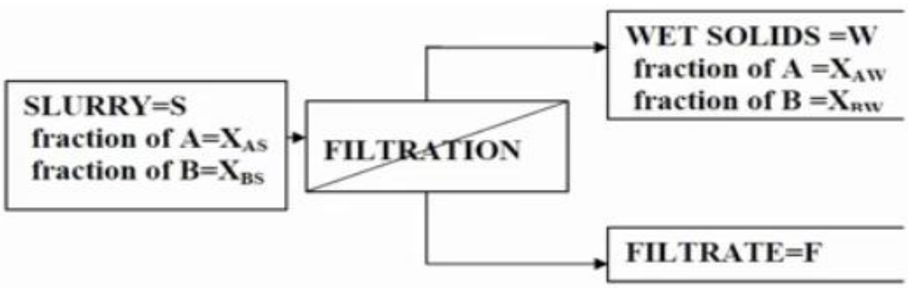
# Filtration

- This operation is used for separation of solids from suspension in liquid (slurry).
- Filter media is used for separation.
- The product removed from media is called wet solids or residue. The particles suspended in the fluid whish will not pass through aperture , are retained and build up into what is called ***filter cake*** .
- The product passes through filter media is called filtrate.
- Cake thickness increases during filtration and the resistance (hydraulic) offered by the cake–material is larger than that by the filtering medium.

Block diagram of filtration operation (***A-Solid, B-Liquid***)




**The main factors to be considered when selecting equipment and operating conditions are:**

(1) the nature of the slurry and the cake formed.

(2) The properties of the fluid, particularly its viscosity, density and corrosive properties.

(3) The nature of the solid—its particle size and shape, size distribution, and packing characteristics.

(4) The concentration of solids in suspension.

(5) The quantity of material to be handled, and its value.

(6) Whether the valuable product is the solid, the fluid, or both.

(7) Whether it is necessary to wash the filtered solids.

(8) What the cake washing required.

(9) Whether the feed liquor may be heated.

## *Types of operation:*

There are two types of operation:

1. Constant-pressure (pressure drop over the filter is constant throughout the run so that the rate of filtration is maximum at the start of filtration and decreases continuously towards the end of run ).

2. Constant filtering rate (pressure–drop increases with time, pressure drop is varied usually from minimum at the start of filtration to the maximum at the end of filtration so that the rate of filtration is constant throughout the run ).

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

***The most important factors on which the rate of filtration depends will be:***

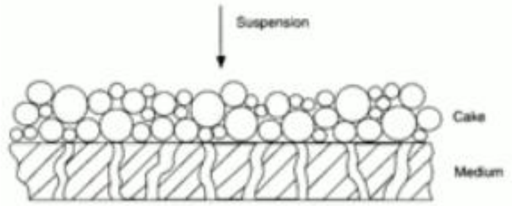
(a) The drop in pressure from the feed to the far side of the filter medium.

(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:

The initial stage in the formation of the cake are therefore of special importance for the following reasons:

1- For any filtration pressure the rate of flow is greatest at the beginning of the process since the resistance is the minimum.

2- High initial value of filtration may results in plugging of the poles of the filter cloth and cause a very high resistance to flow.

3- The concentration of particles in the initial layers may be appreciably influence the structure of the whole filter cake.

4- The fluid passes through the filter medium which offers resistance to its passage under the influence of a force which pressure differential across the filter , thus we can write the equation.

$$Rate\ of\ filteration = \frac{Driving\ \ force}{resistance}$$

***Driving force***: Pressure drop differential across the medium.

***Resistance*** : A rise from the filter resistance and to this added the resistance of filter cake as it accumulates.

*Filter resistance = Specific resistance ×Thickness of filter cake*

The flow rate of the filtrate may be represented by the following form of equation:

$$u_C = \frac{1}{A}\frac{dV}{dt} = \frac{-\Delta P}{r\mu L} = \frac{1}{5}\frac{\varepsilon^3}{(1-\varepsilon)^2}\frac{-\Delta P}{S^2\mu L} \qquad \ldots(1)$$

$$r = \frac{5\,S^2(1-\varepsilon)^2}{\varepsilon^3}$$

Where:
$u_c$ = Superficial velocity of the filtrate
***r*** = Specific resistance
***μ*** = Viscosity of filtrate.
***L*** = The cake thickness.
***S*** = Specific surface of the particles.
***ε*** = The voidage.
***P*** = The applied pressure difference.
***A*** = Is the total cross-sectional area of the filter cake.
***V*** = The volume of filtrate which has passed in time *t*.

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 $L^{-2}$ and the units $m^{-2}$ in the ***SI*** system.

If $v$ is the volume of cake deposited by unit volume of filtrate then:

$$v = \frac{lA}{V} \quad or \quad l = \frac{vV}{A} \qquad \ldots(2)$$

Substituting for l in equation (1)

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

or
$$\frac{dV}{dt} = \frac{A^2(-\Delta P)}{r\mu vV} \qquad \ldots(3)$$

Equation (3) 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***

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

So that $$\frac{V}{t} = \frac{A^2(-\Delta P)}{r\mu vV} \qquad \ldots.(4)$$

or: $$\frac{t}{V} = \frac{r\mu v}{A^2(-\Delta P)}V \qquad \ldots.(5)$$

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

***for a filtration at constant pressure difference***

$$\frac{V^2}{2} = \frac{A^2(-\Delta P)t}{r\mu v} \qquad \ldots(6)$$

$$\frac{t}{V} = \frac{r\mu v}{2A^2(-\Delta P)}V \qquad \ldots(7)$$

Thus for a constant pressure filtration, there is a linear relation between $V_2$ 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 $V_1$ of filtrate passes, then integration of equation (7) gives:

$$\frac{1}{2}(V^2 - V_1^2) = \frac{A^2(-\Delta P)}{r\mu v}(t - t_1) \qquad \ldots(8)$$

Or

$$\frac{t-t_1}{V-V_1} = \frac{r\mu v}{2A^2(-\Delta P)}(V - V_1) + \frac{r\mu v V_1}{A^2(-\Delta P)} \qquad \ldots(9)$$

Thus, there where is a linear relation between $V_2$ and $t$ and between $(t - t_1)/(V - V_1)$ and $(V - V_1)$, where $(t - t_1)$ represents the time of the constant pressure filtration and $(V - V_1)$ 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:

$$\frac{1}{A}\frac{dV}{dt} = \frac{(-\Delta P)}{r\mu\,(l+L)} \qquad \ldots(10)$$

Which may be compared with equation (1).

$$\frac{dV}{dt} = \frac{A(-\Delta P)}{r\mu\left(\frac{Vv}{A}+L\right)} = \frac{A^2(-\Delta P)}{r\mu\left(V+\frac{LA}{v}\right)} \qquad \ldots(11)$$

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***:

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

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

or

$$V_1^2 + \frac{LA}{v}V_1 = \frac{A^2(-\Delta P)}{r\mu v}t_1 \qquad \ldots(12)$$

For a subsequent ***constant pressure filtration***:

$$\frac{1}{2}(V^2 - V_1^2) + \frac{LA}{v}(V - V_1) = \frac{A^2(-\Delta P)}{r\mu v}(t - t_1) \qquad \ldots(13)$$

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

or: $$\frac{t-t_1}{V-V_1} = \frac{r\mu v}{2A^2(-\Delta p)}(V-V_1) + \frac{r\mu v V_1}{A^2(-\Delta P)} + \frac{r\mu L}{A(-\Delta P)} \quad \ldots(14)$$

## *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 percent*** 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:

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

## Filtration Equipment information:

Filtration equipment is used to filter, thicken, or clarify a mixture of different elements. There are several different ways to classify products. Examples include:

- Driving force (gravity, pressure, vacuum centrifuge).
- Filtration mechanism (filter medium).
- Process goal (cake, clarified liquid, or both ).
- Operating cycle (continuous or batch)
- Material size ( particle size)

## Types of filtration equipment:

Different types of filtration equipment including: sedimentation, gravity, vacuum, pressure, thickeners, clarifiers and centrifugal separators.

### Sedimentation equipment

Sedimentation equipment uses a gravitational or chemical process to cause particles to settle to the bottom.

**Flocculation -** Flocculation is the formation of a cake or aggregate, usually through a chemical process, although a magnetic field may be used for particles containing iron. Flocculation is an important process in the treatment of wastewater.

**Gravity sedimentation -** Gravity sedimentation is used to reduce the solids concentration of the material to be processed. It can be either a clarification or a thickening process.

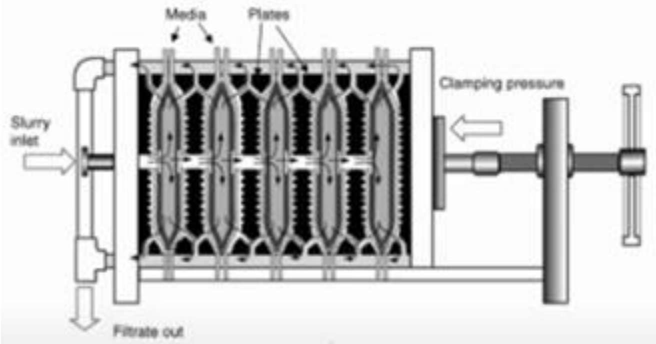
## Gravity Filtration Equipment

Gravity filtration equipment uses the hydrostatic pressure of a pre-filter column above the filter surface to generate the flow of the filtrate. Common products include bag filters, sand filters.

**Bag filter -** Bag filters are used mainly as collection equipment. They use bag-shaped woven-fabric or felt filters. Bag filters are not recommended for process filtration.

## Discontinuous pressure filter.

### Plate and frame filter press.




Consist of plates and frames arranged alternately. Plate having ribbed surface and frame is hollow provide space for filter cake. Filter clothes are placed over each plate on both sides.
Filtrate passes through the cloth, runs down the faces of the plates and finally leaves the filter through discharge channel. The solids are deposited on filter cloth.

### Advantages and disadvantages of pressure filter.

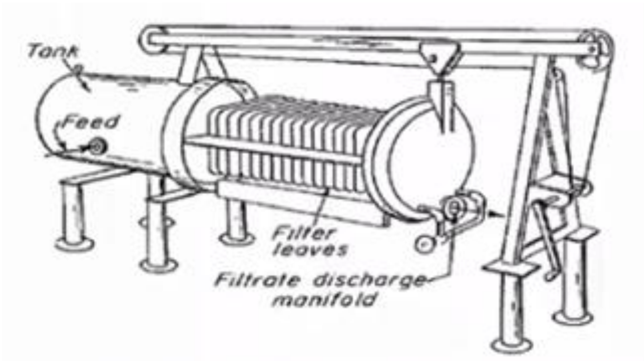
❖ Advantages:

- Simple in construction.
- Low initial cost.
- Low maintenance cost.
- Provide large filtering area.

❖ Disadvantages:

- Labour requirement is very high.
- Filter cloth life is short.

## Shell and Leaf Filter.




A set of vertical leaves is held on a rack. During the operation leaves are inside the closed tank. Feed enters through the side of the tank , filtrate passes through the leaves into a discharge.

Clear liquid flow from both side into the leaves, flows along the tubular channel and get discharged from bottom of the leaf. All the leaves are mounted on same shaft.

## Advantages and disadvantages of Shell and Leaf filter

### ❖ Advantages:

- Close and compact operation.
- High rate of filtration.
- Cheap and economical operational costs.

### ❖ Disadvantages:

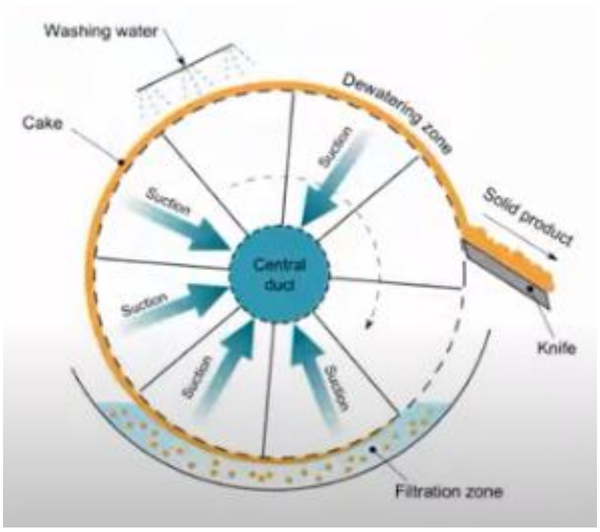
- Not adaptable for washing of cake.
- The filtrate is usually not clear.

## Continuous pressure / vacuum filter

### ROTARY AND DRUM FILTER:

Working of drum is divided into three parts:

1. Filtration
2. Washing
3. Drying



A horizontal drum with slotted face rotates at 0.1 to 2 RPM in an agitated slurry trough. A filter medium cover on the outer surface of the drum which is partially submerged into liquid.

## Advantages and disadvantages of rotary drum filter.

❖ Advantages:

- Continuous and automatic operation so operating cost is low.
- Control the cake thickness.
- Can produce relatively clean product.

❖ Disadvantages:

- Agitators and vacuum pumps are required.
- High energy consumption by vacuum pump.

### *Example(1):*

A slurry containing **100 kg** of whiting, of density **3000 kg/m$^3$**, per **m$^3$** of water, and, is filtered in a plate and frame press, which takes 900 s to dismantle, clean, and re assemble. If the cake is incompressible and has a voidage of 0.4, what is the optimum thickness of cake for a filtration pressure **($-\Delta P$ )** of **1000 kN/m$^2$**? The density of the whiting is **3000 kg/m$^3$**. If the cake is washed at **500 kN/m$^2$** and the total volume of wash water employed is **25 per cent** of that of the filtrate, how is the optimum thickness of the cake affected? The resistance of the filter medium may be neglected and the viscosity of water is **1 mNs/m$^2$**. In an experiment, a pressure difference of **165 kN/m$^2$** produced a flow of water of **0.02 cm$^3$/s** through a centimetre cube of filter cake.

Home work