

KLM Technology Group Practical Engineering Guidelines for Processing Plant Solutions	 Engineering Solutions www.klmtechgroup.com	Page : 1 of 110
		Rev: 01
		Rev 01 January 2020
KLM Technology Group P. O. Box 281 Bandar Johor Bahru, 80000 Johor Bahru, Johor, West Malaysia	Kolmetz Handbook of Process Equipment Design FILTER SEPARATOR SIZING AND SELECTION (ENGINEERING DESIGN GUIDELINES)	Co Author Rev 01 Utami Ledyana
		Editor / Author Karl Kolmetz

Table of Contents

INTRODUCTION	8
Scope	8
GENERAL DESIGN CONSIDERATION	8
Mechanical – Physical separation	8
Filtration in solid-liquid separation	9
Filtration Equipment	10
DEFINITIONS	15
NOMENCLATURE	16
THEORY	17
Basic Theory of Filtration	17
Filtration Equations for Constant-Pressure Filtration	20
Filtration Equations for Constant-Rate Filtration	24
Filtration technology	25

KLM Technology Group Practical Engineering Guidelines for Processing Plant Solutions www.klmtechgroup.com	Kolmetz Handbook of Process Equipment Design FILTER SEPARATOR SIZING AND SELECTION ENGINEERING DESIGN GUIDELINES	Page 2 of 110
		Rev: 01
		JANUARY 2020

Types of filter	27
Rotary disc filters	29
Horizontal belt filters	30
Band filters	30
Florentine filter	31
Vacuum belt filters	32
Conical basket centrifuges	33
Pusher centrifuge	34
Pad and panel filters	34
Dust characteristics	35
Back flushing filters	36
Leaf and plate filters	37
Leaf filters	37
Plate filters	38
Filtration parameters	40
Filter presses	40
Plate and frame press	41
Belt presses	43
Variable volume filters	43
Cross-flow filtration	44
Magnetic filters	45
Pipeline filters	47
Trough filters	48
Filter media	49
Bonded porous media	55
Inorganic materials	56
Woven wire and screens	59
Woven wire mesh	60
Sintered wire mesh,k,kkkk	65
Perforated plate	67
Bar and wire structures	71
Filter ratings	72
Absolute ratings	73
Nominal rating	73

KLM Technology Group Practical Engineering Guidelines for Processing Plant Solutions www.klmtechgroup.com	Kolmetz Handbook of Process Equipment Design FILTER SEPARATOR SIZING AND SELECTION ENGINEERING DESIGN GUIDELINES	Page 3 of 110
		Rev: 01
		JANUARY 2020

Mean filter rating	74
Beta ratio	74
Filter efficiency	75
Filter permeability	75
Filter tests	78
Filter selection	79
The selection process	81
Filter size	85
Surface vs depth filtration	85
Compatibility	88
Contamination levels	88
Particle settlement	90
Airborne contaminants	90
Effect on humans	94
Effect on machines	94
Liquid contaminants	95
Applications	95
Liquid flow contaminants	96
Applications	96
Pre filters	96
Filter selection	97
<i>Air filters</i>	100
Reference standards	102
The range is from terminology:	103

KLM Technology Group Practical Engineering Guidelines for Processing Plant Solutions www.klmtechgroup.com	Kolmetz Handbook of Process Equipment Design FILTER SEPARATOR SIZING AND SELECTION ENGINEERING DESIGN GUIDELINES	Page 4 of 110
		Rev: 01
		JANUARY 2020

APPLICATION 104

Example 1 Evaluation of filtration constant for constant pressure 104

Example 2 Time required to perform filtration 106

Example 3 Rate of Washing and Total Filter Cycle time 107

Example 4 Filtration in a continuous rotary drum filter 108

REFERENCES 110

LIST OF TABLE

Table 1 Classification of filter 27

Table 2 Particle size range 35

Table 3 Types of filter media by material 49

Table 4 Filter media types by format 51

Table 5 Comparative properties of filter media fabric 52

Table 6 Typical applications for filter fabrics 54

Table 7 Properties of high temperature media 57

Table 8 Typical set if wire mesh dimensions 62

Table 9 Test sieves – international comparisons 64

Table 10 Principle weaves for wire cloths 66

Table 11 Metal filter performance comparisons 67

Table 12 Typical set of perforated plate hole dimensions 67

Table 13 Beta ratio and efficiency 74

KLM Technology Group Practical Engineering Guidelines for Processing Plant Solutions www.klmtechgroup.com	Kolmetz Handbook of Process Equipment Design FILTER SEPARATOR SIZING AND SELECTION ENGINEERING DESIGN GUIDELINES	Page 5 of 110
		Rev: 01
		JANUARY 2020

Table 14 Summary of media characteristics	81
Table 15 approximate settling velocities in still air	90
Table 16 Basic type of fluid filters	97
Table 17 General selection guide for filters	98
Table 18 Eurovent and cen classification of ventilation air filters	100
Table 19 Beta ratios	102

LIST OF FIGURE

Figure 1 Simple Filtration	10
Figure 2 Bed filter of solid particles	11
Figure 3 Plate and Frame	12
Figure 4 Leaf filter	13
Figure 5 Schematic of continuous rotary drum filter	14
Figure 6 section through a filter cake	17
Figure 7 Determination of constants in a constant-pressure filtration	21
Figure 8 Elements of rotary disc filter	30
Figure 9 Band filter	31
Figure 10 Florentine filter	32
Figure 11 Reciprocating tray filter	33
Figure 12 Tumbler centrifuge schematic	33
Figure 13 Pusher centrifuge schematic	34

KLM Technology Group Practical Engineering Guidelines for Processing Plant Solutions www.klmtechgroup.com	Kolmetz Handbook of Process Equipment Design FILTER SEPARATOR SIZING AND SELECTION ENGINEERING DESIGN GUIDELINES	Page 6 of 110
		Rev: 01
		JANUARY 2020

Figure 14 Pusher centrifuge rotors	34
Figure 15 Backflusing arrangement	37
Figure 16 Leaf and plate filter elements	37
Figure 17 Vertical leaf pressure filter	38
Figure 18 Horizontal plate pressure filter	39
Figure 19 Horizontal plate filter with scavenger plate	39
Figure 20 Plate and frame press with side bars	42
Figure 21 Vacuum belt filter with auxiliary belt press	43
Figure 22 Variable chamber filter	44
Figure 23 Cross-flow filtration	45
Figure 24 Magnetic crankcase drain plug	46
Figure 25 Typical magnetic filter assembly	47
Figure 26 Magnetic pipeline filter	47
Figure 27 Magnetic trough filter components	48
Figure 28 Complete trough filter	48
Figure 29 Complete trough filter	52
Figure 30 porous plastic sheet media	56
Figure 31 metal fiber cartridge media	57
Figure 32 Mesh dimensions	61
Figure 33 Typical perforated plate patterns	70

KLM Technology Group Practical Engineering Guidelines for Processing Plant Solutions www.klmtechgroup.com	Kolmetz Handbook of Process Equipment Design FILTER SEPARATOR SIZING AND SELECTION ENGINEERING DESIGN GUIDELINES	Page 7 of 110
		Rev: 01
		JANUARY 2020

Figure 34 Drilled plate profiles	70
Figure 35 Milled hole profiles	71
Figure 36 expand metal pattern	71
Figure 37 <i>wedge wire screen</i>	72
Figure 38 filter size curves	76
Figure 39 effect of temperature change	77
Figure 40 effect of solid loading	77
Figure 41 Pressure drop / time curve	78
Figure 42 Depth Filtration	86
Figure 43 Cake filtration	87

KLM Technology Group Practical Engineering Guidelines for Processing Plant Solutions www.klmtechgroup.com	Kolmetz Handbook of Process Equipment Design FILTER SEPARATOR SIZING AND SELECTION ENGINEERING DESIGN GUIDELINES	Page 8 of 110
		Rev: 01
		JANUARY 2020

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.

- 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.
- 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.
- Centrifugal settling and sedimentation. In centrifugal separations the particles are separated from the fluid by centrifugal forces acting on the various size and

KLM Technology Group Practical Engineering Guidelines for Processing Plant Solutions www.klmtechgroup.com	Kolmetz Handbook of Process Equipment Design FILTER SEPARATOR SIZING AND SELECTION ENGINEERING DESIGN GUIDELINES	Page 9 of 110
		Rev: 01
		JANUARY 2020

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. Commercial 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

KLM Technology Group Practical Engineering Guidelines for Processing Plant Solutions www.klmtechgroup.com	Kolmetz Handbook of Process Equipment Design FILTER SEPARATOR SIZING AND SELECTION ENGINEERING DESIGN GUIDELINES	Page 10 of 110
		Rev: 01
		JANUARY 2020

itself also acts as a filter for the suspended particles. As the cake builds up, resistance to flow also increases.

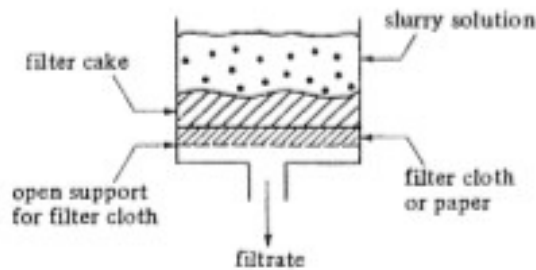


Figure 1 Simple Filtration

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. An important method of classification depends upon the mechanical arrangement of the filter media. The filter cloth can be in a series arrangement 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 baffle which spreads the water out. The clarified liquid is drawn out at the bottom.

KLM Technology Group Practical Engineering Guidelines for Processing Plant Solutions www.klmtechgroup.com	Kolmetz Handbook of Process Equipment Design FILTER SEPARATOR SIZING AND SELECTION ENGINEERING DESIGN GUIDELINES	Page 11 of 110
		Rev: 01
		JANUARY 2020

The filtration continues until the precipitate of filtered particles has clogged the sand so that the flow rate drops. 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.

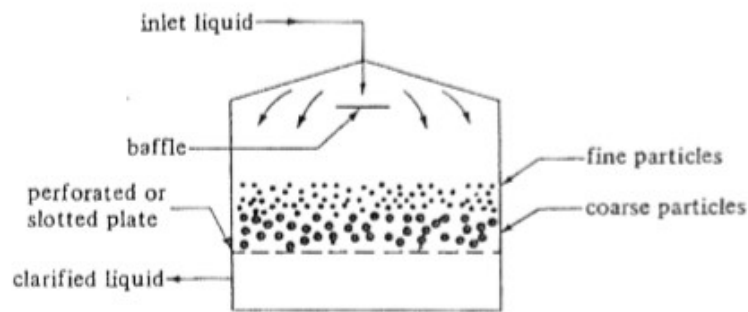


Figure 2 Bed filter of solid particles

3. Plate-and-frame filter presses. One of the important types of filters is the plate-and-frame 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

KLM Technology Group Practical Engineering Guidelines for Processing Plant Solutions www.klmtechgroup.com	Kolmetz Handbook of Process Equipment Design FILTER SEPARATOR SIZING AND SELECTION ENGINEERING DESIGN GUIDELINES	Page 12 of 110
		Rev: 01
		JANUARY 2020

wash water inlet. The wash water enters the inlet, which has 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 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 solutions are being used or the filter cake has a high resistance.

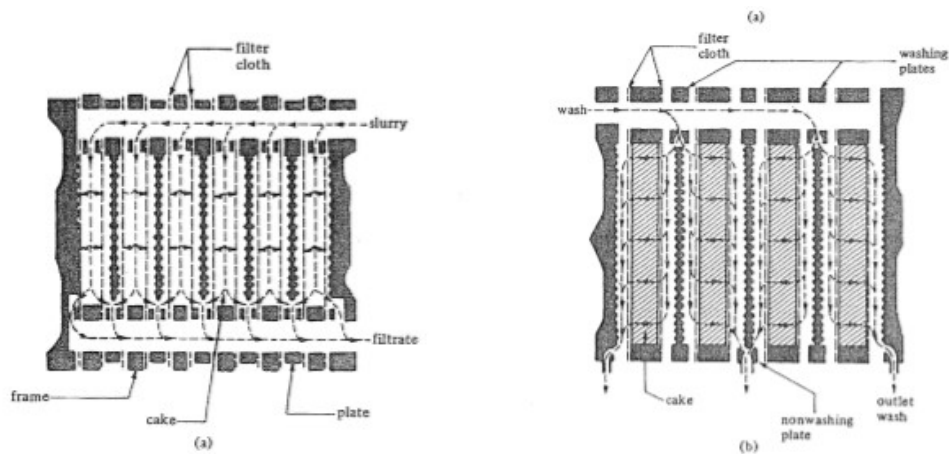


Figure 3 Plate and Frame

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

KLM Technology Group Practical Engineering Guidelines for Processing Plant Solutions www.klmtechgroup.com	Kolmetz Handbook of Process Equipment Design FILTER SEPARATOR SIZING AND SELECTION ENGINEERING DESIGN GUIDELINES	Page 13 of 110
		Rev: 01
		JANUARY 2020

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 flows 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.

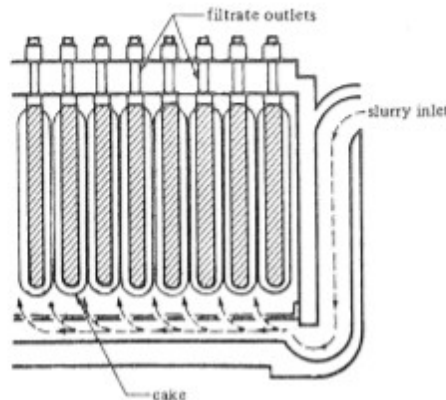


Figure 4 Leaf filter

- Continuous rotary filters. 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, if 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

KLM Technology Group Practical Engineering Guidelines for Processing Plant Solutions www.klmtechgroup.com	Kolmetz Handbook of Process Equipment Design FILTER SEPARATOR SIZING AND SELECTION ENGINEERING DESIGN GUIDELINES	Page 14 of 110
		Rev: 01
		JANUARY 2020

filter is only 1 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.

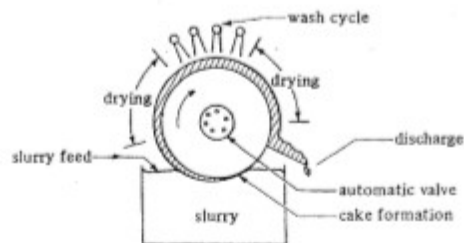


Figure 5 Schematic of continous rotary drum filter

KLM Technology Group Practical Engineering Guidelines for Processing Plant Solutions www.klmtechgroup.com	Kolmetz Handbook of Process Equipment Design FILTER SEPARATOR SIZING AND SELECTION ENGINEERING DESIGN GUIDELINES	Page 15 of 110
		Rev: 01
		JANUARY 2020

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.

KLM Technology Group Practical Engineering Guidelines for Processing Plant Solutions www.klmtechgroup.com	Kolmetz Handbook of Process Equipment Design FILTER SEPARATOR SIZING AND SELECTION ENGINEERING DESIGN GUIDELINES	Page 16 of 110
		Rev: 01
		JANUARY 2020

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 _ε	Volume of filtrate
V _f	Total volume of filtrate, m ³ (ft ³)
$\bar{V}$	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