Filtration

- Removal of solids from fluid (gas or liquid) by a filtering medium on which solid particles are deposited.

- For filtration, external force is applied to a (gas or liquid + solid) mixture to make it flow through the medium.

- Filtration, when applied to gas cleaning, usually refers to the removal of fine particles like dust from air or flue gas. In such case, a polymeric fiber or cloth is wrapped over a pretreated metallic cylinder, capable of capturing micron size particles, including soot and fly-ash.

- Very large size ceramic based filters for high temperatur applications are also commercially available.

- The liquid–solid filtration is often called “cake–filtration”, because the separation of solids from the slurry by the filtering medium is effective during the initial stages of filtration. Later, the ‘cakes' or deposits collected over the medium act as the filter. Therefore, cake thickness increases during filtration and the resistance (hydraulic) offered by the cake–material is larger than that by the filtering medium.

There are two types of operation:

a. Constant-pressure

b. Constant filtering rate

In the 1st case, filtering rate varies with time, whereas in the 2nd case, pressure–drop increases with time.

For ideal cake filtration, cake should be stable and large porosity. There are two common types of filters:

a. The plate and frame press

b. Rotary-drum filter

Thus, the main factors to be considered when
selecting equipment and operating conditions are:
(a) The properties of the fluid, particularly its viscosity, density and corrosive properties.
(b) The nature of the solid—its particle size and shape, size distribution, and packing characteristics.
(c) The concentration of solids in suspension.
(d) The quantity of material to be handled, and its value.
(e) Whether the valuable product is the solid, the fluid, or both.
(f) Whether it is necessary to wash the filtered solids.
(g) Whether very slight contamination caused by contact of the suspension or filtrate with the various components of the equipment is detrimental to the product.
(h) Whether the feed liquor may be heated.
(i) Whether any form of pretreatment might be helpful.

LIQUID FILTRATION

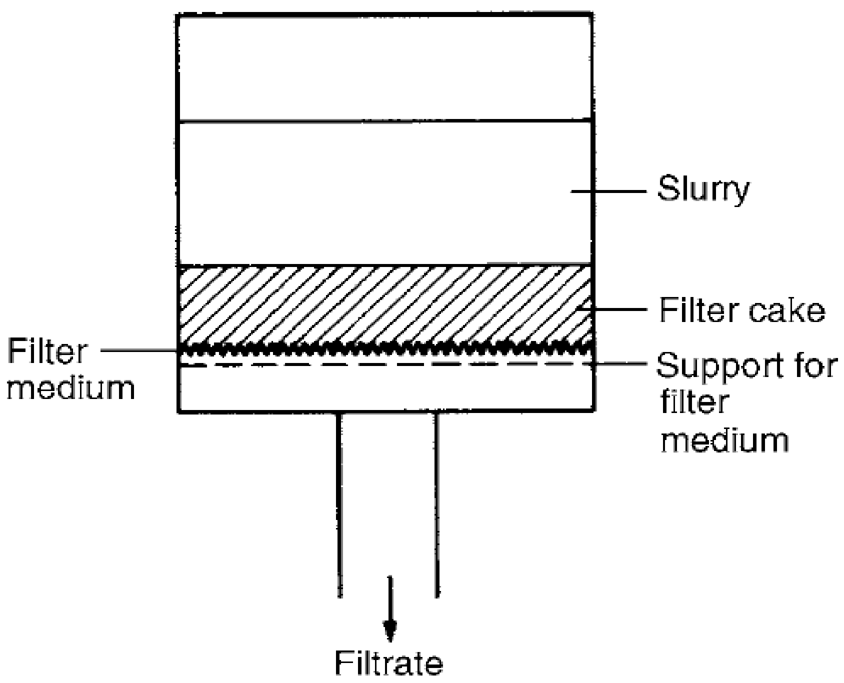

Figure 7.1. Principle of filtration

The most important factors on which the rate of filtration depends will be:
(a) The drop in pressure from the feed to the far side of the filter medium.
(b) The area of the filtering surface.
(c) The viscosity of the filtrate.
(d) The resistance of the filter cake.
(e) The resistance of the filter medium and initial layers of cake.

FILTRATION THEORY

Because the particles forming the cake are small and the flow through the bed is slow, streamline conditions are almost invariably obtained, and, at any instant, the flowrate of the filtrate may be represented by the following form of equation:

$$u_c = \frac{1}{A}\frac{\mathrm{d}V}{\mathrm{d}t} = \frac{1}{5}\frac{e^3}{(1-e)^2}\frac{-\Delta P}{S^2\mu l} \tag{7.1}$$

where *V* is the volume of filtrate which has passed in time *t* , *A* is the total cross-sectional area of the filter cake, *uc* is the superficial velocity of the filtrate, *l* is the cake thickness, *S* is the specific surface of the particles, *e* is the voidage, *μ* is the viscosity of the filtrate, and *P* is the applied pressure difference.

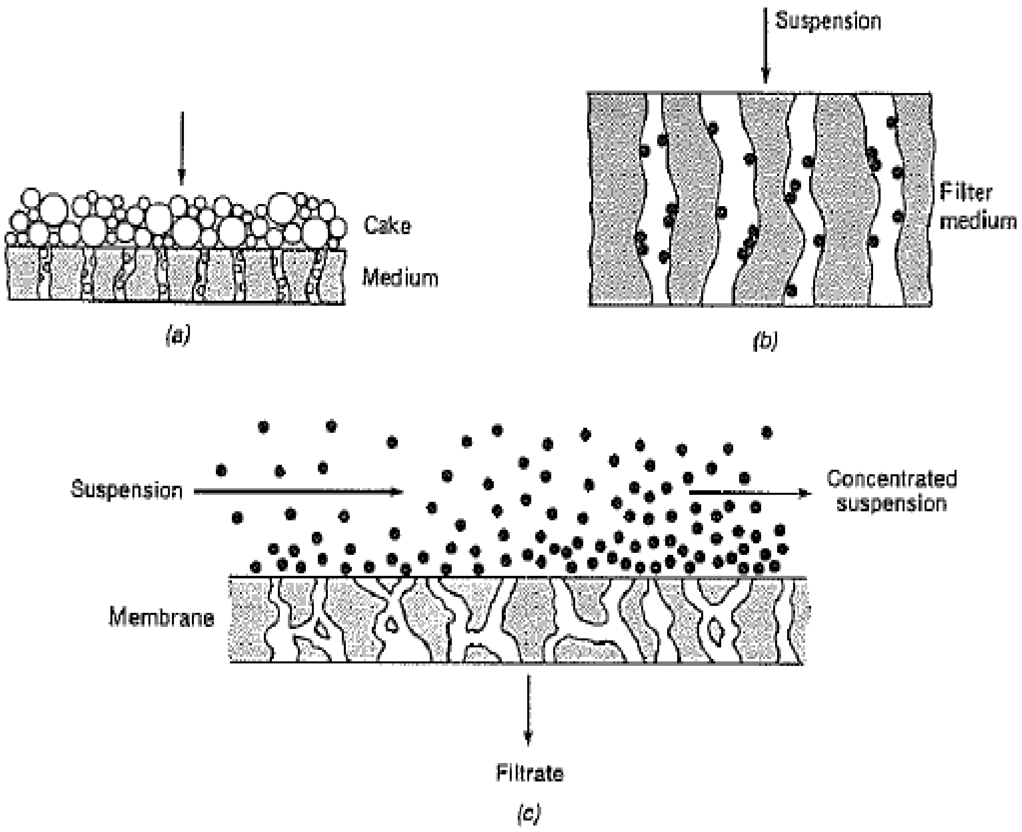

FIGURE 30.4
Mechanisms of filtration: (*a*) cake filter; (*b*) clarifying filter; (*c*) crossflow filter.

The initial stages in the formation of the cake are therefore of special importance for the following reasons:
(a) For any filtration pressure, the rate of flow is greatest at the beginning of the process since the resistance is then a minimum.
(b) High initial rates of filtration may result in plugging of the pores of the filter cloth and cause a very high resistance to flow.
(c) The orientation of the particle in the initial layers may appreciably influence the structure of the whole filter cake.

For incompressible cakes e in equation 7.1 may be taken as constant and the quantity $\mathbf{e^3/[5(1-e)^2S^2]}$ is then a property of the particles forming the cake and should be constant for a given material.

Thus:
$$\frac{1}{A}\frac{dV}{dt} = \frac{-\Delta P}{\mathbf{r}\mu l} \tag{7.2}$$

where:
$$\mathbf{r} = \frac{5(1-e)^2 S^2}{e^3} \tag{7.3}$$

For incompressible cakes, **r** is taken as constant, although it depends on rate of deposition, the nature of the particles, and on the forces between the particles. **r** has the dimensions of $\mathbf{L^{-2}}$ and the units $\mathbf{m^{-2}}$ in the **SI** system.

If *υ* is the volume of cake deposited by unit volume of filtrate then:

$$v = \frac{lA}{V} \quad \text{or} \quad l = \frac{vV}{A} \tag{7.6}$$

Substituting for *l* in equation 7.2:

$$\frac{1}{A}\frac{dV}{dt} = \frac{(-\Delta P)}{\mathbf{r}\mu}\frac{A}{vV}$$

or:
$$\frac{dV}{dt} = \frac{A^2(-\Delta P)}{\mathbf{r}\mu v V} \tag{7.8}$$

Equation 7.8 may be regarded as the basic relation between −*P*, *V*, and *t*. Two important types of operation are: (i) where the pressure difference is maintained constant and (ii) where the rate of filtration is maintained constant.

For a filtration at constant rate

$$\frac{dV}{dt} = \frac{V}{t} = \text{constant}$$

so that:
$$\frac{V}{t} = \frac{A^2(-\Delta P)}{\mathbf{r}\mu V v} \tag{7.9}$$

or:
$$\frac{t}{V} = \frac{\mathbf{r}\mu v}{A^2(-\Delta P)} V \tag{7.10}$$

and $-\Delta P$ is directly proportional to V.

For a filtration at constant pressure difference

$$\frac{V^2}{2} = \frac{A^2(-\Delta P)t}{\mathbf{r}\mu v} \tag{7.11}$$

or:
$$\frac{t}{V} = \frac{\mathbf{r}\mu v}{2A^2(-\Delta P)} V \tag{7.12}$$

Thus for a constant pressure filtration, there is a linear relation between ***V*** $_{\mathbf{2}}$ and ***t*** or between ***t/V*** and ***V*** .
Filtration at constant pressure is more frequently adopted in practice, although the pressure difference is normally gradually built up to its ultimate value.
If this takes a time t_1 during which a volume $\boldsymbol{V_1}$ of filtrate passes, then integration of equation 7.12 gives:

$$\frac{1}{2}(V^2 - V_1^2) = \frac{A^2(-\Delta P)}{\mathbf{r}\mu v}(t - t_1) \tag{7.13}$$

Or

$$\frac{t - t_1}{V - V_1} = \frac{\mathbf{r}\mu v}{2A^2(-\Delta P)}(V - V_1) + \frac{\mathbf{r}\mu v V_1}{A^2(-\Delta P)} \tag{7.14}$$

Thus, there where is a linear relation between *V* 2 and *t* and between $\mathbf{(t - t_1)/(V - V_1)}$ and $\mathbf{(V - V_1)}$, where $\mathbf{(t - t_1)}$ represents the time of the constant pressure filtration and $\boldsymbol{(V - V_1)}$ the corresponding volume of filtrate obtained.

Flow of filtrate through the cloth and cake combined

If the filter cloth and the initial layers of cake are together equivalent to a thickness L of cake as deposited at a later stage in the process, and if $-\Delta P$ is the pressure drop across the cake and cloth combined, then:

$$\frac{1}{A}\frac{\mathrm{d}V}{\mathrm{d}t} = \frac{(-\Delta P)}{\mathbf{r}\mu(l+L)} \qquad (7.15)$$

which may be compared with equation 7.2.

Thus:

$$\frac{\mathrm{d}V}{\mathrm{d}t} = \frac{A(-\Delta P)}{\mathbf{r}\mu\left(\frac{Vv}{A}+L\right)} = \frac{A^2(-\Delta P)}{\mathbf{r}\mu v\left(V+\frac{LA}{v}\right)} \qquad (7.16)$$

This equation may be integrated between the limits $t = 0$, $V = 0$ and $t = t_1$, $V = V_1$ for constant rate filtration, and $t = t_1$, $V = V_1$ and $t = t$, $V = V$ for a subsequent constant pressure filtration.

For the period of *constant rate filtration*:

$$\frac{V_1}{t_1} = \frac{A^2(-\Delta P)}{\mathbf{r}\mu v\left(V_1 + \dfrac{LA}{v}\right)}$$

or:
$$\frac{t_1}{V_1} = \frac{\mathbf{r}\mu v}{A^2(-\Delta P)}V_1 + \frac{\mathbf{r}\mu L}{A(-\Delta P)}$$

or:
$$V_1^2 + \frac{LA}{v}V_1 = \frac{A^2(-\Delta P)}{\mathbf{r}\mu v}t_1 \tag{7.17}$$

For a subsequent *constant pressure filtration*:

$$\frac{1}{2}(V^2 - V_1^2) + \frac{LA}{v}(V - V_1) = \frac{A^2(-\Delta P)}{\mathbf{r}\mu v}(t - t_1) \tag{7.18}$$

or:
$$(V - V_1 + 2V_1)(V - V_1) + \frac{2LA}{v}(V - V_1) = \frac{2A^2(-\Delta P)}{\mathbf{r}\mu v}(t - t_1)$$

or:
$$\frac{t - t_1}{V - V_1} = \frac{\mathbf{r}\mu v}{2A^2(-\Delta P)}(V - V_1) + \frac{\mathbf{r}\mu v V_1}{A^2(-\Delta P)} + \frac{\mathbf{r}\mu L}{A(-\Delta P)} \tag{7.19}$$

Washing of the filter cake

Washing may be regarded as taking place in two stages. First, filtrate is displaced from the filter cake by wash liquid during the period of displacement washing and in this way up to 90 per cent of the filtrate may be removed. During the second stage, diffusional
washing, solvent diffuses into the wash liquid from the less accessible voids and the following relation applies:

$$\left(\frac{\text{volume of wash liquid passed}}{\text{cake thickness}}\right) = (\text{constant}) \times \log\left(\frac{\text{initial concentration of solute}}{\text{concentration at particular time}}\right)$$