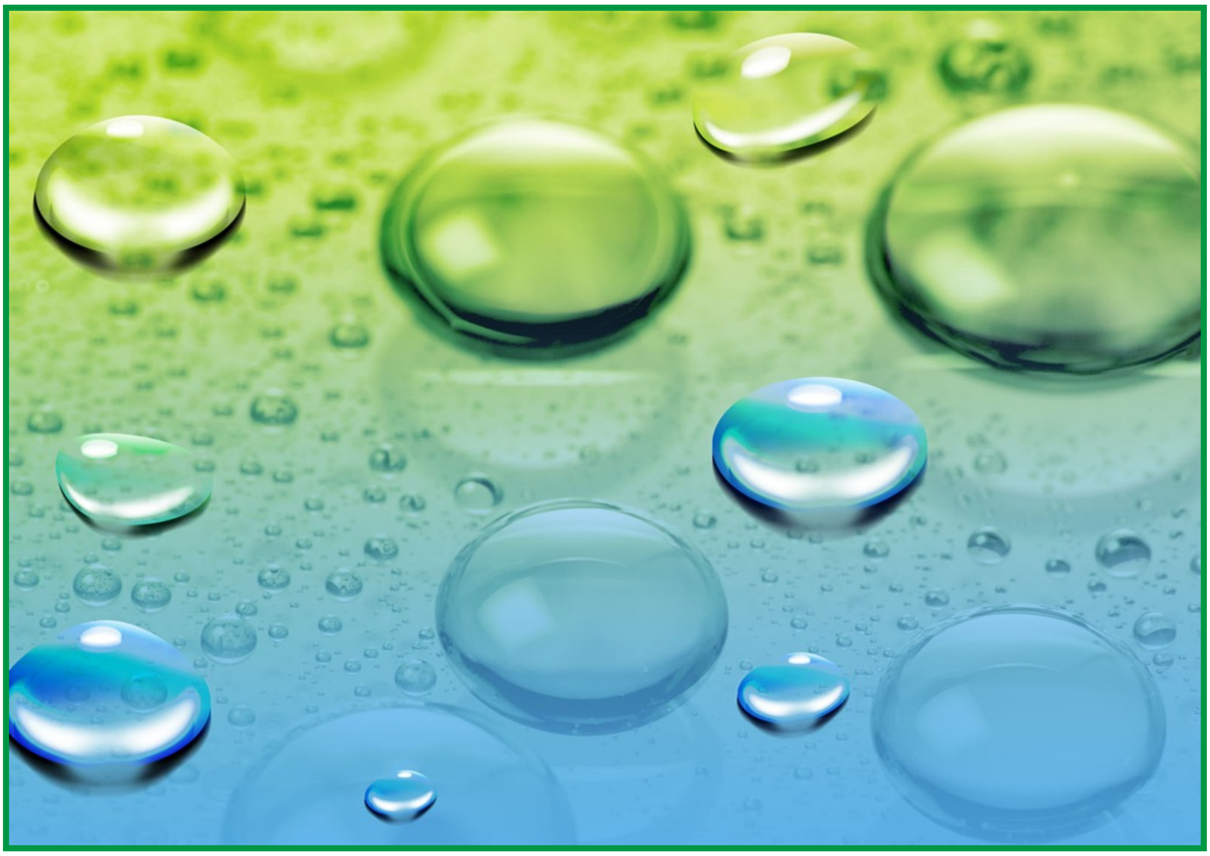
Droplet Separation

Technical Literature



Content

1 Introductions

In a lot of chemical and process industrie applications the gas and vapour streams have the most important roll for the complete Porcess functionality.

Different process steps necessitate generation, cleaning and separation of this streams. An enrichment of gas streams with liquids can be reached both through mechanical (jetting, pressure) or thermal droplet generation - as e.g. in scrubbers and absorption columns - as well as through physical-chemical reactions (condensation).

Certain process runs then require a separation of liquid portions from the gas or vapour stream.
Different systems are used depending on liquid amount, droplet size and required purity.
Beneath cyclones and impact plates mainly droplet separators made of knitted wire mesh are employed.
With little expenditure of energy (low pressure drop) finest droplets with diameters of nearly 1 µm can be separated and efficiencies up to 99.9 % can be achieved.

Therefore, separation problems with gas-liquid-separation are solved economically and cost-saving.

2 Fundamentals

A RASCHIG knitted wire mesh droplet separator is a process instrumentation which retains droplets carried by a gas or vapour stream, i.e. which effects a phase separation between gas and liquid stream.

Droplet separators are predominantly used for exhaust air decontamination. Besides liquid droplets carried in process gas streams have to be separated, too, as they could cause damage on the instrumentation due to corrosion or erosion or due to depositing, caking and product contamination.

The efficiency of a droplet separator can be characterized with its fraction efficiency curve. The required expenditure of the separation is crucially governed by the feed droplet spectrum and the specified size limit of the droplets.

2.1 Droplet Size

The size of the droplets mostly depends on their kind of origin and their prehistory.
Two principal mechanisms are responsible for their formation: mechanical generation as well as condensation.

A rough distinction of the droplet size can be made to the effect, that droplets bigger than 10 µm are called spray and smaller ones are called mist or aerosoles.

Spray is mainly formed when liquids are atomized and the droplet spectrum is the finer the more energy is put into the atomization process.

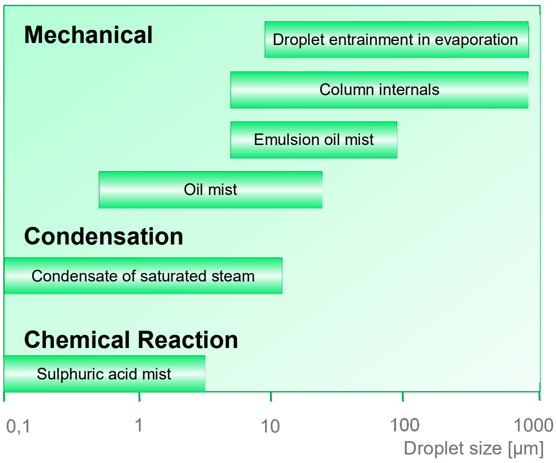


Fig. 1: *Characteristic droplet size*

Aerosols are mainly generated by condensation of saturated steam and occur as mist in chemical reactions of gas mixtures, e.g. during the formation of liquid sulphuric acid through gaseous SO3 and H2O.

Beneath the formation of the droplets also the physical properties of the fluids are very important.

A low **surface tension** favours the formation of small droplets, a high viscosity on the other hand favours the formation of large droplets.

The liquid droplets in a gas flow normally have different sizes.

The distribution of the droplet sizes is similar to the normal distribution by Gauß.

2.2 Forces on the Single Droplets

In order for a liquid droplet may be impinged on an impact body, as in this case the individual wire of a wire mesh packing, it must move relatively to the gas.

The force causing this relative motion, the centrifugal force begins to act as soon as the gas is redirected. With the relative movement, a flow resistance is brought about. In equilibrium, the droplet moves so that the forces compensate each other. The equation for the centrifugal force Z (equation 1), as well as the resilience of W (equation 2) are:

$$Z = \rho_T \circ \frac{\pi \circ d^3}{6} \circ \frac{\upsilon^2}{r} \qquad (1)$$

$$W = \frac{1}{2} \circ \rho_g \circ \upsilon^2{}_r \circ F \circ c_w = 3 \circ \pi \circ \mu \circ d \circ \upsilon_r \qquad (2)$$

mit:

r	Radius of the curve
ρ_T	Droplet density
d	Droplet diameter
υ	Gas velocity
υ_r	Relativ gas velocity between droplet and gas
ρ_g	Gas density
F	Droplet cross section ($= \frac{\pi \circ d^2}{4}$)
c_w	resistance value of the droplet
μ	Dynamic viscosity of the gas

These relationships are based on simplistic assumptions that the curvature of the flow lines with the radius of curvature r can be described, and that the following Stokes' resistance law is valid:

$$c_w = \frac{24}{\mathrm{Re}} \qquad (3)$$

$$\mathrm{Re} = \frac{\rho \circ \upsilon_r \circ d}{\mu} \qquad (4)$$

with: $\mathrm{Re} \leq 0{,}1$

In spite of this simplification, it is acceptable for many cases, to use this relationship in order to establish the equation of motion, to therefrom calculate the trajectories. Significantly, however, that this knowledge of the flow field is necessary. If the droplet paths known results from the so-called striking.

The deposition conditions are thereby more favorable the greater the relative velocity between droplets and gas. Large drops at a high speed, low gas viscosity and small radius of curvature favoring the deposition.

The radius of curvature is a function of the magnitude of the impact body. The drop separation is on thin wire lighter than the thick wire.

2.3 Separation Mechanisms

The separation of droplets bigger than 10 µm normally causes no problems, as an inertia separation can easily be carried out due to the relatively large mass of drops.
Therefore, the application of RASCHIG knitted wire mesh droplet separators predominantly yields droplet size ranges smaller than 10 µm.

In this droplet size range and a liquid load of about 1 - 5 weight-% the disperse phase follows the streamlines, so that the gas flow itself is not influenced.

The separation of liquid droplets is based on the effect, that the particles cannot follow the streamlines of the gas when they hit an obstacle and stick to a periphery.

In principle, there are three separation mechanisms for droplet separation inertia.

Figure 2 shows the droplet separation by inertia, locking effect and diffusion is shown schematically.

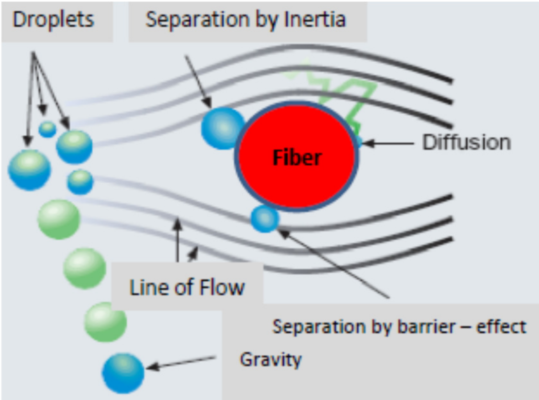


Fig. 2: *Separation Mechanisms*

2.31 Separation by Inertia

Each individual wire of the knitted wire mesh separator constitutes an obstacle in a gas stream, so that a deflection of the streamlines occurs. Entrained droplets cannot follow due to its inertia this redirection and rebound on the single wire. This effect is relevant mainly for drop greater than 10 microns. On the wires the single droplets grow into larger drops together (coalesce), form a liquid film on the

Wire surface and drops by gravity down to where the liquid is then subtracted.

The efficiency of the droplet separation increases with increasing number of the gas diversion.

2.32 Separation by Barrier - Effect

The separation by blocking action is of significant importance as the diameter of a drop in relation to the diameter of a fiber (wire) is relatively large (Figure 2).

Drops whose inertia is insufficient incident, be worn around the obstacle. Come here so close to the single wire so that the distance is smaller than the droplet radius, then the drop touches the flow body, remains on that hanging and is thus deposited.

The barrier effect is so consequently, based on the direction of gas flow a fiber edge - zone phenomenon.

2.34 Separation by Diffusion

For droplets that are smaller than 1 micron, the separation mechanisms such as inertial effects and blocking effect are negligible.

These are namely predominantly deposited by Brownian motion. This is understood as a continuous stochastic movement of particles caused by the collision with gas molecules. This particle increases with decreasing particle size.

A particle with a wire diameter of 0.1 microns reaches about five times the Brownian motion of a particle of 1-micron diameter.
The probability that a particle with a fiber (wire) collides and is deposited increases with Brownian motion and is only at very low gas velocities significantly to realize less than 1 m / s.
This process is shown in Figure 2. The characteristic separation number for this mechanism is the Peclet - numbers Pe:

$$Pe = \frac{\upsilon \circ D_b}{D_v} \qquad (5)$$

mit:

υ Gas velocity

D_b Diameter of the barrier (wire diameter)

D_v Droplet diffusion coeffizient

The droplet diffusion coefficient D_v is:

$$D_v = \frac{k \circ T}{3 \circ \pi \circ d \circ \mu} \qquad (6)$$

mit:

k Boltzmann – constant value

T Temperature

d Droplet diameter

μ dynamic viscosity of the gas

A comparison of the separation mechanisms diffusion and inertia shown in the following Figure 3. Here the separation of a single fiber to the particle size and the flow velocity is applied, to obtain a Separation curve showing a minimum at the center.

This Separation curve results from the addition of Separation by diffusion curve and Separation by interia curve.

While the inertial separation increases with increasing droplet diameter and increasing velocity, the diffusion separation takes with respect from these parameters.

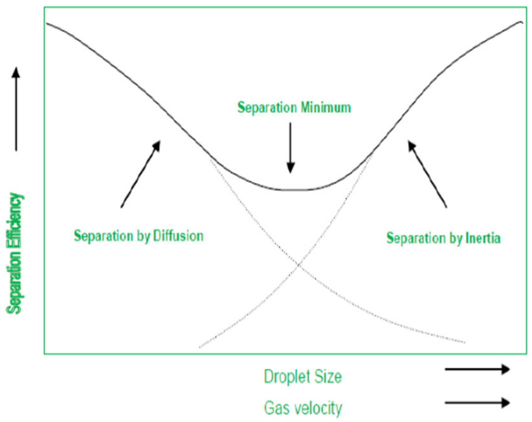


Fig. 3: Influence of the Separation Mechanisms regarding to the Separation Efficiency

This droplet size range contains the most difficult conditions for a droplet separation because in this area the droplets are too small for a sufficient utilization of the mass inertia, but in the same time to large that a pronounced separation by diffusion takes effect.

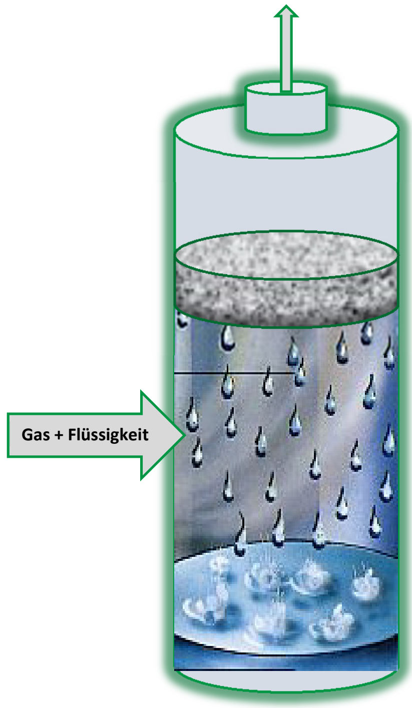


Fig. 4: *Droplet Separation Process*

3 Overview of the Separation Systems

The following figure provides information about commercially available Droplet Separation Systems and precisely defined, in which process conditions with respect to the limit drop size and stream velocity existing one separator is used.

Separation - System	***Limit Droplet [µm]***	***Gas Velocity [m/s]***
Separation by Inertia (vessel/ column)	> 100	- - -
Cyclone or Cyclone liquid Collector	50 – 100	10 - 20
Impact baffle or Vane Type Separator	> 15	3 – 10
Knitted Wire Mesh Separator	> 3	3
Knitted Wire Mesh + Agglomerator	> 1	< 3

Tab. 1: *Overview of different Separation Systems*

4 Design- Droplet Separator

The interpretation of mist in the gas-liquid separation using a RASCHIG - performed design software.
In the hydraulic calculation of the wire mesh package it depends among other things on the following operating data:

- Gas velocity
- Max. allowable pressure drop
- Required separation efficiency
- Amount of liquid to be separated
- Max. Temperature
- Installation situation

4.1 Gas Flow Velocity
(by Souders Brown)

The maximum flow velocity refers to the operating point of the drop, in which the wire-knit pack is flooded and a liquid re-entrainment in the form of mostly agglomerated drop after the trap occurs. The operating point of mist must be below the flood point accordingly.

To calculate the maximum free-stream velocity u(max) a number of material parameters into account, such as gas and liquid density and surface tension of the separated liquid.
The following Souders - Brown equation can be used:

$$u_{\max} = K \cdot \sqrt{\frac{\rho_{Fl} - \rho_G}{\rho_G}} \qquad (7)$$

with:

u_{max} [m/s] Maximum gas velocity

ρ_{Fl} [kg/m³] Liquid density

ρ_G [kg/m³] Gas density

Typische K – Faktoren:

- 0,06 m/s – high pressures and entrained vapor
- 0,09 m/s – low liquid load
- Vertical flow - 0,11 m/s – low pressures and high liquid loading
- Horizontal flow - 0,14 m/s – low pressures and high liquid loading

4.2 Semi-Empirical Design (*Design – by Bürkolz, A. und Muschelknautz, E.*)

Based on the described in 2.2 Z centrifugal and frictional forces W to the single drop, can be determined by E. Bürkholz, A. and Muschelnautz, a force - represent equilibrium relationship.

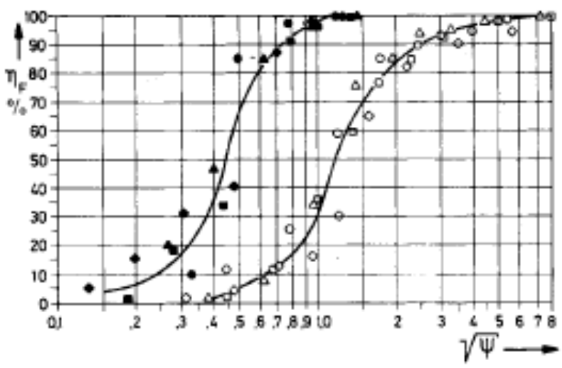
The ratio of the radial droplet velocity v_r and gas velocity v is called inertia parameters Ψ.

$$\psi = \frac{v_r}{v} \qquad (8)$$

This parameter describes the probability that a drop is separated. The greater its speed relative to the gas velocity is, the larger Ψ.

To act on of the consideration of the separation on the single wire presented "Löffler, F. and Muhr, W." along with Bürkholz, A. a multi-unit complicated expression with:

The inertia parameters, the Reynolds number and the ratio of droplet diameter to wire diameter as deposition parameters ΨA.



$$(\psi_A)^{1/2} = \frac{1}{2}\,(\varrho_1^{1/2}\,\varrho^{-1/6}\,\mu^{-2/3})\,(D^{*\,-1/3}\,\Delta p^{1/3}\,d)\,;$$

Fig. 5: *Separation Curve of a Fiber and Knitted Wire Mesh Packing as a Function of Ψ_A.*

with:

Ψ Dimensionsless Parameter by Inertia

Ψ_A Dimensionsless Separation Parameter

4.3 Pressure Drop

The pressure drop of knitted wire mesh droplet separators is very low due to the large free volumes even at higher velocities.

It rises almost proportional with the thickness of the package and acts nearly proportional to its density (with the same wire diameter and knitted wire mesh specification).
Liquid load, viscosity, surface tension and wetting behaviour of the liquid, as well as the contamination level of the gas stream (solid particles) have a strong influence on the pressure drop.

Saemundsson gives a theoretical pressure drop calculation for pouring knitted wire mesh.

This relation is valid for dry packages and takes all relevant parameters of different knitted wire mesh specifications into account (e.g. wire diameter and porosity).
This relation is:

$$\Delta p = \zeta \cdot \frac{H}{R_h} \cdot \frac{\rho_L}{2} \cdot \frac{u^2}{(1-\alpha)^2} \qquad (9)$$

with:

$$R_h = \frac{1-\alpha}{\alpha} \cdot \frac{D_F}{4}$$ Hydraulic radius

$$\zeta = \frac{g}{\mathrm{Re}} + \frac{f}{\mathrm{Re}^{0,2}}$$ Pressure loss coeff.

$$\mathrm{Re} = \frac{u}{1-\alpha} \cdot 4 \cdot R_h \cdot \frac{\rho_L}{\mu_L}$$ Reynolds numb.

D [m]	Wire diamter
H [m]	Thickness of the packing
α [-]	Packing density (1-ε)
μ [Pas]	Dynamic viscosity
ρ [kg/m^3]	gas density
g,f	Function
p [kg/m^3]	Density of the knitted wire mesh packing
Index:	L reffering to gas (air)
	F reffering to wire (Fiber)

4.3 Separation Efficiency

Below the flooding limit efficiency increases with increasing gas flow velocity.
At the same time the pressure drop rises square what causes higher investments and essentially higher operating costs. Therefore, each plant operator has to find out the optimum point between high separation efficiency and economic efficiency.
The evaluation will turn out in favour of efficiency or low operating costs depending on the kind of application.

Proper design of the RASCHIG droplet separators yields separation efficiencies up to 99.9 %.
Separation efficiencies always have to be seen in connection with the size limit of the droplets.

Therefore, RASCHIG always specifies separation efficiencies with the corresponding size limit, e.g. efficiency 99.9 % for droplets ≥ 5 µm.

5 Agglomeration

In order to achieve high efficiencies for droplet spectrums in the range of a few microns either an increase of the gas flow velocity or the use of a two-stage separator is necessary.
This construction ensures high operational flexibility at a comparatively low pressure drop.

The first stage acts as an agglomerator. Increasing the gas flow velocity (e.g. by reducing the gas flow area) as well as choosing appropriate packages ensures that the packing will be flooded.
In this process it has to be taken into account that the stage of coalescence is run with sufficient liquid.
If necessary, a part of the separated liquid can be sprayed before the first stage.
In the first stage an agglomeration of very small droplets into larger ones takes place, and these are subsequently separated without any problems in a second stage that is run with lower velocity.
An additional - often desirable - effect comes with the use of an agglomerator, namely the liquid column forming in the package facilitates a post-absorption of gaseous hazardous substances.

6 Literature

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Chemische Industrie, Jan. 1983

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MVT (Mainz) 1972/1974

7 Applications

From the many possible applications of RASCHIG droplet separators, a few may be listed here:

- ***Evaporators***
  To avoid entrainment and to improve product purity
- ***Absorption- and distillation columns***
  Increase of flow rates and products purity at the same time
- ***Vacuum- and compressed air systems***
  Separation of the condensate generated
- ***Oil mist Separator***
  Waste air abatement and recovery of oils and lubricants
- ***Fat filters / fatty acid systems***
  Separation of fatty acids
- ***Paint shops***
- ***Sulphuric acid plants***
  Separation of sulphuric acid mist
- ***Air conditioning and waste air systems***
  Separation of liquid and solid particles
- ***Cooling towers***
  Retaining aerosols
- ***Seawater desalination plants***
  See evaporators
- ***Steam drum***
  See evaporators

8 Maintenance

Due to their high porosity of 89 to 99 % droplet separators are relatively insensitive to soiling. Under normal operating conditions with sufficient high liquid flow the droplet separator cleans automatically by itself.

Solids are washed out by the liquid flow. In case of less liquid flow and high solid concentration it is advisable to install a scrubber in front of the knitted wire mesh droplet separator.

However, in the event of deposits or caking in the knitted wire mesh package, it can be cleaned by jets of water, vapour, or diluted bases or acids. This treatment must be chemically compatible with the materials involved.

The cleaning may be done within the vessel with an equipment already installed (counter stream rinsing equipment) or externally.
For designing the cleaning equipment, the kind and quantity of the pollution has to be taken into account.

RASCHIG suggest the following standard values:

- quantity of water: 20-80 l/m2min
- jetting time: 5-10 min
- distance of the nozzles: 300-500 mm
- Distance nozzles wire mesh: 300-500 mm
- jetting admission pressure: approx. 3 bar

9 Materials and Diameters

Metals	Plastics	Fiber - Material
Galvanized steel Stainless steel - Variants Aluminum Monel Inconel Incoloy Titan Copper Brass	PP (Polypropylen) PE (Polyethylen) PVDF (Polyvinylidenfluorid) ETFE (modif. PTFE) PFA (Perfluoralkoxycoplymer) FEP (Perfluorethylenpropylen) PVC (Polyvinylchlorid) PTFE coated PFA coated	GSF (Glas staple fiber) GF (Glas fiber) PP-Fiber PES-Fiber PTFE-Fiber

Wire Diameters: Ø 0,25 – 0,70 mm (ironed material available)	Dimensions of monofilament: Ø 0,22 – 0,50 mm Dimensions of coated wire: Ø 0,28 – 0,45 mm	Fiber materials: 4 µm – 100 µm

Tab. 2: *Materials and Dimensions*

10 RASCHIG - Standard Types

Types	Density [kg/m³]	Density [lbs/ft³]	Surface [m²/m³]	Surface [ft²/ft³]	Porority [%]	Application
Metal - Types						
RA-80-S0-0,28	80	5	145	44	99,0	High liquid load – big droplets > 15 µm
RA-130-S0-0,28	130	8	236	72	98,3	High gas velocity
RA-145-S0-0,28	145	9	265	80	98,1	Normal process conditions
RA-192-S0-0,28	192	12	350	107	97,5	Emuslsion mist - droplets > 5 µm
RA-240-S0-0,28	240	15	435	133	97,0	
RA-240-S0-0,15	240	15	868	265	97,0	Agglomeration droplets > 2-3 µm
RA-350-S0-0,10	350	21,8	1772	545	95,6	Oil - mist droplets 1 - 3 µm
Plastic - Types						
RA-50-P0-0,40	50	3,1	550	167	94,5	Normal process conditions High separation efficiency
RA-100-P0-0,40	100	6,2	1100	335	89,0	
RA-100-P0-0,22	100	6,2	2000	610	89,0	
RA-80-P2-0,27	80	5	665	200	95,5	Acid mist - droplets 2 - 3 µm
RA-100-P3-0,27	100	6,2	870	265	94,2	Special for high temperatures ≥ 150 °C
Combination - Types						
RA-200-S0/P0-F	200	12,5	> 900	> 280	92,8	Oil-Emulsion mist separation ≤ 10 mg/m³
RA-240-S0/Y3	240	15	> 480	> 150	96,6	Acid - droplets 2-3 µm
RA-175-Y3/P8	175	11	> 360	> 110	97,5	High concentrated sulphuric acid mist by high temperature up to 220 °C

Tab. 3: *Declaration of Raschig – Standard Types*

11 Questionnaire

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Von/ From:	**Fon/ Fax:**
Betreff/ Reference:	**Seiten/ Pages:**

Problem Description

Application

Flow direction vertical ☐ horizontal ☐

Existing dimensions [mm]

Required efficiency [%] Droplet size limit [µm]

Max. permissible pressure drop [mbar, Pa]

Calculation to ☐ existing dimensions ☐ max. efficiency

Operational Process data

Operational pressure [bar abs.] Temperature [°C]

Gas/ vapour density [kg/m^3] or molecular weight

Flow rate [kg/h, Nm^3/h, m^3/h]

Kind and quantity oft he liquid to be separated [kg/h]

Liquid density [kg/m^3] Liquid viscosity [mPas/ cP]

Surface tension [mN/m]

Construction

Existing RA-Type ☐ yes ☐ no

RA-Type: Pad density [kg/m³]: Height [mm]: Wire diameter [mm]:

Required design ☐ square ☐ rectangular ☐ circular

☐ without grid system ☐ complete with grid system

☐ with U-frame (cassette design)

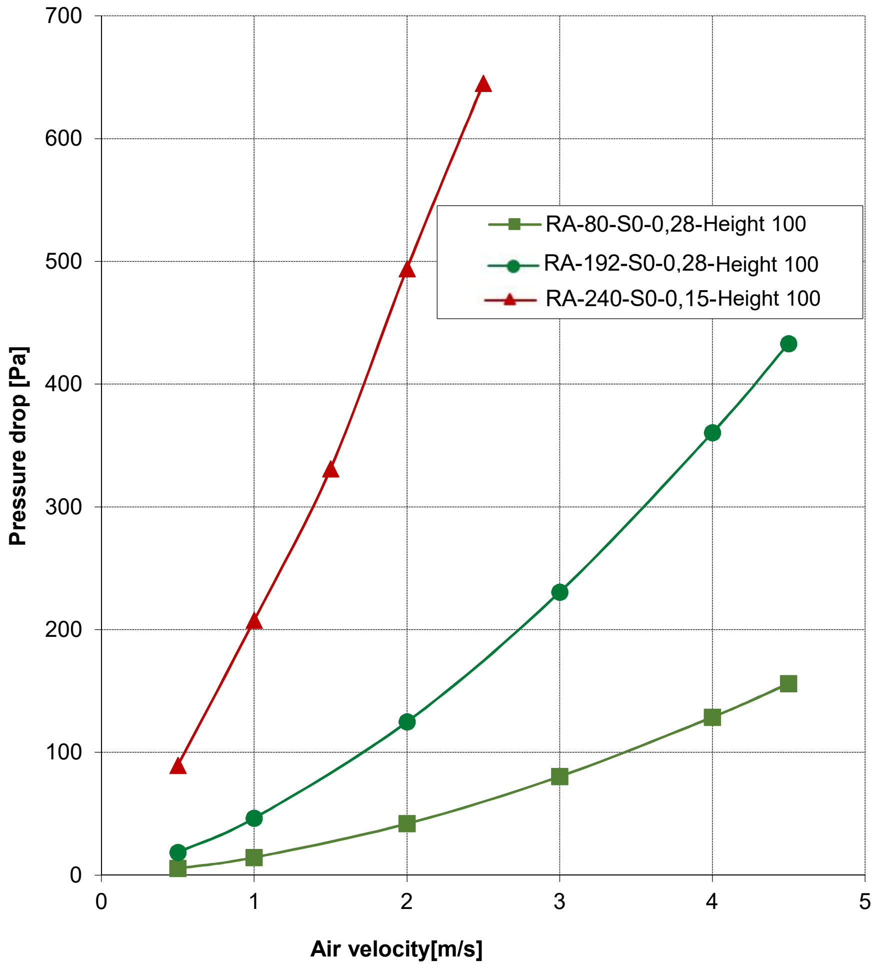
☐ with expanded / wave metal

Material:

12 Pressure Drop

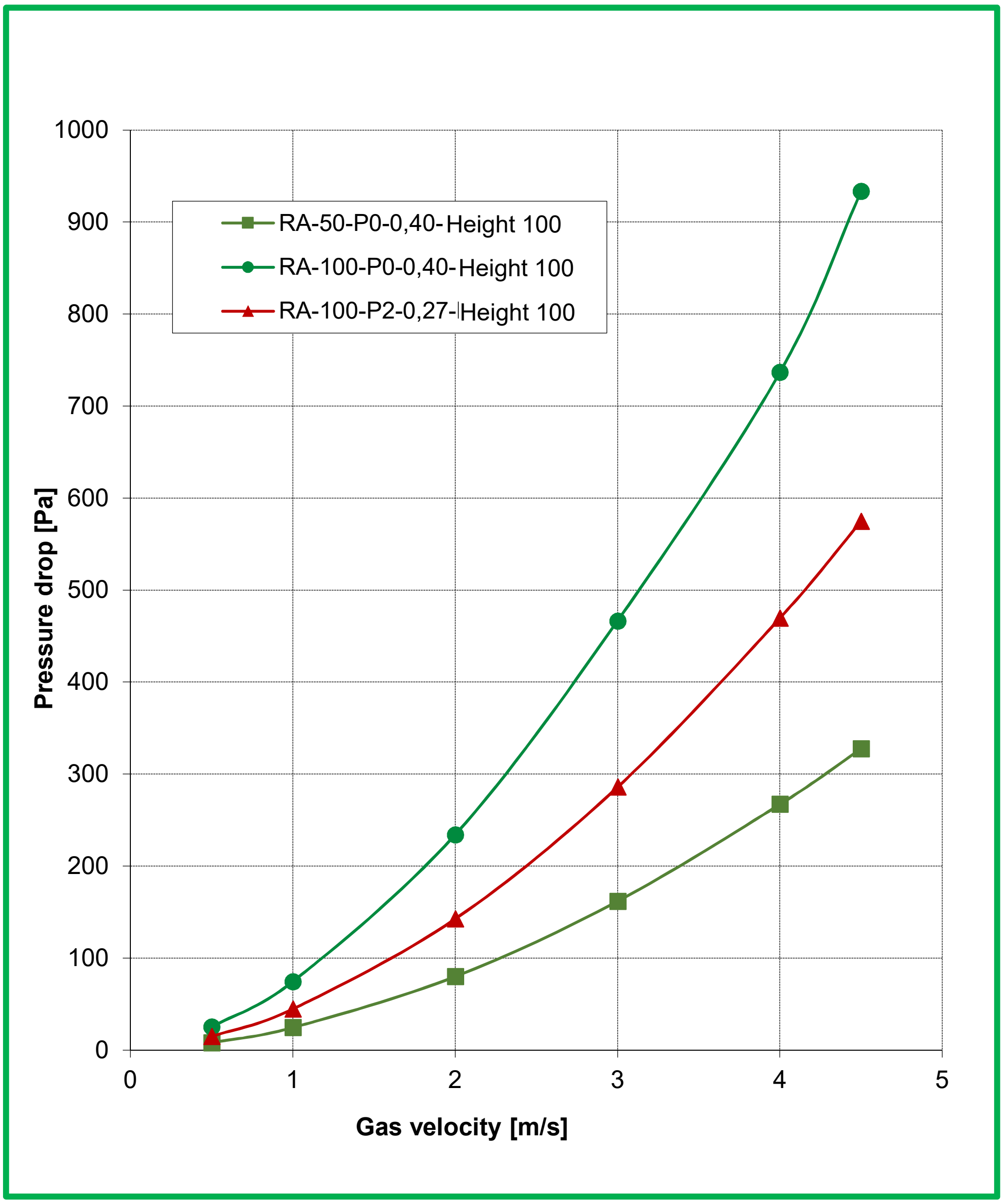
12.1 Metal – Types

Wetted/ 1 bar/ 20 °C



12.2 Synthetic – Types

Wetted/ 1 bar/ 20 °C

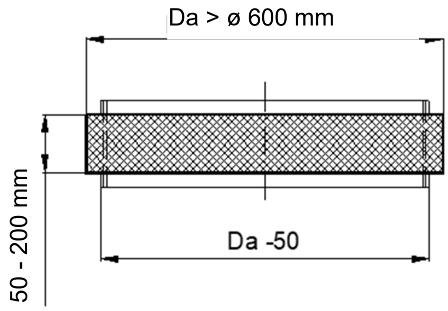


13 RASCHIG Standard - Design

13.1 Metal – Types

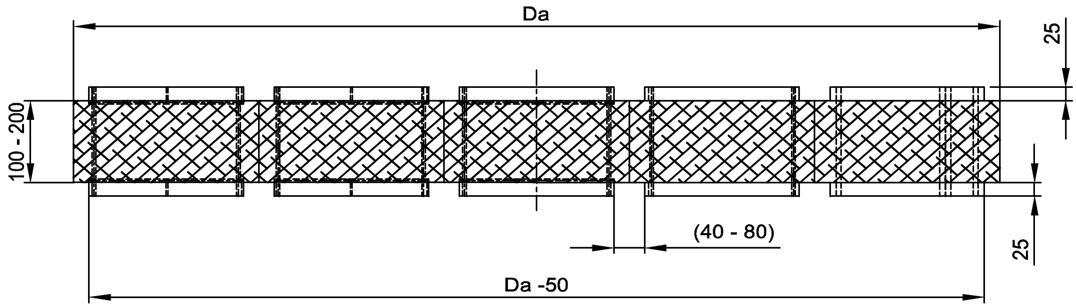
Wound Design

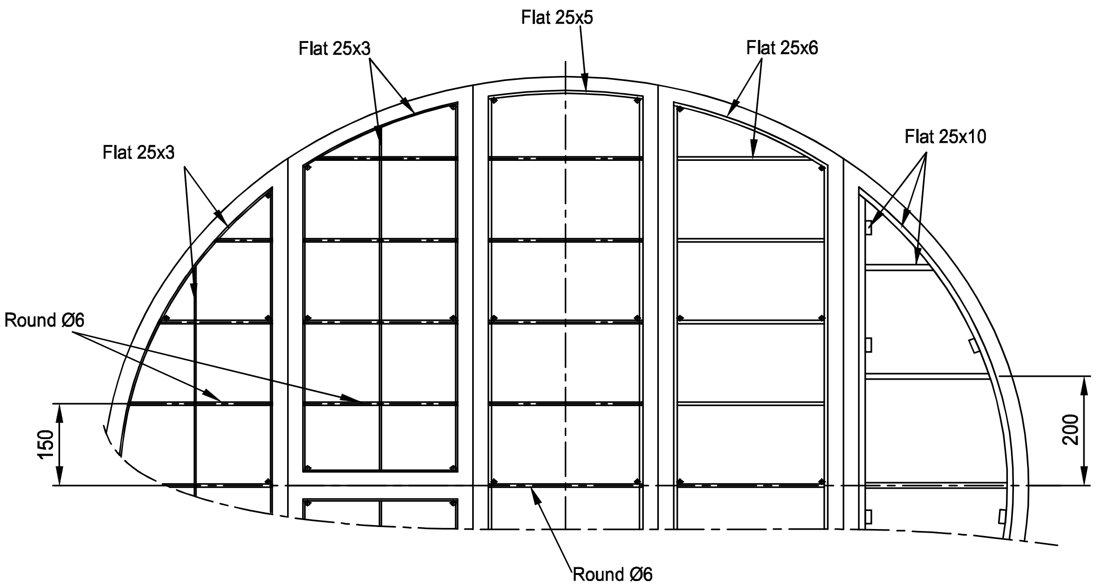
Layered Design



Type – Multi piece

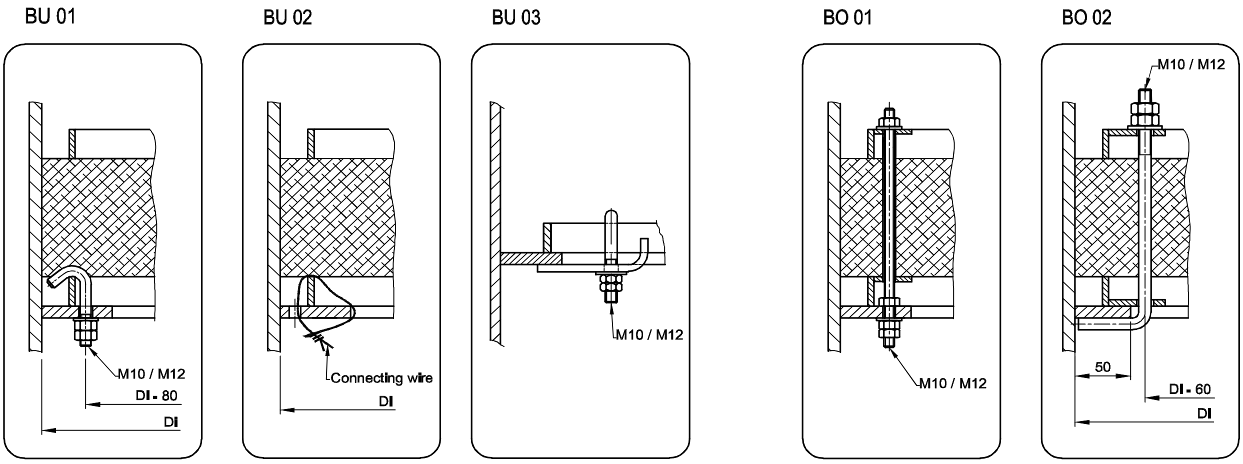
Da > Ø 500 mm
Standard – Single segment width from 300 – 450 mm
Da > Ø 2000 mm – additional splitting of the Separator in the middle line is needed



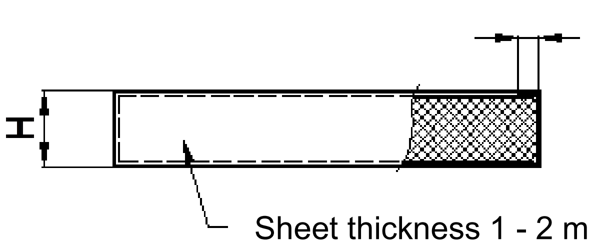


13.2 Installation Instructions

Installation from below	Installation from above
→ Hook screws M10 - M12	→ threaded bar M10 – M12
→ Fixing wire 2 - 3 mm	



13.3 Knitted wire mesh with U-frame

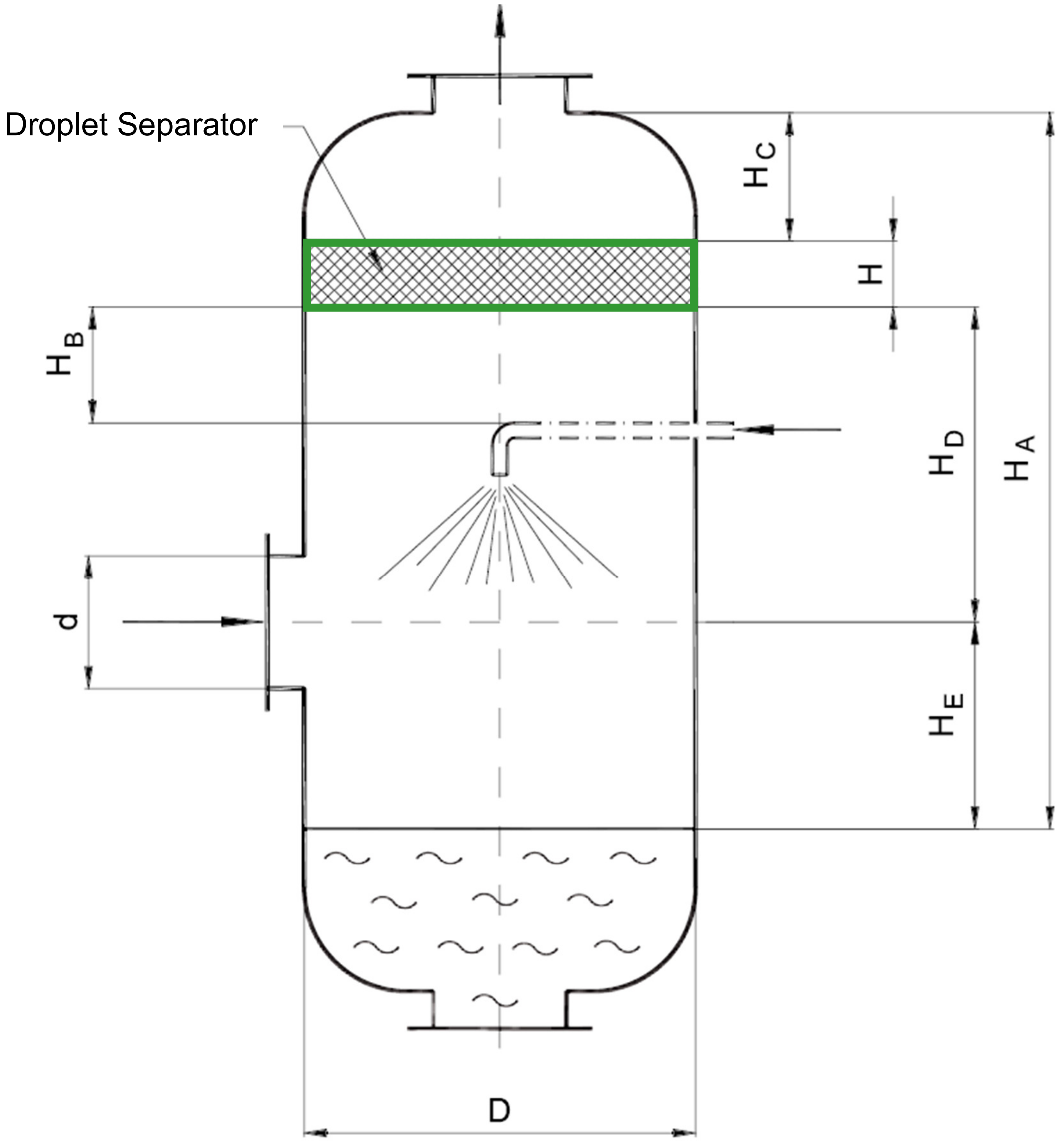


Disign possible with:

- handholds
  Welded mesh/ Expanded metal

The specified standard design is a design proposal. Also costumer – specific requests can be implemented.

13.4 Installation- Dimensions



H_A ~ 1,4 x D + $H_{Separator}$ + d, mind. 0,4 x D +700 (mm)

H_B ~ 0,4 x D

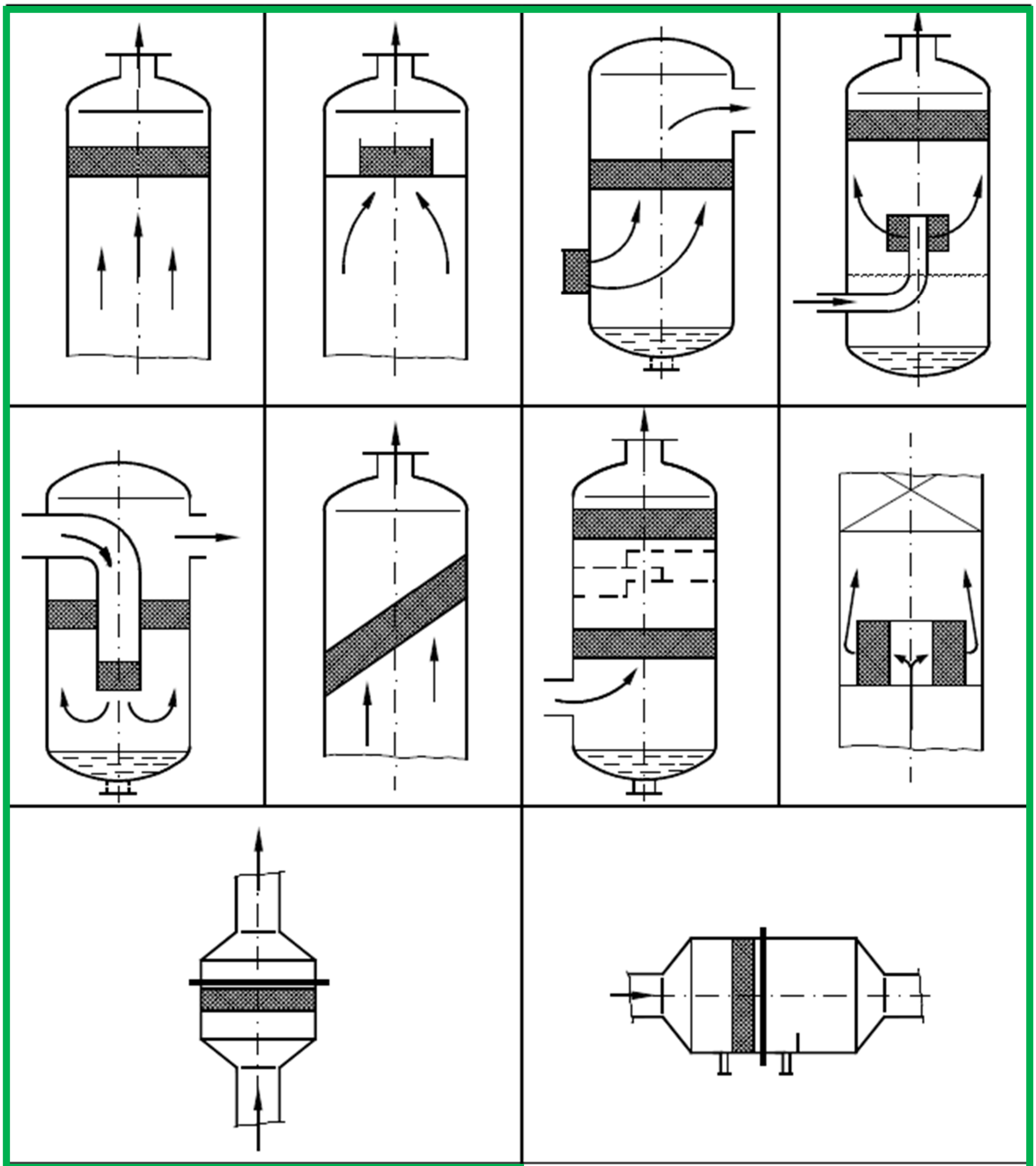
H_C ~ 0,4 x D

H_D ~ 0,7 x D (Min. thickness ca. 150mm) + d/2

H_E ~ 0,3 x D (Min. thickness ca. 150mm) + d/2

$H_{Separator}$: 100 – 350mm (incl. grids)

13.5 Installation Design in different Vessel Types



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