FILTRATION BY FRAME-AND- FILTER PRESS

Filtration (liquid) is the separation of solid from a fluid by means of a porous medium that retains the solid but allows the fluid to pass.

OBJECTIVES

- To study the filtration processes by a frame and filter press
- To determine the flow rate through the filter
- To determine specific cake resistances and filter medium resistance for a number of constant pressure runs

THEORY

Filtration is a mechanical or physical operation by which solids are separated from fluids (liquids or gases) in a mixture with the help of a medium that is called a filter. When the mixture is brought in contact with a filter, the filter allows the fluid to pass through, but it retains at least part of the solid material. The fluid that passes through the filter is called the **filtrate** and the solid material that remains on the filter is called the **residue.** In filtration processes it has to be kept in mind that the separation may not be complete. Solids will be contaminated with some fluid and filtrate will contain fine particles. And this degree of separation will depend on the pore size and the thickness of the filter medium as well as the mechanisms that occur during filtration.

Filtration is used by the oil, gas, food and beverage, and pharmaceutical industries, among others.

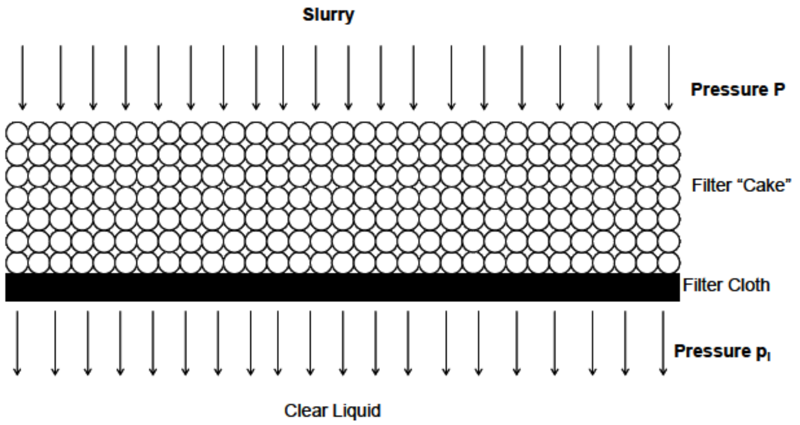
Liquid filtration is used basically for two different actions; 1) To remove contaminates from a liquid. 2) To collect suspended solid particles from the liquid that may be valuable for another use.

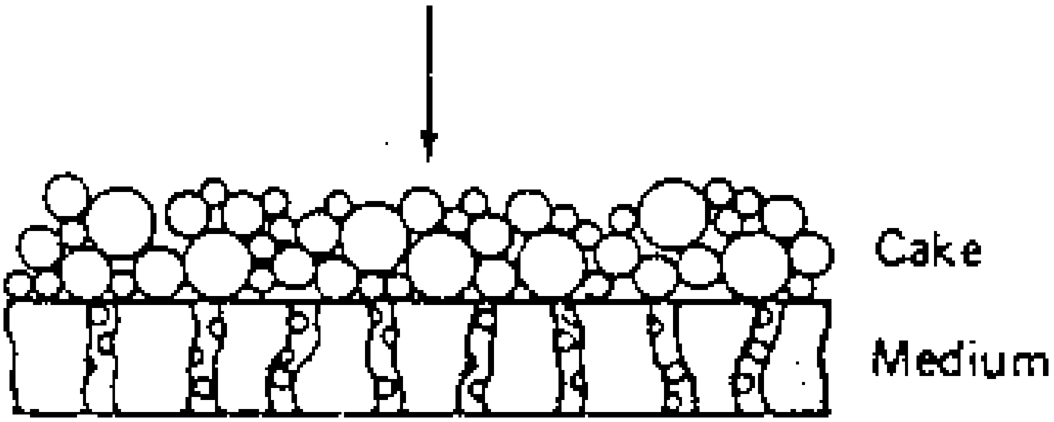
In the filtration, slurry or suspension flows through the filter medium by virtue of pressure drop across it. This pressure difference may be of two types. One is the case when pressure on upper side of the filter medium is greater than atmospheric pressure may be developed due to head of the liquid or by pump and on the other side; pressure is equal to atmospheric pressure. Other case of operation is where pressure on upper side is atmospheric and on the lower side, a vacuum is created. So it can be said that main driving force for filtration is pressure difference across the filter medium.

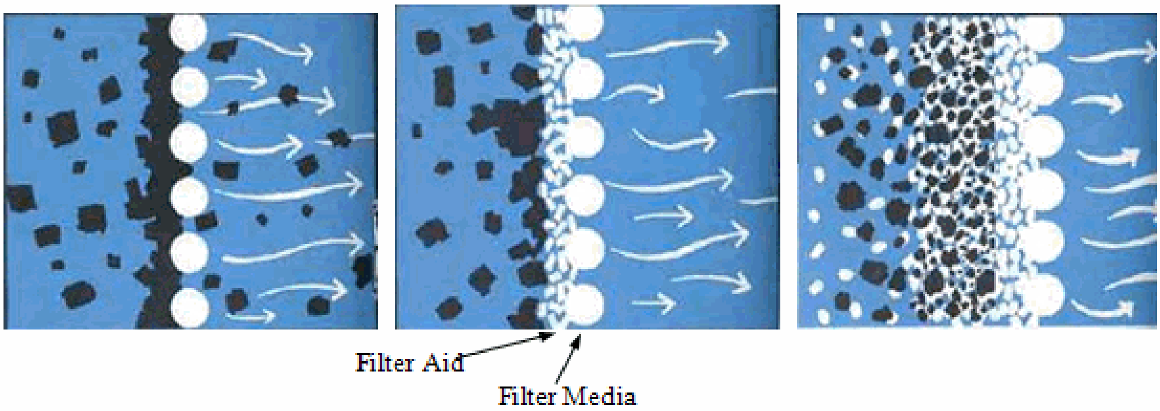
In general, the pores of the medium are larger than the particles which are to be removed, and the filter works efficiently only after an initial deposit has been trapped in the medium.

Industrially, difficulties are encountered in the mechanical handling of much larger quantities of suspension and solids. A thicker layer of solids has to form to achieve highly efficient separation and, in order to achieve a high rate of passage of liquid through the solids, higher pressures are needed, and a far greater area has to be provided. As the cake gradually builds up on the medium and the resistance to flow progressively increases. During the initial period of flow, particles are deposited in the surface layers of the cloth to form the true filtering medium. This initial deposit may be formed from a special initial flow of precoat material.

Filter cake formation is illustrated in the following schematic diagrams:

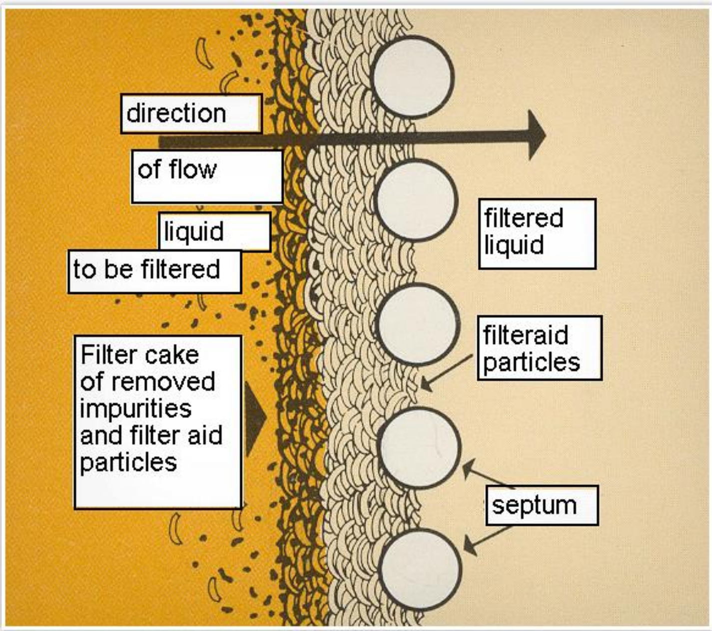






(a) Filtration without Filter Aid; (b)Filtration with "Precoat" (c)Filtration with "Admix" and "Precoat"

Fig. 1 Mechanism of Filtration with Filter Aids



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

- The drop in pressure from the feed to the far side of the filter medium.
- The area of filtering surface.
- The viscosity of the filtrate.
- The resistance of the filter cake.
- The resistance of the filter medium and initial layers of cake.

Some differences in general behavior may be expected, however, because the cases so far considered relate to uniform fixed beds, whereas in filtration the bed is steadily growing in thickness. Thus, if the filtration pressure is constant, the rate of (low progressively diminishes whereas, if the flowrate is to be maintained constant, the pressure must be gradually increased. So, it may be noted that there are two quite different methods of operating a batch filter. If the pressure is kept constant then the rate of flow progressively diminishes, whereas if the flowrate is kept constant then the pressure must be gradually increased. Because the particles forming the cake are small and the flow through the bed is slow, streamline conditions are almost invariably obtained

The mechanical details of the operation, particularly of the flow channel and the support for the medium, influence the way the cake is built up and the ease with which it may be removed. A uniform structure is very desirable for good washing and cakes formed from particles of very mixed sizes and shapes present special problems. Although filter cakes are complex in their structure and cannot truly be regarded as composed of rigid non-deformablc particles. Voidage of the cake, formed during course of filtration, is very important factor. And it depends on the nature of the support, including its geometry and surface structure, and on the rate of deposition. The initial stages in the formation of the cake are therefore of special importance for the following reasons:

- For any filtration pressure, the rate of flow is greatest at the beginning of the process since the resistance is then a minimum.
- High initial rates of filtration may result in plugging of the pores of the filter cloth and cause a very high resistance to flow.
- The orientation of the particle in the initial layers may appreciably influence the structure of the whole filter cake.

On the bases of voidage, filter cakes may be divided into two classes: i) **incompressible cakes** and ii) **Compressible cakes**;

In the cake obtained by filtration, the specific strength of this varies with the pressure drop produced as it is deposited, this is because the cake becomes more dense as the pressure becomes greater and therefore has to less corridors with a smaller size to pass the flow. This phenomenon is known as the compressibility of the cake. A cake composed of flexible and deformable solids, soft and flocculent, has a flow resistance depends on the pressure drop varies throughout the thickness of the cake, being higher near the filter media, these cakes he called “compress”.

Cakes called “incomprehensible” are those made of rigid and deformable solids where the resistance is independent of pressure and does not vary with the depth of the cake. Highly compressible cakes are those arising from soft and flocculent substance, as opposed to hard and granular substances such as sugar and salt crystals, which are very little affected by pressure (the rate is independent of pressure).

Experimental work on the flow of the liquid under streamline conditions has shown that the flow rate is directly proportional to the pressure difference. It is the resistance of the cloth plus initial layers of deposited particles that is important since the latter, not only form the true medium, but also tend to block the pores of the cloth thus increasing its resistance. Cloths may have to be discarded because of high resistance well before they arc mechanically worn. No true analysis of the buildup of resistance is possible because the resistance will depend on the way in which the pressure is developed and small variations in support geometry can have an important influence. It is therefore usual to combine the resistance of the cloth with that of the cake.

Filter Media

The function of the filter medium is generally to act as a support for the filter cake, and the initial layers of cake provide the true filter. The filter medium should be mechanically strong, resistant to the corrosive action of the fluid, and offer as little resistance as possible to the flow of filtrate.

The filter media are manufactured from cloth, paper, cotton, polymers, asbestos, glass, cellulose, metals, fabrics, refractories, ceramics, sands, particulate solids, etc. The filter medium’s function is to promote the formation of a solid cake

Apart from the media, a filter aid may also be employed to improve filter performance, particularly when filtrate clarity is required.

Woven materials are commonly used, though granular materials and porous solids are useful for filtration of corrosive liquids in batch units. An important feature in the selection of a woven material is the case of cake removal, since this is a key factor in the operation of modem automatic units. When selecting the filter medium, one should consider whether the filter has the following properties:

* Ability to trap the solid particles
* Minimum resistance for the filtrate to flow through
* Resistance to chemical attack
* Minimum cost
* Long life

The filter medium may be paper or a porous solid such as a ceramic or bed of sand, but most frequently a woven cloth is used. This has given rise to the term filter cloth, which is often used for the filter medium even in cases where the medium is not woven. The pore size is often somewhat larger than the average size of particles to be separated. If this is not so, each pore in turn tends to be blocked by a single particle and the hydraulic resistance of the medium rises rapidly. However, with larger pores, filtration will at first be somewhat inefficient, but the pores will become blocked by loose brings of two or three particles that will allow easy passage of liquid. Thus, after an initial period, the filtration is effected by the residue itself. Because of the large pore size the hydraulic resistance of the filter medium is usually small compared with that of residue, and hence the nature of the filter medium has a minor effect on the rate of filtration except in early stages.

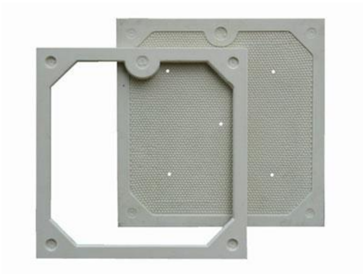
Cake Filtration:

Cake filtration is perhaps the most widely used filtration system in the food industry. In cake filtration, the solid material separated from the liquid accumulates on the surface of the medium so that, after a short initial period, the deposited solids form a cake through which the liquid must pass. The cake, in the form of diatomaceous earth, is deposited initially, on a coarse screen in the case of pressure leaf filters, or pads in the case of plate and frame filters. In the wine industry, filter cloths made of cotton, or other suitable synthetic fiber, such as nylon, are used. The process may continue, increasing in depth of the cake, until the space available is filled or until the pressure differential becomes so great that the flow is reduced to an uneconomical level.

Plate and Frame Filter Press:

This type of filter consists of plates and frames arranged alternately and supported on a pair of rails (See below figures).

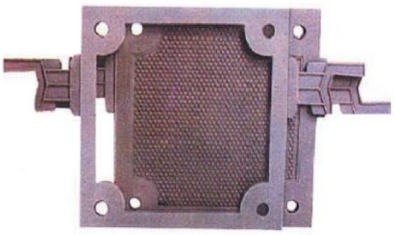
A typical plate and frame filter press



frame and filter

A Plate with filter cloth

Plate and frame



The plates have a ribbed surface and the edges stand slightly proud and are carefully machined. The hollow frame is separated from the plate by the filter cloth, and the press is closed either by means of a hand screw or hydraulically, using the minimum pressure in order to reduce wear on the cloths. A chamber is therefore formed between each pair of successive plates. The slurry is introduced through a port in each frame and the filtrate passes through the cloth on each side so that two cakes are formed simultaneously in each chamber, and these join when the frame is full. The frames are usually square and may be 100 mm -2.5 m across and 10 mm-75 mm thick.

The slurry may be fed to the press through the continuous channel formed by the holes in the corners of the plates and frames, in which case it is necessary to cut corresponding holes in the cloths which themselves act as gaskets. Cutting of the cloth can be avoided by feeding through a channel at the side although rubber bushes must then be fitted so that a leak-tight joint is formed. The filtrate runs down the ribbed surface of the plates and is then discharged through a cock into an open launder so that the filtrate from each plate may be inspected and any plate can be isolated if it is not giving a clear filtrate. In some cases the filtrate is removed through a closed channel although it is not then possible to observe the discharge from cach plate separately.

In many filter presses, provision is made for steam heating so that the viscosity of the filtrate is reduced and a higher rate of filtration obtained. Materials, such as waxes, that solidify at normal temperatures may also be filtered in steam- heated process. Steam heating also facilities the production of dry cake.

The plates have channels cut in them so that clean filtrate liquid can drain dawn along each plate. A larger of cake builds up on the cloths until the space between the plates is filled. The filtrate flows between the filter cloth and the face of the plate through the channels to the outlet. The filtration proceeds until the frames are completely filled with solids, all the discharge outlets go to a common header. In many cases the filter press will have a separate discharge to the open for each frame.

When the frames are completely full, the frame plates are separated and the cake removed. Then the filter is reassembled and the cycle is repeated. Filter press are used in batch processes but cannot be employed for high throughput processes. They are simple to operate, very versatile and flexible in operation and can be used at high pressures, when necessary if viscous solution is being used or the filter cake has a high resistance.

Advantages of the plate and frame filter press:

- Because of its basic simplicity the filter press is versatile and may be used for a wide range of materials under varying operating conditions of cake thickness and pressure.
- Maintenance cost is low.
- It provides a large filtering area on a small floor space and few additional associated units are needed.
- Most joints are external and leakage is easily detected.
- High pressure operation is usually possible.
- It is equally suitable whether the cake or the liquid is the main product.

Disadvantages of the filter pres:

- It is intermittent in operation and continual dismantling is apt to cause high wear on the cloths.
- Despite the improvements mentioned previously, it is fairly heavy on labour.

Filter cake washing is an operation performed at the end of a filtration, in which residual liquid impurities are washed out of the cake by the flow of another liquid through the cake.

Filter aids:

Certain filter aids may be used to aid filtration. These are often incompressible diatomaceous earth (also known as DE, kieselgur/kieselguhr, and diatomite) which is composed primarily of silica . Other filter aids are wood cellulose and other inert porous solids,perlite,

These filter aids can be used in two different ways. They can be used as a precoat (**thin layer (0.1 to 0.2 lb/ft^2) of filter aid is deposited)** before the slurry is filtered. This will prevent gelatinous-type solids from plugging the filter medium and also give a clearer filtrate. They can also be added to the slurry before filtration. This increases the porosity of the cake and reduces resistance of the cake during filtration. In a rotary filter, the filter aid may be applied as a precoat; subsequently, thin slices of this layer are sliced off with the cake.

In order to improve the filtration characteristics of this system, the food industry generally use diatomaceous earth (D.E.) for precoating of the screen or filter pads, as well as for a continuous proportioned body feed throughout the filtration cycle. By selecting the particle size of the D.E. used, different fineness of filtration can be achieved, from rough filtration to polish filtration.

D.E. is composed of the fossil remains of microscopic marine plants called diatoms. These plants extract silica from the water and form exoskeletons or shells. The skeleton remains after the plant dies and settles to the bottom and accumulates.

Diatomaceous earths are processed at 1500-2000 ^{o}F to burn off all organic matter. This leaves a residue which is almost pure silica.

There are various grades of D.E. depending on the fineness or particle size which range from about 2.5 to 38 microns. The finer particle size produces a more polished filtration.

The amount of D.E. needed to deposit an effective precoat depends on the flow characteristics of the filter, the type of screens and filter pads used and the pump characteristics. The most effective amount can only be determined by actual experimentation.

THEORY:

The analysis of filtration is largely a question of studying the flow system. The fluid passes through the filter medium, which offers resistance to its passage, under the influence of a force which is the pressure differential across the filter. Thus, we can write the familiar equation:

Rate of filtration = driving force/resistance

Resistance arises from the filter cloth, mesh, or bed, and to this is added the resistance of the filter cake as it accumulates. The filter-cake resistance is obtained by multiplying the specific resistance of the filter cake, that is its resistance per unit thickness, by the thickness of the cake. The resistances of the filter material and pre-coat are combined into a single resistance called the filter resistance. It is convenient to express the filter resistance in terms of a fictitious thickness of filter cake. This thickness is multiplied by the specific resistance of the filter cake to give the filter resistance. Thus the overall equation giving the volumetric rate of flow $\mathrm{d}V/\mathrm{d}t$ is:

$$\mathrm{d}V/\mathrm{d}t = (A\Delta P)/R \qquad (1)$$

As the total resistance is proportional to the viscosity of the fluid, we can write:

$$R = \mu r(L_c + L) \qquad (2)$$

where R is the resistance to flow through the filter, μ is the viscosity of the fluid, r is the specific resistance of the filter cake, L_c is the thickness of the filter cake and L is the fictitious equivalent thickness of the filter cloth and pre-coat, A is the filter area, and ΔP is the pressure drop across the filter.

If the rate of flow of the liquid and its solid content are known and assuming that all solids are retained on the filter, the thickness of the filter cake can be expressed by:

$$L_c = wV/A \qquad (3)$$

where w is the fractional solid content per unit volume of liquid, V is the volume of fluid that has passed through the filter and A is the area of filter surface on which the cake forms.

The resistance can then be written

$$R = \mu r[w(V/A) + L) \qquad (4)$$

and the equation for flow through the filter, under the driving force of the pressure drop is then:

$$\mathrm{d}V/\mathrm{d}t = A\Delta \mathrm{P}/\mu r[w(V/A) + L] \qquad (5)$$

Equation (5) may be regarded as the fundamental equation for filtration. It expresses the rate of filtration in terms of quantities that can be measured, found from tables, or in some cases estimated. It can be used to predict the performance of large-scale filters on the basis of laboratory or pilot scale tests. Two applications of eqn. (5) are filtration at a constant flow rate and filtration under constant pressure.

Constant-rate Filtration

In the early stages of a filtration cycle, it frequently happens that the filter resistance is large relative to the resistance of the filter cake because the cake is thin. Under these circumstances, the resistance offered to the flow is virtually constant and so filtration proceeds at a more or less constant rate. Equation (5) can then be integrated to give the quantity of liquid passed through the filter in a given time. The terms on the right-hand side of eqn.(5) are constant so that integration is very simple:

$$\int \mathrm{d}V/A\mathrm{d}t = V/At = \Delta P/\mu r[w(V/A) + L]$$

$$\text{or } \Delta P = V/At \times \mu r[w(V/A) + L] \qquad (6)$$

From eqn. (6) the pressure drop required for any desired flow rate can be found. Also, if a series of runs is carried out under different pressures, the results can be used to determine the resistance of the filter cake.

Constant-pressure Filtration

Once the initial cake has been built up, and this is true of the greater part of many practical filtration operations, flow occurs under a constant-pressure differential. Under these conditions, the term ΔP in eqn. (5) is constant and so

$$\mu r[w(V/A) + L]dV = A\Delta P dt$$

and integration from $V = 0$ at $t = 0$, to $V = V$ at $t = t$

$$\eta r[w(V^2/2A) + LV] = A\Delta P t$$ and rewriting this

$$tA/V = [\mu rw/2\Delta P] * (V/A) + \mu rL/\Delta P$$

$$t / (V/A) = [\mu rw/2\Delta P] * (V/A) + \mu rL/\Delta P \qquad (7)$$

rearrange Equation (7),

$$t / V = [\mu rw/2A^2\Delta P] * V + \mu rL/A\Delta P \qquad (8)$$

Equation (8) is useful because it covers a situation that is frequently found in a practical filtration plant. It can be used to predict the performance of filtration plant on the basis of experimental results. If a test is carried out using constant pressure, collecting and measuring the filtrate at measured time intervals, a **filtration graph** can be plotted of t/V against (V) and from the statement of eqn. (8) it can be seen that this graph should be a straight line. The slope of this line will correspond to $\mu rw/2A^2\Delta P$ and the intercept on the t/V axis will give the value of $\mu rL/A\Delta P$. Since, in general, μ, w, ΔP and A are known or can be measured, the values of the slope and intercept on this graph enable L and r to be calculated.

PROCEDURE

1. Arrange the filter-press in the following way;
   End cover, end plate, filter cloth, frame, filter cloth, plate, filter cloth, frame, filter cloth, frame, filter cloth, plate, etc….
   No filter cloths are placed between the end-covers and end plate/frame. The filter cloths rest on support rods.
2. Compress the filter assembly using the pressure spindle. Ensure that all the filter cloths are positioned and line up correctly.
3. Fill the feed tank with water and run the pump (Don't run the pump dry) and check if there is a leek, if yes, reorganize the filter cloths
4. Weigh approximately 40-50 grams of dry mint flakes and transfer it into the empty feed tank and fill the tank with water (approximately 20 Lt) and stir it
5. Run the pump and record the pressure and obtain time versus volume of filtrate every 2 liters. Stop the pump when 16 Lt filtrate is collected.
6. Dismantle and clean your equipment, all filter cloths, frames and plates
7. You may apply the same procedure at different pressure (start over from #2).
8. Dismantle and clean your equipment, all filter cloths, frames and plates

Note: If you use filter sheet instead of cloth, filter sheet's smooth side must be placed against the plate and rough side must be placed against the frame.

DATA

Volume of filtrate, liters, V	**Time, t (sec)**
3	
6	
9	
12	
15	
18	
21	
24	

CALCULATIONS

From this information, plot t/V vs V (see eqn. 8) calculate the cloth resistance and specific cake resistance from the slope and intercept.

Note: (i) All calculations and units of measurement are to be clearly shown.

(ii) S.I. units are to be used throughout.

Please read "filtration" section in your textbook (Transport Processes and Separation Process Principles, Author Christie J. Geankoplis) before the lab.

Average Specific Cake Resistance values with ease of separation are given below. W Leu (1986), Principles of Compressible Cake Filtration

Ease of Separation	Average Specific Cake Resistance (a), m/kg
Very Easy	$1x10^{9}$
Easy	$1x10^{10}$
Moderate	$1x10^{11}$
Difficult	$1x10^{12}$
Very Difficult	$1x10^{13}$

QUESTIONS

1. Why do solid particles not go through the filter cloth or membrane in the filter press?
2. Filter presses are used in the food industry. What are the types of things (foodstuff) that might be filtered before they are bought?
3. Discuss the working principle of filter aids and what are they?

4. Why do we need washing process for plate and frame filter pres?

References:-

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3. Earle, R.L. and Earle, M.D. 2004. Unit Operations In Food Processing, web edition, The New Zealand Institute of Food Science & Technology (Inc.)

4. W. Leu, Principles of Compressible Cake Filtration, in Encyclopedia of Fluid Mechanics (N.P. Cheremisinoff, ed), Gulf, 1986