<table>
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Malaysia</td><td colspan="2">PROCESS DESIGN OF SOLID-LIQUID SEPARATORS

(PROJECT STANDARDS AND SPECIFICATIONS)</td></tr>
</table>

TABLE OF CONTENT

SCOPE

This Project Standards and Specifications 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.

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.

DEFINITIONS AND TERMINOLOGY

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

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

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.

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

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.,:

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

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:

$$F_o = \frac{w^2}{(w+d)} x100 \qquad \text{Eq. (2)}$$

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.

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".

SYMBOLS AND ABBREVIATIONS

SYMBOL/ABBREVIATION	DESCRIPTION
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).
Eq	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 (m^3).
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)].
ω(omega)	Angular velocity, in radian/s, (rad/s).
η(eta)	Efficiency of hydrocyclone in separating particles of diameter dp, in percent (%).
Σ(sigma)	Theoretical capacity factor of a sedimentation centrifuge, in (m^2).

UNITS

This Standard is based on International System of Units (SI) except where otherwise specified.

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.

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.

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.

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.

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

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.

   a. Patterns of filtration process

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

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

- Constant-Rate filtration. Positive displacement pumps of various types are employed.
- Variable-Pressure, variable rate filtration. The use of a centrifugal pump results in this pattern.

LIQUID FILTERS

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".

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.

2. Types of liquid filters

   Considering the flow characteristics, as mentioned above, 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.

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.

   a. 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	90	nexpensive.	Subject to attack by mildew and
	acids			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.

b. 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.

c. 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.

d. 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.

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.

a. 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.

b. 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.

c. 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.

d. 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.

e. Filter efficiency for a given particle size

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

$$E_x = \frac{\beta_x - 1}{\beta_x} x100 \quad \text{Eq. (4)}$$

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** βλ	**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 β5 rating of 100, this would mean that the filter is capable of removing 99% of all particles of greater size than 5 μm.

f. 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:

$$1 - \frac{\text{Number of emergent particles}}{\text{Number of incident particles}} x100\,(\%) \quad \text{Eq. (5)}$$

g. 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.