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INTRODUCTION

Scope

Filtration is commonly the mechanical or physical operation which is used for the separation of solids from fluids (liquids or gases) by interposing a medium (a permeable fabric or porous bed of materials) through which only the fluid can pass. The solid can be retained on the surface of the filter medium, which is *cake filtration*, or captured within the filter medium, which is *depth filtration*.

Separator vessels are commonly used in refinery, petrochemical plants, or gas processing plants to separate the vapor-liquid-solid mixtures, and three phase mixtures, these vessel may be called knockout drums, accumulators, flash drums, vapor/liquid separators, reflux drums, or three-phase separators. The performance is determined by the characteristics of the fluid being separated, the size of the vessel and the type of internals installed. This guideline will provide a review of the important parameters in filter separator sizing and selection.

GENERAL DESIGN CONSIDERATION

Mechanical – Physical separation

These mechanical-physical separation processes are considered under the following classifications.

a. Filtration. The general problem of the separation of solid particles from liquids can be solved by using a wide variety of methods, depending on the type of solids, the proportion of solid to liquid in the mixture, viscosity of the solution, and other factors. In filtration a pressure difference is set up and causes the fluid to flow through small holes of a screen or cloth which block the passage of the large solid particles, which, in turn, build up on the cloth as a porous cake.

b. Settling and sedimentation. In settling and sedimentation the particles are separated from the fluid by gravitational forces acting on the various size and density particles.

c. Centrifugal settling and sedimentation. In centrifugal separations the particles are separated from the fluid by centrifugal forces acting on the various size and density particles. Two general types of separation processes are used. In the first type of process, centrifugal settling or sedimentation occurs.

d. Centrifugal filtration. In this second type of centrifugal separation process, centrifugal filtration occurs which is similar to ordinary filtration where a bed or cake of solids builds up on a screen, but centrifugal force is used to cause the flow instead of a pressure difference.

e. Mechanical size reduction and separation. In mechanical size reduction the solid particles are broken mechanically into smaller particles and separated according to size.

Filtration in solid-liquid separation

In filtration, suspended solid particles in a fluid of liquid or gas are physically or mechanically removed by using a porous medium that retains the particles as a separate phase or cake and passes the clear filtrate. Commerical filtrations cover a very wide range of applications. The fluid can be a gas or a liquid. The suspended solid particles can be very fine (in the micrometer range) or much larger, very rigid or plastic particles, spherical or very irregular in shape, aggregates of particles or individual particles.

The valuable product may be the clear filtrate from the filtration or the solid cake:. In some cases complete removal of the solid particles is required and in other cases only partial removal. The feed or slurry solution may carry a heavy load of solid particles or a very small amount. When the concentration is very low, the filters can operate for very long periods of time before the filter needs cleaning. Because of the wide diversity of filtration problems, a multitude of types of filters have been developed.

Industrial filtration equipment differs from laboratory filtration equipment only in the amount of material handled and in the necessity for low-cost operation. A typical laboratory filtration apparatus is shown in Fig. 1, which is similar to a Buchner funnel. The liquid is caused to flow through the filter cloth or paper by a vacuum on the --exit end. The slurry consists of the liquid and the suspended particles.

The passage of the particles is blocked by the small openings in the pores of the filter cloth. A support with relatively large holes is used to hold the filter cloth. The solid particles build up in the form of a porous filter cake as the filtration proceeds. This cake itself also acts as a filter for the suspended particles. As the cake builds up, resistance to flow also increases.

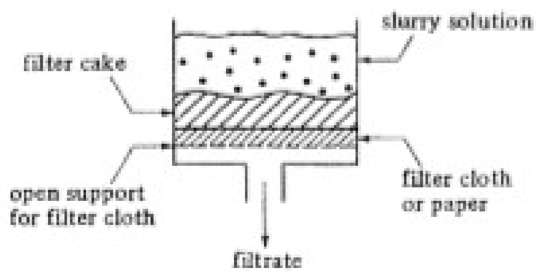

Figure 1 Simple Filtration

Filtration Equipment

1. Classification of filters. There are a number of ways to classify types of filtration equipment, and it is not possible to make a simple classification that includes all types of filters. In one classification filters are classified according to whether the filter cake is the desired product or whether the clarified filtrate or outlet liquid is desired. In either case the slurry can have a relatively large percentage of solids so that a cake is formed, or have just a trace of suspended particles.

   Filters can be classified by operating cycle. Filters can be operated as batch, where the cake is removed after a run, or continuous, where the cake is continuously removed. In another classification, filters can be of the gravity type, where the liquid simply flows by a hydrostatic head, or pressure or vacuum can be used to increase the flow rates. And important method of classification depends upon the mechanical arrangement of the filter media. The filter cloth can be in a series arrangemen t as flat plates in an enclosure, as individual leaves dipped in the slurry. or on rotating-type rolls in the slurry.

2. Bed filters. The simplest type of filter is the bed filter shown schematically in Fig. 2. This type is useful mainly in cases where relatively small amounts of solids are to be removed from large amounts of water in clarifying the liquid. Often the bottom layer is composed of coarse pieces of gravel resting on a perforated or slotted plate. Above the gravel is fine sand, which acts as the actual filter medium. Water is introduced at the top onto a baffie which spreads the water out. The clarified liquid is drawn out at the bottom.

The filtration continues until the precipitate of filtered particles has clogged the sand so that the flow rate'cirops. Then the flow is stopped and water introduced in the reverse direction so that it flows upward, back washing the bed and carrying the precipitated solid away. This apparatus can only be used on precipitates that do not adhere strongly to the sand and can be easily removed by backwashing. Open tank filters are used in filtering municipal water supplies.

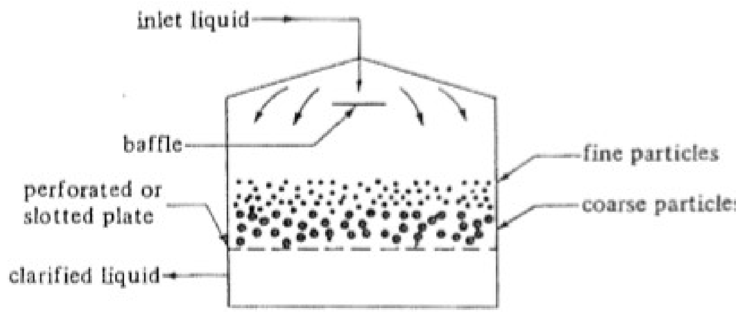

Figure 2 Bed filter of solid particles

3. Plate-and-frame filter presses. One of the important types of filters is the plate-andframe filter press, which is shown diagrammatically in Fig 3a. These filters consist of plates and frames assembled alternatively with a filter cloth over each side of the plates. The plates have channels cut in them so that clear filtrate liquid can drain down along each plate. The feed slurry is pumped into the press and flows through the duct into each of the open frames so that slurry fills the frames. The filtrate flows through the filter cloth and the solids build up as a cake on the frame side of the cloth. 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. In Fig.3a 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. Then visual inspection can be made to see if the filtrate is running clear. If one is running cloudy because of a break in the filter cloth or other factors, it can be shut off separately. When the frames are completely full, the frames and plates are separated and the cake removed. Then the filter is reassembled and the cycle is repeated.

   If the cake is to be washed, the cake is left in the plates and through washing is performed, as shown in Fig.3b. In this press a separate channel is provided for the wash water inlet. The wash water enters the inlet, whichhas ports opening behind the filter cloths at every other plate of the filter press. The wash water then flows through the filter cloth, .through the entire cake (not half the cake as in filtration), through the filter cloth at the other side of the frames, and out the discharge channel. It should be noted that there are two kinds of plates in Fig. 3b: those having ducts to admit wash water behind the filter cloth, alternating with those without such ducts.

The plate-and-frame presses suffer from the disadvantages common to batch processes. The cost of labor for removing the cakes and reassembling plus the cost of fixed charges for downtime can be an appreciable part of the total operating cost. Some newer types of plate-and-frame presses have duplicate sets of frames mounted on a rotating shaft. Half of the frames are in use while the others, are being cleaned, saving downtime and labor costs. Other advances in automation have been applied to these types of filters. Filter presses are used in batch processes but cannot be employed for highthroughput processes. They are simple to operate, very versatile and flexible in operation, and can be used at high pressures, when necessary, if viscous solutions are being used or the filter cake has a high resistance.

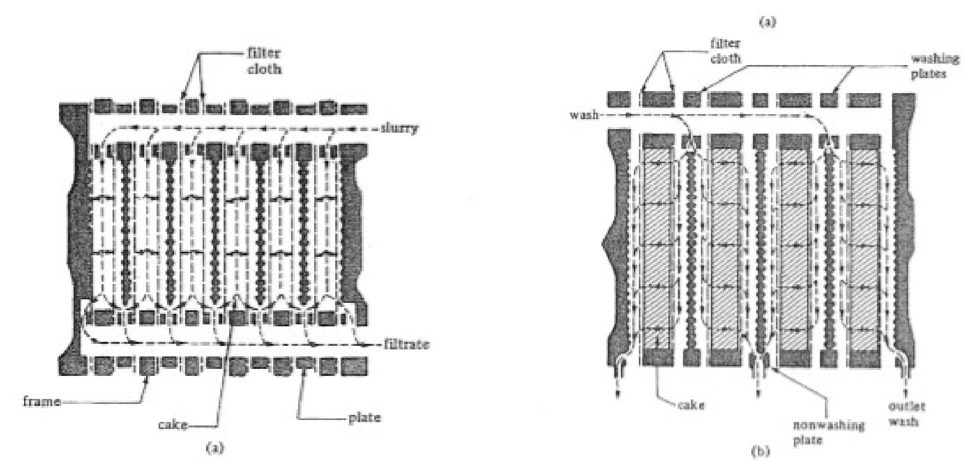

Figure 3 Plate and Frame

4. Leaf fillers. The filter press is useful for many purposes but is not economical for handling large quantities of sludge or for efficient washing with a small amount of wash water. The wash water often channels in the cake and large volumes of wash water may be needed. The leaf filter shown in Fig.4 was developed for

larger volumes of slurry and more efficient washing. Each leaf is a hollow wire framework covered by a sack of filter cloth. A number of these leaves are hung in parallel in a closed tank. The slurry enters the tank and is forced under pressure through the filter cloth, where the cake deposits on the outside of the leaf. The filtrate Hows inside the hollow framework and out a header.

The wash liquid follows the same path as the slurry. Hence, the washing is more efficient than the through washing in plate-and-frame filter presses. To remove the cake, the shell is opened. Sometimes air is blown in the reverse direction into the leaves to help in dislodging the cake. If the solids are not wanted, water jets can be used to simply wash away the cakes without opening the filter. Leaf filters also suffer from the disadvantage of batch operation. They can be automated for the filtering, washing, and cleaning cycle. However, they are still cyclical and are used for batch processes and relatively modest throughput processes.

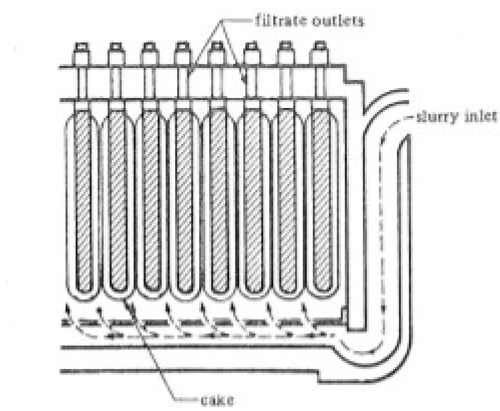

Figure 4 Leaf filter

5. Continuous rotary filcers. The plate-and-frame filters suffer from the disadvantages common to all batch processes and cannot be used for large capacity processes. A number of continuous-type filters are available as discussed below. (a). Continuous rotary vacuum-drum filter. This filter shown in Fig. 5 filters, washes, and discharges the cake in a continuous repeating sequence. The drum is covered with a suitable filtering medium. The drum rotates and an automatic valve in the center serves to activate the filtering, drying, washing, and cake discharge functions in the cycle. The filtrate leaves through the axle of the filter. The automatic valve provides separate outlets for the filtrate and the wash liquid. Also, jf needed, a connection for compressed air blowback just before discharge can be used to help in cake removal by the knife scraper. The maximum pressure differential for the vacuum

filter is only I atm. Hence, this type is not suitable for viscous liquids or for liquids that must be enclosed. If the drum is enclosed in a shell, pressures above atmospheric can be used. However, the cost of a pressure type is about two times that of a vacuum-type rotary drum filter (PZ). Modern, high-capacity processes use continuous filters. The important advantages are that the filters are continuous and automatic and labor costs are relatively low. However, the capital cost is relatively high. (b). Continuous rotary disk filter. This filter consists of concentric vertical disks mounted on a horizontal rotating shaft. The filter operates on the same principle as the vacuum rotary drum filter. Each disk is hollow and covered with a filter cloth and is partly submerged in the slurry. The cake is washed, dried, and scraped off when the disk is in the upper half of its rotation. Washing is less efficient than with a rotating drum type. (e). Continuous rotary horizontal filter. This type is a vacuum filter with the rotating annular filtering surface divided into sectors. As the horizontal filter rotates it successively receives slurry, is washed, dried, and the cake is scraped off. The washing efficiency is better than with the rotary disk filter. This filter is widely used in ore extraction processes, pulp washing, and other large-capacity processes.

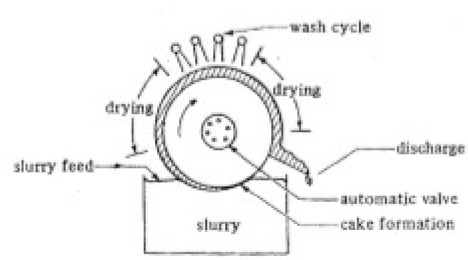

Figure 5 Schematic of continous rotary drum filter

DEFINITIONS

Filtration – A process used to separate solids from liquids or gases using a filter medium that allows the fluid to pass through but not the solid

Filter Media – The granular filtering materials which are installed in the filters. Their function is to retain the suspended solids during the filtration process.

Filter rating – The measurement of the average pore size of a filter element. It establishes the particle size above which the filter starts to be effective. It is determined by the bubble point test and it is more meaningful than a nominal rating and, in case of filter elements with varying pore size, more realistic than an absolute rating.

Filter Test – A small section of a continuous filter incorporating typical filter medium support and filtrate drainage.

Filter Efficiency – Rate a medium by the percentage of contaminant removed by the filter medium. The quantity can be by weight or mass, by number of particles, by volume, and interestingly enough by cross-section area of the particles.

Filter permeability – A significant term used to measure the endothelial permeability to fluid.

Surface – Particles are retained mostly on the surface of the media, forming a layer of material that increases the efficiency or fineness of particles retained.

Depth Filtration – Solid particles are retained in a deep filter layer.

Cake – The most frequently used model. Here it is assumed that the solids are deposited on the upstream side of the filter medium as a homogeneous porous layer with a constant permeability.

NOMENCLATURE

A	Radius-sectional area, ft^2 (m^2)
B	Basic equations for filtration, s/m^3 (s/ft^3)
C	Constant characteristic of the slurry
C_s	Material balance of filtrate , kg solid/m^3 (lbm/ft^3)
D	Internal diameter , ft (m)
f	Dancy's friction factor, dimensionless
f_t	Friction factor for fitting
ΔP	Pressure drop, N/m^2(lb/ft^2)
K	Resistance coefficient, dimensionless
K_1	Resistance coefficient for enlargement/contraction, dimensionless
K_p	Constant pressure, s/m^3 (s/ft^3)
L	Length, ft (m)
N	Number of particles
P	Pressure, lbf/in^2(kg/cm^2)
q	Volumetric flow rate, ft^3/hr (m^3/hr)
R_m	Resistance of the filter medium to filtrate flow, m^{-1}(ft^{-1})
S	Specific gravity of a liquid, dimensionless (hydrocarbon in API)
T	Absolute temperature, R (460+°F)
t	Pressure design minimum thickness, in. (mm)
t	Time, s
V	Mean velocity, ft/s (m/s)
V_e	Volume of filtrate
V_f	Total volume of filtrate, m^3 (ft^3)
$\overline{V}$	Specific volume, ft^3/lbm (m^3/kg)
ΔV	Change of linear flow velocity, ft/s (m/s)
W	Mass flow rate, lbm/hr (kg/hr)

Greek letters

ρ	Weight density of fluid, lbm/ft^3 (kg/m^3)
μ_e	Absolute viscosity, lbm.s /ft (kg.s/m)
μ	Absolute (dynamic) viscosity, cp
ε	Absolute roughness, in (mm)
Δ	Differential between two points
α	Specific resistance of cake, m/kg (ft/lbm)
β	Beta ratio