ENGINEERING STANDARD

FOR

PROCESS DESIGN

OF

SOLID-LIQUID SEPARATORS

ORIGINAL EDITION

JULY 1997

This standard specification is reviewed and updated by the relevant technical committee on Jan. 2006. The approved modifications are included in the present issue of IPS.

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APPENDICES:

0. INTRODUCTION

"Process Design of Separators" are broad and contain various subjects of paramount importance. Therefore, a group of process engineering standards are prepared to cover the subject of mechanical separators. This group includes the following standards:

STANDARD CODE	**STANDARD TITLE**
IPS-E-PR-850	"Process Requirements of Vessels, Reactors and Separators"
IPS-E-PR-880	"Process Design of Gas (Vapor) -Liquid Separators"
IPS-E-PR-895	"Process Design of Solid-Liquid Separators"

"Filters and Filtration Handbook" by Christopher Dickenson has been used as main source throughout this Standard. Therefore, the details to be referred to the mentioned source where required.

This Engineering Standard Specification covers:

"PROCESS DESIGN OF SOLID-LIQUID SEPERATORS"

1. SCOPE

This Engineering Standard Specification, covers minimum requirements for the process design (including criteria for type selection) of solid-liquid separators used in the production of the oil and/or gas, refineries and other gas processing and petrochemical plants.

Typical sizing calculation together with introduction for proper selection is also given for guidance.

Note:

This standard specification is reviewed and updated by the relevant technical committee on Jan. 2006. The approved modifications by T.C. were sent to IPS users as amendment No. 1 by circular No. 275 on Jan. 2006. These modifications are included in the present issue of IPS.

2. REFERENCES

Throughout this Standard the following dated and undated standards/codes are referred to. These referenced documents shall, to the extent specified herein, form a part of this standard. For dated references, the edition cited applies. The applicability of changes in dated references that occur after the cited date shall be mutually agreed upon by the Company and the Vendor. For undated references, the latest edition of the referenced documents (including any supplements and amendments) applies.

IPS (IRANIAN PETROLEUM STANDARDS)

IPS-E-GN-100	"Engineering Standards for Units"
IPS-E-PR-310	"Engineering Standards for Process Design of Water Systems"
IPS-E-PR-880	"Engineering Standards for Process Design of Gas (Vapor) -Liquid Separators"

3. DEFINITIONS AND TERMINOLOGY

The following is a glossary of terms used in the solid-liquid separation technology.

3.1 Critical Diameter

"Critical diameter" is the diameter of particles larger than which will be eliminated in a sedimentation centrifuge.

3.2 Filter

A Filter is a piece of unit operation equipment by which filtration is performed.

3.3 Filter Medium

The "filter medium" or "septum" is the barrier that lets the liquid pass while retaining most of the solids; it may be a screen, cloth, paper, or bed of solids.

3.4 Filtrate

The liquid that passes through the filter medium is called the filtrate.

3.5 Mesh

The "mesh count" (usually called "mesh"), is effectively the number of openings of a woven wire filter per 25 mm, measured linearly from the center of one wire to another 25 mm from it. i.e.,:

$$\textbf{Mesh} = 25/(w+d) \qquad \textbf{(Eq. 1)}$$

(see Clause 4 for Symbols and Abbreviations).

3.6 Open Area

Open area is defined as a percentage of the whole area of a woven wire filter, is shown by (Fo) and can by calculated from the equation:

$$Fo = \frac{w^2}{(w + d)} \times 100 \qquad \textbf{(Eq. 2)}$$

(see Clause 4 for Symbols and Abbreviations).

3.7 Overflow

The stream being discharged out of the top of a hydrocyclone, through a protruding pipe, is called "overflow". This stream consists of bulk of feed liquid together with the very fine solids.

3.8 Septum

See 3.3.

3.9 Underflow

The stream containing the remaining liquid and the coarser solids, which is discharged through a circular opening at the apex of the core of a hydrocyclone is referred to as "underflow".

4. SYMBOLS AND ABBREVIATIONS

The following is a list of symbols and abbreviations of parameters used in this Standard and their units of measurement.

AISI	American Iron & Steel Institute.
BG	Standard Birmingham Gage for sheet and hoop metal.
BSWG	British Standard Wire Gage.
D	Wire diameter, in (mm).
d_{50}	The particle diameter for which a hydrocyclone is 50 percent efficient, in (µm).
d_p	size of particles separated in a hydrocyclone, (in µm).
D_c	Diameter of hydrocyclone chamber, in (m).
D_{pc}	Critical diameter of particles in centrifuge, in (m).
E_q	Equation.
E_x	liter efficiency for particles with x micrometer diameter size.
g or G	Local acceleration due to gravity, in (m/s²).
HEPA	High Efficiency Particulate Air (Filter).
L	Hydrocyclone feed rate , in (L/min.).
N	Number of particles per unit volume in upstream or downstream of filter.
OGP	Oil, Gas and Petrochemical.
P	Liquid, feed pressure for a hydrocyclone, in (kPa).
PVC	Polyvinyl Chloride.
PTFE	Polytetraflouroethylene.
Qc	Volumetric flow rate of liquid through the bowl of a sedimentation centrifuge, in percent (%).
r	Radial distance from centre, (in centrifuge), in (m).
s	Thickness of liquid layer in a centrifuge, in (m).
Vg	Terminal settling velocity of a particle in gravitational field, in (m/s).
V	Volume of the liquid held in the bowl of a centrifuge, in (m³).
w	Width of woven wire opening, in (mm).
x	Particle size, in (µm).

GREEK LETTERS

β **(beta)**	Beta rating or Beta ratio of filter, (dimensionless).
ρ_l **(rho)**	Liquid phase density, in (kg/m^3).
ρ_p **(rho)**	Density of particle, in (kg/m^3).
μ**(mu)**	Dynamic viscosity of continuous phase, in [cP=(mPa.s)].
ϖ **(omega)**	Angular velocity, in radian/s, (rad/s).
η **(eta)**	Efficiency of hydrocyclone in separating particles of diameter dp, in percent(%).
$\sum$ **(sigma)**	Theoretical capacity factor of a sedimentation centrifuge, in (m^2).

5. UNITS

This Standard is based on International System of Units as per IPS-E-GN-100, (SI) except where otherwise specified.

6. GENERAL

In this Standard, process aspects of three types of most frequently used solid-liquid separators are discussed more or less n details. These three types are:

- Filters.
- Centrifuges.
- Hydrocyclones.

Another frequently used type, i.e., gravity settlers, (e.g., clarifiers), is mentioned in brief, since this type is discussed in details in IPS-E-PR-310 "Process Design of Water Systems". Types of mechanical separators are generally shown in Fig. F.1 of IPS-E-PR-880, "Process Design of Gas (Vapor) - Liquid Separators".

6.1 Solid-Liquid Separator Types

Solid-Liquid separator types often used in OGP Processes which are discussed in this Standard are:

- Filters.
- Centrifuges.
- Hydrocyclones.
- Gravity Settlers.

6.2 Separation Principles

Solid-Liquid separation processes are generally based on either one or a combination of "Gravity Settling", "Filtration" and "Centrifugation", principles.

The principles of these kinds of mechanical separation techniques are briefly described in the following clauses. Note that as a general rule, mechanical separations occurs only when the phases are immiscible and/or have different densities.

6.2.1 Mechanical separation by gravity

Solid particles will settle out of a liquid phase if the gravitational force acting on the droplet or particle is greater than the drag force of the fluid flowing around the particle (sedimentation). The same phenomenon happens for a liquid droplet in a gas phase and immiscible sphere of a liquid immersed in another liquid.

Rising of a light bubble of liquid or gas in a liquid phase also follows the same rules, i.e., results from the action of gravitational force (floatation).

Stokes' law applies to the free settling of solid particles in liquid phase.

6.2.2 Mechanical separation by momentum

Fluid phases with different densities will have different momentum. If a two phase stream changes direction sharply, greater momentum will not allow the particles of heavier phase to turn as rapidly as the lighter fluid, so separation occurs. Momentum is usually employed for bulk separation of the two phases in a stream. Separation by centrifugal action is the most frequently technique used in this field.

6.2.3 Mechanical separation by filtration

Filtration is the separation of a fluid-solid or liquid gas mixture involving passage of most of the fluid through a porous barrier which retains most of the solid particulates or liquid contained in the mixture.

Filtration processes can be divided into three broad categories, cake filtration, depth filtration, and surface filtration.

6.2.3.1 Patterns of filtration process

Regarding the flow characteristic of filtration, this process can be carried out in the three following forms:

a) Constant-Pressure filtration. The actuating mechanism is compressed gas maintained at constant pressure.

b) Constant-Rate filtration. Positive displacement pumps of various types are employed.

c) Variable-Pressure, variable rate filtration. The use of a centrifugal pump results in this pattern.

7. LIQUID FILTERS

7.1 General

Filtration is the separation of particles of solids from fluids (liquid or gas) or liquid from liquid gas mixture by use of a porous medium. This Standard Practice deals only with separation of solids from liquid, i.e., "Liquid Filtration".

7.1.1 Mechanisms of filtration

Three main mechanisms of filtration are cake filtration, depth filtration and surface filtration. In cake filtration, solids form a filter cake on the surface of the filter medium. In depth filtration, solids are trapped within the medium using either, cartridges or granular media such as sand or anthracite coal. Surface filtration, also called surface straining, works largely by direct interception. Particles larger than the pore size of the medium are stopped at the upstream surface of the filter.

7.1.2 Types of liquid filters

Considering the flow characteristics, as mentioned in Clause 6.2.3.1, three types of filtration processes exist, constant pressure, constant rate and variable pressure-variable rate. Regarding the manner of operation, filtration may be continuous or batch.

Filter presses and vacuum drum filters are well known examples for batch and continuous filters respectively.

Most commonly used types of liquid filters may be named as follows:

- Strainers.
- Screens.
- Cartridge Filters.
- Candle Filters.
- Sintered Filters.
- Precoat Filters.
- Filter Presses.

- Rotary Drum Filters.
- Rotary Disk Filters.
- Belt Filters.
- Leaf Filters
- Tipping Pan Filters.

7.1.3 Filter media

There are many different types of filter media available and all have an important role in filtration.

The range includes: paper, natural and synthetic fibres, powders, felt, plastic sheet and film, ceramic, carbon, cotton yarn, cloth, woven wire, woven fabric, organic and inorganic membranes, perforated metal, sintered metals and many other materials. These may be generally divided into four groups, General media, Membrane type media, Woven wire, and Expanded sheet media.

7.1.3.1 General types of media

Papers, with good capability of removing finer particles and limited mechanical strength as main advantage and disadvantage, filter sheets, natural fabrics, syntethic fabrics either monofilament or multifilament felts, needle felts, bounded media, wool resin electrostatic media, mineral wools, diatomaceous earth, perlite, silica hydrogels, glass fibre, charcoal cloth, carbon fibre, anthracite and ceramic media are some types of filter media in this group. Applications of filter cloths including some advantages and disadvantages of this type of media are shown in Table 1.

TABLE 1 - APPLICATIONS OF FILTER CLOTHS

Material	Suitable for:	Maximum service temp.°C	Principal advantage(s)	Principal disadvantage(s)
Cotton	Aqueous solutions, oils, fats, waxes cold acids	90	nexpensive.	Subject to attack by mildew and fungi.
Jute wool	and volatile organic acids.	85	Easy to seal joints in filter	High shrinkage, subject to moth
	Aqueous solutions.	80	presses.	attack in store. Absorbs water; not
Nylon	Aqueous solutions and dilute acids.	150	High strength or flexibility.	suitable for alkalis.
	Acids, petrochemicals, organic solvents,		Easy cake discharge. Long	Not suitable for alkalis.
Polyester	alkaline suspensions.	100	life.	
(Terylene)	Acids, common organic solvents, oxidising		Good strength and flexibility,	May become brittle.
PVC	agents. Acids and alkalis.	up to 90	Initial shrinkage.	Heat resistance poor.
				High cost.
PTFE	Virtually all chemicals.	200		
			Extreme chemical resistance.	Soften at moderate temperatures.
Polyethylene	Acids and alkalis.	70	Excellent cake discharge.	
Polypropylene	Acids, alkalis, solvents (except aromaties	130	Easy cake discharge.	
	and chlorinated hydrocarbons). Acids,		Low moisture absorption.	
Dynes	alkalis, solvents, petrochemicals. Acids	110		
Orlon	(including curomic acid), petrochemicals.	over 150	Suitable for a wide range of	
Vinyon	Acids, alkalis, solvents, petroleum products.	110	chemical solutions, hot or	Lacks fatigue strength for flexing.
Glassfibre	Concentrated hot acids, chemical solutions.	250	cold (except alkalis).	Abrasive resistance poor.

7.1.3.2 Membrane filters

Particles with diameters from smaller than 0.001 µm up to 1 µm can be filtered by Microfiltration, Ultrafiltration, Reverse Osmosis, Dialysis, Electrodialysis processes using Porous, Microporous and Non-porous membranes.

Membranes may be made from polymers, ceramic and metals. Typical specification for metal membranes are shown in Table A.1 of Appendix A.

7.1.3.3 Woven wire

Woven wire cloth is widely used for filtration and is available in an extremely wide range of materials and mesh sizes.

It can be woven from virtually any metal ductile enough to be drawn into wire form, preferred materials being phosphor bronze, stainless steel of the nickel/chrome type-AISI 304, 316 and 316L and monel.

Woven wire cloth is described nominally by a mesh number and wire size, i.e., N mesh M mm (or swg). Mesh numbers may range from 2 (2 wires per 25.4 mm or 1 inch) up to 400. Fine mesh with more than 100 wires per lineal 25.4 mm (inch) is called gauze. Woven wires may also be described by aperture opening, e.g.,:

- coarse-aperture opening 1 to 12 mm;
- medium-aperture opening 0.18 to 0.95 mm (180 to 950 µm);
- fine-aperture opening 0.020 to 0.160 mm (20 to 160 µm).

Characteristics of different weaves for woven wire cloths and wire cloth specification are shown in Tables A.2 and A.3 of Appendix A respectively.

7.1.3.4 Expanded sheet and non-woven metal mesh

Perforated metal sheets, Drilled plates, Milled plates and Expanded metal mesh are examples of this type of filter media.

Most of the strainers, air and gas filters, etc., are usually made using the type of filters media. Predictable and consistent performance is the main characteristic of it which results from the controllability of the size of screen opening by the manufacturer. Some useful data for Perforated plates are shown in Tables A.4 and A.5 of Appendix A.

7.1.4 Filter rating

Filters are rated on their ability to remove particles of a specific size from a fluid, but the problem is that a variety of very different methods are applied to specifying performances in this way. Quantitative figures are only valid for specific operating or test conditions.

7.1.4.1 Absolute rating

The absolute rating, or cut-off point of a filter refers to the diameter of the largest particle, normally expressed in micrometers (µm), which will pass through the filter. It therefore represents the pore opening size of the filter medium. Filter media with an exact and consistent pore size or opening thus, theoretically at least, have an exact absolute rating.

Certain types of filter media, such as papers, felts and cloths, have a variable pore size and thus no absolute rating at all. The effective cut-off is largely determined by the random arrangement involved and the depth of the filter. Performance may then be described in terms of nominal cut-off or nominal rating.

7.1.4.2 Nominal rating

A nominal filter rating is an abritrary value determined by the filter manufacturer and expressed in terms of percentage retention by mass of a specified contaminant (usually glass beads) of given size. It also represents a nominal efficiency figure, or more correctly, a degree of filtration.

7.1.4.3 Mean filter rating

A mean filter rating is a measurement of the mean pore size of a filter element. It establishes the particle size above which the filter starts to be effective.

7.1.4.4 Beta (ß) ratio

The Beta ratio is a rating system introduced with the object of giving both filter manufacturer and user an accurate and representative comparison amongst filter media. It is determined by a Multi-Pass test which establishes the ratio of the number of upstream particles larger than a specific size to the number of down-stream particles larger than a specified size, i.e.,

$$\beta_x = \frac{N_u}{N_d} \qquad \text{(Eq. 3)}$$

Where:

β_x is beta rating (or beta ratio) for contaminants larger than x µm;

N_u is number of particles larger than x µm per unit of volume upstream;

N_d is number of particles larger than the x µm per unit of volume downstream.

7.1.4.5 Filter efficiency for a given particle size

Efficiency for a given particle size (E_x) can be derived directly from the ratio by the following equation:

$$E_x = \frac{\beta_x - 1}{x} \times 100 \qquad \text{(Eq. 4)}$$

Where:

E_x is filter efficiency for particles with x micrometer diameter size;

β_x**(beta)** is rating or B ratio of filter, (dimentionless);

x is particle size, in (m).

TABLE 2 - FILTER RATING

β Value at x mm β_λ	Cumulative efficiency μ % particles x µm	Stabilised downstream count x μ m where filter is challenged upstream with 1,000,000 particles x µm
1.0	0	1,000,000
1.5	33	670,000
2.0	50	500,000
10	90	100,000
20	95	50,000
50	98.0	20,000
75	98.7	13,000
100	99.0	10,000
200	99.5	5000
1000	99.90	1000
10,000	99.99	100

Example:

If a filter has a β_5 rating of 100, this would mean that the filter is capable of removing 99% of all particles of greater size than 5 µm.

7.1.4.6 Filter efficiency (separation efficiency)

As noted previously the nominal rating is expressed in terms of an efficiency figure. Efficiency usually expressed as a percentage can also be derived directly from the Beta ratio as this is consistent with the basic definition of filter efficiency which is:

$$1 - \frac{\text{Number of emergent particles}}{\text{Number of incident particles}} \times 100\ (\%) \qquad \text{(Eq. 5)}$$

7.1.4.7 Filter permeability

Permeability is the reciprocal expression of the resistance to flow offered by a filter. It is normally expressed in terms of a permeability coefficient, but in practice, permeability of a filter is usually expressesd by curves showing pressure drop against flow rate.

7.2 Filter Selection

7.2.1 Factors to be considered in filter selection

Three major factors which should be considered in filter selection are performance, capital and operating costs and availability. Performance and some other important factors are discussed in the following sections.

7.2.1.1 Performance

Filter performance may be determined by the "cut-off" achieved by the filter (see 7.1.4.1) and/or other methods explained in Clause 7.1.4. The most meaningful figure now widely adopted is the "Beta Rating" associated with a particle size and efficiency figure (see 7.1.4.5)

7.2.1.2 Filter size

The size of filter needs to be selected with regards to the acceptable pressure drop and time required between cleaning or element replacement. This is closely bound up with the type of element and the medium employed.

Where space is at a premium, the overall physical size can also be a significant factor.

7.2.1.3 Surface versus depth filters

Surface type filters generally have relatively low permeability. To achieve a reasonably low pressure drop through the filter, the element area must be increased so that the velocity of flow through the element is kept low.

7.2.1.4 Compatibility

Other essential requirements from the filter element are complete compatibility with the fluid and system. Compatibility with the fluid itself means freedom from degradation or chemical attack or a chemically compatible element. At the same time, however, ’mechanical compatibility’ is also necessary to ensure that the element is strong enough for the duty involved and also free from migration.

7.2.1.5 Contamination levels

Contamination level may also affect the type of filter chosen for a particular duty, thus an oil bath filter for example may be preferred to a dry element type in a particularly dust laden atmosphere (e.g., internal combustion engines operating under desert conditions) due to its large dust holding capacity.

7.2.1.6 Prefiltering

Particularly where fine filtering is required, the advisability or even necessity of prefiltering should be considered. In fact, with any type of filter which shows virtually 100% efficiency at a particle size substantially lower than the filtering range required, prefiltering is well worth considering as an economic measure to reduce the dirt load reaching the filter depending on the level of contamination involved.

7.2.2 Liquid filter selection guide

7.2.2.1 Selection of media

Basic types of fluid filters are summarised in Table 3 whilst Table 4 presents a basic selection guide.

It must be emphasised, however, that such a representation can only be taken as a general guide.

Particular applications tend to favour a specific type of filter and element or range of elements. Furthermore, filtering requirements may vary considerably. Thus, instead of being a contaminant, the residue collected by the filter may be the valuable part which needs to be removed easily (necessitating the use of a type of filter which builds up a cake). Equally, where the residue collected is contamination, ease of cleaning or replacement of filter elements may be a necessary feature for the filter design.

As a rough or primary selection procedure, the following steps may be followed:

1) Find the particle size range, either from design data or use Table 5.

2) Find suitable filter media using Tables 4 and 6.

3) Considering other process factors, find the proper filteration type and filter medium from Tables 3 and 7.

7.2.2.2 Selection of filter type

When the filter medium type is fixed, filter type selection should be performed based upon the process requirements like the allowable pressure drop, physical size, cleaning period, cleaning method, the value of the residue and the actions which should be taken on it, etc. There are the factors which dictate whether a continuous or a batch filter should be choosen.

Other important factors to be taken into consideration are cost and maintainability of the filter.

More information about liquid filters may be found in the Appendices of this Standard and in other sources.

TABLE 3 - BASIC TYPES OF FLUID FILTERS

Type	Media	Remarks
Surface	(i) Resin-impregnated paper (usually pleated). (ii) Fine-wove fabric cloth (pleated or 'star' form) (iii) Membranes. (iv) Wire mesh and perforated metal.	Capable of fine (nominal) filtering Low permeability. Low resistance than paper. Ultra-fine filtering. Coarse filtering and straining.
Depth	(i) Random fibrous materials (ii) Felts (iii) Sintered elements	Low resistance and high dirt capacity. Porosity can be controlled/graduated by manufacture Provide both surface and depth filtering. Low resistance. Sintered metals mainly, but ceramics for high temperature filters.
Edge	(i) Stacked discs. (ii) Helical wound ribbon	Paper media are capable of extremely fine filtering. Metallic media have high strength and rigidity.
Precoat	Diatomaceous earth, pearlite powered volcanic rock, etc.	Form filter beds deposited on flexible semi-flexible or rigid elements. Particularly suitable for liquid clarification.
Adsorbent	(i) Activated clays (ii) Activated charcoal	Effective for removal of some dissolved contaminants in water, oils, etc. Also used as precoat or filter bed material. Particularly used as drinking water filters.

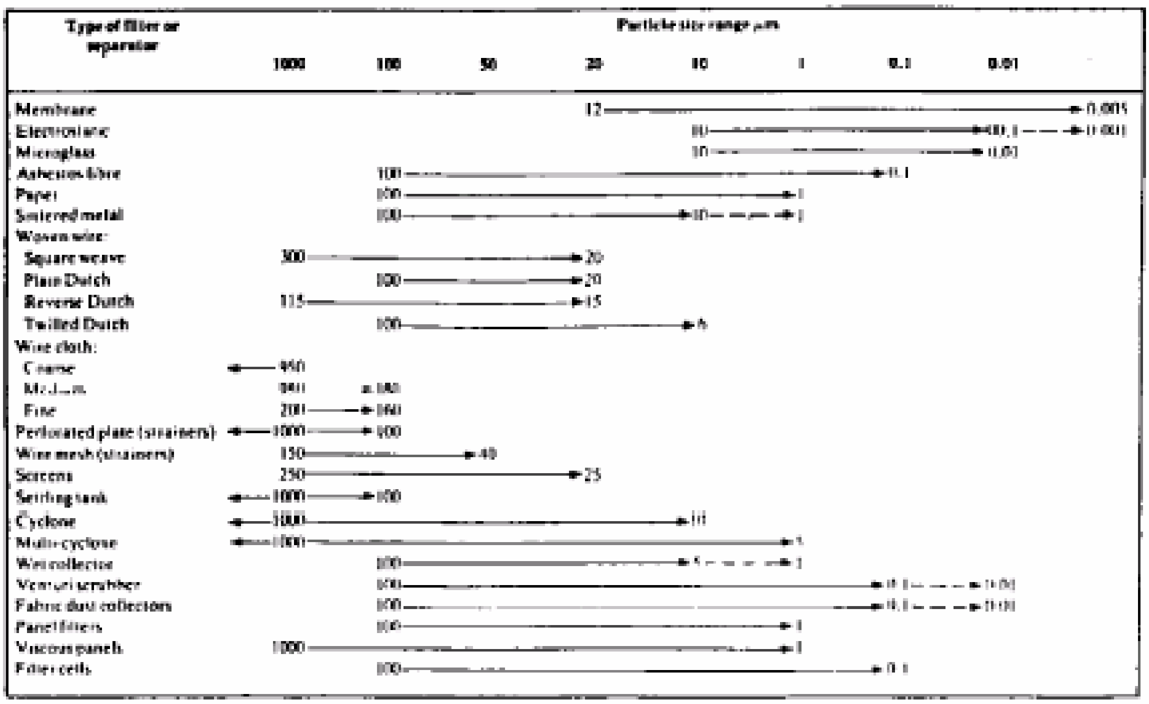
TABEL 4 - GENERAL SELECTION GUIDE FOR FLUID FILTERS

Element	Sub-micrometre (under 1)	Ultra-fine (1-2.5)	Very fine (2.5-5)	Fine (5-10)	Fine/medium (10-20)	Medium (20-40)	Coarse (over 50)
Perforated metal							×
Wire mesh							×
wire gauze						×-×	×
pleated paper					×-×	×-×	
Pleated fabric						×-×	
Wire wound					×	×-×	
Wire cloth				×	×-×	×-×	×
Sintered wire cloth				×	×-×		
Felt						×-×	
Metallic felt	×	×-×	×	×-×	×-×		
Edge type, paper			×-×	×-×		×	×
Edge type, ribbon element					×	×-×	×
Edge type, nylon	×	×-×		×-×	×-×	×-×	×
Microglass			×-×	Limited application for liquids			
Mineral wool							
	×	×-×					
Ceramic			×-×	×-×			
Filter cloths	×	×-×		×	×-×	×-×	×
Membrane		×	×-×				
Sintered metal			×-×	×-×	×-×	×-×	
Sintered PTFE				×-×	×-×		
Sintered polythene						×-×	×

TABEL 5 - GENERAL GUIDE TO CONTAMINANT SIZES

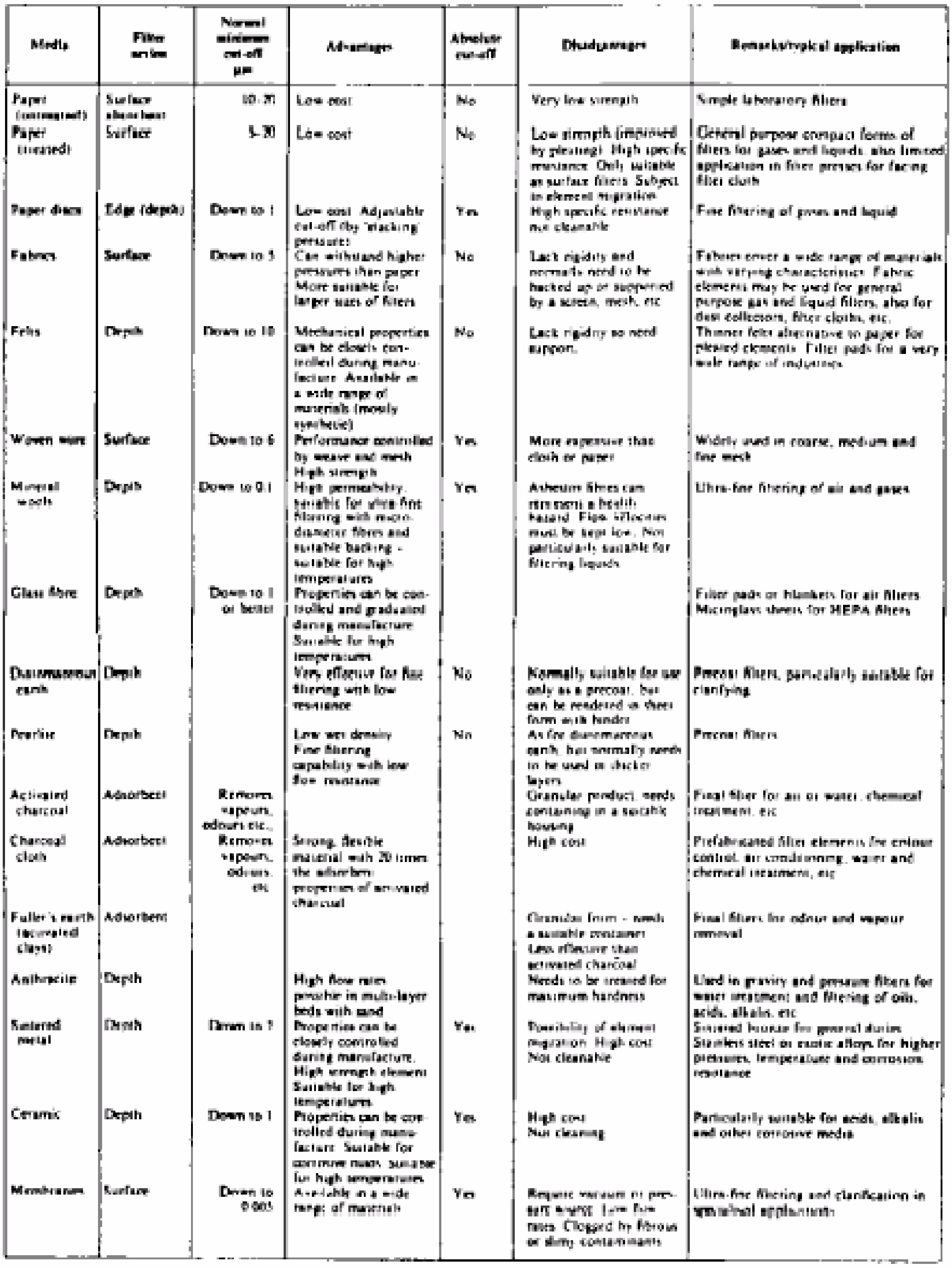
Contaminant	Particle size mm					
	under 0.01	0.01-0.1	0.1-1	1-10	10-100	100-1000
Hemoglobin	×					
Viruses	×	×				
Bacteria			×-×	×		
Yeasts and fungi			×-×	×		
Pollen				×-×	×	
Plant spores					×	
Inside dust	×	×-×	×-×	×-×	×	
Atmospheric dust				×-×	×-×	
Industrial dusts				×	×-×	×-×
Continuously suspended dusts	×	×-×	×-×			
Oil mist		×	×-×	×-×		
Tobacco smoke		×-×	×-×	×		
Industrial gases			×-×			
Aerosols	×	×-×	×-×	×		
Powdered insecticides				×-×		
Permanent atmospheric pollution	×	×-×	×-×			
Temporary atmospheric pollution				×-×	×-×	×-×
Contaminants harmful to machines				×	×-×	×-×
Machine protection normal				×	×-×	×-×
Machine protection maximum				×-×	×-×	×-×
Silt control				× (3-5)		
Partial silt control					× (10-15)	
Chip control					× (25-40)	
Air filtration, primary					×-×	×-×
Air filtration, secondary				×-×		
Air filtration, ultra-fine		×	×-×			
Staining particle range			×-×	×		

TABLE 6 - REPRESENTATIVE RANGE OF CONTAMINANT REMOVAL



Type of filter or separator	Particle size range μm
Membrane	12 → 0.005
Electrostatic	10 → 0.01 – – → 0.001
Microglass	10 → 0.01
Asbestos fibre	100 → 0.1
Paper	100 → 1
Sintered metal	100 → 10 – – → 1
Woven wire:	
Square weave	300 → 20
Plain Dutch	100 → 20
Reverse Dutch	115 → 15
Twilled Dutch	100 → 6
Wire cloth:	
Coarse	← 950
Medium	900 → 180
Fine	200 → 160
Perforated plate (strainers)	← 1000 → 100
Wire mesh (strainers)	150 → 40
Screens	250 → 25
Settling tank	← 1000 → 100
Cyclone	← 1000 → 10
Multi-cyclone	← 1000 → 5
Wet collector	100 → 5 – – → 1
Venturi scrubber	100 → 0.1 – – → 0.01
Fabric dust collectors	100 → 0.1 – – → 0.01
Panel filters	100 → 1
Viscous panels	1000 → 1
Filter cells	100 → 0.1

TABLE 7 - SUMMARY OF MEDIA CHARACTERISTICS



Media	Filter action	Normal minimum cut-off µm	Advantages	Absolute cut-off	Disadvantages	Remarks/typical application
Paper (corrugated)	Surface absorbent	10-20	Low cost	No	Very low strength	Simple laboratory filters
Paper (treated)	Surface	5-20	Low cost	No	Low strength (improved by pleating). High specific resistance. Only suitable as surface filters. Subject to element migration	General purpose compact forms of filters for gases and liquids, also limited application in filter presses for facing filter cloth
Paper discs	Edge (depth)	Down to 1	Low cost. Adjustable cut-off (by 'stacking' pressure)	Yes	High specific resistance not cleanable	Fine filtering of gases and liquid
Fabrics	Surface	Down to 5	Can withstand higher pressures than paper. More suitable for larger sizes of filters	No	Lack rigidity and normally need to be backed up or supported by a screen, mesh, etc	Fabrics cover a wide range of materials with varying characteristics. Fabric elements may be used for general purpose gas and liquid filters, also for dust collectors, filter cloths, etc.
Felts	Depth	Down to 10	Mechanical properties can be closely controlled during manufacture. Available in a wide range of materials (mostly synthetic)	No	Lack rigidity so need support.	Thinner felts alternative to paper for pleated elements. Filter pads for a very wide range of industries
Woven wire	Surface	Down to 6	Performance controlled by weave and mesh. High strength	Yes	More expensive than cloth or paper	Widely used in coarse, medium and fine mesh
Mineral wools	Depth	Down to 0.1	High permeability, suitable for ultra fine filtering with micro-diameter fibres and suitable backing - suitable for high temperatures	Yes	Asbestos fibres can represent a health hazard. Fibre offtake must be kept low. Not particularly suitable for filtering liquids	Ultra-fine filtering of air and gases
Glass fibre	Depth	Down to 1 or better	Properties can be controlled and graduated during manufacture. Suitable for high temperatures			Filter pads or blankets for air filters. Microglass sheets for HEPA filters
Diatomaceous earth	Depth		Very effective for fine filtering with low resistance	No	Normally suitable for use only as a precoat, but can be rendered in sheet form with binder	Precoat filters, particularly suitable for clarifying
Perlite	Depth		Low wet density. Fine filtering capability with low flow resistance	No	As for diatomaceous earth, but normally needs to be used in thicker layers	Precoat filters
Activated charcoal	Adsorbent	Removes vapours, odours etc.,			Granular product, needs containing in a suitable housing	Final filter for air or water, chemical treatment, etc
Charcoal cloth	Adsorbent	Removes vapours, odours, etc	Strong, flexible material with 20 times the adsorbent properties of activated charcoal		High cost	Prefabricated filter elements for colour control, air conditioning, water and chemical treatment, etc
Fuller's earth (activated clays)	Adsorbent				Granular form - needs a suitable container. Less effective than activated charcoal	Final filters for odour and vapour removal
Anthracite	Depth		High flow rates possible in multi-layer beds with sand		Needs to be treated for maximum hardness	Used in gravity and pressure filters for water treatment and filtering of oils, acids, alkalis, etc
Sintered metal	Depth	Down to 3	Properties can be closely controlled during manufacture. High strength element. Suitable for high temperatures.	Yes	Possibility of element migration. High cost. Not cleanable	Sintered bronze for general duties. Stainless steel or exotic alloys for higher pressures, temperature and corrosion resistance
Ceramic	Depth	Down to 1	Properties can be controlled during manufacture. Suitable for corrosive fluids. Suitable for high temperatures.	Yes	High cost. Not cleaning	Particularly suitable for acids, alkalis and other corrosive media
Membranes	Surface	Down to 0.005	Available in a wide range of materials	Yes	Require vacuum or pressure source. Low flow rates. Clogged by fibrous or slimy contaminants	Ultra-fine filtering and clarification in specialised applications

8. CENTRIFUGES

8.1 General

Centrifugal separation is a mechanical means of separating the components of a mixture by accelerating the material in a centrifugal field.

Commercial centrifuges can be divided into two broad types, sedimentation centrifuges and centrifugal filters.

8.1.1 Sedimentation centrifuges

Sedimentation centrifuge remove or concentrate particles of solids in a liquid by causing the particles to migrate through the fluid radially toward or away from the axis of rotation, depending on the density difference between particles and liquid.

In commercial centrifuges the liquid-phase discharge is usually continuous.

8.1.1.1 Sedimentation by centrifugal force

A solid particle settling through a liquid in a centrifugal-force field is subjected to a constantly increasing force as it travels away from the axis of rotation. It therefore never reaches a true "terminal" velocity.

However, at any given radial distance r the settling velocity of a sufficiently small particle is very nearly given by the Stokes-law relation.

If Stokes settling of a dilute suspension of uniform particles occurs in a tubular bowl of radius r, containing a thin layer of liquid of thickness s, with a given flow rate Q, the critical diameter

D_{pc} of centrifuge is given by:

$$D_{pc} = \sqrt{\frac{9Q.\mu.s}{(\rho_p - \rho_1)V.\varpi^2.r}}$$

(Eq. 6)

Most particles with diameters larger than D_{pc} will be eliminated by the centrifuge, most particles with smaller diameters will appear in the effluent, and particle with diameter D_{pc} will be divided equally between effluent stream and settledsolids phase.

8.1.1.1.1 The Σ concept

The following equation can be derived from the stoke's law:

$$Q_c = 2\ V_g.\ \Sigma \qquad \textbf{(Eq. 7)}$$

In which V_g is the terminal settling velocity of a dispersed particle in the gravitational field. Equation 7 defines the theoretical capacity factor which has the dimension of an area and can simply be interpreted as the area of a gravity settling tank that has a separation performance equal to that of the centrifuge, provided that the factor V_g is the same for both.

In theory, the concept allows comparison between geomertically and hydrodynamically similar centrifuges operating on the same feed material, Equation 7 shows, that the sedimentation performance of any two similar centrifuges handling the same suspension is the same if the quantity Q_c/Σ is the same for each. In practice, an efficiency factor is often introduced to extend the use of $\sum$ to compare dissimilar centrifuges. The $\sum$ concept permits scale-up between similar centrifuges solely on the basis of sedimentation performance.

Table C.1 of Appendix C, lists operating characteristics of some typical contrifuges.

8.1.2 Centrifugal filters

The centrifugal filter supports the particulate solids phase on a porous septum, usually circular in cross section, through which the liquid phase is free to pass under the action of centrifugal force. The density of the solid phase is important only for calculation of the mass loading in the available volume of the basket. A more important parameter is the permeability of the filter cake under the applied centrifugal force.

Centrifugal filtration is often applied to batch production on fine, slow draining solids, but it is better suited to handle medium to coarse particles that require fair to good washing and a low residual liquid content.

8.1.2.1 Performance charateristics of centrifugal filters

Table C.2 of Appendix C shows the classification of centrifugal filters and their performance characteristics.

8.2 Selection of Centrifuges

Table 8 indicates the particle size range to which the centrifuge types are generally applicable.

Table 9 summarizes the several types of commercial centrifuges, their manner of liquid and solid discharge, their unloading speed, and their relative maximum (pumping) capacity. When either the liquid or the solid discharge is not continuous, the operation is said to be cyclic.

Cyclic or batch centrifuges are often used in continuous processes by providing appropriate upstream and downstream surge capacity.

Note:

That unless operating data on similar material are available from other sources, continuous centrifuges should be selected and sized only after tests on a centrifuge of identical configuration.

TABLE 8 - CLASSIFICATION OF CENTRIFUGES BY SIZE OF DISPERSED PARTICLES

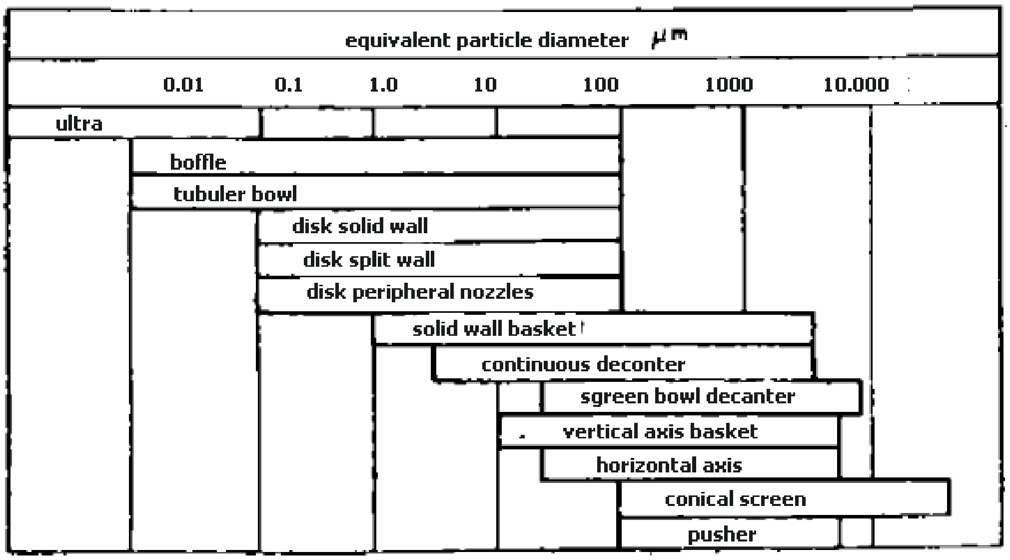
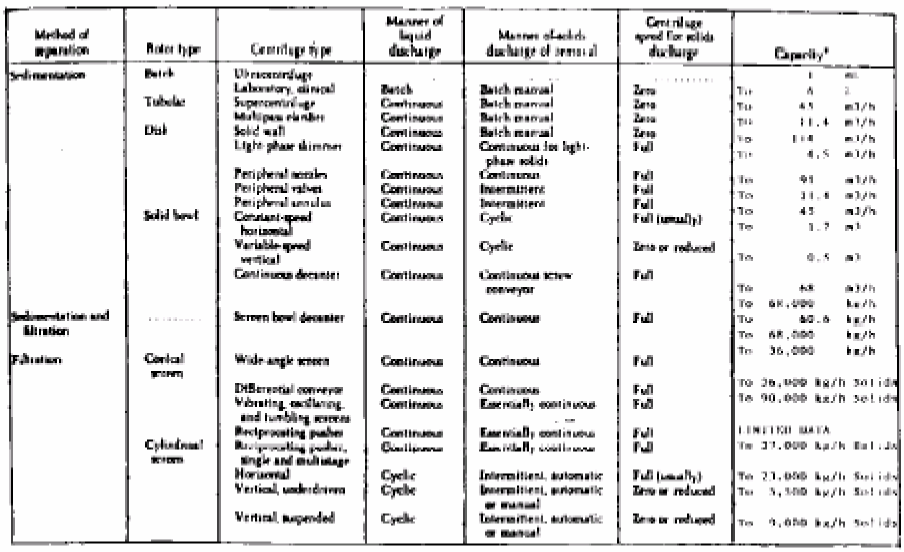


TABLE 9 - CHARACTERISTICS OF COMMERCIAL CENTRIFUGES



Method of separation	Rotor type	Centrifuge type	Manner of liquid discharge	Manner of solids discharge of removal	Centrifuge speed for solids discharge	Capacity*
Sedimentation	Batch	Ultracentrifuge				1 ml
		Laboratory, clinical	Batch	Batch manual	Zero	To 6 l
	Tubular	Supercentrifuge	Continuous	Batch manual	Zero	To 4.5 m3/h
		Multipass clarifier	Continuous	Batch manual	Zero	To 11.4 m3/h
	Disk	Solid wall	Continuous	Batch manual	Zero	To 114 m3/h
		Light-phase skimmer	Continuous	Continuous for light-phase solids	Full	To 4.5 m3/h
		Peripheral nozzles	Continuous	Continuous	Full	To 91 m3/h
		Peripheral valves	Continuous	Intermittent	Full	To 31.8 m3/h
		Peripheral annulus	Continuous	Intermittent	Full	To 45 m3/h
	Solid bowl	Constant-speed horizontal	Continuous	Cyclic	Full (usually)	To 1.7 m3
		Variable-speed vertical	Continuous	Cyclic	Zero or reduced	To 0.5 m3
		Continuous decanter	Continuous	Continuous screw conveyor	Full	To 68 m3/h To 68,000 kg/h
Sedimentation and filtration		Screen bowl decanter	Continuous	Continuous	Full	To 40.6 kg/h To 68,000 kg/h
Filtration	Conical screen	Wide-angle screen	Continuous	Continuous	Full	To 36,000 kg/h
		Differential conveyor	Continuous	Continuous	Full	To 36,000 kg/h solids
		Vibrating, oscillating, and tumbling screens	Continuous	Essentially continuous	Full	To 90,000 kg/h solids
		Reciprocating pusher	Continuous	Essentially continuous	Full	LIMITED DATA
	Cylindrical screen	Reciprocating pusher, single and multistage	Continuous	Essentially continuous	Full	To 27,000 kg/h solids
		Horizontal	Cyclic	Intermittent, automatic	Full (usually)	To 21,000 kg/h solids
		Vertical, underdriven	Cyclic	Intermittent, automatic or manual	Zero or reduced	To 5,500 kg/h solids
		Vertical, suspended	Cyclic	Intermittent, automatic or manual	Zero or reduced	To 9,000 kg/h solids

8.2.1 Power requirement

Typical energy demand values for sedimentation centrifuges handling dilute slurries, in joules per liter of feed, are, for tubular and disk, 950 to 9500, for nozzle-discharge disk, 1900 to 11500, and for helical-conveyer decanters, 2800 to 14300. Nozzle-discharge centrifuges typically consume 54000 to 144000 kJ/1000 kg of solids discharged through the nozzles.

Typical values for centrifugal filters handling moderately concentrated feeds, in killojoules per tonne (1000 kg) of dry solids, are, for automatic batch (constant speed), 10800 to 36000, for automatic batch (variable speed), 18000 to 90000, for "pusher" centrifuges, 7200 to 27000, and for vibrating and oscillating conical-screen machines, 1080 to 36000.

8.2.2 Required data for selection

For preliminary screening as to the suitability of the application for centrifugal separation and tentative selection of suitable centrifuge types, the following information is needed:

1) Nature of the liquid phase (s)

  a) Temperature.

  b) Viscosity at operating temperature.

  c) Density at operating temperature.

  d) Vapor pressure at operating temperature.

  e) Corrosive characteristics.

  f) Fumes are noxious, toxic, inflammable, or none of these.

  g) Contact with air is not important, is undesirable, or must be avoided.

2) Nature of the solids phase

  a) Particle size and distribution.

  b) Particles are amorphous, flocculant, soft, friable, crystalline, or abrasive.

  c) Particle size degradation is unimportant, undesirable, or highly critical.

  d) Concentration of solids in feed.

  e) Density of solids particles.

  f) Retained mother liquid content,-------% is tolerable, ------% is desired.

  g) Rinsing to further reduce soluble mother liquor impurities is unnecessary or required.

3) Quantity of material to be handled per batch or per unit time.

9. HYDROCYCLONES

9.1 General

Hydrocyclones are used for solid-liquid separations; as well as for solid classification, and liquid-liquid separation. It is a centrifugal device with a stationary wall, the centrifugal force being generated by the liquid motion.

9.1.1 Variables affecting hydrocyclone performance

9.1.1.1 Effects of process variables

The ability of this gravity-force machine to effect an adequate solids/liquid separation is governed by Stokes law. Specifically, the ease of separation is directly proportional to the suspended particle diameter, squared times the relative density (specific gravity), differential between the solid and the liquid phases, and inversely proportional to the viscosity of the continuous liquid phase.

9.1.1.2 Effect of mechanical design characteristics

The ability of a hydrocyclone to meet required solids/liquid separation needs is governed by the design variables of the equipment itself. These variables include cone diameter, overall body length, as well as the dimensions of the feed, apex, and vortex openings. Regardless of the "Stokes" data available and the equipment design formulas that may exist, the suitability of a hydrocyclone to a given process must depend upon existing information known from past experience or upon results developed by laboratory or field testing.

9.2 Hydrocyclone Size Estimation

The following procedure can be used to estimate the size of Hydrocyclone needed for a particular application.

1) Estimate d_p and from process requirements, **(Eq.9)**

Where:

d_p is the selected particle diameter, i.e., particles with diameters of d_p(depending on efficiency,) and larger should be separated, in µm;

η is the efficiency of the cyclone in separating any particle of diameter d_p, in percent.

2) Calcudate d_{50} using the following equation:

$$(d_p/d_{50} - 0.115)^3 = -1n\,(1 - \frac{\eta}{100}) \qquad \textbf{(Eq. 8)}$$

Where:

d_{50} is the particle diameter for which the hydrocyclone is 50 percent efficient, in µm.

The d_{50} particle diameter is actually the diameter of the particle, 50 percent of which will appear in the overflow, and 50 percent in the underflow. (See 3.7 and 3.9 for definitions).

3) Calculate the diameter of the hydrocyclone chamber, D_c (in meters), from the equation:

$$D_c = \frac{d_{50} \times L^{1.2} (\rho_p - \rho_1)^{1/3}}{4.5 \times 10^9 \times \mu\P}$$

Where:

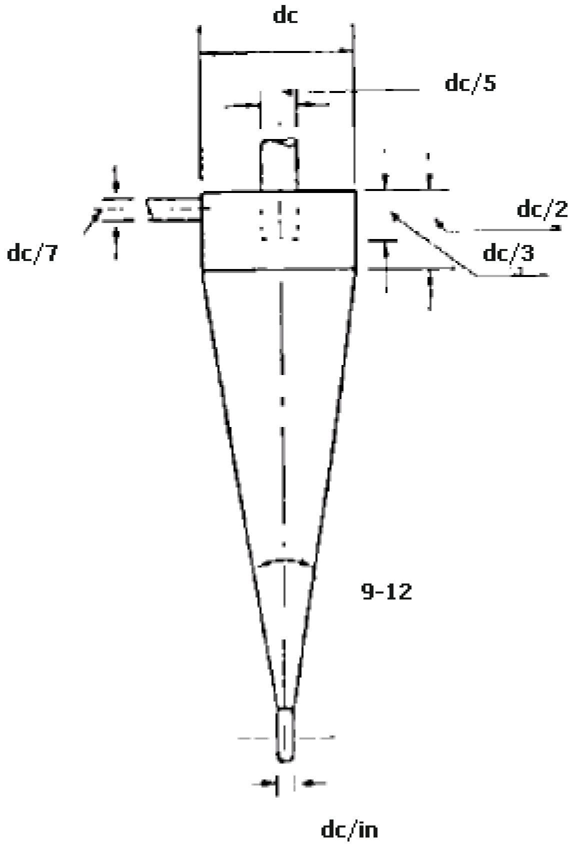
ρ_p is the density of solid particles, in kg/m³;

ρ_l is the density of the liquid, in kg/m³;

µ is viscosity of the liquid, in c P, (mPa.s);

L is the rate of flow of feed, in L/min.

4) Other dimensions of the hydrocyclone can be estimated from Fig. 1.



HYDROCYCLONE-TYPICAL PROPORTIONS

Fig. 1

5) Feed Pressure

Normally, a centrifugal pump produces the pressure needed for the operation of the Hydrocyclone. A minimum feed pressure must be provided at the inlet of the Hydrocyclone in order to keep a steady centrifugal field inside the apparatus, and to make up for static-pressure losses (friction losses and the centrifugal head). The minimum allowable feed pressure, P_{min}, is given by Equation 10:

$$P_{min} = 190.7 - 21.26 \ln (1000 D_C) \qquad \textbf{(Eq. 10)}$$

Where:

P_{min} ***is in kilopascals, (kPa).***

Feed pressure should not be allowed to rise, in general, above a certain value, Pmax, in order to avoid excessive power consumption; P_{max} can be estimated from Equation 11:

$$P_{max} = 533.3 + 31.04 D_c - 66.93 \ln (1000 D_c) + 2.088/D_c \qquad \textbf{(Eq. 11)}$$

Where:

P_{max} ***is in kilopascals, (kPa).***

Note:

If available pressure differential and flow rate of a Hydrocyclone is fixed by the process, then the suitability of the selected unit can be checked by the chart presented in Appendix C.

APPENDICES

APPENDIX A

SPECIFICATIONS FOR FILTER MEDIA

TABLE A.1 - TYPICAL SPECIFICATIONS FOR METAL (MEMBRANE) FILTERS

Max. pore size of filters♣ (diameter in mm)	Open pore area per 1 dm^2 (approx. values)	Models available	
		Discs (max. diameter in mm)	Squares (max. edge length in mm)
2.0	4.6 mm^2	140	150
3.0	10.5 mm^2	140	150
5.0	29.0 mm^2	140	300
8.0	74.0 mm^2	140	300
10.0	1.2 cm^2	140	300
15.0	3.3 cm^2	140	500
20.0	5.8 cm^2	140	500
25.0	9.0 cm^2	140	500
30.0	13.0 cm^2	140	500
40.0	23.6 cm^2	140	500
50.0	39.0 cm^2	140	500
70.0	32.0 cm^2§	140	500
80.0	38.0 cm^2§	140	500
90.0	48.0 cm^2§	140	500
100.0	44.0 cm^2§	140	500

TABLE A.2 - PRINCIPAL WEAVES FOR WIRE CLOTHS

Name	Characteristics	Absolute rating range µm	Remarks
Square Plain or twilled	Largest open area and lowest flow resistance. Aperture size is the same in both directions.	20-300+	Most common type of weave. Made in all grades from coarse to fine.
Plain Dutch single weave	Good contaminant retention properties with low flow resistance.	20-100	Openings are triangular.
Reverse plain Dutch weave	Very strong with good contaminant retention.	15-115	
Twilled Dutch double weave	Regular and consistent aperture size.	6-100	Used for fine and ultra-fine filtering.

(to be continued)

APPENDIX A (continued)

TABLE A.3 - A TYPICAL LIST OF WIRE CLOTH SPECIFICATIONS *

Aperture		Wire Dia Mm	Open Area %	Mech ---	Wire Dia in
μm	Mm				
25	0.025	0.025	25	500	0.0010
28	0.028	0.025	28	480	0.0010
32	0.032	0.028	28	425	0.0011
38	0.038	0.025	36	460	0.0010
40	0.04	0.032	31	425	0.0012
42	0.042	0.036	29	400	0.0014
45	0.045	0.036	31	350	0.0014
50	0.05	0.036	34	325	0.0014
56	0.056	0.040	34	115	0.0016
63	0.063	0.040	47	300	0.0016
75	0.075	0.036	46	270	0.0014
75	0.075	0.053	36	250	0.0021
80	0.08	0.050	38	230	0.0020
85	0.085	0.040	46	200	0.0016
90	0.09	0.050	41	200	0.0020
95	0.095	0.045	46	200	0.0018
100	0.1	0.063	38	180	0.0025
106	0.106	0.05	46	180	0.0020
112	0.112	0.08	34	150	0.0032
125	0.125	0.09	34	165	0.0035
140	0.14	0.112	31	130	0.0045
150	0.15	0.10	36	120	0.0040
160	0.16	0.10	38	100	0.0040
180	0.18	0.14	32	100	0.0055
200	0.2	0.125	38	100	0.0050
200	0.2	0.14	35	80	0.0055
224	0.224	0.16	34	80	0.0065
250	0.25	0.16	37	75	0.0065
280	0.25	0.22	31	65	0.009
315	0.315	0.20	37	60	0.008
400	0.4	0.22	42	50	0.009
400	0.4	0.25	38	50	0.010
435	0.425	0.38	36	40	0.011
500	0.5	0.20	51	40	0.008
500	0.5	0.25	44	36	0.010
500	0.5	0.32	37	36	0.012
560	0.56	0.28	44	33	0.011
560	0.56	0.36	37	30	0.014
630	0.63	0.25	51	30	0.010
630	0.63	0.28	48	28	0.011
630	0.63	0.40	37	30	0.016
710	0.71	0.32	48	28	0.012
710	0.71	0.45	37	25	0.018
800	0.8	0.32	51	25	0.012
800	0.8	0.5	38	22	0.020
---	1	0.36	54	22	0.0014
---	1	0.61	38	20	0.0025
---	1.25	0.4	57	18	0.0016
---	1.6	0.5	58	16	0.0020
---	2	0.56	61	16	0.0022
---	2.5	0.71	61	12	0.0028
---	3.15	0.8	64	10	0.0022
---	4	1.0	64	8	0.04
---	5	1.25	64	6	0.05
---	6.3	1.25	70	5	0.05
---	7.1	1.4	70	4	0.055
---	8	2	64	3	0.08
---	10	2.5	64	3	0.10
---	12.5	2.8	67	2	0.11
---	16	1.2	69	---	0.12

*** "Filters & Filtration Handbook", CHRISTOPHER DICKENSON, 3rd. Ed., 1992, Elsevier Advanced Technology.**

(to be continued)

APPENDIX A (continued)

TABLE A.4 - PERFORATED MESH SIEVES *

Nominal width of aperture (side of square)		Plate thickness BG	Aperture tolerances			
			Average		Maximum	
mm	in		%	units	%	Units
101.60	4	10	0.20	80	0.50	200
88.90	3½	10	0.20	70	0.49	170
76.20	3	12	0.20	60	0.50	150
69.85	2¾	12	0.20	55	0.51	140
63.50	2½	14	0.20	50	0.52	130
57.15	2¼	14	0.20	45	0.53	120
50.80	2	16	0.20	40	0.50	100
47.63	17/8	16	0.21	40	0.53	100
44.45	1¾	16	0.20	35	0.51	90
41.28	15/8	16	0.21	35	0.55	90
38.10	1½	16	0.20	30	0.53	80
34.93	13/8	16	0.22	30	0.58	80
31.75	1¼	16	0.24	30	0.56	70
28.58	11/8	16	0.26	30	0.62	70
25.40	1	16	0.25	25	0.60	60
22.23	7/8	16	0.23	20	0.69	60
19.05	¾	16	0.27	20	0.80	60
15.88	5/8	16	0.32	20	0.80	50
12.70	½	16	0.40	20	1.00	50
9.53	3/8	18	0.53	20	1.06	40
7.94	5/16	18	0.58	18	1.16	36
6.35	¼	18	0.60	15	1.20	30
4.76	3/16	20	0.64	12	1.33	25

1 Unit = 0.0001 (in) and/or 2.54 μm

*** Source : See Table A.3.**

(to be continued)

APPENDIX A (continued)

TABLE A.5 - PERFORATED METAL DATA *

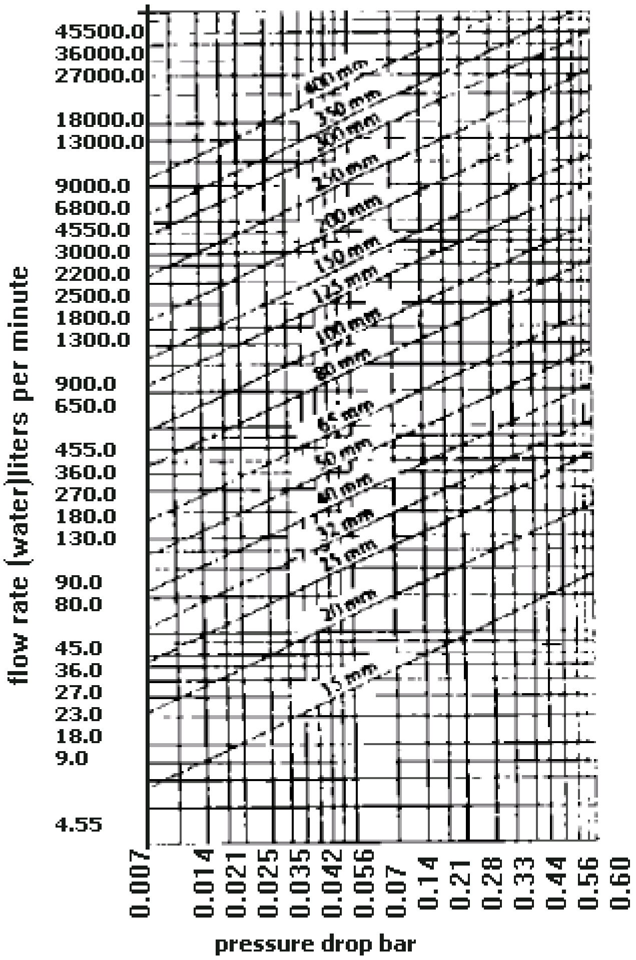
Size of hole		½ open area
mm	In	
Round hole		
0.38	0.015	10
0.55	0.0215	20
0.70	0.0275	30
0.80	0.0315	32
1.09	0.043	25
1.40	0.049	25
1.50	0.055	32
1.5	0.059	37
1.64	0.065	36
1.75	0.069	19
2.16	0.085	33
2.45	0.097	36
2.85	0.112	50
Square hole (parollel)		
1.50	0.059	44
3.17	0.125	44
6.00	0.236	54
6.35	0.256	44
7.00	0.273	41
9.52	0.375	44
11.00	0.437	49
12.70	0.500	44
19.05	0.750	56
25.40	1.00	44
Square hole (alternate)		
1.75	0.069	32
3.17	0.125	32
4.75	0.187	44
6.75	0.250	44
7.93	0.312	64
9.53	0.375	56
11.10	0.437	60
12.70	0.500	53
19.05	0.750	56
25.40	1.0	57
Diamond squares		
4.75	0.178	36
9.52	0.375	49
12.70	0.500	48
15.87	0.625	42
19.05	0.750	44
25.40	1.0	43

Size of hole		½ open area
mm	In	
Round end slots		
10.00×0.50	0.394×0.019	13
10.00×1.00	0.394×0.039	23
10.00×1.50	0.394×0.059	32
20.00×2.00	0.787×0.059	34
10.00×2.00	0.394×0.079	30
30.00×2.00	0.787×0.079	30
13.00×2.50	0.518×0.098	28
20.00×2.50	0.787×0.098	31
12.00×3.00	0.427×0.118	38
20.00×3.00	0.787×0.118	47
25.00×3.50	0.984×0.117	38
Square and slots (parallel)		
10.00×0.40	0.394×0.016	14
10.00×0.56	0.394×0.022	19
10.00×0.76	0.394×0.03	25
20.00×1.10	0.812×0.043	33
20.32×1.44	0.800×0.057	29
19.05×1.59	0.730×0.0625	27
13.00×3.50	0.511×0.089	37
20.00×3.35	0.787×0.128	41
19.84×1.96	0.781×0.150	41
19.05×4.75	0.730×0.187	45
15.87×6.35	0.625×0.250	47
20.00×8.00	0.787×0.314	49
Diagnrial slots		
12.29×0.50	0.484×0.020	14
12.29×0.62	0.484×0.024	19
11.91×0.73	0.469×0.029	12
11.91×1.07	0.469×0.042	25
20.62×1.09	0.812×0.043	27
9.90×2.38	0.390×0.093	27
11.91×3.17	0.469×0.125	37
12.70×1.96	0.500×0.156	36
12.70×1.04	0.500×0.041	28
20.00×2.00	0.787×0.078	29
11.50×1.50	0.454×0.059	24
19.05×3.17	0.750×0.059	40
Triangular holes		
3.17	0.125	26
5.00	0.197	15
6.50	0.256	26
9.52×11.11	0.375×0.437	16
Oral holes		
7.00×3.00	0.276×0.118	32
9.00×4.25	0.354×0.167	38
9.00×5.00	0.354×0.197	45
14.00×6.00	0.551×0.236	46
13.50×7.00	0.531×0.276	45

*** Source : See Table A.3.**

APPENDIX B

PRESSURE DROP CHARACTERISTICS OF STRAINERS



ESTIMATION OF PRESSURE LOSS IN TYPICAL Y-TYPE STRAINERS

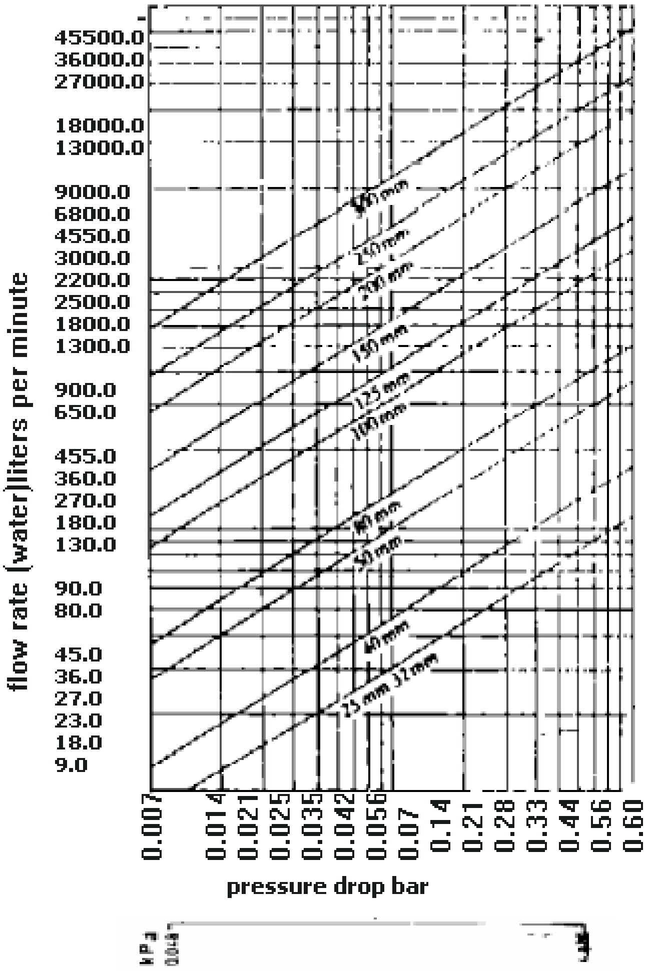
Fig. B.1

Note:

This chart is based on water of relative density (specific gravity) 1.0 and viscosity 2-3 cSt. Screens are clean and are 40 × 40 woven wire mesh.

(to be continued)

APPENDIX B (continued)



TYPICAL PRESSURE DROP CHARACTERISTICS FOR BASKET WITH 3mm PERFORATIONS

Fig. B.2

APPENDIX C

SPECIFICATIONS OF CENTRIFUGES AND CAPACITY CHECKING FOR HYDROCYCLONES

TABLE C.1 - SPECIFICATIONS AND PERFORMANCE CHARACTERISTICS OF TYPICALSEDIMENTATION CENTRIFUGES

Type	Bowl Diameter Mm	Speed r/min.	Maximum Centri fugal	[illegible]		Typical Motor size K w
				LIQUID m^3/h	SOILD kg/h	
Tubular	**45**	**50.000**	**62.400**	**0.021-0.056**		
	105	**15.000**	**13.200**	**0.023-2.3**		**1.49**
	25	**15.000**	**15.900**	**0.045-4.5**		**2.24**
Disk	**178**	**12.000**	**14.300**	**0.023-2.3**		**0.246**
	330	**7.500**	**10.400**	**1.14-11.4**		**4.74**
	610	**4.000**	**5.500**	**4.5-45**		**5.6**
Nozzle	**254**	**10.000**	**14.200**	**4.3-9**	**91-910**	**14.9**
Discharge	**406**	**6.250**	**8.900**	**5.68-34**	**360-3600**	**29.8**
	685	**4.200**	**6.750**	**9-90**	**910-10.000**	**93.2**
	762	**3.300**	**4.600**	**9-90**	**910-10.000**	**93.2**
Helical	**152**	**8.000**	**5.500**	**To 4.5**	**27-227**	**3.73**
Convever	**356**	**4.000**	**3.380**	**To 17**	**453-1360**	**14.9**
	457	**3.500**	**3.130**	**To 11.4**	**453-1360**	**11.2**
	635	**3.000**	**3.190**	**To 50.8**	**2270-11000**	**112**
	813	**1.800**	**1.470**	**To 56.8**	**2720-9100**	**44.7**
	1016	**1.600**	**1.450**	**To 58**	**9100-163000**	**74.6**
	1372	**1.000**	**770**	**To 170**	**18150-54400**	**112**
Knife	**508**	**1.800**	**920**	**	**0.028 ***	**14.9**
discharge	**915**	**1.200**	**740**	**	**0.115 ***	**22.4**
	1727	**900**	**780**	**	**0.574 ***	**29.8**

Notes:

*** Turbine drive.**

**** Widely variable.**

***** Maximum volume of solids that the bowl can contain, in m^3.**

(to be continued)

APPENDIX C (continued)

TABLE C.2 - CENTRIFUGAL FILTERS CLASSIFIED BY FLOW PATTERN

FLOW PATTERN	**FIXED-BED TYPE**	**CENTRIFUGAL FORCE****	**BASKET CAPACITY* (UNDER LIP RING). m³**
Liquid: continuous	Vertical axis		
(interrupted for discharge of solids)	Manual unload	1200	0.453
Solids: batch	Container unload	550	0.566
	Knife unload	1800	0.453
	Horizontal axis	1000	0.566
	Knife unload		
Flow pattern	Moving-bed type	Centrifugal force**	Solids capacity, *** kg/h
Liquid: continuous	Conical scree		
Solids: continuous	Wide angle	2400	
	Differential scroll	1800	68,000
	Axial vibration	600	136,000
	Torsional vibration	600	
	Oscillating	600	
	Cylindrical scree		
	Differential	600	36,000
	Reciprocating	600	27,000

*** Reduce by 1/3 for volume of processed solids ready to be discharged.**

**** Nominal maximum centrifugal force ($w^2.r/g$) developed, usually less in larger sizes,**

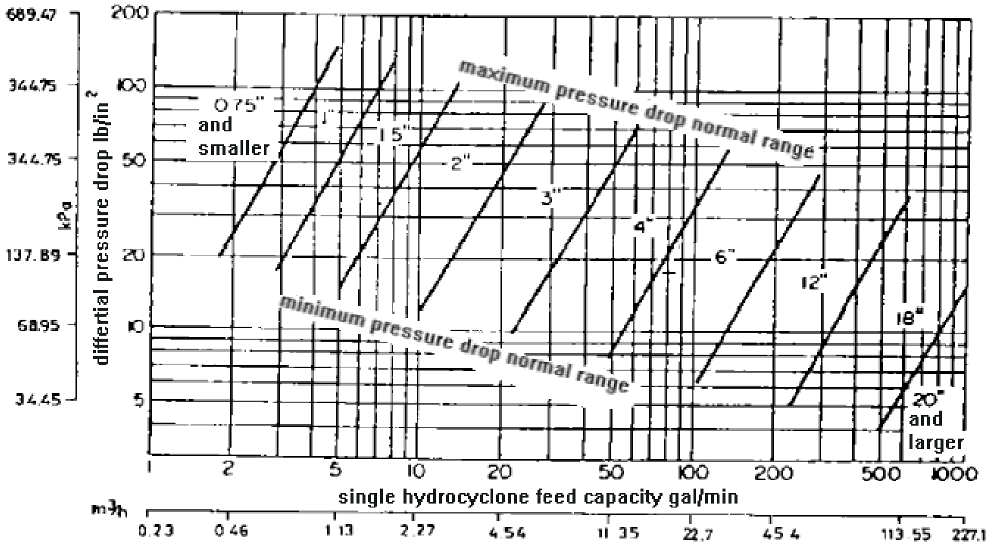
***** Nominal maximum capacity of largest sizes, subject to reduction as necessary to meet required performance on a given application.**

(to be continued)

APPENDIX C (continued)

C.1 CAPACITY CHECKING FOR SIZED HYDROCYCLONES

If the pressure differential for a hydrocyclone separation Unit is fixed by the process conditions and a properly sized device has been selected, the capacity of the Unit can be determined as shown in Fig. C.1. When a hydrocyclone does not have adequate capacity over the pressure range indicated to handle a given problem, multiple hydrocyclones are manifolded in parallel.



HYDROCYCLONE CAPACITY

Fig. C.1