing the water through under pressure (fig. 49). With regard to the built-up of the filter cake to a thickness of 10-40 mm and to provide easy access for the raw water, without excessive velocities of flow which might endanger the cake by erosion, the filtering elements must be set at adequate distances, with openings in-between of at least 50-100 mm. This still allows a large filtering area in a limited volume, giving even with small vessels and low rates of flow a high capacity and an enormous saving in weight and cost compared to ordinary rapid filters. The installation in the meanwhile

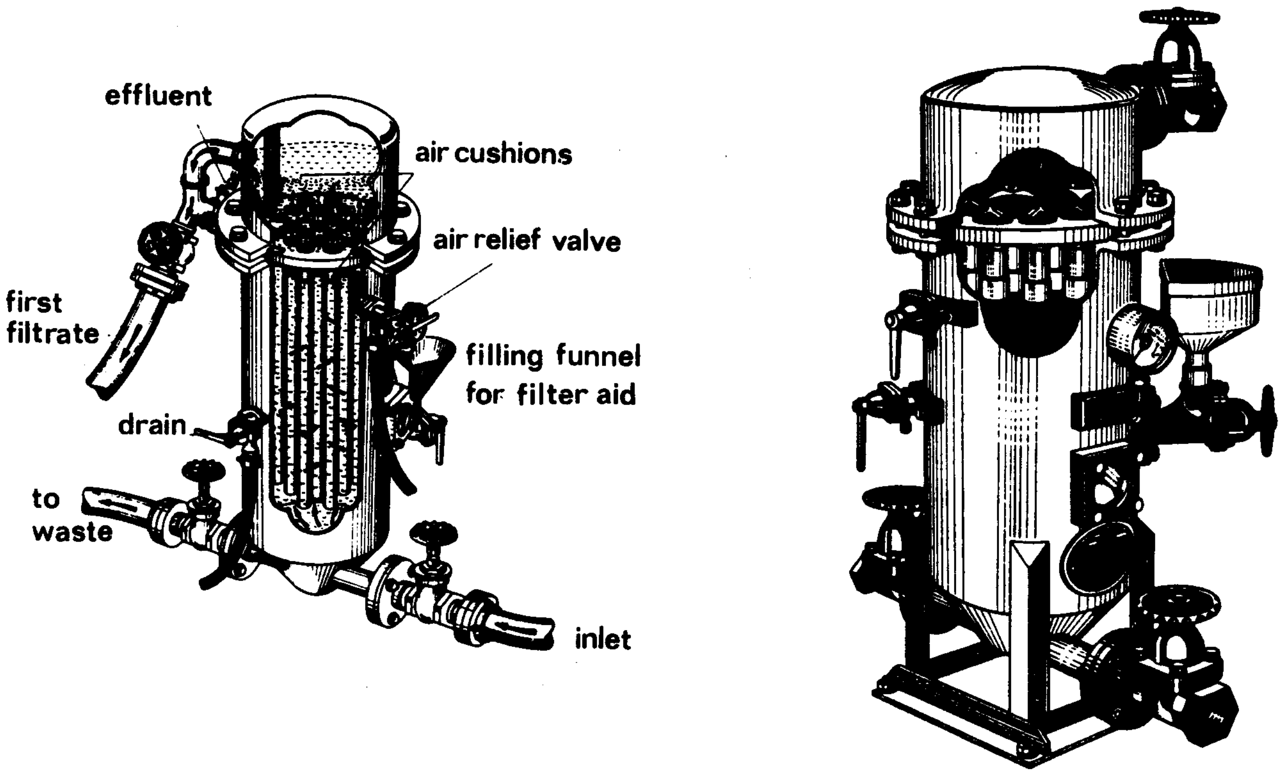


Fig. 49 Pressure filters.

is not complete with the diatomite filter alone, various accessories are still needed, in particular those to provide the body feed for building up the filter cake and pre-coat. Schematically the full installation is shown in fig. 50, while fig. 51 presents the filter aid feeder system in greater detail.

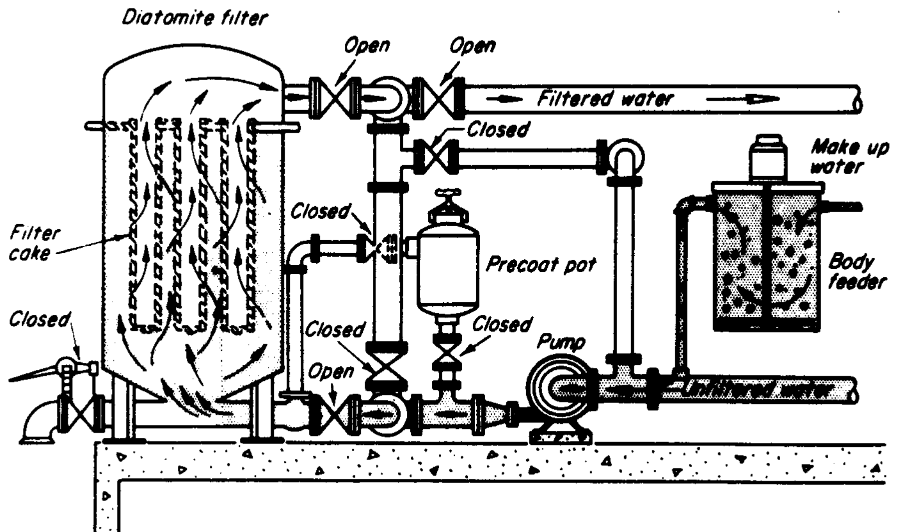


Fig. 50 Flowing through diagram of a diatomite filter.

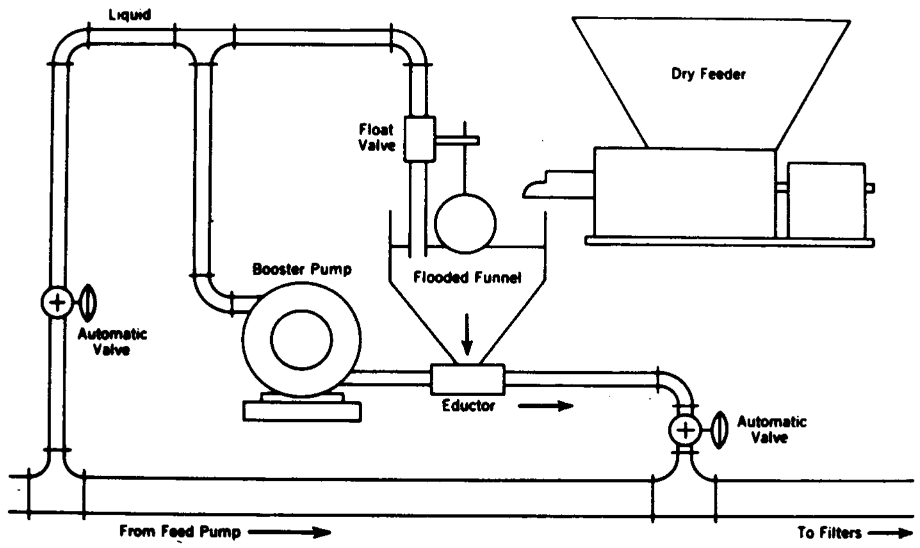


Fig. 51 Diagram of a filter aid feeder system.

Operation of a diatomite filter starts by applying the pre-coat. In a pressure vessel with detachable lid, the amount of diatomite necessary to prevent fouling of the septum, about 500-700 grams per m^2 is inserted and mixed with water to a slurry. After closing the lid and adjusting the various valves, filtered water from the pressure pump (fig. 50) flushes this slurry to the filter. In first instance a major part of the diatomite will pass the septum openings, leaving the filter through the discharge valve and flowing back to the suction side of the pump and from there again to the filter. After some time of re-circulation, however, the pre-coat will have been formed to the required extend, that is to say able to produce a clear effluent. The various valves are now reset, allowing raw water to be pumped directly to the filter and from there to the filtered water conduit. During this process of filtration, additional diatomite in amounts of 10-20, in exceptional cases 50-100 grams/m^3 is added as a slurry to the raw water, preventing a clogging of the pre-coat and together with the retained suspended solids building up a rigid, porous but retentive filter cake of ever increasing thickness and flow resistance. After reaching the maximum allowable head loss the filtration process is stopped, pre-coat and filter cake drop to the bottom of the filter shell and the septa with supporting members are cleaned by back-washing and by spraying with powerful water jets. In drinking water practice the spent material is usually discharged to waste, but in other applications it is re-used, up till 5 or 10 times, giving an appreciable saving in the cost of operation. For the purification of drinking water, normal filtration rates (capacity per unit area of septum) are (0.7 - 2)10^{-3} m/sec. The resistance increases linearly with the amount vt of water filtered and for the same rate will be lower as the body feed rate is higher (fig. 52). With pressure filters maximum allowable head losses vary between 5 and 15 m watercolumn, giving lengths of filterrun of 10-50 hours with ultimate cake thicknesses of 10-40 mm. Notwithstanding all precautions, including air-wash, fouling of the septa is difficult to prevent and a reduction of the effective open area by 5% after 100 cycles of operation is commonly allowed. Sometimes better results can be obtained with expendable septa, but still they must be constructed and operated in such a way, that renewal within one year of continuous operation is not required.

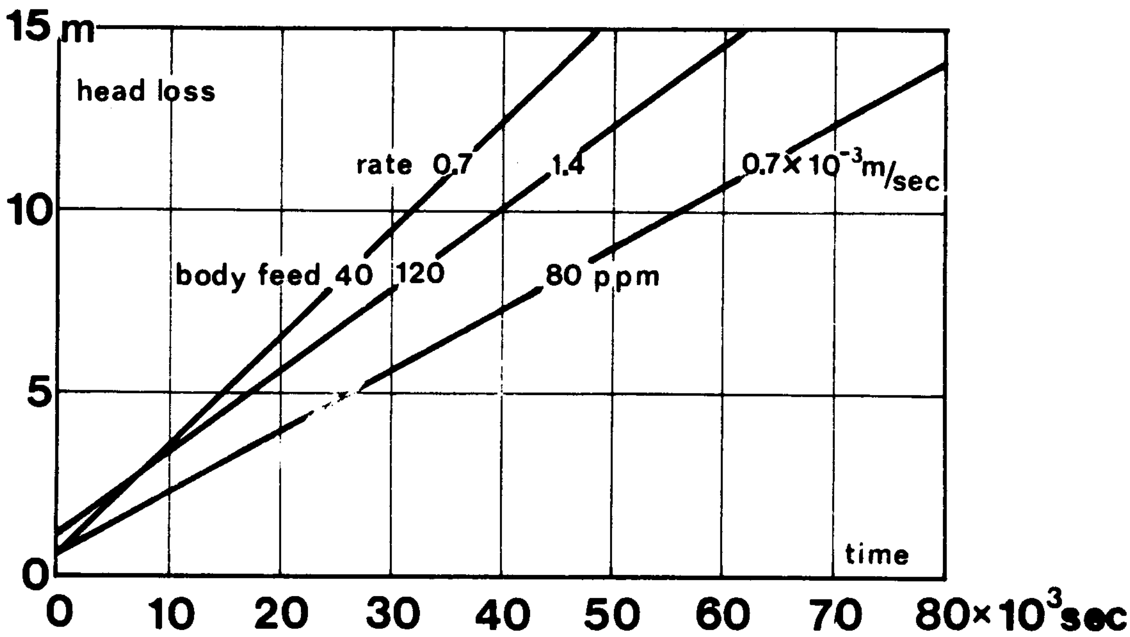


Fig. 52 Diatomite filtration of groundwater containing 7-8 ppm Fe.

Diatomite filtration is a purely physical process, in principle only removing particulate matter from the raw water. With the small grain sizes(fig. 44) and keeping in mind the ratio between pore and grain diameters (fig. 26), they are very effective in this respect, removing suspended particles with sizes larger than 0.1-1 μm, depending on the diatomite grade applied. This not only results in an effluent of extreme clarity, but it also means a nearly 100% removal of coli-bacteria, having dimensions of 1-5 μm, and a water safe in bacteriological respect. Moreover, these results are obtained immediately after filtration starts, without the need of a breaking-in period, while the regular disposal of the filtering materials prevents a persistant clogging of the filterbed. Indeed, chemical and biological actions are absent, but taste and odor producing substances may still be removed by adding powdered activated carbon to the body feed. Colloïdal particles with sizes of 0.001-1 μm are only partly removed by diatomite filtration. If this results in a too high color of the effluent, improvement may be obtained by providing the diatomite particles with an electro-positive coating of aluminium or ferric hydroxyde.

Diatomaceous earth filtration has already been applied for many decades in the food industry, for the clarification of sugar and fruit juices, wine, vinegar, beer, etc. For similar purposes it is used in the chemical, petro-chemical and pharmaceutical industry while an interesting application concerns the de-oiling of high pressure boiler feed water. In the field of drinking water supply, diatomite filtration was first used during the second world war to provide the American soldiers with a reliable water, in particular free from Entamoeba histolytica cysts which cannot be inactivated by chlorination. There they also offered the adventage of a large capacity in a small volume, especially when higher filtration rates of $(2 - 5)10^{-3}$ m/sec are applied. Today a small number of diatomite filters can be found in municipal plants. From the foregoing description it will be clear that in technical respect they are excellently suited for the sole treatment of aerated, iron and manganese containing groundwaters or rather clear surface waters and for the final treatment of more turbid water after chemical coagulation or lime-soda ash softening. Although not strictly neccessary, the effluent of diatomite filters treating surface water is often subjected to safety chlorination. With the extreme clarity of the effluent, the dose required is commonly low, 0.1-0.3 ppm. With regard to the cost of filtration, a subdivision must be made between those of construction and operation. Diatomite filters are low in first cost, about half that of a rapid filtration plant, but the operating costs are much higher. All-together, a diatomite filtration plant is more expensive to run than a plant containing rapid filters, limiting their use to small capacity supplies, for instance less than 0.05-0.1 m^3/sec, to emergency and stand-by services and to periods of peak consumption. As mentioned before, diatomite filters are excellently suited for those part-time duties, the effluent satisfying all quality requirements as soon as the pre-coat is formed. They can also be used to advantage where space is at a premium. In the field of water treatment, however, their greatest application is still the purification of water for swimmingpools, giving a visibility much better than that of ordinary good quality drinking water. With higher filtration rates, $(1.5\text{-}2)10^{-3}$ m/sec and re-using the filter aid 5-10 times, the costs are appreciably reduced, while the saving in weight and space is here often of great importance.

In diatomite filtration only a thin layer of pre-coat and filter cake, with an initial thickness of not more than 2 mm, separates the filtered from the raw water. This layer moreover is easily damaged, by a short interruption of pumping for instance and many water engineers therefore hesitate to apply this process for public supplies.

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