

CHAPTER 2

FILTRATION

THE FILTERS

Water treatment by filtration has utilized principally either deep granular filters or precoat filters.

The deep granular filters used are either silica sand or a dual medium or multi-media filters. A dual medium filter of coal over sand is widely used. The multi-media filters consisting, for example, of coal over silica sand over garnet sand, are finding increasing application. The precoat filters use diatomaceous earth, perlite or powdered activated carbon.

The sand filters were developed in England in the middle of the 19th century. These filters operated at a relatively low rate, between 0.1 and 0.3 m/h. Nowadays the same filters are used at rates of up to 0.6 m/h. These filters are called slow sand filters, in contrast to the rapid sand filters which were developed later in the 19th century in the U.S.A. and which operate with a filtration velocity of 3 to 6 m/h.

The precoat filters, which consist of a number of porous septa in a filter housing, have found wide application since the second World War. The septa support is a thin-layer filter medium, which is deposited on the outside of the septa at the beginning of the filtration cycle.

Sand filters

As mentioned above, sand filters can be divided into two classes - slow filters and rapid filters. There are two main differences between the two filters:

(1) As shown in Table 2.1, the properties of the filter media are different. The effective grain size is the diameter of the largest grain of the sand in that 10% of the sample by weight which contains the smallest grains. The uniformity coefficient is the ratio of the largest grain in the 60% of the sample by weight which contains the smallest grain, to the effective size.

As can be seen the rapid filters operate with a higher effective size and a smaller uniformity coefficient. The finer the sand which is used, the smaller will be the turbidity of the treated

water and the flow rate.

TABLE 2.1

Typical properties of filter media

	Slow sand filter	Rapid sand filter
Effective size(mm)	0.45-0.60	0.6-1.0
Uniformity coefficient	1.50-1.80	1.2-1.8
Material	sand and/or crushed anthracite	multi media

(2) The slow filters operate for 10 to 30 days. By then the head loss will be 1 m of water or more. The filtration is interrupted and 1.5 to 4 cm of the filter sand is removed. When the sand layer reaches a height of about 40 cm, new or washed sand is added to replace up to 30 cm of the sand layer removed. In rapid filtration, impurities are removed by back-washing, usually by reversing the flow of water through the filter at a rate adequate to lift the grains of the filter medium in suspension. The deposited material thus flushed up through the expanded bed is washed out of the filter.

The minimum flow velocity, v_f , is calculated from the following empirical non-homogeneous equation:

$$v_f = \frac{0.242(d_{60\%})^{1.82}(\rho_1(\rho_s - \rho_1))^{0.94}}{\mu^{0.88}} = m^3/m^2 \cdot h \quad (2.1)$$

where

$d_{60\%}$ = 60% of the sand size(in mm) equal to the effective size x the uniformity coefficient

ρ_s = the specific weight of sand (kg/m^3)

ρ_1 = the specific weight of the water (kg/m^3)

μ = water viscosity in Pa·s

For further details see Baumann et al. (1962) and Baumann and Oulman (1970).

The rapid filter can either be an open filter or a pressure filter. Open filters mainly are built of concrete, whereas pressure filters are water-tight steel tanks which are usually cylindrical and may stand either horizontally or vertically. The most common use of pressure filters is in small cities treating ground water supplies for iron and manganese removal, or in swimming pool filtration, or for polishing industrial water.

Precoat filtration

The filtration cycle consists of three steps:

- (1) Precoating,
- (2) Filtration,
- (3) Removal of the spent filter cake.

A precoat thickness of 1.3-3 mm is generally used. During filtration the suspended solids are removed on the precoat surface resulting in an increasing pressure drop across the filter. Due to the hydraulic compression of the solid, the filtration cycle may be very short unless additional filter aid is added during filtration. The amount required varies with the type and concentration of suspended solids in the treated water. A typical pressure filter flow diagram is shown in Fig. 2.1.

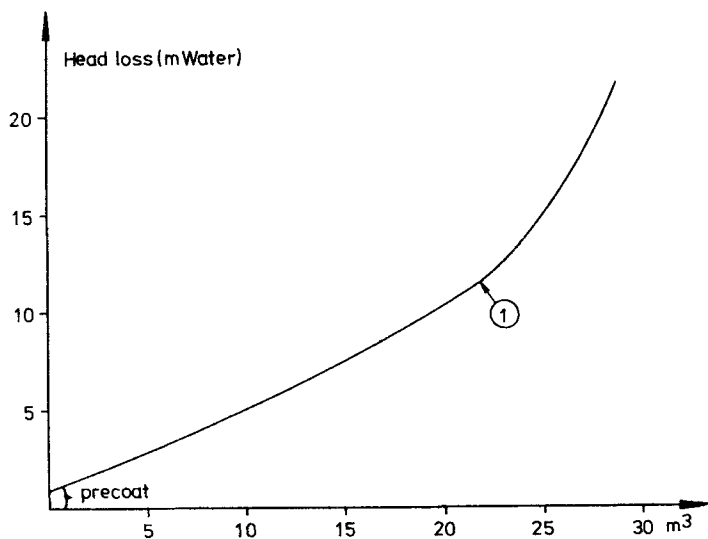


Fig. 2.1. Head loss plotted to volume for a precoat filter. Filtration should be interrupted at (1).

Head loss and precoat filtration

The total head loss, H_t , through the filter is:

$$H_t = H_p + H_f \quad (2.2)$$

where

H_p = the head loss of the precoat layer,

H_f = the head loss of the filter cake (plus filter aid).

When filtering through cylindrical septa, the outer surface area of the filter cake increases as the thickness of the cake increases. This increasing area is of significance and must be included in the equation. For any septum we have:

$$H_p = v \cdot \nu \cdot \epsilon \frac{W}{g} \quad (2.3)$$

For a cylindrical septum:

$$H_f = \frac{r' \nu \beta \cdot C \cdot v^2}{g \cdot E} \ln\left(1 + \frac{r' \cdot E \cdot \Lambda}{r}\right) \quad (2.4)$$

$$E = \frac{2\rho \cdot C \cdot v}{\rho_p} \cdot 10^{-6} \quad (2.5)$$

$$\Lambda = t - \frac{1 - e^{-\delta \cdot t}}{\delta} \quad (2.6)$$

For a flat septum:

$$H_f = \frac{\nu \cdot \beta \cdot C \cdot v^2}{g} \cdot \Lambda \quad (2.7)$$

The following symbols are used:

C = body feed concentration as ppm by weight,

δ = $\frac{Q}{v}$ (v , volume of filter housing, Q , flow rate),

r = initial radius of septum + precoat layer,

r' = outer radius of septum,

ν = filtration rate,

W = weight of precoat per unit area,

β = filter cake resistance index,

ϵ = filter aid resistance index,

ρ = specific gravity of liquid,

ρ_p = bulk specific weight of precoat,

ν = kinematic viscosity.

The β -index representing the filter cake resistance is a function of the concentration of suspended solids, C_s , the body feed in the filter aid, C , in the water and of the filter aid resistance index, ϵ . A β -index prediction equation has been developed (Dillingham et al., 1966, 1967 a,b).

$$\beta = 10^q \left(\frac{C_s}{C}\right)^m \cdot C^n \quad (2.8)$$

where

q , m and n = empirically determined exponents.

For most suspensions a simplified equation can be used:

$$\beta = 10^q \left(\frac{C_s}{C}\right)^m \quad (2.9)$$

The empirical constant, m , is generally about 2.

From the equations it is seen that the head loss is proportional to the filtration rate squared (v^2), the kinematic viscosity, ν , the filter cake resistance index, β , and the body feed rate, C . Since, m , is about 2, β increases with the square of C_s and inversely with the square of C .

Based upon these equations it is possible from a set of observations to predict head loss for other filtrations of the same type of waste water and precoat medium.

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