MANUAL

LIQUID/LIQUID AND GAS/LIQUID/LIQUID (THREE-PHASE) SEPARATORS - TYPE SELECTION AND DESIGN RULES

DEP 31.22.05.12-Gen.

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APPENDICES

1. INTRODUCTION

1.1 SCOPE

This DEP specifies requirements and gives recommendations for the selection and design of liquid/liquid and three-phase (gas/liquid/liquid) separators. Design rules are given only for **vessel** separators. Settling tanks, e.g. those used for the dewatering of crude, and basin-type settlers such as the API interceptor used for de-oiling of oil-contaminated surface water, are excluded from the scope of this DEP.

Gas/liquid separators are excluded from the scope of this DEP but are specified by DEP 31.22.05.11-Gen. (which is also applicable to the gas/liquid separation part of three-phase separators).

In this DEP two-phase and three-phase separators will also be referred to as two-phase and three-phase settlers, respectively.

The term "settling" will also be used for the separation of light-phase droplets in this DEP in order to be consistent with the term "settlers" which is used both for the separation of light-phase and heavy-phase droplets.

Design rules are given for the following types of separators (or settlers):

L/L separators (in Section 3):
- Horizontal open settler
- Horizontal plate pack settler
- Coalescers (with either a coalescer bed, mat or cartridges)

Three-phase (G/L/L) separators (in Section 4):
- Horizontal open settler
- Plate pack settlers (both horizontal and vertical)

Users of this DEP should first consult Section 2 to make an initial selection of a suitable type of separator for a given duty.

After selection of the desired separator the design rules can be obtained from either Section 3 or 4.

Information on the vessel internals, L/L separation mechanism and the vessel sizing calculation schemes are given in the Appendices.

1.2 DISTRIBUTION, INTENDED USE AND REGULATORY CONSIDERATIONS

Unless otherwise authorised by SIOP and SIEP, the distribution of this DEP is confined to companies forming part of the Royal Dutch/Shell Group managed by a Group company and to Contractors nominated by them (i.e. the distribution code is "C" as described in DEP 00.00.05.05-Gen.).

This DEP is intended for use in oil refineries, chemical plants, gas plants, exploration and production facilities and supply and marketing installations.

If national and/or local regulations exist in which some of the requirements may be more stringent than in this DEP, the Contractor shall determine by careful scrutiny which of the requirements are the more stringent and which combination of requirements will be acceptable as regards safety, economic and legal aspects. In all cases the Contractor shall inform the Principal of any deviation from the requirements of this document which is considered to be necessary in order to comply with national and/or local regulations. The Principal may then negotiate with the Authorities concerned with the object of obtaining agreement to follow this document as closely as possible.

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The **Contractor** is the party which carries out all or part of the design, engineering, procurement, construction, commissioning or management of a project or operation of a facility. The Principal may undertake all or part of the duties of the Contractor.

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The **Principal** is the party which initiates the project and ultimately pays for its design and construction. The Principal will generally specify the technical requirements. The Principal may also include an agent or consultant authorised to act for, and on behalf of, the Principal.

The word **shall** indicates a requirement.

The word **should** indicates a recommendation.

1.4 CROSS-REFERENCES

Where cross-references are made, the number of the section or sub-section referred to is shown in brackets.

All documents referenced in this DEP are listed in (6.).

Attention is drawn to the copyright and confidentiality statement on the title page of this manual and to the fact that some of the referenced documents cover Shell-proprietary items.

1.5 SYMBOLS AND ABBREVIATIONS

A	area	m^2
BTL	bottom tangent line	
conc	local volumetric fraction of dispersed phase	-
D	internal diameter of vessel, skirt, large pipe, etc. (if no subscript, internal diameter of vessel)	m
d	diameter of pipe, nozzle, bubble or droplet	m
	plate distance in plate packs	m
F	correction factor (in plate pack design)	-
	distance (e.g. of plates in plate pack)	m
Fr_G	gas Froude number: $$Fr_G = v_G\sqrt{\frac{\rho_G}{(\rho_L - \rho_G)gD}}$$	-
Fr_L	liquid Froude number: $$Fr_L = v_L\sqrt{\frac{\rho_L}{(\rho_L - \rho_G)gD}}$$	-
f	correction factor	-
G	gas	
g	acceleration due to gravity	m/s^2
H	height	m
h	height of vessel for liquid hold-up (to LZA(HH))	m

ID	inside diameter	m
IL	interface level (normally used for L/L interface)	
L	length	m
	liquid	
LA(H)	high level pre-alarm	
LA(L)	low level pre-alarm	
LZA(HH)	high level trip	
LZA(LL)	low level trip	
NFA	net free area	-
NL	normal level	
$max(a_1,a_2)$	maximum value of the numbers a_1 and a_2	
$min(a_1,a_2)$	minimum value of the numbers a_1 and a_2	
n	number	
P	pressure	Pa
p	pressure	Pa
Q	volumetric flow rate	m^3/s
Re	Reynolds number: $Re = \rho v d_H / \eta$	-
SMS	Shell-proprietary G/L separator with Schoepentoeter, Mistmat and Swirldeck	
TFC	Shell Twin-Flange Coalescer	
TTL	top tangent line	
t	thickness (e.g. of plates in plate pack)	m
	duration	sec
V	volume	m^3
v	velocity	m/s
W	width	m
w	width	m
X	distance	m

Greek symbols

α	ratio of the short and long axes of the vessel head	
Δ	difference (used in conjunction with other symbols)	
η	dynamic viscosity	Pa.s
λ	load factor	m/s
λ_G	gas load factor:	m/s

$$\lambda_G = \frac{Q_G}{A_G}\sqrt{\frac{\rho_G}{(\rho_l - \rho_G)}}$$

θ	angle	degrees
ρ	density	kg/m^3
σ	interfacial tension	N/m

Subscripts:

ax	axial
bed	coalescer bed
d	dispersed phase
c	continuous phase
col	collection compartment
coleff	effective length of collection compartment
con	control requirements or specific control band
conc	local volumetric fraction of dispersed phase
contot	total control band
crit	critical
db	dispersion band
dh	droplet of heavy liquid phase
dl	droplet of light liquid phase
f	front
feed	feed flow
fp	feed pipe
	(perforated) front plate of L/L separation plate pack
fw	front weir of a collection compartment
G	gas

H	hydraulic diameter
h	heavy liquid phase
hd	header
in	inlet
int	L/L interface
L	liquid (in general)
l	light liquid phase
laminar	laminar flow
loss	part of plate pack front face available for flow
low	lower part
m	mixture
max	maximum
min	minimum
out	outlet
ow	overflow weir of a collection compartment in horizontal three-phase settler with double weir
p	droplet or particle
pp	plate pack for L/L separation
ret	retention time
set	settling compartment or settling process
spec	specified
tl	transition from turbulent to laminar flow
turbulent	turbulent flow
up	upper part
	underflow passage of front weir of heavy-phase compartment in horizontal three-phase settler with double weir
ves	vessel
ww	the two heavy-phase weirs in horizontal three-phase settler with weir configuration
1	feed inlet
2	gas outlet
3	outlet of the light liquid phase
4	outlet of the heavy liquid phase

(numbers 0 to 6 inclusive also refer to principal distances/clearances in the separator vessels (see the individual layout drawings and Appendix VI))

Superscript

* dimensionless representation of length or area (see Appendix VI)

2. SELECTION OF L/L AND G/L/L (THREE-PHASE) SEPARATORS

The selection of a suitable L/L or G/L/L separator for a given application depends on several factors, such as:

- Required separation efficiency.
  If an efficient separation is required, then in general separation internals are needed.
- Required gas and liquid handling capacity.
- Whether the L/L separation or the G/L separation is the controlling factor (in G/L/L separators).
- Required fouling tolerance.

Several requirements may be conflicting, such as high fouling tolerance and high separation efficiency.

To facilitate the choice of suitable separator types for a given application, Table 2.1 has been included, indicating for each separator described in this DEP those applications for which it is specifically recommended or shall not be used.
It serves as a first selection guide, after which a final choice can be made after consulting the parts of the DEP where the provisionally selected separator types are described (see also the Table for reference).
Each of these parts starts with the profile of the separator (e.g. detailed characteristics and typical process applications) and then subsequently gives the sizing rules to be followed for a proper design. The detailed vessel sizing procedures are given in the corresponding appendices.

The various terms used in the first column of Table 2.1 are explained below and the relevant sizing criteria for L/L and G/L/L separators are defined.

L/L separation:

- **Type of dispersion**
  A primary dispersion is one in which the majority of the dispersed droplets are larger than 30 µm. A secondary dispersion is one in which the majority of the dispersed droplets are smaller than 30 µm.
- **Separation efficiency**
  Since in general the drop size distribution of the dispersed phase in the feed is not known, it is impossible to quantify the separation efficiency of L/L separators in terms of % removal. It is common practice to specify the separation efficiency in terms of "**cut-off diameter**". This is the diameter of the smallest droplets to be removed with an efficiency of 100%.

  The following definitions are used:
  Primary dispersion:
  - bulk separation in open settlers: droplets larger than 150 µm removed
  - efficient separation in plate packs: droplets larger than 50 µm removed
  - efficient separation in coalescer mat (C2 in Table 2.1): droplets larger than 30 µm removed.

G/L separation:

- **Separation efficiency**
  It is common practice to characterise the separation efficiency of G/L separators in terms of % removal. This is justified for the more efficient G/L separators, where the liquid remaining in the gas stream after passing through the separator consists of re-entrained droplets of which the size is little affected by drop size distribution in the feed.
  A bulk G/L separation is defined as a separation where less than 90-95% of the liquid is removed from the gas phase. This can be achieved in separators without demisting internals.
  The efficiency of G/L separators equipped with a mist mat, vane pack or swirl deck (or a combination of these internals) is higher.
  For more information see DEP 31.22.05.11-Gen.

- **Gas handling capacity**
  The gas handling capacity in three-phase separators is characterised by the gas load

factor, λ_G:

$$\lambda_G = \frac{Q_G}{A_G}\sqrt{\frac{\rho_G}{(\rho_l - \rho_G)}}$$

where Q_G is the volumetric gas flow rate,

ρ_l and ρ_G are the densities of the lightest liquid phase and the gas phase respectively.

If the volumetric flow rate of the light liquid phase is less than 5% of the total volumetric liquid flow rate, then ρ_l should be replaced by a flow rate averaged liquid density, ρ_L (see also Appendix VII for definition of ρ_L).

A_G is the area available for gas flow (vessel cross-section in vertical separators and gas cap in horizontal separators).

The separator shall be sized such that it is able to handle the gas flow rate under the most severe process conditions. The gas load factor shall not exceed a critical value, the maximum allowable gas load factor λ_{max}, whose value is dependent on the type of G/L separation used. For more information see DEP 31.22.05.11-Gen.

Liquid handling or gas handling controlled (in G/L/L separators):

A three-phase separator is liquid handling controlled if one of more of the following conditions apply:

- The feed to the separator is mainly liquid;
- A low downward liquid velocity is required (for de-gassing or foam breakdown purposes, or in cases of difficult L/L separation).

Normally a horizontal vessel will then be selected.

If the three-phase separator is gas handling controlled, e.g if a relatively large gas flow rate has to be handled, the first choice will be a vertical vessel.

The final choice between a horizontal vessel and a vertical vessel will be influenced by various factors including the available plan area or head room.

Fouling service

Normally the requirements of high fouling tolerance and high separation efficiency are conflicting, because the internals required for efficient separation are normally sensitive to fouling. Measures shall be taken to achieve efficient L/L separation, such as prefiltering if cartridge coalescers are used.

In fouling service measures shall also be taken to keep the settler clean, such as by installing a sandwash system in open settlers (SIEP application).

Under severe fouling conditions it may be advantageous to select a vertical settler with a conical lower end to facilitate the removal of solids.

Plate packs may only be used under no worse than moderately fouling conditions. If used under those conditions the plate pack layout and supports should be adapted to facilitate the removal of solids.

Table 2.1 Screening of L/L and G/L/L separators

√ : Recommended use X : Non-recommended use

	L/L separators					G/L/L separators			
Separator types	**L1**	**L2**	**C1**	**C2**	**C3**	**T1**	**T2**	**T3**	**T4**
L/L separation									
primary dispersion	√	√		√		√	√	√	√
bulk separation	√					√	√		
efficient separation		√		√				√	√
secondary dispersion	X	X	√,1	X	√	X	X	X	X
ill-defined L/L interface	X	X					√,2	√,2	
G/L separation									
bulk separation						√	√	√	
efficient separation									√,3
liquid handling controlled (in G/L/L separators)						√	√	√	X
gas handling controlled (in G/L/L separators)								X	√
Fouling service	√		X,4	X,4	X,4	√	√		
High temperature			X,5	X,5	X,5				

L1: Horizontal open two-phase settler (3.1 and Appendix IV)
L2: Horizontal two-phase settler with plate pack (3.2 and Appendix IV)
C1: Coalescer fitted with a compressed coalescer bed (3.3.1 and Appendix III)
C2: Coalescer fitted with a prefabricated coalescer mat (3.3.2 and Appendix III)
C3: Coalescer fitted with coalescer cartridges (3.3.3 and Appendix III)
T1: Horizontal open three-phase settler with boot (4.1.1 and Appendix V.1)
T2: Horizontal open three-phase settler with weir arrangement (4.1.2 and Appendix V.2)
T3: Horizontal three-phase settler with plate pack and weir arrangement (4.2 and Appendix V.2)
T4: Vertical three-phase settler with plate pack (4.3 and Appendix V.3)

1 : If properly packed and **NO compressed** crinkled wiremat is installed.
2 : Provided there is a double weir arrangement with no IL control; also to be used if there are corresponding L/L separators.
3 : If wiremesh or wiremesh/ swirl deck assembly is installed.
4 : If no prefiltering is applied.
5 : Above 80°C, if polypropylene is used as coalescer material.

3. DESIGN RULES FOR L/L SEPARATORS

In this Section the design rules for the various liquid/ liquid separators are given.

If the separators do not contain L/L separation internals, then they are referred to as "open settlers".

For information on the mechanism of liquid/liquid separation, see Appendix I.

Unless explicitly stated otherwise, the liquid flow rates will contain a design margin or surge factor as defined in Appendix IX.

3.1 HORIZONTAL OPEN TWO-PHASE SETTLER

3.1.1 Selection criteria

Application:
Bulk separation of primary dispersions with good separation characteristics (i.e. relatively low viscosity of the continuous phase, relatively large droplets and a well-defined interface).

Characteristics:
- insensitive to fouling
- only for separation of a primary dispersion (i.e. droplets larger than 30 µm).

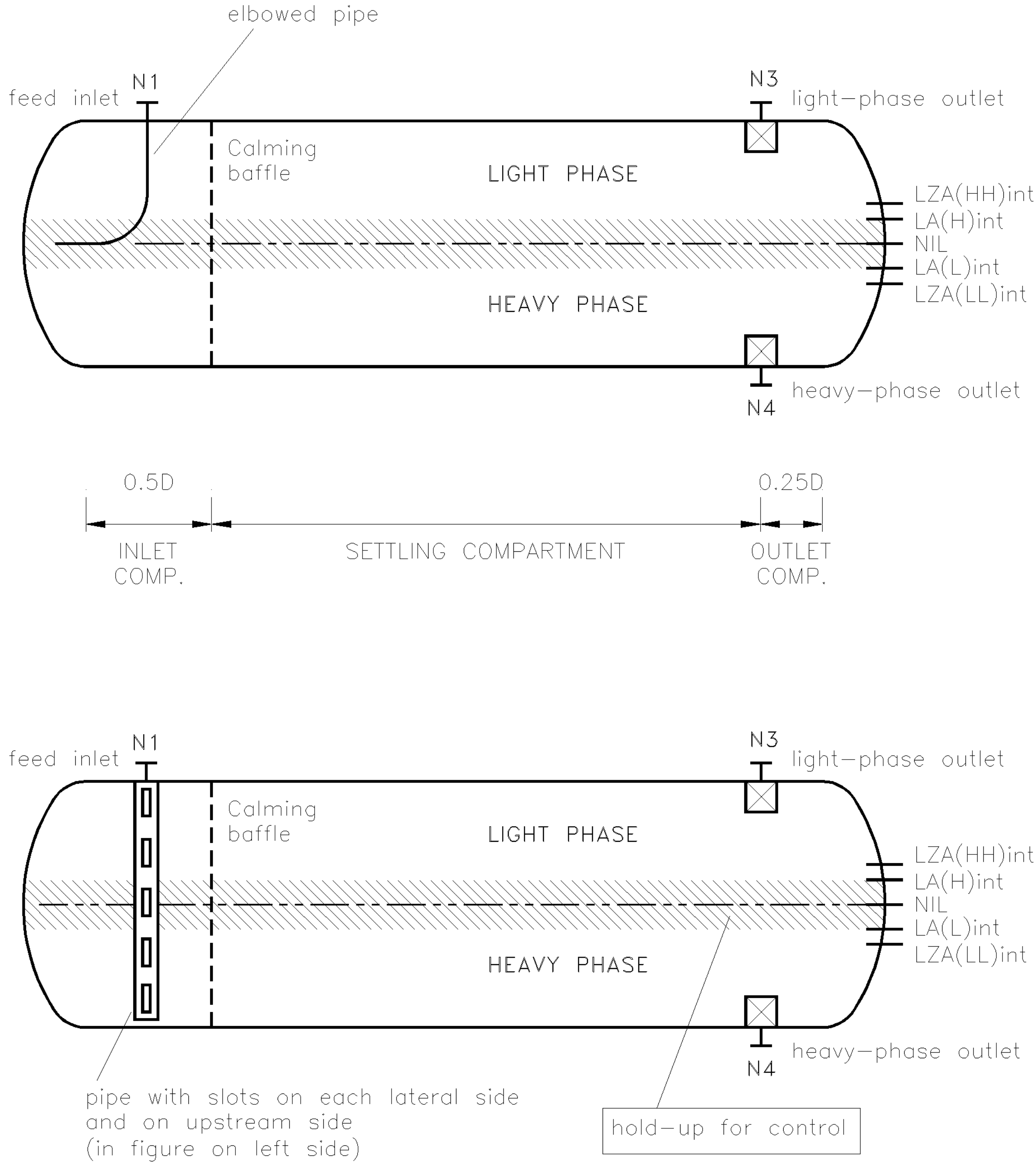
Recommended use:
- fouling service;
- where only bulk separation is required;
- where the dispersion has good separation characteristics.

Not recommended:
- for secondary dispersions (i.e. droplet smaller than 30 µm);
- where a high separation efficiency is required;
- where the interface is ill-defined (this will affect the interface level control).

If the interface is ill-defined, the three-phase separator layout with a double weir system should be used because direct IL control is then avoided (see also (4.1)).

Typical process applications:
- settler in mixer/settler arrays in extraction processes;
- side decanter;
- rectifying absorber side draw-off vessel.

FIGURE 3.1 HORIZONTAL OPEN TWO-PHASE SETTLER (FEED INTERNAL EITHER ELBOWED OR SLOTTED PIPE)



3.1.2 General description

Figure 3.1 shows a typical layout of a horizontal open two-phase settler for cases where both phases have to be cleaned. If the cleaning of only one phase is required and the other phase is only a small fraction of the total flow (typically less than 20%) then it is not necessary to maintain an interface level in the vessel and a dome or boot is used (e.g. in a rectifying absorber side draw-off vessel). For the use of a boot see also the sizing of three-phase settlers equipped with a boot (4.1.1).

Basically the settler consists of three compartments: an inlet compartment, a settling compartment and an outlet compartment containing the outlet nozzles.

The feed enters the inlet compartment via the feed nozzle equipped with a feed inlet device.

There are two possibilities for the inlet device: a pipe directed to the vessel head or a slotted pipe (as shown in the upper and lower parts of Figure 3.1, respectively).

Between the inlet and settling compartment a calming baffle (perforated plate) shall be installed to create an even flow in the settling compartment which will promote the separation of the two liquid phases.

The settling compartment is terminated at the liquid outlet nozzles which are both fitted with vortex breakers.

3.1.3 Inlet and outlet compartments

The inlet compartment shall be sufficiently large to accommodate the feed inlet and to allow a reasonable flow path length of the feed to the calming baffle.

The inlet compartment should have a length of at least 0.5D (distance between tangent line and calming baffle).

The calming baffle shall occupy the whole vessel cross-section.
Its Net Free Area is typically 30% with 12 mm diameter holes.
The baffle thickness should be at least 12 mm.
The thicker the baffle the more homogeneous the flow downstream of the baffle.
At the bottom of the baffle a small opening is allowed for cleaning purposes.
The outlet compartment shall be sufficiently large to accommodate the outlet nozzles.
Its length is typically 0.25D.

3.1.4 Settling compartment

The settling compartment is divided into three horizontal zones:

- An upper zone through which in every flow scenario the light phase flows and from which the heavy-phase droplets have to be separated.
  This is the zone above high interface trip level, $LZA(HH)_{int}$.
- An intermediate zone for level control and if required, accommodation of an interfacial dispersion band (see Figure I.1 in Appendix I).
- A lower zone through which in every flow scenario the heavy phase flows and from which the light-phase droplets have to be separated.
  This is the zone below low interface trip level, $LZA(LL)_{int}$

3.1.5. Sizing of the settler

For a proper sizing of the settler the following main rules apply:

1. The cross-sectional area of the upper and lower zones shall be large enough for the axial velocity in each zone to be at most 15 times the settling velocity (in laminar flow) of the smallest droplets of the opposite phase to be separated, with a maximum axial velocity of 0.015 m/s.
2. The cross-sectional area of the upper and lower zones shall be at least 14.2% of the vessel cross-sectional area. (This is equivalent to a minimum central height of these cross-sectional areas of 0.2D).

3. The length of the settling compartment shall be sufficiently long to meet the separation specifications (in terms of smallest droplet to be separated).
4. The control volume (contained between $LA(L)_{int}$ and $LA(H)_{int}$) shall be sufficiently large to meet the specified interface level control time (see Appendix X).
5. Preferably $2.5 \leq L/D \leq 6$.

In Appendix IV the procedure is presented for checking the sizing of an existing settler. It can also be treated as the sizing procedure for a new settler starting with the specification of the vessel diameter and length and interface level control heights.

If certain criteria cannot be met, the procedure has to be repeated with adjusted vessel dimensions and level control heights.

A calculation example is given in Appendix IV.

3.1.6 Nozzles

The feed nozzle should be fitted with an inlet device.
There are two options for this:

- an elbowed pipe directed towards the vessel head (as is shown in the upper part of Figure 3.1);
- a vertical pipe with rectangular slots (as is shown in the lower part of Figure 3.1).
  The total area of the slots is typically 3.3 times the cross-sectional area of the feed nozzle. A feed inlet velocity of 1 m/s maximum will then be reduced to 0.3 m/s maximum in the slots. The slots should be on each lateral side and on the upstream side (i.e. the side facing the nearest vessel head, as shown in Figure 3.1).

For the sizing of the feed nozzle, see Appendix VIII.

For the sizing of the outlet nozzles and the specification of the required vortex breakers, see Appendix VIII.
The vortex breaker shall be at least a half nozzle diameter away from the corresponding control level, $LZA(LL)_{int}$ (heavy-phase outlet) and $LZA(HH)_{int}$ (light-phase outlet).

3.2 HORIZONTAL TWO-PHASE SETTLER WITH PLATE PACK

3.2.1 Selection criteria

Application:
Efficient separation of primary dispersions

Characteristics:
- efficient separation, provided the dispersion is of the primary type (i.e. droplets larger than 30 µm)
- not too sensitive to fouling (a certain degree of fouling can be accommodated by e.g. selecting a relatively large plate distance and plate angle).

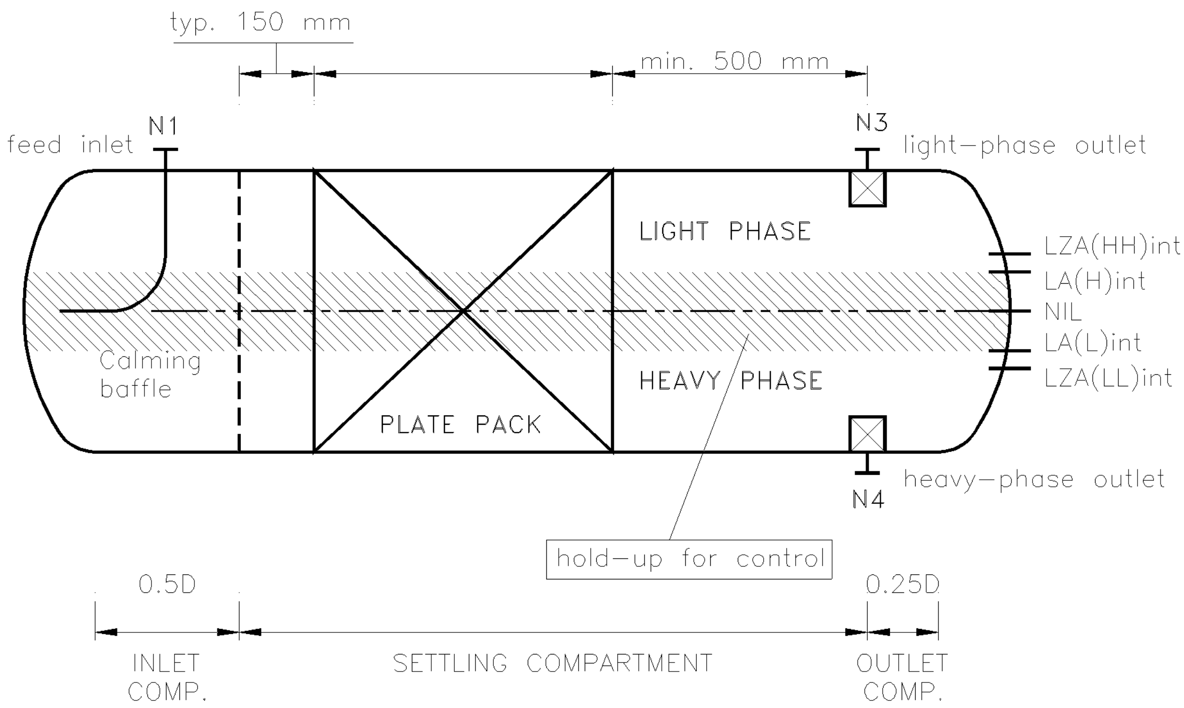
Recommended use:
for the efficient separation of a primary dispersion provided:
- the L/L interface is well-defined;
- the service is at most moderately fouling.

Not recommended:
- for secondary dispersions (i.e. drop size smaller than 30 µm)
- in heavy fouling service
- where the interface is ill-defined (this will affect the interface level control).

If the interface is ill defined the three-phase separator layout with a double weir system should be used because direct IL control is then avoided (see also (4.2)).

Typical process applications:
- acid settler of HF-alkylation plant.

FIGURE 3.2 HORIZONTAL TWO-PHASE SETTLER WITH PLATE PACK



3.2.2 General description

Figure 3.2 shows a typical layout of a horizontal two-phase settler for cases where both phases have to be cleaned from the other liquid phase, fitted with a plate pack in the settling compartment.

The feed inlet shown is a pipe directed to the nearest vessel head, but alternatively a slotted pipe can be used (see (3.1.2)).

The location of the manhole shall be selected such that the plate pack internals can easily be installed.

Other features are equivalent to those described in (3.1.2).

3.2.3 Inlet and outlet compartments

Requirements for inlet and outlet compartments are equivalent to those described in (3.1.3).

3.2.4 Settling compartment

The settling compartment contains the plate pack.
In the standard layout a transversal plate pack (i.e. with the face of the plate pack perpendicular to the central vessel axis) is used. For more information on plate packs and their design, see Appendix II.
The flow through the plate pack is divided into three horizontal zones as described in (3.1.4).
The distance from the perforated baffle to the plate pack should be 150 mm.
The minimum distance from the plate pack to the outlet nozzles should be 500 mm.
To prevent bypass the clearance between the plate pack and the vessel wall shall be sealed apart from a small opening underneath the plate pack required for cleaning purposes.

3.2.5 Sizing of the settler

For a proper sizing of the settler the following main rules apply:

1. The cross-sectional area of the upper and lower zones in the plate pack shall be sufficiently large, to ensure that the flow is laminar.
2. The cross-sectional area of the upper and lower zones shall be at least 14.2% of the vessel cross-sectional area. (This is equivalent to a minimum central height of these cross-sectional areas of 0.2D).
3. The length of the settling compartment (distance between the calming baffle and the outlet nozzles) should be at least the length of the required plate pack + 650 mm.
4. The control volume (contained between $LA(L)_{int}$ and $LA(H)_{int}$) shall be sufficiently large to meet the specified interface level control time (see Appendix X).
5. Preferably $2.5 \leq L/D \leq 6$.

In Appendix IV the procedure is presented to upgrade an existing open settler with the installation of a plate pack.

It can also be treated as the sizing procedure for a new settler starting with the specification of the vessel diameter and length and interface level control heights.

If certain criteria cannot be met, the procedure has to be repeated with adjusted dimensions.

A calculation example is given in Appendix IV.

3.2.6 Nozzles

Requirements for feed nozzle and outlet nozzles are equivalent to those described in (3.1.6).

3.3 COALESCERS

3.3.1 Selection criteria

Types:
1. Coalescer fitted with a compressed coalescer bed
2. Coalescer fitted with a prefabricated coalescer mat
3. Coalescer fitted with coalescer cartridges

Application:
Coalescence of dispersed droplets in primary or secondary dispersions.

Characteristics:
General:
- Sensitive to fouling, in particular the coalescer cartridges;
- In fouling service prefilters are required.

Compressed coalescer bed:
- suitable for the coalescence of primary and secondary dispersions;
- economic because of low-cost material and possibility of backwashing;
- manually packed: extra precautions required to avoid channelling resulting in bypassing.

Coalescer mat:
- suitable for the coalescence of primary dispersions only;
- little likelihood of channelling since it is pre-fabricated.

Coalescer cartridges:
- suitable for the coalescence of primary and secondary dispersions;
- due to the large coalescing area of the cartridges the coalescer vessels can be kept compact;
- little likelihood of channelling because they are pre-fabricated.

Recommended use:
Compressed coalescer bed:
- secondary dispersion, if properly packed and **NO compressed** crinkled wiremat installed.

Coalescer mat:
- primary dispersion;
- if local phase inversion is very likely (i.e. the dispersed phase becomes locally the continuous phase), use dual material (stainless steel and polymer filaments).

Coalescer cartridges:
- secondary dispersion;
- to upgrade Shell Twin-Flange Coalescers (equipped with compressed coalescer bed).

Not recommended:
General:
- In fouling service without prefiltering.
- No polypropylene shall be used if the operating temperature exceeds 80 °C and/or the aromatic content of the feed exceeds 18 wt% (to avoid excessive swelling of the fibres).

Coalescer mat:
- secondary dispersion.

Typical process application:
- dewatering of hydrocarbons (ranging from LPG to kerosene fractions).

3.3.2 General

The function of a coalescer is to promote the growth of droplets in a dispersion by the utilisation of a coalescer medium. In Appendix III more information is given on the coalescence mechanism in the various types of coalescer media.

In practice the following coalescing media are in use:

1. compressed coalescer bed made from fibres (either polymeric material (e.g. polypropylene) or stainless steel wire);

2. pre-fabricated mat;

3. cartridges.

3.3.3 Treatment of the coalescer feed

3.3.3.1 Selection of feed pump

Normally centrifugal pumps are used to pump the feed to the coalescer. However, due to the high level of energy dissipation in this type of pump, the droplets in the feed will be dispersed further to much smaller droplets and even stable emulsions could be formed.

In critical systems where emulsification can readily take place, the use is recoomended of other types of pumps should be used in which less energy is dissipated, e.g. displacement pumps.

3.3.3.2 Measures to avoid flashing in the coalescer

In cases where the feed of the coalescer originates from a three-phase separator in which vapour and liquids are in equilibrium and no pump upstream of the coalescer is used, precautions have to be taken to avoid flashing in the coalescer due to the pressure drop across the coalescer bed.

This can be done by placing the upstream three-phase vessel at a higher elevation relative to the coalescer. Further, the coalescer vessel shall always be equipped with a vent.

3.3.3.3 Prefilters

In fouling service prefiltering should be done upstream of a coalescer.

Two prefilters should be used in parallel, with one in use and the other standby. Measurement of the pressure drop across the prefilter in use will indicate the fouling degree.

If the fouling of the prefilter in operation has become unacceptably high, then the flow has to be routed to the other prefilter. This will allow cleaning out of the fouled prefilter without putting the coalescer at risk.

Within the Group both cartridge and filter basket (which may include a filter bag) systems are applied; cartridge systems should normally be used and are now the industry standard. Both cleanable (steel) and propylene/cellulose paper cartridges are used. Steel type filters, typically cleaned with LP steam, are used in high temperature applications or in systems which require frequent cleaning.

Sometimes, filter cartridges are classified by the Manufacturer as absolute rated for a given particle size. This means that the pores of the filter cartridge are smaller than that particle size. (If the pores of the cartridge are larger than the particle size, the particles will penetrate the filter medium where they will be trapped by adhesion and other mechanisms.)

The pre-filter shall retain all solid particles larger in size than the pore size of the coalescer cartridge. This would rarely be larger than 5 μm.

Normally the prefilters are sized such that under the prevailing flow conditions the pressure across the clean cartridges is 0.1 bar. Change-out will take place at a cartridge pressure drop as recommended by the manufacturer and is typically 3 bar for absolute rated pre-filters and 1 bar for other types.

The area and number of cartridges and the sizing of the prefilter pressure vessel shall be specified by the prefilter manufacturer.

Since a higher velocity (typically by a factor of 5) through the filter medium can be tolerated than in the case of coalescer cartridges and therefore less cartridge surface area is required, a prefilter vessel will be smaller than a coalescer vessel for a given feed flow rate.

3.3.4 Coalescer fitted with a compressed coalescer bed (Shell Twin-Flange Coalescer)

3.3.4.1 General

Within the Group the most common representative of this type of coalescers is the Shell

Twin-Flange Coalescer (TFC).

A schematic layout is presented in Figure 3.3.

The detailed layout is defined in Standard Drawing S 22.027.

The TFC is a top-flanged vessel of which the lower part has a larger diameter than the upper part. The coalescer bed is compressed in a skirt between two grids. The feed (in most cases a hydrocarbon feed which has to be dewatered) flows downwards through the bed where coalescence of the dispersed phase takes place. After this the heavy liquid phase leaves the vessel via a bottom outlet and the light liquid phase leaves via four side outlets. These side outlets are located just below where the skirt is attached to the vessel wall. A vent is connected to the upper part of this annular compartment to evacuate any vapour formed locally.

The sizing rules of the Shell Twin-Flange Coalescer are given below.

3.3.4.2 Skirt and coalescer bed

In its standard layout the coalescer bed consists of compressed polypropylene wool of which the fibres have typically a diameter of 30 µm.

If polypropylene is used, no steaming out can be applied since the maximum alllowable temperature is 80°C. Where steaming out is required or any other process where the temperature will rise above this limit, more heat-resistant material shall be used.

Also, if the feed contains a high content of aromatics (> 18 wt%), polypropylene should not be used because of excessive swelling of the fibres.

In a non-corrosive environment stainless steel wool may then be the alternative in the above two cases, and the filament diameter should also be in the order of 30 µm. The bed is manually packed using rolls/blankets of uncompressed coalescer material.

The uncompressed bed shall not extend above the lower flange face.

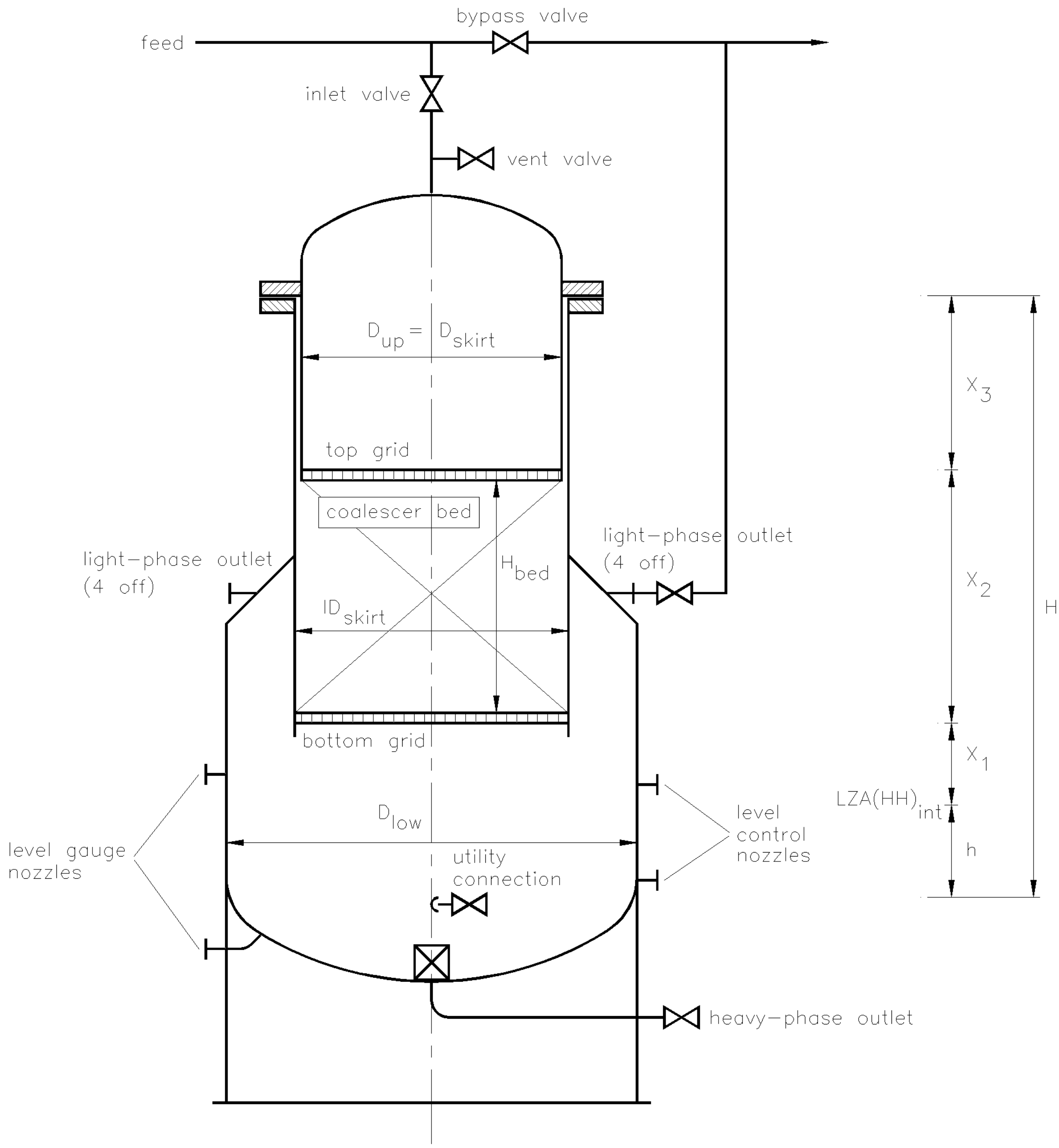
The top grid has an upstanding rim which fits into the inner groove of the flange face of the top cover. The compression of the bed takes place by placing the top cover on the top grid and pulling it down onto the lower flange face by means of long bolts.

After the packing and compression procedure the beds shall satisfy the following requirements:

If made from polypropylene filaments:
- Bulk density 110 kg/m^3 and typical height in range of 540 mm to 700 mm.

If made from stainless steel filaments:
- Bulk density in the range of 400 - 425 kg/m^3 and typical height in range of 640 mm to 800 mm.

FIGURE 3.3 SCHEMATIC LAYOUT OF THE SHELL TWIN-FLANGE COALESCER



NO crinkled wiremat shall be used underneath the PP-wool bed **unless** measures are taken to prevent the compression of the mat during the compression of the PP-wool bed, since a compressed mat will spoil the effect of the PP-wool bed. The reason for this adverse effect is that due to this compression its bulk density and the liquid velocity in the bed becomes too high. This will spoil the coalescence process because the relatively high velocities will lead to redispersion of the coalesced droplets.

For the same reason propylene felt mats should not be used as an alternative for polypropylene wool.

In Standard Drawing S 22.027 two options are given for the packing in the TFC:

1. **Only a PP-wool bed**
2. **PP-wool bed with one underlying layer of crinkled wiremat which is safeguarded against compression.**

Before the coalescer can be used it shall be de-gassed first by filling it up with either the process liquid or mains water via the utility connection. Degassing will then take place via a venting connection on the feed piping.

The ID of the skirt shall be sufficiently large to limit the average velocity of the total liquid flow through the bed to at most 1.5 cm/s.

$$ID_{skirt} \geq 9.21\sqrt{Q_l + Q_h} \qquad \text{m}$$

Q_h and Q_l are the volumetric flow rates of the heavy and light liquid phase respectively.

The Net Free Area of the grids of the bed shall be at least 80%.

3.3.4.3 Upper and lower vessel diameter

The inner diameter of the upper part of the coalescer vessel, D_{up}, is equal to the inner diameter of the skirt.

The inner diameter of the lower part of the coalescer vessel, D_{low}, should be selected such that the upward velocity of the continuous light phase in the entrance of the annular space between the vessel wall and coalescing bed is equal to the superficial velocity of this phase through the bed.

Consequently, ignoring the wall thickness of the skirt

$$D_{low} = \sqrt{2}\ D_{up} = \sqrt{2}\ ID_{skirt} \geq 13\sqrt{Q_l + Q_h} \qquad \text{m}$$

3.3.4.4 Vessel tangent-tangent (H)

The bottom compartment of the TFC shall be sufficiently large to provide a sufficiently long control time of the interface level.

More over, the distance between the highest level of the interface ($LZA(HH)_{int}$) and the bottom of the skirt, X_1 shall be such that the local velocity of the continuous light phase is not higher than its superficial velocity in the bed, hence X_1 is at least $0.25D_{up}$.

Let h be the height required for interface level control (up to $LZA(HH)_{int}$), then:

$H = h + X_1 + X_2 + X_3$ (see also Figure 3.3)

$X_1 = 0.25\ D_{up}$

$X_2 = H_{bed} + 2\ H_{grid}$

X_3 is typically 450 mm for stainless steel packing and 650 mm for polypropylene packing

X_3 shall be sufficiently large to accommodate the coalescer material before compression.

3.3.4.5 Nozzles

The diameter of the feed nozzle and the liquid outlet nozzles shall be chosen such that the velocity does not exceed 1 m/s. The minimum diameter is 50 mm.

The bottom liquid outlet nozzle shall be equipped with a vortex breaker in accordance with Standard Drawing S 10.010.

The vent connection on the vessel and the utility connection shall both have a minimum diameter of 50 mm.

3.3.4.6 Pressure drop

The pressure drop across a clean standard compressed polypropylene coalescer bed with a bulk density of 110 kg/m^3 is about 0.1 bar at a total superficial liquid velocity of 1.5 cm/s and a dynamic viscosity of about 1 mPa.s. However, the pressure drop will increase, due to fouling.

To monitor the degree of fouling during service, a facility should be installed for pressure differential measurement across the coalescer bed. It is common practice to allow a maximum pressure drop of 1 bar across the bed before the bed is exchanged or back-washed.

3.3.5 Coalescer fitted with a prefabricated coalescer mat

A brief description of prefabricated coalescer mats is given in Appendix III.

They can be used both in horizontal and in vertical coalescer vessels.
For instance, they can be applied in the Shell Twin-Flange Coalescer to replace the coalescer wool packing if conditions are slightly fouling and the dispersion is of the primary type.

If there is a high volume fraction of dispersed phase and local phase inversion is likely (locally the dispersed phase becomes the continuous phase) or with a water-in-oil dispersion where slugs of water regularly pass through the coalescer vessel, a coalescer mat made from dual material should be used (see Appendix III) of which the coalescing performance is not very sensitive to the nature of the continuous phase

In the case of a horizontal vessel, the sizing rules of the horizontal two-phase settler fitted with a plate pack basically apply, with the following main differences:

1. The plate pack is replaced with a vertical coalescer mat over the whole vessel cross-section.
2. The cross-section of the mat shall be sufficiently large to limit the average velocity of the total liquid flow to at most 1.5 cm/s.

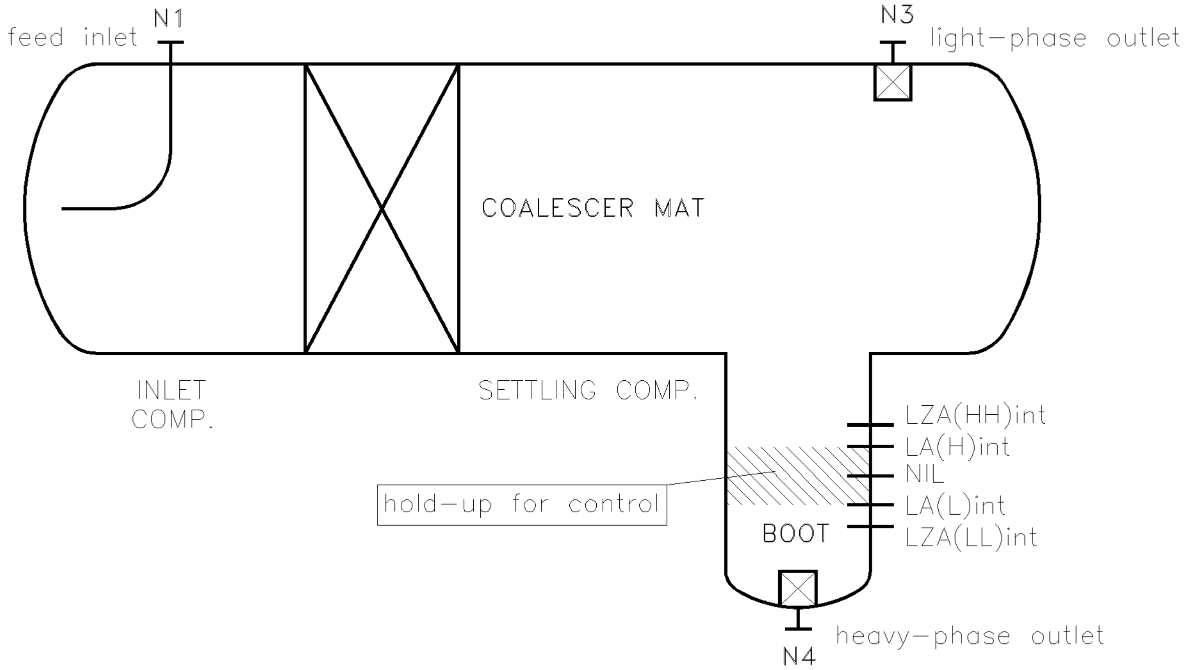
See further (3.2) where the sizing rules of the horizontal two-phase separator fitted with a plate pack are given.

If only a small amount of heavy phase is present and the "de-oiling" of it is not critical, then it is not necessary to maintain an interface level in the vessel and a boot can be used.

For the sizing of the boot see (4.1.3) in which the sizing of open three-phase settlers equipped with boot is given.

A schematic layout of a (two-phase) coalescer vessel equipped with boot is shown in Figure 3.4.

FIGURE 3.4 SCHEMATIC LAYOUT OF COALESCER VESSEL WITH BOOT AND WITH PREFABRICATED COALESCER MAT



3.3.6 Coalescer fitted with coalescer cartridges

There are two different options:

- Retrofit of the Shell Twin-Flange Coalescer with coalescer cartridges replacing (the coalescer wool bed)
- Installation of a new coalescer vessel equipped with cartridges.

3.3.6.1 Retrofit of Shell Twin-Flange Coalescer with coalescer cartridges

In Figure 3.5 a schematic layout is shown of a Shell Twin-Flange Coalescer retrofitted with coalescer cartridges. As shown, use is made of the skirt in which the coalescer bed was previously installed.

The cartridges are suspended from a plate mounted in the skirt.
The feed flows downward through the cartridges from in to out.
In general, the interface level is below the cartridges. The presence of the skirt prevents short-circuiting of the light phase to the light phase outlet.

As compared to the original wool bed, the surface area has been increased substantially (typically by a factor 3) resulting in much lower velocities through the coalescer medium.

3.3.6.2 Installation of a new coalescer vessel equipped with cartridges (commercially available design)

There are several types of new cartridge-type coalescer vessel available on the market.
Normally this type of coalescer is supplied as a complete package of vessel and internals based on a Manufacturer-proprietary design.

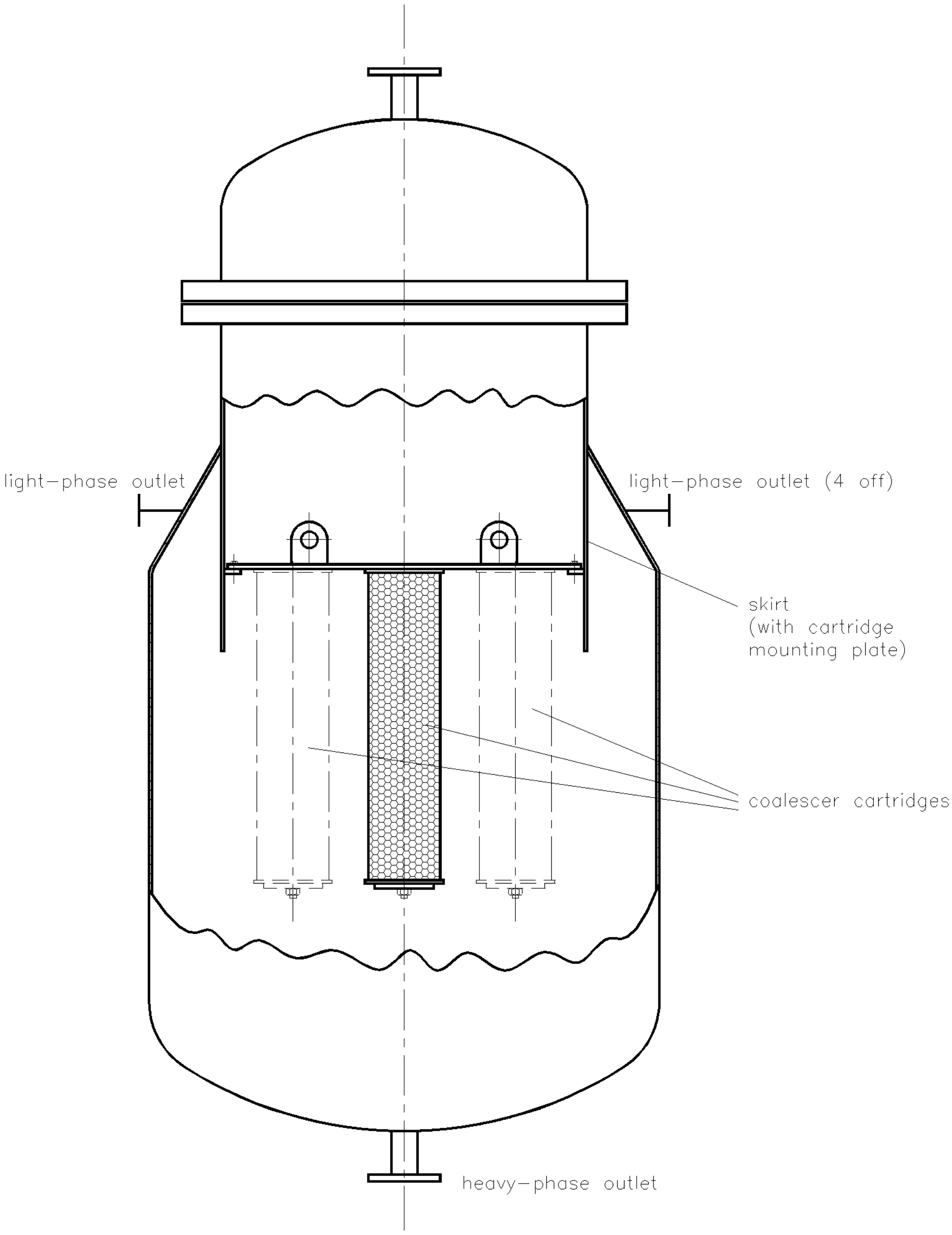
In Appendix III a number of these cartridge coalescer vessels as manufactured by Shell-approved Manufacturers are described. All quoted Manufacturers have R and D facilities.

In cases of difficult and/or critical separation, the Manufacturer should be provided with a sample to enable him to optimise the design of the coalescer.

Although the design of the separator is the primary responsibility of the Manufacturer, special attention shall be paid to the proper choice of coalescer material of the cartridges:

- If polypropylene is used, the maximum allowable temperature is 80 °C.
- Polypropylene shall not be used if the feed contains a high percentage of aromatics (> 18 wt%).
- If the pH of the feed falls outside the range 5 to 9, special coalescer material has to be selected.

FIGURE 3.5 THE RETROFIT OF THE SHELL TWIN-FLANGE COALESCER WITH COALESCER CARTRIDGES



4. DESIGN RULES FOR G/L/L (THREE-PHASE) SEPARATORS

In this section the design rules are given for a number of G/L/L (three-phase) separators.

If the separators do not contain L/L separation internals, then they are referred to as "open settlers".

Unless explicitly stated otherwise, the maximum liquid flow rates and slug volume will contain a design margin or surge factor as defined in Appendix IX.

NOTE Often L/L separators are designed as a vessel with a gas cap to facilitate the IL control of the two phases which converts them, strictly speaking, into a three-phase separator geometry.

4.1 HORIZONTAL OPEN THREE-PHASE SETTLER

4.1.1 Selection criteria:

Types:
1. SETTLER WITH BOOT
2. SETTLER WITH WEIR ARRANGEMENT

Application:
Bulk separation of primary L/L dispersion and a relatively small gas flow rate.

Characteristics:
- large liquid handling capacity
- insensitive to fouling.

Recommended use:
General:
- fouling service;
- where the L/L separation is the controlling factor and only bulk L/L separation is required.

Settler with boot:
- where the volume ratio of the heavy to light liquid phase in the feed is smaller than 0.2 and the de-oiling of the heavy phase is not important.

Settler with weir arrangement:
- ill-defined L/L interface (use double weir arrangement with no IL control);
- de-oiling of the heavy phase required.

Not recommended:
- for efficient L/L separation

Typical process applications:
- F(ree) W(ater) K(nock) O(ut) Drums (in SIEP applications)
- Overhead Accumulators (in SIOP applications).
- Ejector Effluent Separators (in SIOP applications)

4.1.2 General description

In general the horizontal open three-phase settler consists of three compartments (see Figures 4.1 - 4.5).

- inlet compartment;
- settling compartment;
- outlet compartment
  if the settler has a boot, this is the part of the vessel past the outlet of the heavy liquid phase;
  if the settler has a weir arrangement, this compartment contains the liquid collection compartment(s).

In the following the design rules are given for the two main types (equipped with either a boot or weirs) which will lead to a proper sizing of the settler and its internals.

In Appendix V the detailed sizing procedure is given.

As already stated in (4.1.1.), in general the boot option will be selected for the horizontal open settler if the following criteria are satisfied:

1. "De-oiling" of the heavy liquid phase is not important;
2. The ratio of the volumetric flow rates of the heavy and light liquid phase is smaller than 0.2.

In all other cases the weir configuration should be used.

Apart from the sizing procedure for new settlers, a retrofit procedure is also given in Appendix V to optimise existing open settlers by the installation of weirs.

4.1.3 Settler with boot

4.1.3.1 Inlet compartment

As shown in Figure 4.1, the feed enters the inlet compartment through a top entry with an inlet device connected by an elbow. For details of feed inlet device see (4.1.3.5).

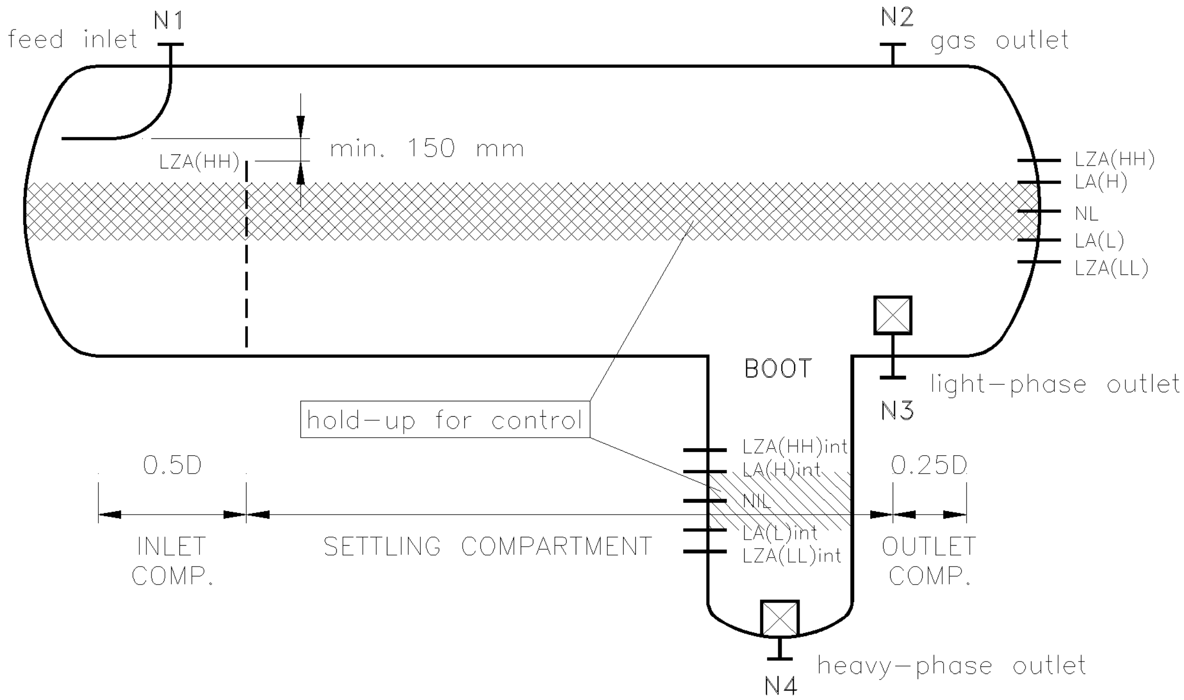
The length of the inlet compartment (i.e. distance from inlet tangent line to baffle) is typically minimum 0.5D.

A calming baffle (perforated plate) shall be installed between the inlet and settling compartment of the vessel. The function of this baffle is to promote an even flow in the settling compartment which will facilitate the separation of the two liquid phases.

Recommended calming baffle characteristics:

- net free area (NFA) typically 30%;
- hole diameter typically 12 mm;
- baffle thickness should be at least 12 mm (the thicker the baffle the more homogeneous the flow downstream of the baffle);
- the baffle shall be extended from the vessel bottom to LZA(HH) with at the bottom a small opening for cleaning purposes.

FIGURE 4.1 HORIZONTAL OPEN THREE-PHASE SETTLER FITTED WITH BOOT



4.1.3.2 Settling compartment

In this compartment the separation of the two liquid phases takes place.
It extends from the calming baffle to the outlet of the light liquid phase and it contains the boot.
Since in this case only the removal of the heavy phase from the light phase ("dewatering") is important, it is not necessary to maintain a liquid/liquid interface in the settling compartment.

The boot will be used to withdraw the heavy phase from the vessel.

4.1.3.3 Boot

The function of the boot is to collect the heavy liquid phase.
Also some additional "de-oiling" will be achieved.

The minimum boot length (i.e. the distance between the bottom of the vessel and the boot bottom tangent line) and the boot diameter should be 1 m and 0.4 m, respectively.

The diameter of the boot connection to the vessel should be less than $D_{ves}/3$.

By maximising the boot diameter, the de-oiling of the heavy phase collected in the boot will be improved, because the downflow rate of the heavy phase will be minimised. Theoretically, all light-phase droplets larger than the critical droplet having a rising velocity equal to the heavy-phase downflow velocity are able to escape. However, in practice, the flow of the heavy phase into the boot will not be uniform, which will adversely affect the de-oiling process.

If the various control volumes are fixed (= flow rate of the heavy-phase times the specified control time), maximising the boot diameter will lead to a shorter boot. The boot shall still be sufficiently long to enable proper interface level control and the proper accommodation of all the nozzles required for IL control plus, if the interface is ill-defined, an allowance for the occurrence of a dispersion band.

The boot outlet shall be equipped with a vortex breaker. The boot should be located as far from the inlet as possible (whilst still leaving space downstream for the outlet of the light liquid phase), in order to minimise disturbance of the settling process in the settling compartment.

The outlet of the light liquid phase shall intrude into the vessel (by typically 150 mm) and it should be located downstream of the boot. It shall be equipped with a vortex breaker.

4.1.3.4 Sizing of the settler

For a proper sizing of the settler the following main rules apply:

1. The cross-section of the gas cap above LZA(HH) shall be large enough for adequate liquid knockout (for bulk separation the maximum allowable gas load factor is 0.07 m/s).
   The central height shall be at least 0.3 m.
2. The cross-sectional area above LZA(HH) (A_G) and below LZA(LL) shall both be at least 14.2% of the vessel cross-sectional area. (This is equivalent to a minimum central height of these areas of 0.2D.)
3. In slugging flow service the volume of the G/L interface control zone contained between LA(H) and normal level, NL, shall be sufficiently large to contain the hold-up volume required for the light liquid phase PLUS the hold-up volume required for the heavy liquid phase PLUS the slug volume.
   The size of the anticipated slug is the product of the estimated time that the feedpipe is 100% liquid-filled and the gas volumetric flow rate prevailing under non-slugging conditions. See Appendix X for a default estimate of the slug volume.
4. The vessel cross-section below LZA(LL) shall be sufficiently large to ensure that the axial total liquid velocity in that zone is at most 15 times the settling velocity (in laminar flow) of the smallest heavy-phase droplets to be separated, with as upper limit an axial velocity of 0.015 m/s.

5. The boot shall be sized such that the velocity of the heavy phase in the boot does not exceed the settling velocity of the smallest light-phase droplet to be separated.
   The diameter of the boot connection to the vessel should be less than 1/3 of the vessel diameter.
6. The length of the settling compartment (i.e. the distance between the calming baffle and the light-phase outlet) shall be sufficiently long to meet the separation specifications (in terms of smallest heavy-phase drop size to be separated).
7. If de-gassing and/or de-foaming are required, it has to be verified whether the vessel has sufficient capacity for this. For the criteria to be applied, see Appendix V.1 (calculation steps 1 and 2).
   The foam has to be accommodated between LA(H) and LZA(HH). Between these two levels an additional foam allowance of 250 mm shall therefore be included.
8. If a feed inlet internal is required it has to be verified whether the gas cap is sufficiently large to accommodate the device.
9. Preferably $2.5 \leq L/D \leq 6$.

In Appendix V.1 the procedure is presented for checking the sizing of an existing three-phase settler fitted with a boot. It can also be treated as the sizing procedure for a new settler starting with the specification of the vessel dimensions and the various level control heights.

If certain criteria cannot be met (for instance, the settling compartment is too short) the procedure has to be repeated with adjusted vessel dimensions.

A calculation example is given in Appendix V.1.

4.1.3.5 Nozzles

Feed nozzle:

A top feed inlet equipped with an inlet device should be used. This device is connected to the inlet via an elbow and shall be directed to the nearest vessel head. Its location shall be at least 150 mm above LZA(HH).

The choice of the feed inlet device depends on the following factors:

- If the gas volumetric fraction of the feed is less than 0.15, the inlet device is a horizontal pipe section.
- If the gas volumetric fraction of the feed is beween 0.15 and 0.7 the inlet device is a horizontal half-open pipe and its opening is directed upwards.
- If the gas volumetric fraction is larger than 0.7, then a Schoepentoeter should be selected.

If the gas flow is negligible and/or the separator has a sealing function (in the case of an Ejector Effluent Separator, for instance) a bottom rather than a top inlet is used.
For the sizing of the feed inlet nozzle, see Appendix VIII.
For the detailed design of a Schoepentoeter see Appendix III of DEP 31.22.05.11-Gen.

Outlet nozzles:

The outlet of the light liquid phase shall be elevated (typically 150 mm).
Both liquid outlet nozzles shall be equipped with a vortex breaker in accordance with Standard Drawing S 10.010.
The diameter of the liquid outlet nozzles shall be chosen such that the liquid velocity does not exceed 1 m/s. The minimum diameter is 50 mm (or 2 inch).
The top of its vortex breaker shall be at least a half nozzle diameter below the corresponding lowest control level (LZA(LL) for the light-phase outlet and $LZA(LL)_{int}$ for the heavy-phase outlet).

4.1.4 Settler with weir arrangement

4.1.4.1 Inlet compartment

The inlet compartment (including feed inlet) is identical to that of the settler with boot.

4.1.4.2 Settling compartment

Since in general the cleaning of both liquid phases is required ("dewatering" and "de-oiling"), a liquid/liquid interface has to be maintained in this compartment (either via direct IL control or via a combination of two weirs).

4.1.4.3 Collection compartment(s)

Figures 4.2 - 4.5 show a number of possible arrangements.

The configuration with only one collection compartment (for the light liquid phase) with either a submerged or an overflow weir is shown in Figure 4.2. In both cases direct control of the interface is required. In the case of the submerged weir the gas/liquid interface varies in the same way throughout the vessel, whereas with an overflow weir the gas/liquid interface upstream of the weir is fairly constant (apart from variations in the height of the weir crest due to changes in the flow rate of the light liquid phase).

If the liquid/ liquid interface is ill-defined, however, direct IL control should be avoided.
Possible weir arrangements are then as shown in Figures 4.3 and 4.4 respectively.
The heights of the light- and heavy-phase overflow weirs plus their weir crest heights will determine the location of the interface level. The advantage of this configuration is that the liquid/liquid interface is very insensitive to variations in the liquid flow rates. Even an incoming slug (temporarily replacing the gas flow in the feed) will have hardly any effect, provided the collection compartments can accommodate the slug.

The weirs shall have handholes for cleaning or removable weir panels.

In the gutter configuration shown in Figure 4.3 a gutter side nozzle instead of the nozzle with internal piping could alternatively be used.

The weir arrangement shown in Figure 4.4 should be used, except that the configurations shown in Figure 4.5 should be applied if Q_l/Q_h is either relatively low or relatively high.

The arrangement for small Q_l/Q_h, shown in Figure 4.5 should be used rather than an arrangement in which the width of the light-phase collection compartment has been made smaller by shifting the separation plate between the two collection compartments (because this could result in unfavourable sizing of the light-phase collection compartment and the need to have a light-phase outlet at the side of the vessel).

An oil skimming pipe should be installed in the water collection compartment, entering from the vessel bottom and extending to LA(H) for the periodic removal of the oil film which will inevitably form on top of the water.

In general, in the two collection compartments the gas/liquid interface will be controlled. The specified control times in conjunction with the liquid flows will determine the size of the collection compartments and, ultimately for a given diameter, the length of the vessel downstream of the hydrocarbon overflow weir.

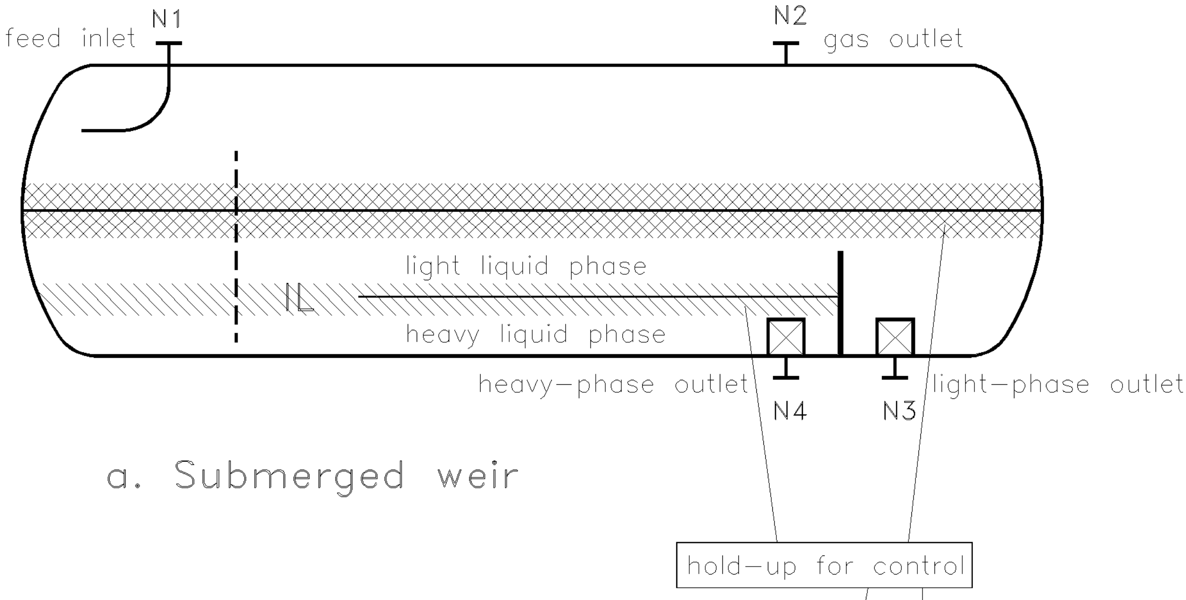
NOTE Sometimes a three-phase flow settler geometry is adopted in practice with a combined inlet/settling compartment in the central part of the separator and with the collection compartments for the two liquid phases at the opposite sides of the vessel.

This geometry shall **NOT** be used because:

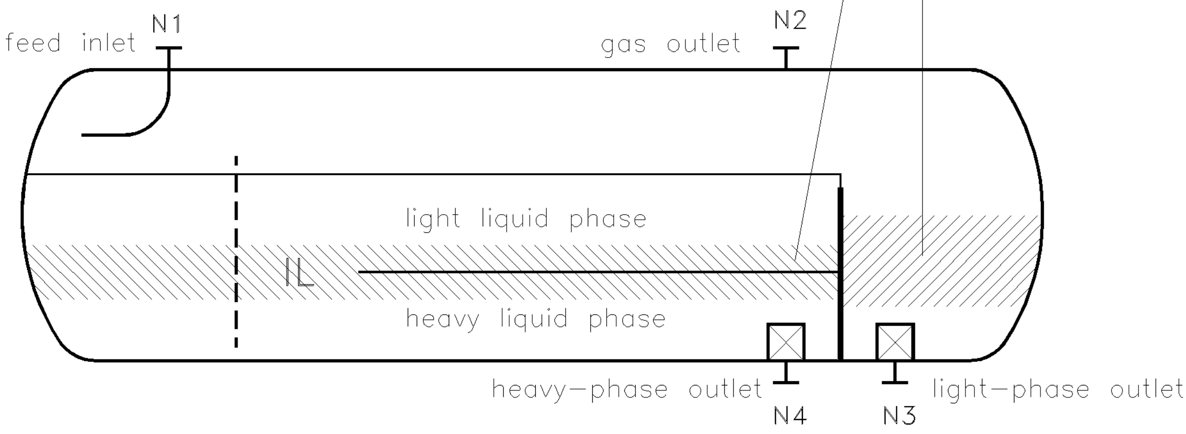
1. The entry of the feed into the central compartment causes disturbance which adversely affects the separation of the two liquid phases.

2. Assuming that the feed enters in the centre of the central compartment at most only half the compartment can be utilised for separation.

FIGURE 4.2 HORIZONTAL OPEN THREE-PHASE SETTLER WITH SINGLE WEIR (SUBMERGED OR OVERFLOW)



a. Submerged weir



b. Overflow weir

FIGURE 4.3 HORIZONTAL OPEN THREE-PHASE SETTLER WITH GUTTER AND SINGLE WEIR

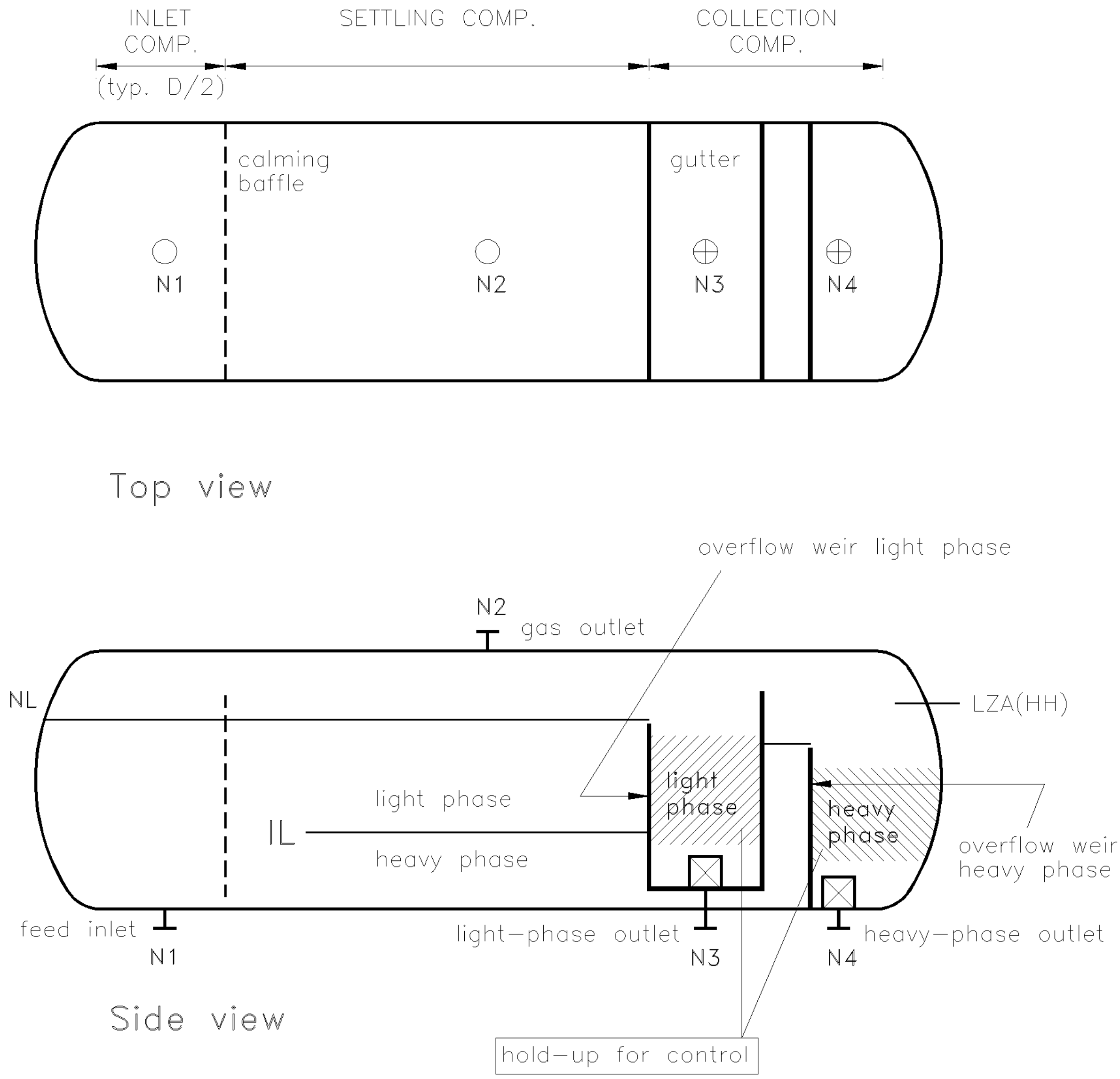
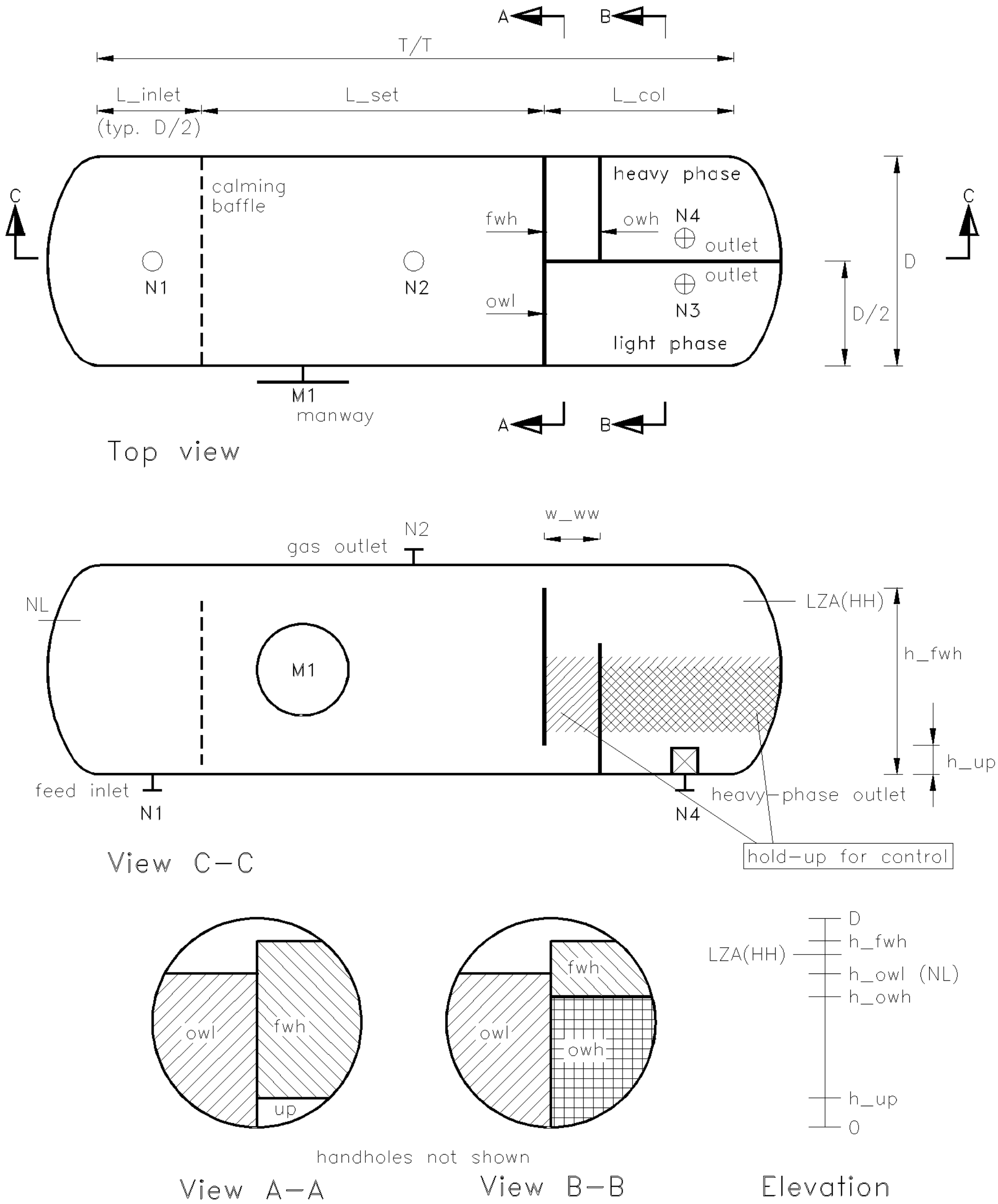


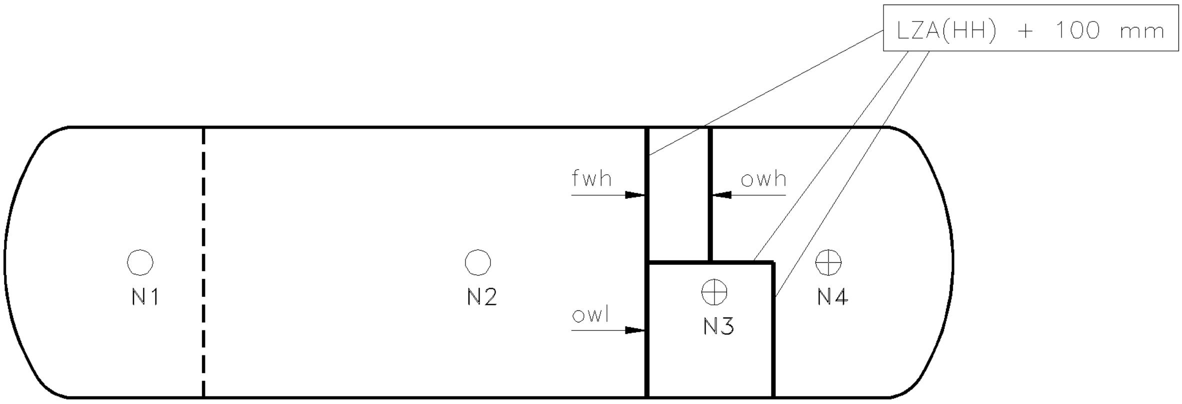
FIGURE 4.4 HORIZONTAL OPEN THREE-PHASE SETTLER WITH DOUBLE WEIR



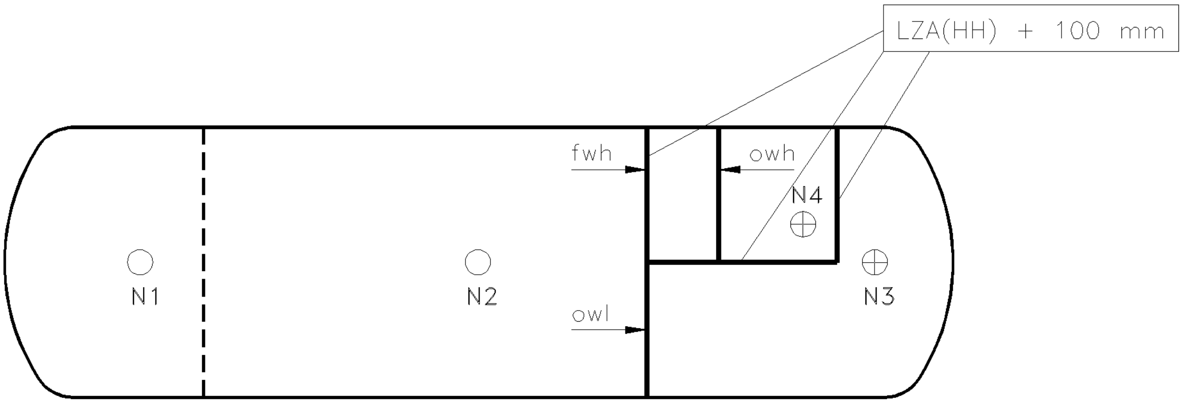
<u>Explanation of principal abbreviations and symbols used in the figure:</u>

col : refers to collection compartments
fwh : front weir of the heavy-phase compartment
owh : overflow weir of the heavy-phase compartment
owl : overflow weir of the light-phase compartment
set : refers to the settling compartments
up : underflow passage of the front weir of the heavy-phase compartment
w-ww : width of the gap between the two heavy-phase weirs

FIGURE 4.5 HORIZONTAL OPEN THREE-PHASE SETTLER WITH DOUBLE WEIR FOR EITHER A SMALL OR A LARGE Q_l/Q_h RATIO (TOP VIEW)



Small Q_l/Q_h ratio



Large Q_l/Q_h ratio

fwh : front weir of the heavy-phase compartment
owh : overflow weir of the heavy-phase compartment
owl : overflow weir of the light-phase compartment

4.1.4.4 Sizing of the settler

The sizing rules for the settler with double weir arrangement (as one of the various ooptions possible) are given below.

In this type of three-phase settler no IL control is required since the liquid/liquid interface is determined by the heights of the overflow weirs for the light and heavy liquid phase.

Moreover, the gas/liquid interface in the vessel upstream of the weirs (NL) is fairly constant (apart from variations in the weir crest height due to changes in the flow rate).

For a proper sizing of the settler the following main rules apply:

1. The cross-section of the gas cap above LZA(HH) shall be large enough for adequate liquid knockout (for bulk separation the maximum allowable gas load factor is 0.07 m/s).
   The central height shall be at least 0.3 m.
2. If liquid slugs or foaming are expected, in this type of settler this shall be accommodated between NL and LZA(HH). If foaming is likely the distance between NL and LZA(HH) has to include a foaming allowance of 0.25 m.
   To prevent carry-over into the heavy-phase compartment, the height of the underflow weir of the heavy-phase compartment shall exceed LZA(HH) by typically 0.1 m.
3. The vessel cross-sections below IL (or liquid/liquid dispersion band if present) and between IL and NL shall be sufficiently large that the axial velocity in each zone is at most 15 times the settling velocity (in laminar flow) of the smallest droplets of the opposite phase to be separated, with as upper limit an axial velocity of 0.015 m/s.
4. The vessel cross-section below IL (or liquid/liquid dispersion band if present) shall be at least 14.2% of the vessel cross-sectional area. (This is equivalent to a minimum central height of this area of 0.2D).
5. The interface level should be halfway between the top of the underflow passage of the heavy-phase underflow weir and the top of the overflow weir of the light phase, in order to minimise the likelihood of carry-over to the liquid compartments.

   At any rate, under normal-flow conditions (i.e. gas/liquid interface controlled by the light phase overflow weir), the interface level (or the dispersion band, if present) shall be at a distance of at least 0.2 m from either the lower rim of the heavy-phase underflow weir or from the upper rim of the light-phase overflow weir.
   (If a dispersion band is expected but there is insufficient information for its width to be estimated using the formula given in Appendix I, it is suggested that 0.2 m be taken as dispersion band width.)
6. The length of the settling compartment shall be sufficiently long to meet the separation specifications (in terms of smallest droplets to be separated).
7. If de-gassing and/or de-foaming are required, it has to be verified whether the vessel has sufficient capacity for this. For the criteria to be applied, see Appendix V.2 (calculation steps 7 and 8).
   The foam has to be accommodated between LA(H) and LZA(HH). Between these two levels an additional foam allowance of 0.25 m has to be included.
8. If a feed inlet device in the gas cap is required and the gas load is high, it has to be verified whether the gas cap is sufficiently large to accommodate the device.
9. Preferably $2.5 \leq L/D \leq 6$.
10. If the vessel has a sealing function (e.g. in the case of Ejector Effluent Separators) the inlet and collection compartment shall contain sufficient liquid to satisfy this requirement. In that case a bottom feed inlet shall also be used.

In Appendix V.2 the procedure is given for converting an existing empty horizontal vessel into an open three-phase settler fitted with a weir configuration.

A calculation example is given in Appendix V.2.

This procedure can also be used for the sizing of new settlers starting from given vessel dimensions and can also be treated as the sizing procedure for a new settler starting with the specification of the vessel dimensions and the various level control heights.

4.1.4.5 Nozzles

Requirements for the feed nozzle and outlet nozzles are analogous to those described in (4.1.3.5).

4.2 HORIZONTAL THREE-PHASE SETTLER WITH PLATE PACK

4.2.1 Selection criteria

Application

- Efficient separation of primary L/L dispersion and a relatively small gas flow rate.

Characteristics

- efficient separation, provided the dispersion is of the primary type;
- not too sensitive to fouling (a certain degree of fouling can be accommodated by selecting a relatively large plate distance and plate angle).

Recommended use

- for the efficient separation of a primary dispersion in a not too fouling service;
- if the L/L interface is ill-defined, use plate pack settler with weir arrangement.

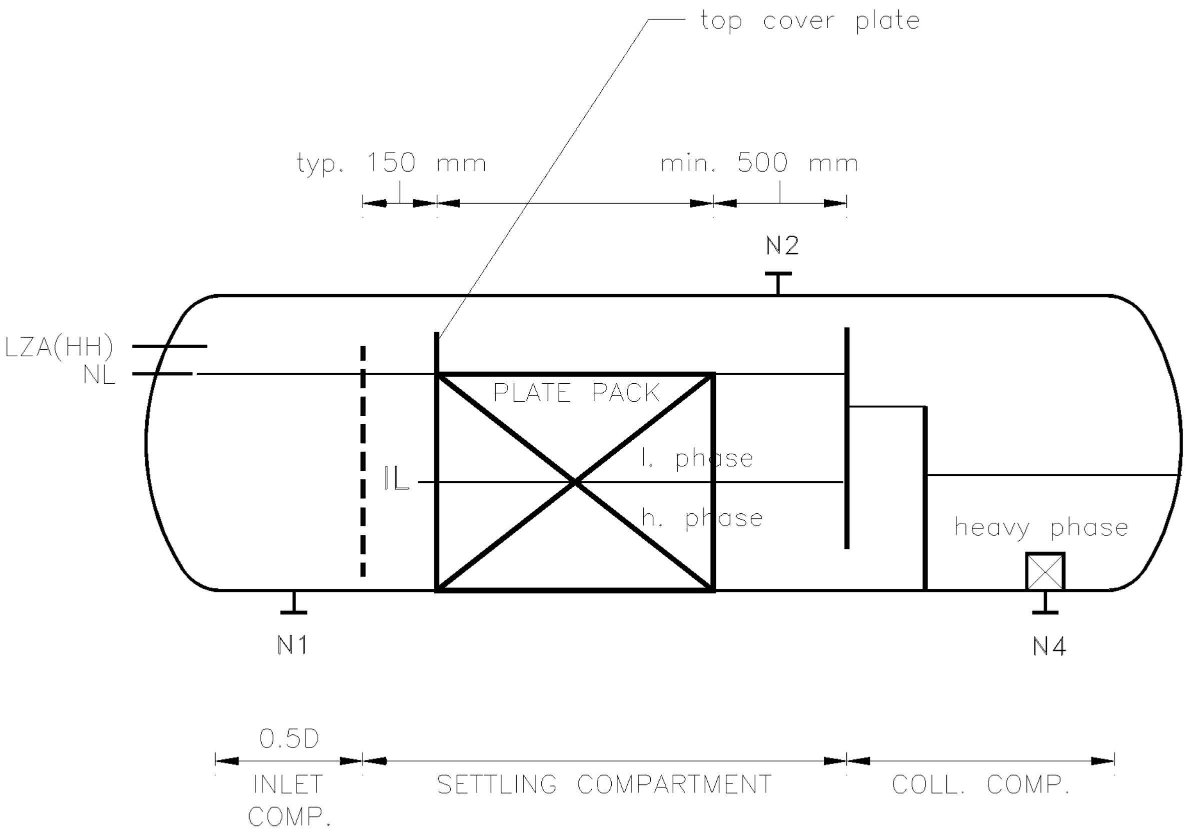
Not recommended

- for secondary dispersions;
- in heavy fouling service.

Typical process application

- Cold Low Pressure Separators in hydroprocessing.

FIGURE 4.6 THE HORIZONTAL THREE-PHASE SETTLER WITH PLATE PACK DOUBLE WEIR ARRANGEMENT; SIDE VIEW (SEE VIEW C-C OF FIGURE 4.4)



4.2.2 General description

A schematic layout of this type of three-phase settler is shown in Figure 4.6.

Like the horizontal open three-phase settler, this settler also consists of three compartments:

- inlet compartment;
- settling compartment (equipped with plate pack);
- liquid collection compartment.

4.2.3 Inlet compartment

The design philosophy of the inlet compartment (including feed inlet) is identical to that of the horizontal open three-phase settler with boot, described in (4.1.3).

4.2.4 Settling compartment

In this compartment a plate pack has been installed. In the standard layout a transversal plate pack (i.e. with the face of the plate pack perpendicular to the central vessel axis) is used.

For more information on plate packs, see Appendix II.

In general a liquid/liquid interface has to be maintained in this compartment either via direct IL control or via the weir arrangement with no IL control, as described in (4.1.4) and shown in the Figures 4.4 and 4.5.

For maintaining an interface level, the latter alternative should be used because:

1. IL is independent of the liquid flow rates, provided the light phase flows over the overflow weir.

2. Economic use is made of the plate pack, because the gas/liquid interface is fairly constant (apart from small variations in the height of the weir crest).
3. The feature that no IL control is required is advantageous in the case of an ill-defined liquid/liquid interface.

The distance between the plate pack and the calming baffle should be 150 mm.

The distance between the plate pack and the collection compartments shall be at least 500 mm.

If the weir system determines the gas/liquid interface level, the top of the plate pack will be at NL.

A top cover plate shall be fitted at the front face of the plate pack, extending from the top of the plate pack to typically 50 mm above LZA(HH), to prevent liquid bypassing.
It shall also cover the plate pack over its full length.

To facilitate the installation of the plate pack, the manhole shall be upstream of the weir arrangement.

4.2.5 Collection compartment(s)

If a weir arrangement with no direct IL control has been adopted, then the collection compartments are sized similar to those in the horizontal open three-phase settler (4.1.4.3).

The schematic layout of a settler with a weir arrangement is shown in Figure 4.6.

4.2.6 Sizing of the settler

The sizing rules of the plate pack settler with a double weir arrangement as given in Figure 4.6 are given below. Also it has been assumed that a transversal plate pack (i.e. with its face perpendicular to the central vessel axis) has been installed.

As stated before, in this type of three-phase settler no IL control is required since the liquid/liquid interface is determined by the heights of the overflow weirs for the light and heavy liquid phases.

Also the gas/liquid interface in the vessel upstream of the weirs (NL) is fairly constant (apart from variations in the weir crest height due to changes in the flow rate).

For a proper sizing of the settler the following main rules apply:

1. The cross-section of the gas cap above LZA(HH) shall be large enough for adequate liquid knockout (for bulk separation the maximum allowable gas load factor is 0.07 m/s).
   The central height shall be at least 0.3 m.
2. If liquid slugs or foaming are expected, this shall be accommodated between NL and LZA(HH). This means that the height of the underflow weir of the heavy phase compartment shall exceed LZA(HH) by typically 0.1 m.
3. The vessel cross-section below NL shall be sufficiently large to contain the plate pack required to achieve the separation specifications.
4. The cross-sectional area above LZA(HH) (gas cap) and below the liquid/liquid interface (heavy-phase zone) shall be at least 14.2% of the vessel cross-sectional area.
5. The interface level should be halfway between the top of the underflow passage of the heavy-phase underflow weir and the top of the overflow weir of the light phase, in order to minimise the likelihood of carry-over to the liquid compartments.

   At any rate, under normal-flow conditions (i.e. gas/liquid interface controlled by the light phase overflow weir), the interface level shall be at a distance of at least 0.2 m from either the lower rim of the heavy-phase underflow weir or from the upper rim of the light-phase overflow weir.
   (If a dispersion band is expected but there is insufficient information for its width to be estimated using the formula given in Appendix I, it is suggested that 0.2 m be taken as dispersion band width.)
6. The length of the settling compartment shall be at least 650 mm + the length of the

plate pack required for the separation.

7. If de-gassing and/or de-foaming are required, it has to be verified whether the vessel has sufficient capacity for this. For the criteria to be applied, see Appendix V.2 (calculation steps 7 and 8).
   The foam has to be accommodated between LA(H) and LZA(HH). Between these two levels an additional foam allowance of 250 mm has to be included.

8. If a feed inlet is required and the gas load is high, it has to be verified whether the gas cap is sufficiently large to accommodate the device. (If the gas load is high, immersion of the feed inlet in the liquid shall be avoided).

9. Preferably $2.5 \leq L/D \leq 6$.

In Appendix V.2 the procedure is given for converting an existing empty horizontal vessel into a three-phase separator fitted with a weir configuration and a plate pack.

A calculation example is given in Appendix V.2.

This procedure can also be treated as the sizing procedure for a new settler starting with the specification of the vessel dimensions and the various level control heights.

4.2.7 Nozzles

Requirements for feed nozzle and outlet nozzles are identical to the ones described in (4.1.3.5).

4.3 VERTICAL THREE-PHASE SETTLER WITH PLATE PACK

4.3.1 Selection criteria

Application:
- efficient L/L separation of a primary dispersion at a relatively high gas load;
- efficient G/L separation provided appropriate separation internals (e.g. mist mat or SMS-internals) are installed.

Characteristics:
- compact;
- high gas handling capacity can be achieved (depends on G/L separation internals).

Recommended use:
- if the gas load is high and L/L separation is readily accomplished (i.e. not high viscosity, primary dispersion).

Not recommended:
- if gas load is low;
- if L/L separation is difficult (i.e. secondary dispersion).

Typical process applications:
- Fractionator overhead vessels in the work-up section of Long Residue Catalytic Cracking Units.

4.3.2 General description

A schematic layout of this type of three-phase separator (or settler) is shown in Figure 4.7.

Basically, it consists of two compartments:

- a vapour compartment equipped with a feed internal and gas/liquid separation internal(s);
- a liquid compartment where a plate pack has been installed for the purposes of liquid/ liquid separation.

4.3.3 Vapour compartment

Feed internal

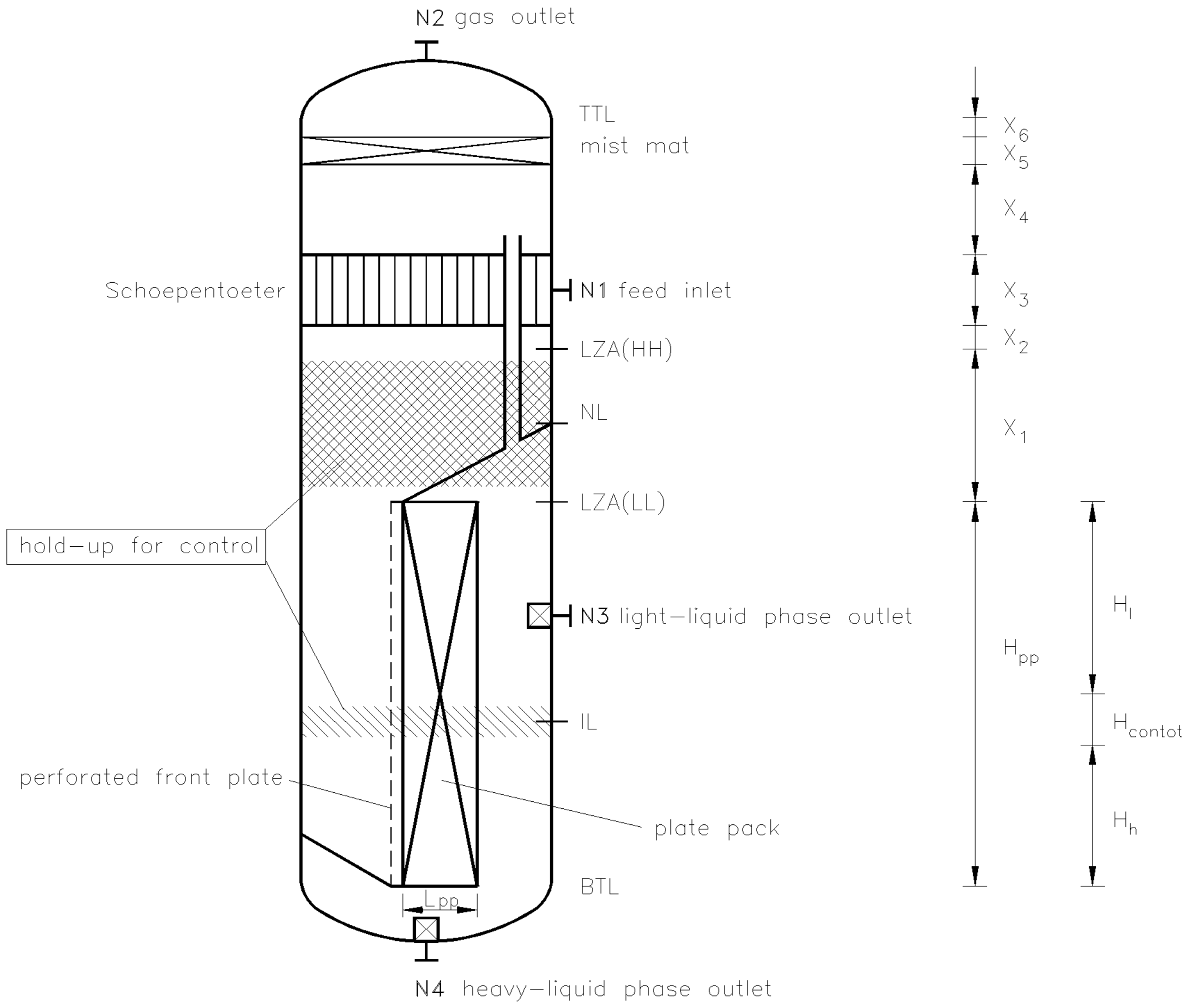
A schoepentoeter shall be used for the feed internal.

Demisting internals

Normally, a wire mesh is selected for the gas/liquid separation, but depending on the desired gas/liquid separation efficiency other gas/liquid separation internals such as swirl tubes can also be selected depending on the required gas/liquid separation efficiency.

The strategy for the choice of the type of gas/liquid separation internals and the design rules for the sizing of the vapour compartment are given in DEP 31.22.05.11-Gen.

FIGURE 4.7 VERTICAL THREE-PHASE SETTLER WITH PLATE PACK



4.3.4 Liquid compartment

Inclined plate

The liquid separated from the gas in the Schoepentoeter flows into the liquid compartment down an inclined plate after which separation of the two liquid phases is achieved in the plate pack.

This plate minimises turbulence in the liquid compartment upstream of the plate pack and also prevents bypassing.

The inclination of this plate should be 10 degrees.

It shall be equipped with a pipe (minimum diameter 50 mm) to vent the gas released from the liquid compartment downstream of the plate pack.

Plate pack

The plate pack extends from the bottom tangent line (BTL) of the vessel to the low liquid level trip, LZA(LL).

The design rules for the plate pack are given in Appendix II.

To ensure an even flow over the plate pack, it shall be equipped with a perforated front plate (distance to plate pack should be 150 mm and the Net Free Area (NFA) is typically 30% with holes of 12 mm).

To prevent bypassing of the plate pack, clearances between the plate pack and the vessel shall be sealed and a bottom plate shall be installed in front of the plate pack.

This bottom plate slopes down towards to the plate pack with an angle of typically 10°.

4.3.5 Diameter

The diameter of the separator shall be sufficiently large to:

1. satisfy the gas handling criterion:

   $D \geq 1.128\ (Q_G/\lambda_{max})^{0.5}\{\rho_G/(\rho_l - \rho_G)\}^{0.25}$

   λ_{max} is the maximum allowable gas load factor and is determined by the choice of the G/L separation internal(s) as prescribed in DEP 31.22.05.11-Gen.

2. satisfy the de-gassing criterion (if required):

   $D \geq \quad 7608\{(Q_l + Q_h)_{max}(\eta_l,\eta_h)/(\rho_l - \rho_G)\}^{0.5}$

3. satisfy the de-foaming criterion (if required)

   $D \geq \quad 95(Q_l + Q_h)^{0.5}\{_{max}(\eta_l,\eta_h)/(\rho_l - \rho_G)\}^{0.14}$

Both in the de-gassing and the de-foaming criterion the viscosity of the most viscous phase, $\max(\eta_l,\eta_h)$, shall be taken.

4.3.6 Layout of plate pack

The width of the plate pack, W_{pp}, shall satisfy the following criterion:

$$W_{pp} < \sqrt{(D - 0.2)^2 - (L_{pp} + \Delta L_{fp\_pp})^2}$$

L_{pp} is the length of the plate pack (min. 0.3 m) and
ΔL_{fp_pp} is the distance between the front plate and the plate pack (typically 0.15 m).

It has been assumed in the above formula that the centre of the plate pack assembly (including front plate) is located on the central axis of the vessel.

The general case has been considered where the plate pack has to cleanup both liquid phases and contains a control band including trip levels and an allowance for a dispersion band.
It is up to the designer to decide if all these controls are necesary.

The height of the plate pack, H_{pp}, is then given by the following relationship:

$$H_{pp} = H_h + H_{contot} + H_l$$

H_h and H_l are the heights of the plate pack sections where the continuous phase is the heavy and light phase, respectively.

$$H_l = (A_{f,gross})_l/W_{pp}$$

$$H_h = (A_{f,gross})_h/W_{pp}$$

$(A_{f,gross})_l$ and $(A_{f,gross})_h$ are the gross frontal areas of the plate pack section associated with cleaning of the light and heavy liquid phase, respectively. These areas are calculated with the plate pack sizing rules presented in Appendix II. The net frontal area, $A_{f,net}$, of each plate pack section shall be sufficiently large to ensure laminar flow in the corresponding section. By allowing for the plate thickness and the presence of gutters, the gross frontal area is then obtained. The length of the plate pack, L_{pp}, will be determined by the required separation performance of the plate pack (expressed in terms of droplet cut-off diameter) and the selected plate pack characteristics (e.g. frontal area, plate distance and plate angle) and is minimal 0.3 m.

To ensure proper separation, neither H_l and H_h should be smaller than 0.3 m. Moreover, the height/width ratio of both sections should be between 0.5 and 2. In extreme cases it may be necessary to select a larger vessel diameter than originally calculated in order to keep the height/width ratio down to reasonable proportions. However, then it should be checked first whether a vertical vessel was the right choice.

H_{contot} is the height of the total interface level control band.

$H_{contot} = \Sigma H_{con} + H_{db}$

H_{db} is the operator-specified dispersion band.
(If a dispersion band is expected but there is insufficient information for its width to be estimated using the formula given in Appendix I, it is suggested that 0.2 m be taken as dispersion band width).

ΣH_{con} is the sum of the heights of the control bands required for L/L control (see Appendix X).

For each H_{con}

$H_{con} \approx Q_h * t_{con} / (\pi/4\ D^2)$

t_{con} is the specified control time.

If the calculated band width is less than the minimum width (see Appendix X), then the minimum width shall be used.

The control heights shall be based on the liquid flow rate of the heavy liquid phase ONLY.

4.3.7 Height

The height of the vessel (from BTL to TTL; see also Figure 4.7) is calculated with the following formula:

$H = H_{pp} + X_1 + X_2 + X_3 + X_4 + X_5 + X_6$

X_1 is the sum of the control bands required for G/L level control.

The liquid hold-up volume of each required control band is the sum of the hold-up volume required for the light phase and the hold-up volume required for the control of the L/L interface (which is based on the heavy phase flow).

Rules for the calculation of the required liquid volume are given in Appendix X.

X_2 is the distance between LZA(HH) and the bottom of the Schoepentoeter.
X_2 = 0.05D with a minimum of 0.15 m.

X_3 is the height of the Schoepentoeter.
$X_3 = d_1 + 0.02$ m
d_1 is the feed nozle diameter.

X_4 is the distance between the top of the Schoepentoeter and the bottom of the demisting internal.
In case of a mist mat: $X_4 = d_1$ with a minimum of 0.3 m.

X_5 is the height (or thickness) of the demisting internal.
In case of a mist mat: X_5 = 0.1 m.

X_6 is the distance between the top of the demisting internal and TTL.
X_6 = 0.15D with a minimum of 0.15 m.

4.3.8 Nozzles

Feed nozzle

The feed inlet shall be fitted with a Schoepentoeter.

For the detailed design see Appendix III of DEP 31.22.05.11-Gen.

For the sizing of the feed nozzle, see Appendix VIII.

Outlet nozzles

For the sizing of the outlet nozzles and the specification of the required vortex breakers, see Appendix VIII.

The vortex breaker of the outlet nozzle of the light liquid should be located halfway between LZA(LL) and $LZA(HH)_{int}$. Its distance from $LZA(HH)_{int}$ shall be at least 0.2 m.

A calculation example of the sizing of this type of separator is given in Appendix V.3.

5. PIPING REQUIREMENTS

Piping to and from the settler shall interfere as little as possible with the performance of the separator. The following constraints should be observed:

a. The use of valves, pipe expansions or contractions within ten pipe diameters of the inlet nozzle should be avoided because of their tendency to generate relatively small liquid droplets (either in the gas phase or in the opposite liquid phase).
If a valve in the feed line near to the settler cannot be avoided, it should be of the gate or ball type, fully open in normal operation. High pressure drops which cause generation of small droplets should be avoided in the feed pipe.
If a pressure-reducing valve in the feed pipe cannot be avoided, it should be located as far upstream of the vessel as practicable.

b. The use of bends within ten pipe diameters of the inlet nozzle should be avoided because they will generate flow maldistribution in the settler, in particular of the gas phase (in the case of three-phase separators).
If bends cannot be avoided within ten pipe diameters of the inlet nozzle, the following rules should be followed:
- in separators with a straight inlet, a bend in the feed pipe is only permitted if this is in the vertical plane through the axis of the feed nozzle.
- in settlers with a tangential inlet (not covered in this DEP) a bend in the feed pipe is only permitted if this is in a horizontal plane and the curvature is in the same direction as the vortex induced by the tangential inlet.

c. If desired, a pipe reducer may be used in the vapour line leading from the three-phase settler, but it should be situated no closer than twice the outlet nozzle diameter from the top of the vessel.

If the above conditions cannot be satisfied, some loss of separation efficiency will result.

6. REFERENCES

In this DEP reference is made to the following publications:

NOTE Unless specifically designated by date, the latest edition of each publication shall be used, together with any amendments/supplements/revisions thereto.

SHELL STANDARDS

Index to DEP publications and standard specifications	DEP 00.00.05.05-Gen.
Gas/ liquid separators - Type selection and design rules	DEP 31.22.05.11-Gen.

STANDARD DRAWINGS

Vortex breakers for nozzles	S 10.010
Twin-Flange Coalescer	S 22.027

APPENDIX I THE MECHANISM OF LIQUID/LIQUID SEPARATION IN OPEN SETTLERS

In the liquid/liquid separation process taking place in a two-phase or three-phase open settler, the following two consecutive steps are identified:

Step 1
Settling of the dispersed phase droplets towards the interface formed by the already separated phases.

(The term "settling" will also be used for the separation of light-phase droplets in this DEP in order to be consistent with the term "settlers" which is used for the separation of both light-phase and heavy-phase droplets).

Step 2
The coalescing of the settled droplets once they have reached the interface.

A. Separation determined by the rate of settling (rate-determining step 1)

At a relatively low concentration of the dispersed phase (say below 5 vol.%) and/or a low feed rate the rate-determining step in the separation process is the settling velocity of the dispersed phase. The coalescence of the droplets in the interface takes place relatively rapidly.

In the case of laminar flow, droplets of larger than 40 µm and very low dispersed phase concentration (say below 1 vol.%), Stokes law applies for the settling velocity, $v_{p,set}$, provided that for the droplet Reynolds number, $Re_p = \rho_c v_{p,set} d_p / \eta_c$, the following is true:

$Re_p \leq 1$

$v_{p,set} = |\rho_d - \rho_c| \, g d_p^2/(18\eta_c)$

ρ_d and ρ_C are the densities of the dispersed and continuous phase, respectively,

g is the gravity constant,

d_p is the droplet diameter,

η_c is the dynamic viscosity of the continuous phase

The following should be noted:

1. In practice the condition $Re_p \leq 1$ is normally satisfied.
   If $Re_p > 1$ (in the case of relatively large droplets and/or a very low viscosity of the continuous phase) the above formula will give an overprediction of the settling velocity.
   However, under these conditions liquid/liquid separation is very readily accomplished, and other requirements such as hold-up for control will determine the size of the settler.
2. The effect of droplet fluidity (degree of internal circulation) on settling velocity has been ignored.
   This internal circulation leads to a higher settling velocity than is given by the above formula.
   However, it has been observed in practice that this internal circulation is negligible if the droplet diameter is smaller than 1 mm, especially if surface-active agents are present.
3. The expression for $v_{p,set}$ only applies if the droplet diameter is sufficiently large that the settling is primarily determined by gravity. Other effects such as Brownian motion and flow convection effects induced by thermal gradients can then still be ignored.
   In general, this is the case if the droplet diameter is larger than 30 µm.
   A dispersion is classified as a primary dispersion if the majority of the dispersed droplets are larger than this value. Otherwise it is classified as a secondary dispersion.
4. In a open settler the flow is nearly always turbulent. The turbulence will hinder the settling process and a correction term has to be applied:
   $(v_{p,set})_{turbulent} \approx (v_{p,set})_{laminar} - 0.05 v_{c,ax}$

Note that the above formula predicts that settling will no longer take place if

$v_{c,ax} \geq 20*(v_{p,set})_{laminar}$

It has hence been specified in the design of open settlers (see (3.1) and (4.1) in the main text) that:

$v_{c,ax} \leq 15(v_{p,set})_{laminar}$

to guarantee that settling will still take place.

The above formula is also applicable to the settling in a boot.

Because in this case $(v_{p,set})_{turbulent} \approx v_{c,ax}$, it can be rewritten as:

$(v_{p,set})_{turbulent} \approx (v_{p,set})_{laminar} /1.05 \approx 0.95(v_{p,set})_{laminar}$

5. If dispersion is less diluted the influence of the neighbouring droplets on the settling velocity can no longer be ignored.

   $(v_{p,set})_{conc} \approx (1\text{-conc})^{4.5}(v_{p,set})_{conc} \rightarrow 0$

   Where conc is the **local** volumetric fraction of the dispersed phase

Strictly, the exponent of 4.5 in the above equation only applies for $Re_p \leq 1$.

For larger Reynolds numbers it decreases to a value of 2.4 at Re_p =1000, hence the above formula is conservative.

Furthermore, in practice the effect of concentration will be much smaller than the effect of turbulence on the settling velocity of the smallest droplets to be separated (which start their settling process at the top of the vessel) since the majority of the other dispersed droplets will settle faster leaving the immediate environment of the small droplets relatively clear so that local concentration is relatively low. In the case of heavy-phase droplets it is the settling velocity of these droplets which determines the size of a settler's settling compartment.

Since the coalescence step takes place faster than the settling step, the interface of the two bulk phases will be well-defined with no intermediate layer (dispersion band).

B. Separation determined by the rate of coalescence (rate-determining step 2)

If the concentration of the dispersed phase and/or feed flow rate increases further, the coalescing step will eventually become the rate-determining step in the separation process.

The interface between the two liquid phases is no longer sharp because the coalescing process in the interface can no longer catch up with the settling process.

An intermediate layer or dispersion band will be formed between the two bulk phases.

In a horizontal open settler this band will generally be wedge-shaped as is shown in Figure I.1.

If the **heavy** phase is the dispersed phase, the **upper** part of the band will consist of the sedimentation zone, a turbulent layer in which drops are in occasional contact but may nonetheless coalesce with one another. Eventually the imperfectly settling coalesced droplets arrive in the **lower** part of the band, the close-packed zone, where they are in close contact with their neighbours and are distorted thereby from the spherical shape.

See also Figure I.2 for the structure of the dispersion band.

In general the average thickness of the dispersion band, H_{db}, is largely a function of Q_d/A where Q_d is the dispersed flow rate and A the cross-sectional area of the interface.

The relationship is typically of the form:

$H_{db} = K(Q_d/A)^n$

Where K is a function of the phase ratio of the liquid phases in the feed and n is a constant, typically in the range of 2.5 to 7.

The sedimentation zone in the dispersion band will tend to increase in thickness.

It is impossible to predict the thickness of the dispersion band from flow rates, physical properties and drop size data alone since interdrop coalescence in particular is substantially influenced by small quantities of surface-active material.

For the assessment of the relationship between H_{db} and Q_d/A settling tests such as batch sedimentation tests ("bottle tests") with the dispersion to be separated could be used.
However, these bottle tests have only limited accuracy.
Because of this inaccuracy, there is a tendency in industry to follow a conservative design approach for open settlers, often leading to oversized vessels.

If liquid/liquid separation is difficult to accomplish, a horizontal vessel should be selected because, in general, the cross-sectional area of the interface is larger ($A \approx DL$) than that of a vertical vessel of the same dimensions ($A = \pi D^2/4$), with L and D being the vessel tangent-to-tangent and diameter respectively, bearing in mind that from an economic point of view the L/D ratio of a horizontal vessel lies between 2.5 and 6.

NOTE Since the drop size distribution of the dispersed liquid phase in the feed is not generally known, it is impossible to quantify the separation efficiency of open settlers in terms of % removal.
It is common practice to specify the separation efficiency in terms of "cut-off diameter".
This is the diameter of the smallest droplets to be removed with an efficiency of 100%.
The same criterion is also commonly used to characterise the separation efficiency of settlers fitted with a plate pack.

In this DEP design rules for open settlers are given, based on the settling velocity in turbulent flow of the smallest droplets to be separated. If the coalescence process in the interface between the bulk liquid phases is the rate-determining step in the separation process, a dispersion band width needs to be specified.

FIGURE I.1 THE FORMATION OF A DISPERSION BAND IN THE INTERFACE OF A LIQUID/LIQUID SEPARATOR

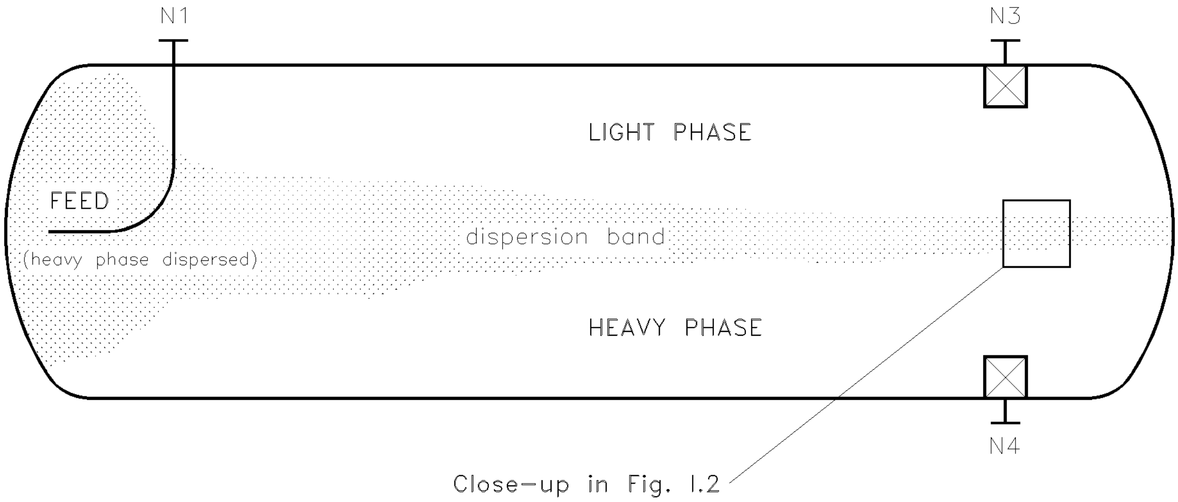
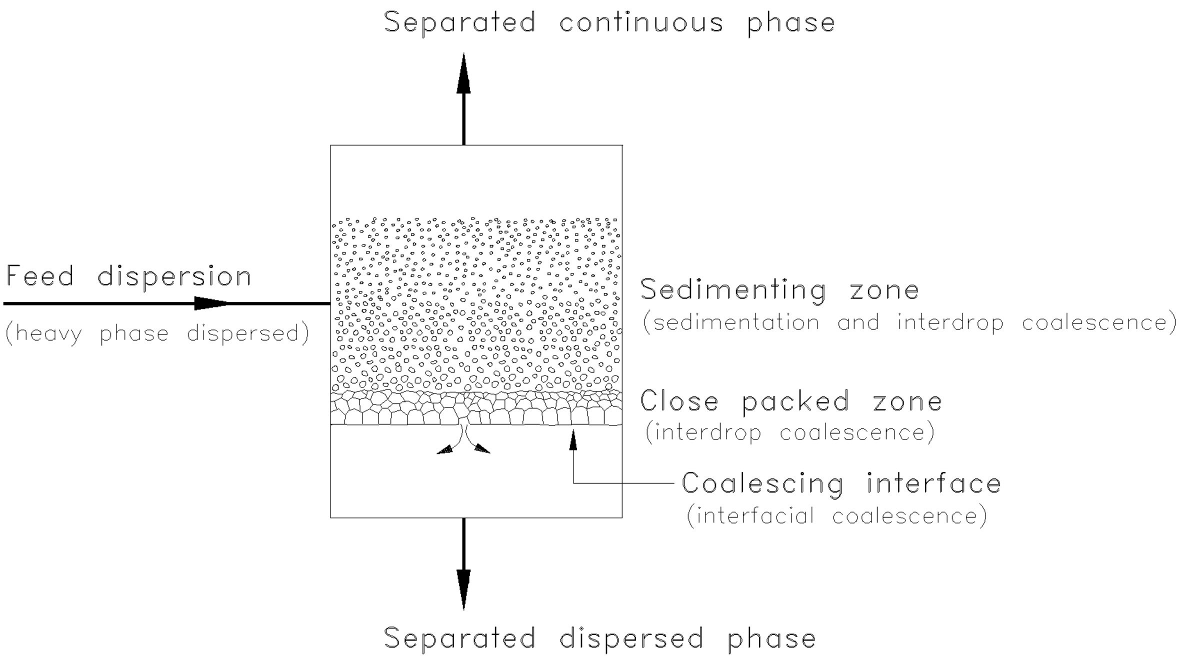


FIGURE I.2 THE STRUCTURE OF THE DISPERSION BAND (CLOSE-UP OF FIGURE I.1)



APPENDIX II PLATE PACKS

A. General considerations

The function of a plate pack is to improve the efficiency of liquid/ liquid separation.

The installation of plate packs in settlers will also result in smaller vessels as compared to open settlers.

Main reasons for this increase in efficiency are:

1. The presence of the plates results in a substantial reduction of the settling distance of the droplets.
2. If the plate pack is properly sized, the flow between the plates is laminar.
(By comparison, in an open settler the flow is nearly always turbulent which hampers the settling process.)

A plate pack is only effective for the separation of primary dispersions.
This means that the dispersion droplets must be large enough for their movement to be primarily caused by gravity. In practice this means that the droplets have to be larger than 30 µm to satisfy the above criterion. In the case of secondary dispersions (i.e. droplets typically smaller than 30 µm) separation can only be achieved with the aid of coalescers. See also Appendix III and (3.3) in the main text.

Basically, a plate pack consists of a set of parallel plates, which are either flat or corrugated. The plates are tilted to facilitate the removal of the separated phase.
With a view to maintaining laminar flow in the plate pack it is advantageous to use flat rather than corrugated plates since with flat plates the flow remains laminar up to a much higher flow rates than is possible with corrugated plates. However, plate packs with corrugated plates are less easily blocked by solids than plate packs equipped with flat plates.
It should be noted that the flat plates sometimes have contours at their upstream and downstream ends to promote laminar flow and enable the removal of the collected dispersed phase.

The plate packs to be used in vessels should be of the cross-flow type. This means that the flow of separated product is perpendicular to the main flow through the plate pack.
The main advantage of a cross-flow plate pack is that its geometry can easily be adapted to the geometry of the vessel and no excess space above or below the plates is required for the entry and exit of the liquid flows. This enables an efficient use of the vessel volume resulting in a relatively small vessel.
The alternatives, plate packs of the co- and countercurrent flow type, require more space and have also a lower separation efficiency, in particular the plate pack of the co-current type.

Figure II.1 shows schematically the principle of the three types of plate packs as used for the de-oiling of water.
In the plate pack of the counter-current flow type (in Shell terminology: **C**orrugated **P**late **I**nterceptor (CPI) if corrugated plates are used) the separated phase flows in the opposite direction to the main flow.
Because of the relatively high velocity of the two phases relative to each other, instabilities may occur in the interface which may lead to re-entrainment.

In de-oiling applications, the main flow flows from top to bottom (as is shown in Figure II.1) and will help sweep solids from the plate pack, minimising the likelihood of blocking by solids.

In the plate pack of the co-current flow type both liquid phases flow through the plate pack from bottom to top (in de-oiling applications). The solids present in the feed move downward.
The liquid/liquid separation efficiency of this type of plate pack separator is relatively poor since there is a high risk of re-entrainment of the separated phases downstream of the plate pack.

If there is an upflow, the likelihood of blocking by solids is relatively high since the upward flow will hinder the settling of solids in the plate pack.

In the cross-flow plate pack the main flow flows horizontally and the separated phase flows perpendicular to this via inclined plates.

As compared to the previous two types this plate pack has a higher liquid/liquid separation efficiency, because re-entrainment is less likely to occur.

The solids removal capacity is only moderate, but can be improved by increasing the inclination of the plates and/or by using corrugated rather than flat plates.

Both measures, however, will adversely affect liquid/liquid separation.

Since the cross-flow plate pack is the common type of plate pack used in vessels, only this type of plate pack will be described in detail in the remaining part of this Appendix.

B. Layout of the plate pack

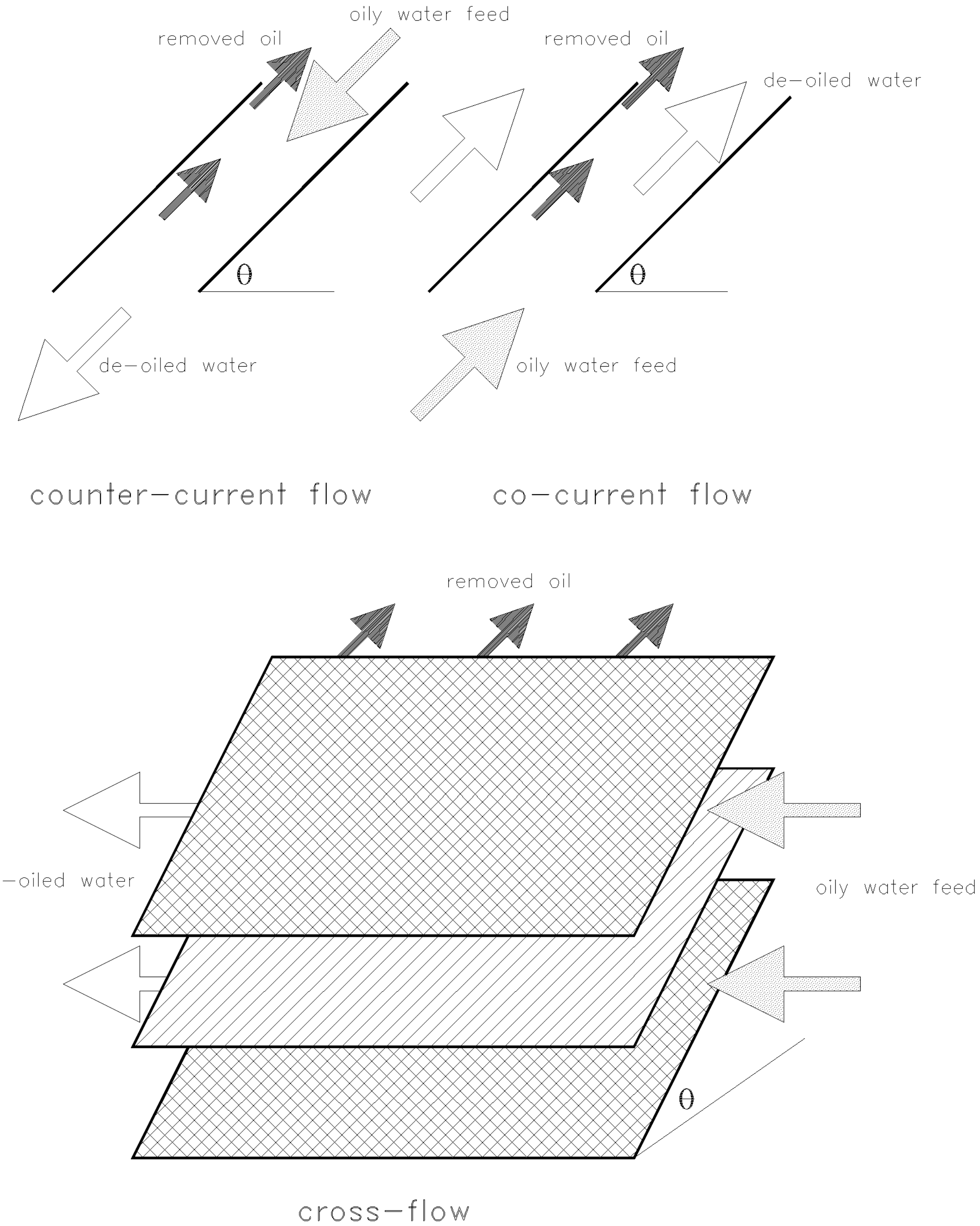
In the standard layout of the cross-flow plate pack the face of the plate pack will be perpendicular to the central axis of the vessel (transversal plate pack) as is shown in Figure II.2.
In the case of a transversal plate pack, the sides of the plate pack will follow to some extent the curvature of the vessel wall in order to maximise the use of the cross-sectional area.

Plate packs should be mounted in panels. Between the panels at least one gutter is present to transport the coalesced separated phase to its bulk phase.
Measures shall be taken to prevent bypassing of the plate pack such as mounting a plate in front of the gutters and sealing the clearance between the plate pack and the vessel wall.
The seal plate underneath the plate pack shall still have a small opening for cleaning purposes.
In the case of a horizontal three-phase settler a cover plate shall be fitted extending from the top of the plate pack to typically 50 mm above LZA(HH).

If fouling is expected a flushing system should be installed.

Figure II.2 shows the configuration of a transversal cross-flow plate pack in a three-phase separator.

FIGURE II.1 PRINCIPLE OF THE CO- AND COUNTER-CURRENT AND CROSS-FLOW PLATE PACKS (for de-oiling)



A perforated baffle (typically NFA of 30% and hole diameter of 12 mm) shall be installed upstream of the plate pack to provide an even distribution of the flow over the plate pack. In practice this is the baffle which separates the inlet compartment from the settling compartment in the settler. The distance between the baffle and the front of plate pack should be 150 mm.
In the case of a three-phase settler with a weir arrangement there should be at least 500 mm between the back of the plate pack and the weir arrangement in order to minimise the disturbance of the separation process.

If viscosity is low, a relatively large plate pack front area is required to maintain laminar flow in the plate pack. Then a settler layout with only one transversal plate pack may no longer be attractive, because it could result in an uneconomically large vessel diameter in order to accommodate the required front area of the plate pack.
Then it would be advantageous to split the feed flow and to use two transversal plate packs as is shown in Figure II.3a for an L/L separator.
An alternative solution is to adopt a layout in which the face of the plate pack is parallel to the central vessel axis (longitudinal plate pack) and the feed enters the vessel through two side nozzles as is also shown in Figure II.3b.
It is even possible to use two longitudinal plate packs. The feed will then enter the vessel through four feed nozzles, two on each side.
The Principal should be consulted for more information on these alternative layouts .

C. Material specification and manufacturing

Plate packs are usually **stainless steel**.

However, sometimes other material is used. For instance, for plate packs to be used in an acid settler of an HF-alkylation plant, carbon steel is commonly used.

The Manufacturer of the plate pack shall supply to the Principal fully dimensioned and detailed drawings of the plate pack for the particular application. Such information shall be treated by the Principal as confidential.

D. Design of the cross-flow plate pack

In a plate pack a liquid/liquid interface level will generally be established.

If the liquid/liquid interface is constant and well-defined, level two zones are identified in a plate pack:

- An upper zone where the light liquid phase is the continuous phase
- A lower zone where the heavy liquid phase is the continuous phase

If interface level control and/or a dispersion band is present, allowance also has to be made for an intermediate zone.

The upper or lower part of the cross-flow plate pack will be sized separately.
For practical reasons both parts will have the same length, plate spacing and plate inclination.

Sizing is performed in the following two steps:

1. First, the front area of each plate pack part is determined with the criterion that the flow between the plates shall be laminar.
2. Subsequently, the length of the plate pack is determined with the criterion that the pack shall be sufficiently long to separate the smallest droplet as defined by the specified cut-off diameter.

FIGURE II.2 TYPICAL LAYOUT OF TRANSVERSAL CROSS-FLOW PLATE PACK IN THREE-PHASE SEPARATOR (COVER PLATES FOR GUTTERS, BOTTOM AND SIDE CLEARANCES NOT SHOWN)

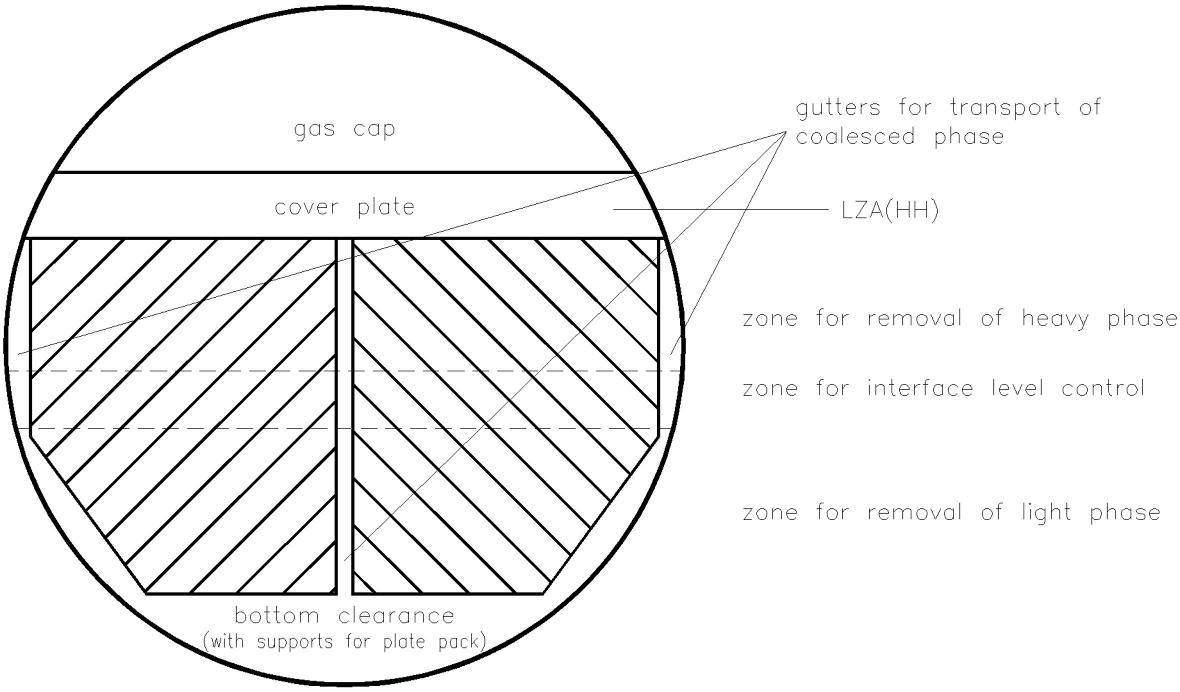
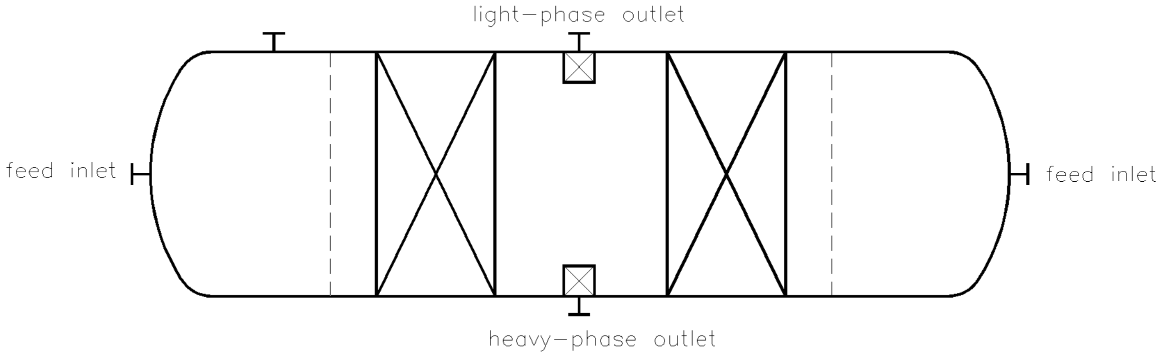
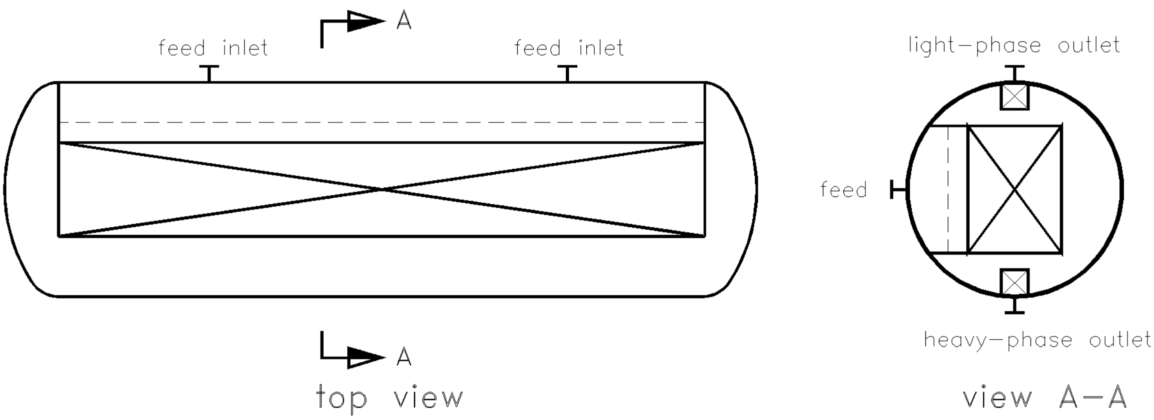


FIGURE II.3 ALTERNATIVE PLATE PACK CONFIGURATIONS FOR L/L SEPARATORS



a. two transversal plate packs (side view)



b. one longitudinal plate pack
(outlets not shown in top view)

D.1 Sizing of front area of plate pack

In a cross-flow plate pack with flat plates, flow is no longer fully laminar at a Reynolds number higher than 850. (In theory with flat plates the transition would be at a Reynolds number of 2000, but in practice transition takes place at a lower Reynolds number, because of the presence of plate pack constructional elements needed to reinforce the plates and of gutters for removal of the separated phase from the plate pack).
If corrugated plates are used, this transition already takes place at a Reynolds number of 450.
Corrugated plates should be used only if many solids are present.
The upper and lower section of the plate pack are considered separately.
The Reynolds number for each plate pack section is defined as:

$$Re = d_H v_{pp} \rho_c / \eta_c$$

where
d_H is the hydraulic diameter;
$d_H = 4W_{pp}d_{pp}/(2W_{pp} + 2d_{pp}) \approx 2d_{pp}$ (since $W_{pp} >> d_{pp}$), with d_{pp} being the plate distance and W_{pp} the plate pack width.
v_{pp} is the mean velocity of the total liquid flow (both dispersed and continuous phase) through the plate pack section to be sized.

$$v_{pp} \approx Q_c / A_{f,net}$$

$A_{f,net}$ is the net frontal area of the plate pack section available for flow (corrections applied for finite plate thickness, etc.).
Q_c is the volumetric flow rate of the continuous phase.
ρ_c is the density of the continuous liquid phase.
η_c is the dynamic viscosity of the continuous phase.

Strictly speaking, in the Reynolds number formula the average density and viscosity of the combined flow should have been used. However, since only at most a few % of the entrained phase will be present, it is a good approximation to use the physical properties of the continuous phase only.

Based on above, for each plate pack part $A_{f,net}$ can be calculated.

$$A_{f,net} = 2d_{pp}Q_c\rho_c/(\eta_c Re)$$

The Reynolds number, Re, has to be specified, but shall not be higher than 850 in the case of flat plates or 450 if corrugated plates are used.

The total gross frontal area of both parts is therefore:

$$A_{f,gross} = \{(A_{f,net})_l + (A_{f,net})_h\}(t_{pp} + d_{pp})/(d_{pp} * F_{loss})$$

t_{pp} is the plate thickness and is typically 1 mm.
F_{loss} is a correction factor to account for the fact that because of the presence of constructional elements, risers etc., not the whole frontal area can be used for liquid/liquid separation.
F_{loss} is typically in the range of 0.90 to 0.95.

The plate pack height H_{pp} of a rectangular plate pack with specified width W_{pp} is therefore:

$$H_{pp} = A_{f,gross}/W_{pp} + H_{contot} = H_l + H_h + H_{contot}$$

H_{contot} is the specified height if there is direct IL control. It also includes the height of the dispersion band (if required).

To guarantee proper separation, H_l and H_h shall be at least 0.3 m.

D.2 Determination of the plate pack length

The assumption is made that the settling of the droplets is the rate-determining step of the separation process in the plate pack.

This means that once the droplets have reached the plate surface of their flow channel, they will coalesce relatively rapidly into a film which will be immediately transported via vertical channels in the plate pack to the droplet bulk phase.

Calculate the plate pack length, L_{pp}, for each plate pack part using the following formula:

$$L_{pp} = v_{pp}d_{pp}/(\cos(\theta)v_{p,set}) + f_{tl}L_{entry}$$

θ is the angle of the plates with the horizontal plane.
$v_{p,set}$ is the settling velocity of the smallest droplet to be separated.

If this droplet is larger than 40 µm, the dispersed phase concentration is say below 1 vol % and $Re_p \leq 1$, then $v_{p,set}$ is given by:

$$v_{p,set} = |\rho_d - \rho_c|\, g d_p^2/(18\eta_c)$$

ρ_d and ρ_c are the densities of the dispersed and continuous phase, respectively,
g is the gravity constant,
d_p is the droplet diameter of the smallest droplet to be separated,
η_c is the dynamic viscosity of the continuous phase.

L_{entry} is the length of the entrance part of the plate pack where the transition of turbulent to laminar flow takes place and is a function of the Reynolds number of the plate pack part and of the plate pack spacing.

$$L_{entry} \approx 0.02 d_{pp} Re$$

For most applications L_{entry} is maximally about $16d_{pp}$.

f_{tl} is a correction factor for the fact that although the flow regime in the entrance part is somewhere between turbulent and laminar flow, there will still be some separation taking place.
$f_{tl} \approx 0.5$, so in practice, if Re = 800 and d_{pp} = 20 mm for instance, the length of the plate pack has to be increased by 160 mm (= $8d_{pp}$) in order to compensate for the non-laminar flow conditions in the entrance region of the plate pack.
The slightly conservative approach is taken that if the flow in the plate pack is laminar, the plate pack length has to be increased by $8d_{pp}$ to compensate for the entry effects.

Take for L_{pp} of the plate pack the largest of the two calculated values.
The minimum value is 0.3 m.

D.3 Choice of plate type, plate spacing and plate angle

In clean service the angle θ of the plates with the horizontal plane is 45 degrees, but if solids are present the angle should be steeper (typically 60 degrees) to facilitate the removal of the solids. If many solids are present, the use of corrugated rather than flat plates should be considered.

The plate spacing in fouling service should be at least 40 mm, whereas in clean service the plate spacing may be as little as 10 mm. The choice of corrugated rather than flat plates and/ or the increase of the plate spacing will reduce the fouling risk but will also reduce the separation efficiency of the plate pack of given overall (width * height * length) dimensions.
The same applies for the plate angle. Choice of plate type, plate angle and plate spacing has to be a compromise between fouling resistance, separation efficiency and economics.

E. Retrofit of plate pack in existing vessel

If a plate pack is to be retrofitted in an existing vessel where there is not sufficient space to install a plate pack in which the flow is laminar or if highly efficient separation is not required, it may be acceptable to go to a higher limit for the plate pack Reynolds number, say 1200.

However, then the settling velocity of the droplets, $v_{p,set}$, shall be corrected for the influence of turbulent flow:

$$(v_{p,set})_{turbulent} \approx (v_{p,set})_{laminar} - 0.05v_{c,ax}$$

with $v_{c,ax}$ being the axial velocity of the flow through the plate pack

Further, the length of the entrance part of the plate, L_{entry}, has to be adjusted, using the expression:

$$L_{entry} \approx 0.02d_{pp}Re$$

APPENDIX III COALESCERS

A. General

The function of a coalescer is to promote the growth of droplets by using a coalescer medium to facilitate the settling of the droplets by gravity. If the droplets are smaller than say 30 µm, normally they would not even settle by gravity because their movements are dominated by diffusion. Due to the coalescing process the droplets will grow and gravity outweighs diffusion.

If the droplets in a dispersion are smaller than 30 µm the dispersion is classified as a secondary dispersion. A primary dispersion contains droplets larger than 30 µm.

For a primary dispersion the choice of the coalescer material is determined by the criterion that the dispersed phase must preferentially wet the packing surface. This means that in de-oiling service polymeric filament such as polypropylene or Teflon should be used but metal wire should be used if water has to be removed. The problem of material choice can be avoided by using both metal and polymeric filaments in the coalescing medium. This has the additional advantage that in the junctions of the two types of filaments, extra coalescence takes place because of the local discontinuity of surface-free energy.

For a secondary dispersion the coalescence is no longer based on wetting of the filament material. Droplets are intercepted and captured onto the fibre surface as a result of adhesion forces. The fibre structure, filament size and free volume of the media are now the important parameters. For instance, the finer the filament the more effective the coalescence process will be for small droplets. Droplet growth will continue until viscous drag forces acting on the droplets as a result of the continuous flow of the mixture through the coalescer medium exceed the force of adhesion. Normally, this coalescence process will subsequently convert the secondary dispersion into a primary dispersion and, if required, the droplets can be coalesced further.

In practice various coalescing media are in use:

1. compressed coalescer bed made from fibres (either polymeric material (e.g. polypropylene) or stainless steel wire)
2. pre-fabricated mat
3. cartridges.

A brief description of each coalescing method is given below, followed by a summary of the advantages and disadvantages.

Finally a few commercially available designs of coalescer vessels fitted with cartridges are described.

B. Compressed coalescer bed made from fibres

This is the coalescing medium in use in the Shell Twin-Flange Coalescer, which has been the standard coalescer in the Group. The design rules for this coalescer are given in (3.3.4). In the standard layout of the Shell Twin-Flange Coalescer, the bed consists of polypropylene material which has been compressed to a bulk density of 110 kg/m^3. This polypropylene wool bed is suitable for the treatment of both primary and secondary dispersion and the packing material is not expensive.

If a **primary** water-in-oil dispersion has to be treated, stainless steel wire rather than polypropylene wool should be used because the coalescing material should be preferentially wetted by the dispersed phase. A disadvantage of the compressed bed in the Shell Twin-Flange Coalescer is that it is manually packed and so it is difficult to achieve a homogeneous bed density. Due to improper packing, channelling may occur in the bed, especially in the case of steel wire, which may cause bypassing.

As stated in (3.3.4), **NO crinkled** wiremat shall be used underneath the PP-wool bed in the Shell Twin-Flange coalescer **unless measures are taken to prevent the compression of the mat during the compression of the PP-wool bed**, since a compressed mat will spoil the effect of the PP-wool bed. It becomes too dense and will act as a disperser rather than a coalescer.

Felt mats should no longer be used since their density is normally too high for a proper coalescing process.

In Standard Drawing S 22.027 two options are given for the packing in the TFC:

1. **Only a PP-wool bed**
2. **PP-wool bed with one underlying layer of crinkled wiremat which is safeguarded against compression**

C. Pre-fabricated mat

By knitting the coalescer fibres into pre-fabricated mats, a more constant quality will be achieved than with the above-described manually packed beds. Consequently there is less likelihood of channelling.

The mats are mainly used to coalesce primary dispersions.

Basically two types are distinguished: mats made from single fibre material or mats made from dual fibre material.

Single material

Use is made of either stainless steel or polymeric (e.g. polypropylene) filament depending on the nature of the dispersed phase: for de-watering stainless steel should be used, whereas in de-oiling service polymeric material should be used.

Dual material

Stainless steel and polymeric filaments are knitted together.
Coalescence tends to occur at the junction points of the polymeric and steel filaments.
The advantage of this is that the nature of the dispersed phase is no longer critical for the coalescence performance of the mat.

D. Cartridges

For the separation of secondary dispersions, instead of a compressed coalescer bed (as in the Shell Twin-Flange coalescers), cartridges as marketed by several Manufacturers can also be used.

The advantages of using cartridges rather than compressed polypropylene wool bed, for instance, are:

1. The cartridges are pre-fabricated which minimises the risk of channelling.
2. It will result in a larger surface area for the dispersion to be treated.

The coalescer material is normally supplied in prefabricated fibre material formed in layers around a central perforated cylinder.

Fibre material is glassfibre or polypropylene or other compatible polymeric material.

The dispersion to be treated should enter the cartridge in the centre and flow from in to out.

Usually there is a gradient in the grade of the packing material. The finer fibres which have to deal with the original secondary dispersion are closest to the centre. The coarse fibres are closer to the periphery where the droplets have grown into the range of primary dispersion.

The following operational limits shall be noted:

- If polypropylene is used, the maximum allowable temperature is 80°C and the aromatic content in the feed shall not exceed 18 wt%.
- Above a kinematic viscosity of 15 mm^2/s the coalescer becomes substantially less effective because the higher viscosity affects adversely the coalescing process.
- If the pH of the feed falls outside the range 5 to 9, different coalescer material has to be selected.

The cartridges can be applied in horizontal or in vertical vessels. In the following paragraph a few vendor proprietary designs are described.

E. Commercially available coalescers equipped with cartridges

Normally coalescers of this type are supplied as a complete package of vessel and internals.

Below details are given of commercially available coalescer/separators.

Knitmesh

Figure III.1 gives the schematic layout of a vertical coalescer vessel fitted with "Dusec" cartridges. This type of coalescer can be used for both de-oiling and dewatering (due to the outer layer of the coalescer cartridges which consists of stainless steel and polymeric filaments knitted together). The cartridge consists of a number of layers of coalescer material, whereby the fibre thickness increases from inside to outside.

To prevent fouling/ plugging a 5 µm (or finer) prefilter has to be used.

The cartridges are mounted in vertical position on a support framework. Feed enters from the bottom of the vessel and flows upwards through the cartridges from in to out. Outside the cartridges the coalesced droplets settle rapidly into the two bulk liquid phases.

To allow inspection of the vessel compartment upstream of the cartridges, the support framework should be bolted rather than welded to the vessel wall.

To facilitate the mounting of the cartridges, the vessel is top-flanged.

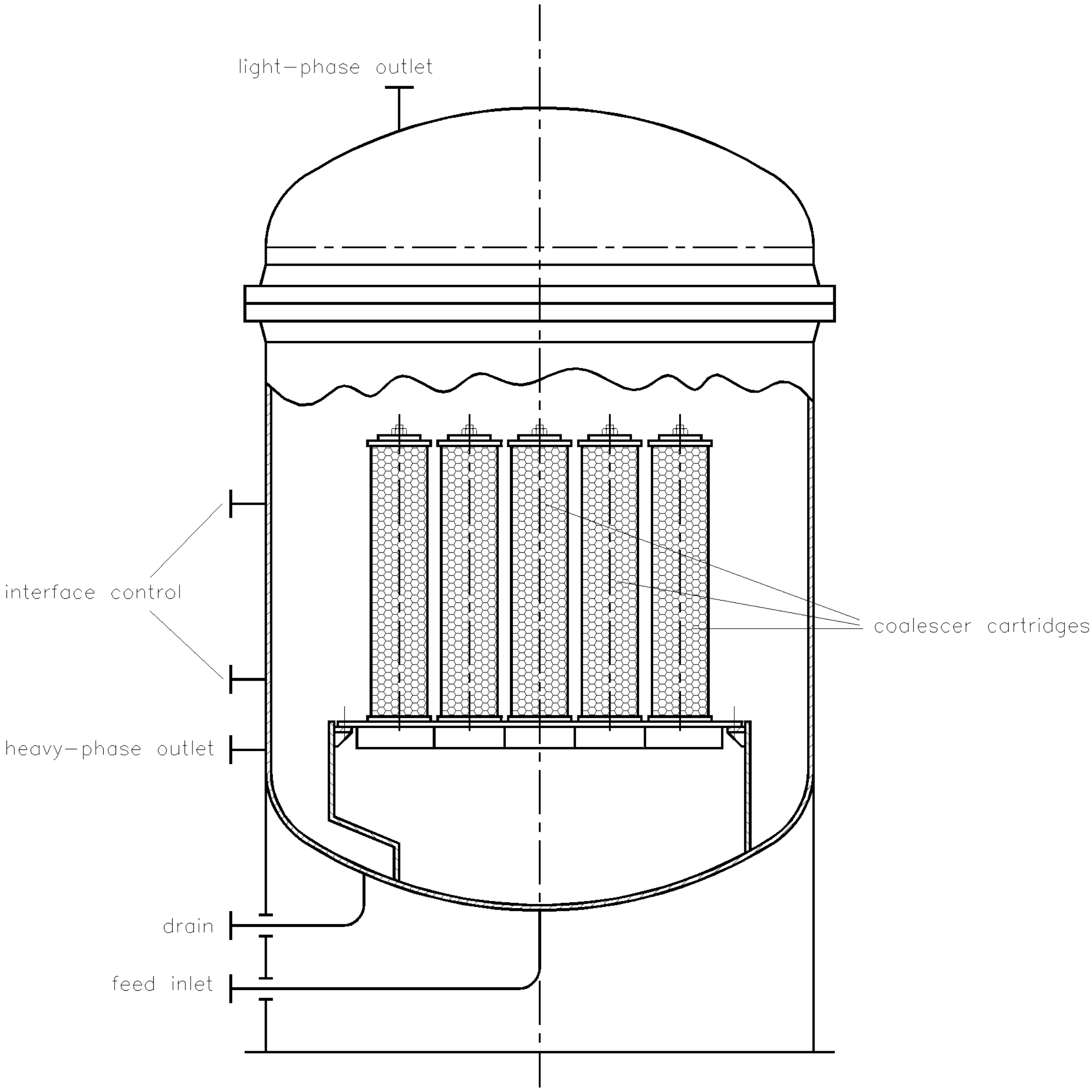
Standard sizes of the cartridges are:
- Inner/outer diameter 115/230 mm;
- Length either 500 or 1000 mm.

The cartridges are installed with a triangular pitch of 270 mm. The support framework should be bolted on rather than welded. If the support framework is bolted on there shall be a clearance of 90 mm between the cartridge and the vessel wall. If the support framework is welded on there shall be a clearance of 40 mm between the cartridge and the vessel wall.

The vessel diameter then follows directly from the number of required cartridges.

The height of the vessel is independent of the number of cartridges. In a top-flanged vessel it is typically 2000 mm (if 1000 mm cartridges are used). If no top-flange is provided, additional height is required to create manoeuvring space to get the cartridges into place via a manhole.

FIGURE III.1 KNITMESH VERTICAL COALESCER EQUIPPED WITH CARTRIDGES



Faudi

Faudi supplies coalescer vessels both for de-oiling and dewatering. They have in particular wide experience in the dewatering of aviation fuels. For de-oiling only one stage (coalescing) is used, whereas dewatering takes place in two steps. The coalescer vessels are either horizontal or vertical.

Although there is prefiltering in the coalescer cartridges (pleated filterpaper) a prefiltering step should also be installed upstream of the coalescer in order to lengthen the life of the cartridges.

In Figure III.2 a typical layout of a horizontal Faudi filter/separator for dewatering is shown.

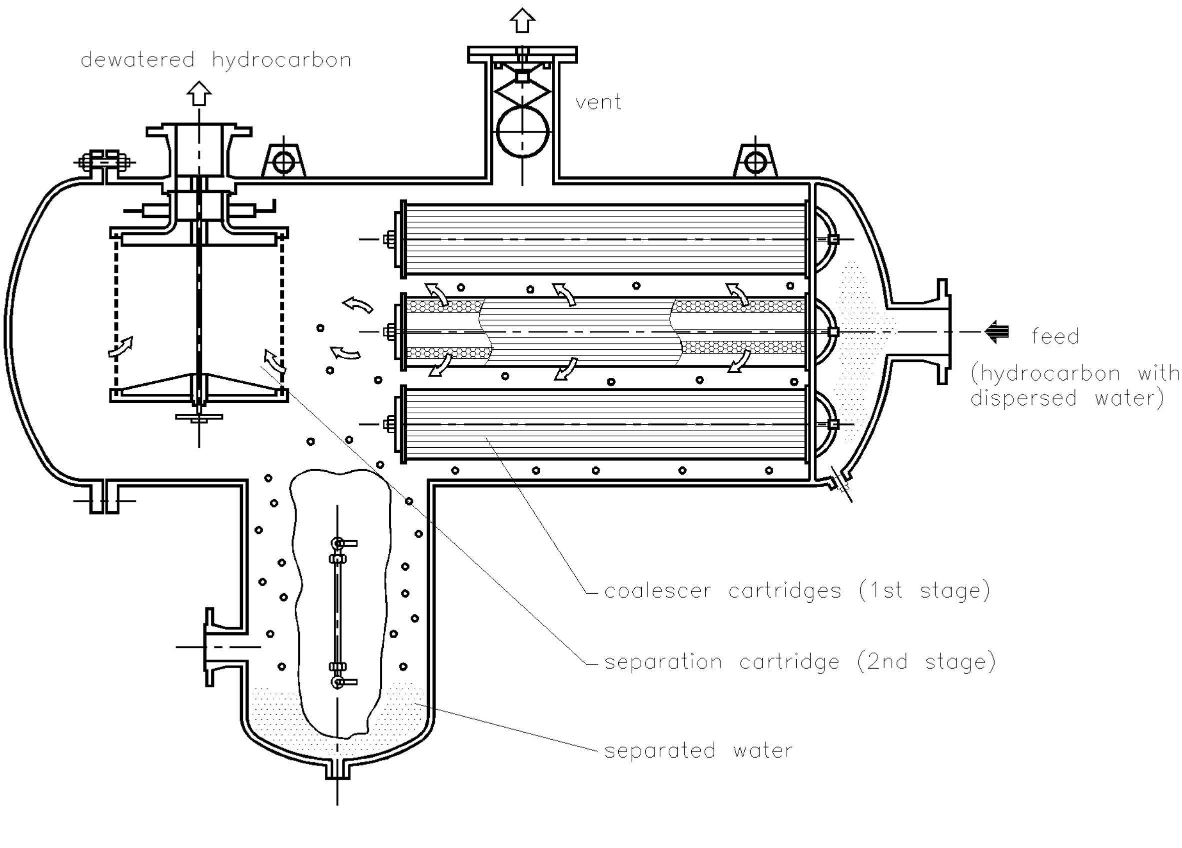
The dewatering of the feed takes place into two stages:
Firstly, the feed flows through the coalescer cartridges (from in to out) where the dispersed water is coalesced. The inner surface of the coalescer cartridges consists of pleated filtration paper supported by a perforated tube. The pleated filtration paper filters out the solids entrained in the feed and initiates the coalescing process.

Subsequently the feed flows through the separation cartridge(s) (from out to in). Because the outer surface consists of hydrophobic material (teflon-coated steel gauze), the coalesced water droplets will not pass the surface of the separation cartridges and will fall into the sump of the coalescer vessel.

There are several types of cartridges, but in most cases the size of the coalescer cartridges is as follows:
- Inner/outer diameter: 50/152 mm;
- Length: 842 mm

The coalescer cartridges are installed with a triangular pitch of 165 mm with a cartridge-vessel wall clearance of 13 mm.
The vessel diameter then follows directly from the number of required cartridges.

FIGURE III.2 HORIZONTAL FAUDI FILTER SEPARATOR (FOR DEWATERING)



Pall

Pall also delivers coalescer vessels both for dewatering and de-oiling either as horizontal or vertical vessels.

The de-oiling takes place in one step whereas for dewatering (if the interfacial tension is larger than 0.0035 N/m) two stages are used.

If interfacial tension is greater than 0.0035 N/m, the vertical "AquaSep" cartridge assembly is used for dewatering, with the coalescence part placed on top of the separation part.

This configuration results in an even distribution of the flow from the coalescing to the separation part and in a smaller overall vessel diameter.

The coalescer feed shall first be pre-filtered to remove dirt/particles down to typically 2 µm particle size before it enters the coalescer.

In Figure III.3 a typical layout of a vertical Pall "AquaSep" coalescer together with its prefilter is shown.

In the coalescer vessel the feed flows into the upper cartridges (which have the coalescing function) from in to out. These cartridges are made from special polymeric material of which the water-coalescing properties are unaffected by the presence of surface-active agents (no "disarming") or by a low interfacial tension (< 0.0035 N/m). In this respect the selected material is less susceptible than in glassfibre or polypropylene, for instance. (Generally, glassfibre is limited to applications with an interfacial tension greater than 0.02 N/m and can disarm in the presence of surface-active agents.)

In the coalescer cartridges coalescence of the dispersed water takes place.

Subsequently the feed flows through the separation (lower) cartridges (from out to in). Because the outer surface of these cartridges consists of hydrophobic material, the coalesced water droplets will not pass the surface of the separation cartridges and will fall into the sump of the coalescer vessel.

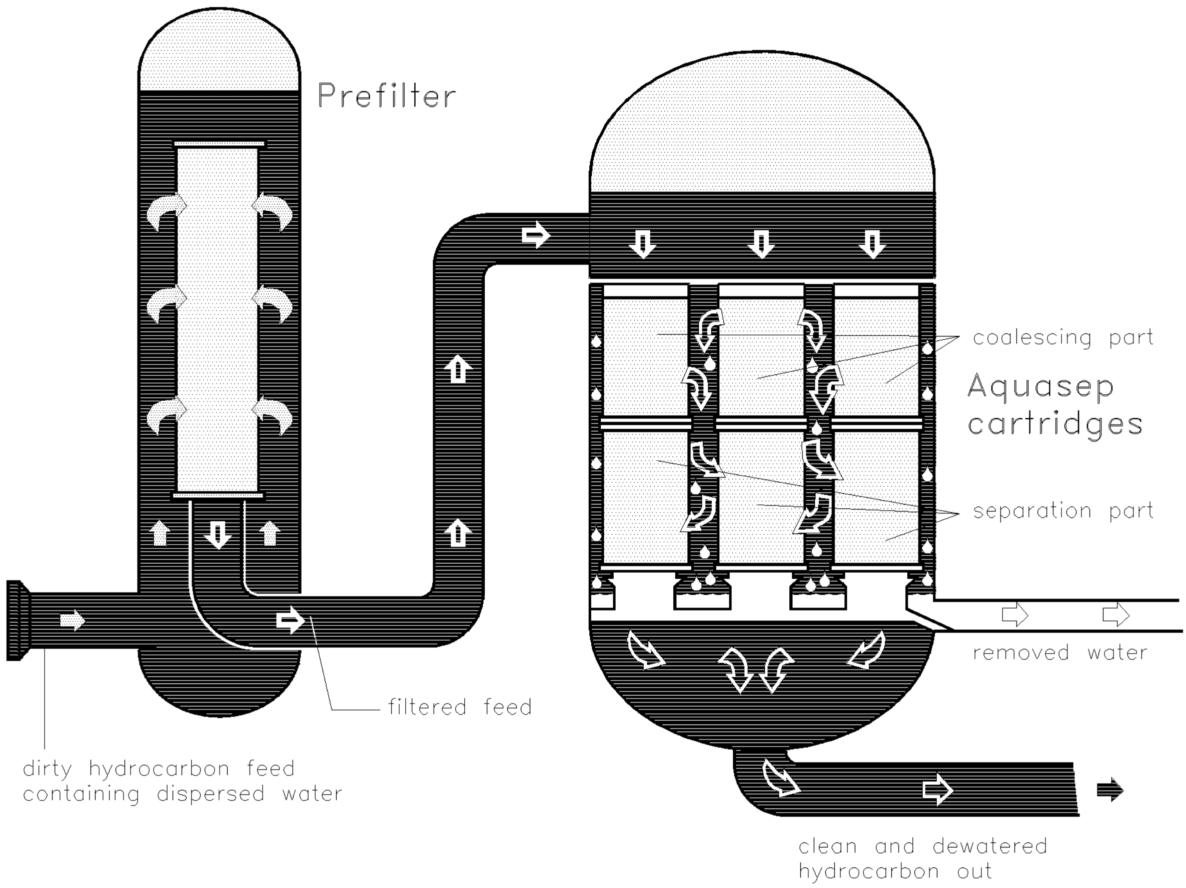
The standard dimensions of the Aquasep cartridge are:
- Inner/outer diameter: 38/95 mm;
- Length of coalescer element either 500 or 1000 mm;
- Length of separation element 500 mm.

The cartridges are installed with a triangular pitch of 120mm with a cartridge - vessel wall clearance of typically 50 mm.

The vessel diameter then follows directly from the number of required cartridges.

In cases where the interfacial tension is smaller than 0.0035 N/m a horizontal vessel with only a coalescing stage should be used.

FIGURE III.3 VERTICAL PALL AQUASEP COALESCER



APPENDIX IV TWO-PHASE SETTLERS

CHECK OF EXISTING HORIZONTAL OPEN TWO-PHASE SETTLERS
(INCLUDING RETROFIT OPTION WITH PLATE PACK)

(See also main text (3.1) and (3.2) and Figures 3.1 and 3.2)

This procedure can also be treated as the sizing procedure for a new settler starting with the specification of the vessel dimensions and the various level control heights.

The various steps taken in the procedure are described below.

Input

1. Vessel diameter and tangent/tangent length
2. Volumetric flow rate, density and dynamic viscosity of both liquid phases
3. Interfacial control levels, width of dispersion band (if any).

   If a dispersion band is present the distance between each pre-alarm and trip level has to be increased by half the width of the dispersion band.

   If a dispersion band is expected there is insufficient information for its width to be estimated using the formula given in Appendix I, it is suggested that 0.2 m be taken as dispersion band width.
4. Required minimum control times for L/L interface control.

Calculations

1. Calculation of A_l and A_h and corresponding axial velocities $v_{l,ax}$ and $v_{h,ax}$

From the vessel diameter D, $LZA(HH)_{int}$ and $LZA(LL)_{int}$, A_l and A_h are calculated using the formulae given in Appendix VI.

Subsequently:

$v_{l,ax} = Q_l/A_l$

$v_{h,ax} = Q_h/A_h$

2. Size of the compartments

Inlet compartment

This is the part between the vessel tangent line closest to feed inlet and calming baffle.

Recommended: $L_{in} = 0.5D$

Outlet compartment

This is the part of the vessel between the other vessel tangent line and the outlet nozzles (assuming both nozzles are in the same vertical plane which is perpendicular to the vessel axis).

Typically: $L_{out} = 0.25D$

Settling compartment

This is the intermediate part of the vessel where settling takes place.

$L_{set} = L_{ves} - L_{in} - L_{out}$

Obviously, if L_{set} is very small, a larger value for L_{ves} has to be taken or in a new vessel a smaller value for L_{in} has to be accepted in an existing vessel.

3. Calculation of the smallest light-phase and smallest heavy-phase droplet which still can be separated off

Settling of heavy-phase droplet:

$v_{dh,set} = \{D\text{-}LZA(HH)_{int}\}v_{l,ax}/L_{set}$

$$d_h = \sqrt{18\eta_l(v_{dh,set} + 0.05v_{l,ax} / \{g(\rho_h - \rho_l)\}}$$

It shall be checked that $v_{l,ax}$ does not exceed 0.015 m/s, because this may result in a larger value of d_h than given by above formula.
$v_{l,ax}$ can be decreased by selecting a lower $LZA(HH)_{int}$

Settling of light-phase droplet:

$v_{dl,set} = LZA(LL)_{int}v_{h,ax}/L_{set}$

$$d_l = \sqrt{18\eta_l(v_{dl,set} + 0.05v_{h,ax} / \{g(\rho_h - \rho_l)\}}$$

It shall be checked that $v_{h,ax}$ does not exceed 0.015 m/s, because this may result in a larger value of d_l than given by above formula.
$v_{h,ax}$ can be decreased by selecting a higher $LZA(LL)_{int}$

4. Calculation of the control times

From D, $LA(L)_{int}$, $LA(H)_{int}$ and L_{ves} the control volume, V_{con,H_L}, contained between the $LA(H)_{int}$ - and $LA(L)_{int}$ -level is calculated.

$t_{con,H\_L} = V_{con,H\_L}/Q_{con,H\_L}$

with $V_{con,H\_L} = A_{con,H\_L}L_{ves} + 2\,\Delta V_{hd,H\_L}$

A_{con,H_L} and $\Delta V_{hd,H\_L}$ are the vessel cross-section and the vessel head volume respectively between $LA(H)_{int}$ and $LA(L)_{int}$. For their calculation, see Appendix VI.

Q_{con,H_L} is the flow rate of the liquid phase used for control.
This is normally the heavy liquid phase.

Similarly, t_{con,HH_H} and t_{con,L_LL}, the control times associated with the control zones

between ($LZA(HH)_{int}$ $-0.5H_{db}$) and $LA(H)_{int}$ and
between $LA(L)_{int}$ and ($LZA(LL)_{int}$ $+0.5H_{db}$) respectively, can be calculated.

If the calculated control times are smaller than the specified minimum control times, then the calculations shall be repeated with adjusted control levels or (in the case of a new vessel) with larger vessel dimensions.

5. Installation of a plate pack in the settling compartment

The performance of the existing horizontal open two-phase settler can be upgraded with the installation of a plate pack.

The plate pack to be installed shall extend from vessel bottom to vessel top and its distance to the calming baffle of the inlet compartment and to the outlet nozzles is 150 mm and 500 mm respectively.
Below the procedure has been given for assessing its performance as a function of the selected plate pack characteristics (plate spacing, angle between plates and horizontal plane and length of the plate pack) and of the flow conditions.

The following steps should be taken:

5a. Determine the part of the gross frontal area of the plate pack, $A_{f,gross}$, which can be accommodated in the vessel cross-sectional area between the top of the vessel and $LZA(HH)_{int}$ and in the vessel cross-sectional area between $LZA(LL)_{int}$ and the bottom of the vessel, respectively.

$(A_{f,gross})_l = F_{pp}A_l$

$(A_{f,gross})_h = F_{pp}A_h$

F_{pp} is assumed to be the same for both areas and is typically 0.8.
A_l and A_h have already been calculated in step 1.

5b. Calculate the corresponding net free area, $A_{f,net}$, taking into account the plate thickness t_{pp}, a selected plate distance d_{pp} and the loss factor F_{loss}

$(A_{f,net})_l = (A_{f,gross})_l * F_{loss} * d_{pp}/(t_{pp} + d_{pp})$

$(A_{f,net})_h = (A_{f,gross})_h * F_{loss} * d_{pp}/(t_{pp} + d_{pp})$

F_{loss} is typically in the range of 0.9 to 0.95

t_{pp} is typically 1 mm

5c. Check the selected d_{pp}.
The distance between the plates, d_{pp}, has to be selected such that it is sufficiently small to ensure laminar flow in the plate pack but it shall not be smaller than a given minimum distance, $d_{pp,min}$. This minimum distance is 10 mm for non-fouling conditions and 40 mm for fouling conditions.
The following two criteria should both be satisfied:
for upper part of plate pack:
$d_{pp,min} \leq d_{pp} \leq (d_{pp,max})_l \approx Re_{crit}\eta_l(A_{f,net})_l/(2\rho_l Q_l)$

for lower part of plate pack:
$d_{pp,min} \leq d_{pp} \leq (d_{pp,max})_h \approx Re_{crit}\eta_h(A_{f,net})_h/(2\rho_h Q_h)$

Re_{crit} is the critical Reynolds number above which deviation from the laminar flow regime will take place.
If flat plates (with front and rear contours) are used, then Re_{crit} is 850;
if corrugated plates are used then Re_{crit} is 450.
$(d_{pp,max})_l$ and $(d_{pp,max})_h$ are the corresponding plate spacings.
If d_{pp} is too large to ensure laminar flow, select a smaller value for d_{pp}
(with $d_{pp} \leq d_{pp,max}$) and repeat steps 5a and 5b.
Please note that the calculated $d_{pp,max}$ values are an approximation, since $A_{f,net}$ is a function of the selected d_{pp}, so probably at least one iteration step is required.
If above criteria still cannot be satisfied for $d_{pp} = d_{pp,min}$, then the minimum distance should be used for d_{pp}, accepting the deviation from laminar flow. It should be then realised that although turbulent flow in the plate pack will affect separation, the separation will still be better than if no plate pack were used.

5d. Determine the angle θ of the plates with the horizontal plane (45° in non-fouling service and 60° in fouling service)

5e. Select the length of the plate pack, L_{pp}

For the length of the plate pack, L_{pp}, it is recommended that:

$L_{pp,max} = L_{set} - 0.65$ m

distance to calming plate and outlet nozzles 0.15 and 0.5 m respectively

$L_{pp,min} = 0.3$ m

If $L_{set} < 0.95$ m, the above requirements cannot be met and compromises will be necessary.

5f. Calculate the separation performance of the plate pack

If laminar flow in the plate pack is laminar, the smallest droplet to be separated for both phases is given by the following relationships:

heavy-phase droplet:

$$d_h = \sqrt{18 \eta_l v_{dh,set} / \{g(\rho_h - \rho_l)\}}$$

with $vd_{h,set} = v_{l,pp} d_{pp} / \{\cos\theta \ (L_{pp} - 8d_{pp})\}$

in which $v_{l,pp} = Q_l / (A_{f,net})_l$

light-phase droplet:

$$d_l = \sqrt{18 \eta_h v_{dl,set} / \{g(\rho_h - \rho_l)\}}$$

with $v_{dl,set} = v_{h,pp} d_{pp} / \{\cos\theta \ (L_{pp} - 8d_{pp})\}$

in which $v_{h,pp} = Q_h / (A_{f,net})_h$

$v_{l,pp}$ and $v_{h,pp}$ are the axial velocities in the uper and lower separation part of the plate pack.
$v_{l,ax}$ and $v_{h,ax}$ are the axial velocies in the light and heavy liquid phase upstream of the plate pack.
The term $8d_{pp}$ in the expression for $v_{dh,set}$ and $v_{dl,set}$ is a correction for the non-laminar flow in the entrance of the plate pack.

Strictly speaking the correction is equal to $0.01 * \max(Re_l, Re_h)$, where Re_l and Re_h are the Reynolds numbers in the light-phase and heavy-phase part of the plate pack respectively, but in most cases the simple term $8d_{pp}$ is equal to or larger than the exact value (see also Appendix II).

If the calculated drop sizes are still too large, a larger L_{pp} has to be selected (if still allowed by the vessel geometry) and step 5f has to be repeated.

CALCULATION EXAMPLE

A check has to be performed on an existing horizontal open two-phase settler to establish whether it is able to perform proper oil/water separation for given process conditions.

If required, its separation performance has to be upgraded by the installation of internals.

Flow conditions are:

Oil: mass flow rate of 500 t/d with a density of 750 kg/m^3 and a dynamic viscosity of 0.5 mPa.s.

Water: mass flow rate of 320 t/d with a density of 990 kg/m^3 and a dynamic viscosity of 0.9 mPa.s.

- Design margin is 1.2
- No dispersion band expected in the oil/water interface
- Level control (based on water flow rate):
  3 minutes between high and low level (pre-alarms)
  1 minute between pre-alarm and trip

Further information:
- Vessel: diameter 1.5 m and T/T of 5 m (heads semi-elliptical with a ratio of 2:1)
- Nozzles: feed inlet is a top inlet located 0.4 m from the "left" vessel tangent line; distance of oil and water outlets from "right" vessel tangent line is 0.4 m; diameters of feed inlet, oil outlet and water outlet are 0.15, 0.10 and 0.10 m respectively
- Internals: only vortex breakers on the oil and water outlet are present

Check

To optimise the settling conditions, it is proposed to convert the vessel layout to the layout shown in the top part of Figure 3.1.

It is proposed to fit the feed nozzle with an elbowed pipe directed to the nearest vessel head and to install a calming baffle (30% NFA) 0.75 m (0.5 vessel diameter) from the left tangent line.
This will result in an effective settling length to the nozzles of 5 - 0.4 - 0.75 = 3.85 m.

The distance between pre-alarm and trip level in each set is at least 0.1 m (no allowance for dispersion band necessary) and the distance between high and low IL is minimal 0.35 m. This results in a total control band of minimal 0.55 m.
As a starting point it is assumed that the control band has this minimum width of 0.55 m.
It should be located in the vessel such that in both the oil and the water layer proper bulk separation takes place i.e. all droplets larger than 150 µm diameter shall be removed.

Initially three locations of this control band in the vessel have been considered:

Position I: At the lowest location ($LZA(LL)_{int} = 0.2*D_{ves} = 0.3$ m)

Position II: In the centre ($A_l = A_h$)

Position III: At the highest location ($LZA(HH)_{int} = 0.8*D_{ves} = 1.2$ m)

For these three positions the various quantities (e.g. cross-sectional areas, velocities, cut-off diameters, control time and maximum allowable axial velocities) have been calculated according to the calculation scheme presented in Appendix IV.3.

They are listed in the following table.

Nozzle velocities (without design margin!) have also been calculated and listed.

In this Table it has been indicated (by bold italic and border) where the various requirements for this type of separator are not satisfied (see last section of Appendix IV.1).

location of control band			position I (low)	position II (medium)	position III (high)	position IV
limits of control band	$LZA(LL)_{int}$	(m)	0.300	0.475	0.650	0.380
	$LZA(HH)_{int}$	(m)	0.850	1.025	1.200	0.930
step 1	A_l	(m^2)	0.734	0.480	0.252	0.616
	A_h	(m^2)	0.252	0.480	0.734	0.352
	$v_{l,ax}$	(cm/s)	1.26	***1.93***	***3.68***	1.50
	$v_{h,ax}$	(cm/s)	***1.78***	0.93	0.62	1.28
step 2	L_{set}	(m)	3.85	3.85	3.85	3.85
step 3	$v_{dh,set}$	(cm/s)	0.21	0.24	0.29	0.22
	$v_{dl,set}$	(cm/s)	0.14	0.12	0.10	0.13
	d_h	(µm)	103	113	134	107
	d_l	(µm)	125	106	96	114
step 4	A_{con}	(m^2)	0.505	0.520	0.505	0.516
	ΔV_{hd}	(m^3)	0.143	0.152	0.143	0.149
	V_{con}	(m^3)	2.813	2.905	2.813	2.878
	t_{con,H_L}	(sec)	627	647	627	641
	t_{con,HH_H}	(sec)	186	177	155	184
	t_{con,L_LL}	(sec)	155	177	186	167
nozzle velocities	feed: v_{N1}	(m/s)	0.65	0.65	0.65	0.65
	oil out: v_{N3}	(m/s)	0.98	0.98	0.98	0.98
	water out: v_{N4}	(m/s)	0.48	0.48	0.48	0.48

The check of the settler leads to the following conclusions:

- The calculations show that for the low, medium and high control band position, adequate bulk separation takes place for both liquid phases (cut-off diameter smaller than 150 µm).
- However, the axial velocity in the light phase exceeds the upper limit of 1.5 cm/s when the control band is in the medium or high position. The axial velocity in the heavy phase exceeds the limit of 1.5 cm/s when the control band is in the low position. Therefore, for

optimum settler performance, a control band position between the low and medium position should be selected.
The Table shows that if $LZA(LL)_{int}$ is at 0.38 m (position IV; 0.08 m above the low position) the velocity requirement for both phases has been satisfied.

- The available time for the various control bands is in all cases much more than the minimum requirements, so the selected width of the control band of 0.55 m is more than sufficient.

Upgrading of the separation performance of the settler by the installation of a plate pack

In this example it will be investigated to which extent the separation performance of the settler can be upgraded by the installation of a plate pack.

The layout of the separator fitted with a plate pack is shown in Figure 3.2.

Input

- The control band will be taken at position IV (see preceding Table)
- Since the service is non-fouling, flat plates and a plate angle of 45º are selected.
- Selected plate thickness is 1 mm.
- Because flat plates have been opted for, the critical Reynolds number is 850.

The maximum space available for the plate pack is 3.85 - 0.65 = 3.2 m.

However, in practice normally such a long plate pack will not normally be installed.

Normally the length of a plate pack is in the range of 0.5 to 1.5 m.

- As a first choice, a plate pack length of 1 m has been selected.

If the calculated cut-off diameters are still not small enough then a longer plate pack could be considered.

- Because the service is non-fouling the minimum allowable plate spacing is 10 mm.

Further input:

- F_{pp} is 0.8
- F_{loss} is 0.9
- correction of effective plate pack length for turbulence in entrance: subtract 8 times the plate spacing.

In the following Table the calculations are presented following the calculation scheme as outlined in Appendix IV.3.

selection of plate spacing			d_{pp} is 30 mm start value	d_{pp} is 13 mm 1st iteration	d_{pp} is 12 mm 2nd iteration
step 5a	$(A_{f,gross})_l$	(m^2)	0.493	0.493	0.493
	$(A_{f,gross})_h$	(m^2)	0.282	0.282	0.282
step 5b	$(A_{f,net})_l$	(m^2)	0.429	0.412	0.410
	$(A_{f,net})_h$	(m^2)	0.245	0.235	0.234
step 5c	$(d_{pp,max})_l$	(mm)	13.1	12.6	12.5
	$(d_{pp,max})_h$	(mm)	21.1	20.2	20.1
	check of d_{pp}		**too large** (turb.) go to step 5b with $d_{pp} \leq 13.1$ mm	**too large** (turb.) go to step 5b with $d_{pp} \leq 12.6$ mm	**OK** no turbulence; proceed with step 5d
step 5d	θ(degrees)	(input)			45
step 5e	L_{pp}(m)	(input)			1.00
step 5f	$v_{l,pp}$	(cm/s)			2.26
	$v_{dh,set}$	(cm/s)			0.042
	d_h	(µm)			40
	$v_{h,pp}$	(cm/s)			1.92
	$v_{dl,set}$	(cm/s)			0.036
	d_l	(µm)			50

The following conclusions can be drawn from above calculations:

- Installation of a plate pack in the settler gives a substantial improvement of the separation performance.
  Comparison of the corresponding two tables shows that with the selected plate pack layout for both phases the cut-off diameter will be reduced from about 110 µm to about 40 - 50 µm.
- Selection of a plate pack length of 1 m results in cut-off diameters close to the diameter which can be achieved with a plate pack in practice. It is therefore concluded that in this particular case it is not necessary to install a longer plate pack.

APPENDIX V THREE-PHASE SETTLERS

V.1. CHECK OF AN EXISTING HORIZONTAL OPEN THREE-PHASE SETTLER FITTED WITH A BOOT

(See also main text (4.1.3) and Figure 4.1)

This procedure can also be treated as the sizing procedure for a new settler starting with the specification of the vessel dimensions and the various level control heights.

The various steps taken in the procedure are described below.

Input

1. Diameter and tangent/tangent length of vessel and boot.
2. The volumetric flow rate and density of the gas and liquid phases and the dynamic viscosity of the liquid phases.
3. Control levels of both G/L and L/L interface.
4. Required minimum control times for G/L and L/L interface control.
5. The maximum allowable gas load factor, λ_{max}, in the gas cap above LZA(HH).
   With bulk separation: λ_{max} = 0.07 m/s.
6. Specification of foam allowance and/or dispersion band.

   If a L/L dispersion band is present in the boot, the distance between each pre-alarm and trip level has to be increased by half the width of the dispersion band.

   If a dispersion band is expected but there is insufficient information for its width to be estimated using the formula given in Appendix I, it is suggested that 0.2 m be taken as dispersion band width.

   If a foaming system is present, normally a foam allowance of 250 mm is taken which has to be accommodated between LA(H) and LZA(HH).
7. Specification of slug size

Calculations

1. Check of vessel dimensions with respect to de-gassing (if required)

$$D_{ves}*L_{ves} \geq \{4.5*10^7(Q_l + Q_h)\eta_l/(\rho_l - \rho_G)\}$$

2. Check of vessel dimensions with respect to de-foaming (if required)

$$D_{ves}*L_{ves} \geq 7000(Q_l + Q_h)\{\eta_l/(\rho_l - \rho_G)\}^{0.27}$$

The de-gassing and de-foaming criteria (also described in DEP 31.22.05.11-Gen.), are based here on the physical properties of the light liquid and the total liquid flow rate.

3. Check of selected G/L control levels

The following criteria shall be satisfied:

1. $LZA(HH)/D_{ves} \leq 0.8$
2. D_{ves} - LZA(HH) ≥ 0.3
3. The gas gap area above LZA(HH), A_G, is expressed as:

$$A_G \geq Q_G / \lambda_{max} \sqrt{\rho_G / (\rho_l - \rho_G)}$$

   A_G follows directly from LZA(HH) and D_{ves} utilising the chord area - chord height relationships presented in Appendix VI.
4. The height of the various control bands shall have a minimum height (including, if required, a foaming and a slug accommodation allowance) as specified in Appendix X.

5. The ratio LZA(LL)/D ≥ 0.2

4. Check of selected L/L control levels in the boot

The following criteria should be satisfied:

1. If trip levels are specified, $LZA(HH)_{int}$ - $LA(H)_{int}$ and $LA(L)_{int}$ - $LZA(LL)_{int}$ shall be at least equal to 100 mm plus half of the dispersion band (if specified)
   If a dispersion band is expected but there is insufficient information for its width to be estimated using the formula given in Appendix I, it is suggested that 0.2 m be taken as dispersion band width.
2. The distance of the control band from the vessel bottom and from the boot bottom tangent should be at least 200 mm.

5. Calculation of the various control times of the L/L level control

From the flow rate of the heavy phase, Q_h, and boot diameter, D_{boot}, the downward liquid velocity in the boot, $v_{h,boot}$, is calculated:

$$v_{h,boot} = Q_h/(\pi/4 * D^2_{boot}) \qquad \text{m/s}$$

From this velocity and the specified control levels the associated control times of the heavy-phase liquid are calculated:

$$t_{HH\_H,h} = (LZA(HH)_{int} - LA(H)_{int} - 0.5H_{db})/\ v_{h,boot}$$

$$t_{H\_L,h} = (LA(H)_{int} - LA(L)_{int})/\ v_{h,boot} - V_{slug}/(Q_l + Q_h)$$

(assumption: the slug has the same ratio of light and heavy liquid phases as the regular feed)

$$t_{L\_LL,h} = (LA(L)_{int} - LZA(LL)_{int} - 0.5H_{db}) / v_{h,boot}$$

It has to be checked whether the calculated control times are at least equal to the specified minimum control times. If not, the control levels shall be adjusted.

In the case of a new vessel, of course D_{boot} and/ or L_{boot} can be adjusted.

6. Calculation of the various control times of the G/L level control

In the case of a foaming system, first the foam allowance has to be subtracted from the value of LZA(HH) for proper calculation of the control time associated with the band between LZA(HH) and LA(H).

Subsequently the cross-sectional areas of the various control bands are calculated from the vessel diameter and the various control levels with the aid of the chord area - chord height relationships presented in Appendix VI.

Finally the various control times of the light-liquid phase are calculated with the following formulae.

$$t_{HH\_H,l} = \{L_{ves}*A_{con,HH\_H} + 2\Delta V_{hd,HH\_H}\}/\ Q_l - (t_{HH\_H,h})_{spec} * Q_h/Q_l$$

$$t_{H\_L,l} = \{L_{ves}*A_{con,H\_L} + 2\Delta V_{hd,H\_L} - V_{slug}\}/\ Q_l - (t_{H\_L,h})_{spec} * Q_h/Q_l$$

$$t_{L\_LL,l} = \{L_{ves}*A_{con,L\_LL} + 2\Delta V_{hd,L\_LL}\}/\ Q_l - (t_{L\_LL,h})_{spec} * Q_h/Q_l$$

In the above formulae the **specified** rather than the calculated control times for the heavy phase have been taken into account.

The relationship for ΔV_{hd} as a function of its boundaries and the vessel diameter is also given in Appendix VI.

It has to be checked whether the calculated control times are at least equal to the specified minimum control times.
If not, the control levels shall be adjusted.
In the case of a new vessel, of course D_{ves} and/ or L_{ves} can be adjusted.

7. Sizing of the compartments

Inlet compartment

This is the part of the vessel between the vessel tangent line closest to feed inlet and calming plate.

recommended: L_{in} =0.5D

Outlet compartment

This is the part of the vessel between the other vessel tangent line and the light phase outlet nozzle

typically: L_{out} =0.25D

Settling compartment

This is the intermediate part of the vessel. It contains the boot.

$L_{set} = L_{ves} - L_{in} - L_{out}$

Obviously, if L_{set} is very small, or even negative (!), smaller values for L_{in} and L_{out} shall be selected.

8. Calculation of the smallest light-phase and smallest heavy-phase droplet which can still be separated off

Heavy-phase droplets in settling compartment

$$d_h = \sqrt{18\eta_l(v_{dh,set} + 0.05v_{l,ax} / \{g(\rho_h - \rho_l)\}}$$

with $v_{dh,set} = LZA(LL)_{int} v_{l,ax} / L_{set}$

and $v_{l,ax} = (Q_l + Q_h) / A_l$

A_l is calculated from the vessel diameter D and LZA(LL), using the formulae given in Appendix VI.

It has to be checked that $v_{l,ax}$ does not exceed 0.015 m/s, because this may result in a larger value of d_h than given by above formula.

$v_{l,ax}$ can be decreased by selecting a lower $LZA(HH)_{int}$

Light-phase droplets in boot

$$d_l = \sqrt{18\eta_h(1.05v_{h,boot} / \{g(\rho_h - \rho_l)\}}$$

CALCULATION EXAMPLE

For an existing three-phase separator with a boot a check has to be performed to establish whether it is still able to perform an adequate three-phase separation in a future flow scenario in which all the flow rates will be increased.

Future flow conditions are :

Gas: mass flow rate of 167 t/d with a density of 10 kg/m^3

Oil: mass flow rate of 410 t/d with a density of 750 kg/m^3 and a dynamic viscosity of 0.5 mPa.s

Water: mass flow rate of 20 t/d with a density of 990 kg/m^3 and a dynamic viscosity of 0.9 mPa.s

- Design margin is 1.2
- Only bulk G/L and L/L separation is required.
- Non-foaming feed but slugs up to 1 m^3 can be expected
- No dispersion band in the oil/water interface
- G/L and L/L level control:
  3 minutes between high and low level (pre-alarms)
  1 minute between pre-alarm and trip

The layout of the vessel is similar to the one shown in Figure 4.1.
The feed nozzle is fitted with an elbowed half-open pipe as is shown in the figure.
However, no calming baffle is present.

Further information:
- Vessel: diameter 1.4 m and T/T of 4.2 m (heads semi-elliptical with a ratio of 2:1)
- Boot: diameter of 0.45 m and a length (to BTL) of 1.20 m
- Nozzles: diameters of feed inlet, gas outlet, oil outlet and water outlet are 0.20, 0.15, 0.10 and 0.05 m respectively; distance of oil outlet from "right" vessel tangent line is 0.35 m

Check

The first action is to propose a perforated baffle (30% NFA and hole diameter of 12 mm at a distance of 0.7 m (=0.5D_{ves}) from the "left" vessel tangent line to promote the dewatering of the oil).

Attempts are made by appropriate selection of the various control levels to meet all the requirements.

As far as G/L separation is concerned, λ_{max} = 0.07 m/s, since there are no G/L internals and bulk separation is required (DEP 31.22.05.11-Gen.: Horizontal Knock-out Drum).

The normal procedure is to select LZA(HH), such that the G/L separation criterion is satisfied, also bearing in mind that D_{ves} - LZA(HH) $\geq$ 0.3 m and that LZA(HH)/D_{ves} $\leq$ 0.8.

The height of the perforated baffle shall be at least as high as LZA(HH).

In the following Table the final choice of the various control levels is presented.
Checks have been carried out on the correctness of this choice.
The nozzles have also been checked and the separation performance of the settler has been calculated following the calculation scheme as outlined in Appendix V.2.

check on de-gassing (step 1)	$D_{ves}*L_{ves}$ (m^2)	5.88	minimal requirement: 0.239 m^2	OK
check of chosen levels +	LZA(HH)(m) (≡ height of calming baffle)	0.98	$LZA(HH)/D_{ves}$ =0.7 < 0.8 D_{ves} - LZA(HH) = 0.42 m > 0.3 m λ_G = 0.069 m/s < 0.07 m/s (λ_{max})	OK OK OK
calculation of control times	LA(H) (m)	0.88	LZA(HH)-LA(H)=0.1 m (min.) t_{HH_H} = 78 sec >60 sec	OK OK
	LA(L) (m)	0.52	LA(H)-LA(L)= 0.38 m > 0.35 m t_{H_L} = 180 sec = 180 sec	OK OK
(steps 3 to 6)	LZA(LL) (m)	0.42	LA(L)-LZA(LL)=0.1 m (min.) t_{L_LL} = 78 sec >60 sec LZA(LL) > 0.3 m $LZA(LL)/D_{ves}$ = 0.3 > 0.2	OK OK OK OK
	$LZA(HH)_{int}$ (m)	-0.20	distance to vessel bottom 0.2 m	OK
	$LA(H)_{int}$ (m)	-0.31	$LZA(HH)_{int}-LA(H)_{int}$=0.1 m (min.) $t_{HH\_H,int}$ = 62 sec > 60 sec	OK OK
	$LA(L)_{int}$ (m)	-0.89	LA(H)-LA(L)= 0.38 m > 0.35 m $t_{H\_L,int}$ = 202 sec > 180 sec	OK OK
	$LZA(LL)_{int}$ (m)	-1.00	$LA(L)_{int}-LZA(LL)_{int}$=0.1 m (min.) $t_{L\_LL,int}$ = 62 sec >60 sec dist. to BTL boot 0.2 m	OK OK OK
step 7	L_{in}(m) L_{out}(m) L_{set} (m)	0.70 0.35 3.15		
step 8	$v_{l,ax}$ (cm/s) $v_{dh,set}$ (cm/s) d_h (µm) $v_{h,boot}$ (cm/s) d_l (µm)	2.03 0.27 119 0.18 113	$v_{l,ax}$ > 1.5 cm/s	NOT OK
nozzle check	N1: $\rho_m v_m^2$ (Pa) N2: $\rho_G v_G^2$ (Pa) N3: v (m/s) N4: v (m/s)	1399 1196 0.81 0.12	$\rho_m v_m^2$ < 1500 Pa $\rho_G v_G^2$ < 3750 Pa v < 1 m/s v < 1 m/s	OK OK OK OK

The following conclusions can be drawn from the calculations:

- The de-gassing criterion has been met.
- The control levels have been properly selected.
- The requirements for proper G/L and L/L separation have also been satisfied.:
  - At maximum gas flow and with the G/L interface at LZA(HH), the gas load factor is just below 0.07 m/s.
  - d_h and d_l are both well below 150 µm.
- $v_{l,ax}$ is somewhat higher than the limit of 1.5 cm/s.
  However this corresponds to the extreme condition that the G/L level is at LZA(LL) (= 0.42 m).
  If the G/L level is at 0.52 m which is still lower than the level at which the settler will operate most of the time, then $v_{l,ax}$ is 1.5 cm/s, so with hindsight the calculated value is acceptable.

V.2. RETROFIT OPTION FOR EXISTING HORIZONTAL OPEN THREE-PHASE SETTLERS TO BE FITTED WITH WEIRS (INCLUDING PLATE PACK OPTION)

(See also main text (4.1.4) and (4.2) and Figures 4.4, 4.5 and 4.6)

This procedure can also be treated as the sizing procedure for a new settler starting with the specification of the vessel dimensions and the various level control heights.

The various steps taken in the procedure are described below.

Input

1. Diameter and tangent/tangent length of vessel.
2. Volumetric flow rate and density of the gas and liquid phases and dynamic viscosity of the liquid phases.
   If there are flow scenarios with different densities, all densities shall be considered.
3. Specification of LZA(HH) and IL.
   (IL can be adjusted during the calculations)
4. The maximum allowable gas load factor, λ_{max}, in the gas cap above LZA(HH).
   In the case of bulk separation with no demisting internals: λ_{max} = 0.07 m/s.
5. The height of the passage underneath the water underflow weir (at least 0.2 m) and the distance between the water underflow and water overflow weir typically 0.2 m).
6. Collection compartments: required minimum control times
7. Specification of foam allowance and/or dispersion band
   If a L/L dispersion band is present in the boot, the distance between each pre-alarm and trip level has to be increased by half the width of the dispersion band.
   In the case of a foaming system, for this type of separator the foam allowance has to be accommodated between LZA(HH) and NL. Typical foaming allowance is 0.25 m.
   If a dispersion band is expected but there is insufficient information for its width to be estimated using with the formula given in Appendix I, it is suggested that 0.2 m be taken as dispersion band width.
8. Specification of slug size for both liquid phases.

Calculations

1. Check of selected LZA(HH)

The following criteria shall be satisfied:

1. $LZA(HH)/D_{ves} \leq 0.8$
2. $D_{ves} - LZA(HH) \geq 0.3$ m
3. The gas gap area above LZA(HH), A_G, is expressed as

$A_G \geq Q_G / \lambda_{max} \sqrt{\rho_G / (\rho_l - \rho_G)}$

A_G follows directly from LZA(HH) and D_{ves} utilising the chord area - chord height relationships presented in Appendix VI.

If the above criteria are not satisfied a smaller value has to be selected for LZA(HH).

2. Calculation of the elevation of the normal liquid level, NL

NL is the sum of the height of the light phase overflow weir and its weir crest.
It follows directly from LZA(HH) by subtracting the specified distance between LZA(HH) and NL, ΔH_{HH_NL}

ΔH_{HH_NL} is typically 0.1 m for non-foaming and 0.35 m for foaming systems.

$NL = LZA(HH) - \Delta H_{HH\_NL}$

3. Calculation of the height of the weirs

The height of the light phase overflow weir follows directly from NL and the height of the weir crest on top of the weir, $h_{crest,l}$

$h_{ow,l} = NL - h_{crest,l}$ m

with $h_{crest,l} = 0.670\{Q_l^2/(D*NL-NL*NL)\}^{0.333}$ m

The height of the heavy liquid phase overflow weir is given by the following function of the light and heavy liquid densities (ρ_l and ρ_h respectively), NL, the liquid/liquid interface level, IL and the weir crest on top of the weir, $h_{crest,h}$:

$h_{ow,h} = IL + (NL-IL)\rho_l/\rho_h - h_{crest,h}$ m

with $h_{crest,h} = 0.670[Q_h^2/(D*\{IL + (NL - IL)\rho_l/\rho_h\} - \{IL + (NL - IL)\rho_l/\rho_h\}^2)]^{0.333}$ m

IL should be halfway between the top of the underflow passage ,h_{up}, of the heavy phase front weir and the top of the light phase overflow weir.

that is: $IL = (h_{ow,l} + h_{up})/2$

The input value for IL can now be changed to this preferred value.
It can also be kept at its original value, provided that the following requirements are satisfied:

- $(IL-0.5H_{db})/D_{ves} \geq 0.2$
- IL shall be at a distance of at least $0.5H_{db}$ + 0.2 m from either the lower rim of the heavy-phase underflow weir or from the upper rim of the light-phase overflow weir.

h_{up} has been specified in the input and is at least 0.2 m.

The height of the heavy phase front weir, $h_{fw,h}$ follows directly from LZA(HH).

$h_{fw,h} = LZA(HH) + 0.1$ m

If there are flow scenarios with different densities it shall be checked that the above requirements are met for all densities.

4. Calculation of the axial liquid velocities in the settling compartment and in the underflow passage

For a given IL, A_l (cross-sectional area between NL and $(IL+H_{db})$) and A_h (cross-sectional area between $(IL-H_{db})$ and vessel bottom) can now be calculated from the various levels with the aid of the formulae of Appendix VI.

Subsequently:

$v_{l,ax} = Q_l/A_l$

$v_{h,ax} = Q_h/A_h$

Similarly, from the given central height of the passage underneath the water front weir, h_{up}, the velocity in the passage can be calculated.

$v_{up} = Q_h/A_{up}$

A_{up} also follows from the relationships given in Appendix VI, taking into account that only a part of the cross-sectional area below h_{up} is used for the underflow passage (50% if the collection compartments have the same width).

5. Sizing of the compartments

Inlet compartment

$L_{in} = 0.5D$.

This determines the location of the calming baffle.

Collection compartments

From the liquid flow rates, estimated slug sizes (if they are expected) and the specified control times it follows which volume has to be contained between the high and low level control in each collection compartment.
For the calculations the slug (if any) has to be split up in a heavy-phase and a light-phase part.
If split-up is not known, take as default:

$V_{slug,l} = V_{slug} * Q_l/(Q_l + Q_h)$

$V_{slug,h} = V_{slug} * Q_h/(Q_l + Q_h)$

For the volume contained between the pre-alarm levels in each collection compartment is given by:

$V_{H\_L,l} = Q_l * (t_{con,l})_{spec} + V_{slug,l}$

$V_{H\_L,h} = Q_h * (t_{con,h})_{spec} + V_{slug,h}$

From the specified high and low liquid levels in each collection compartment (which should be at a distance of 0.2 m from the top of the corresponding overflow weir and 0.2 m from the bottom of the vessel, respectively) follow the effective lengths of the light and heavy liquid phase collection compartments, $L_{coleff,l}$ and $L_{coleff,h}$ respectively.

First for each collection compartment the effective length is calculated (assuming the longitudinal compartment separation plate between the collection compartments is in the middle of the vessel (i.e. coinciding with the vessel axis). In this effective length the contribution of the vessel heads has not been taken into account.

In the case of a large Q_l/Q_h ratio:

$L_{coleff,l} = (Q_l * (t_{con,l})_{spec} - \Delta V_{hd,l} + V_{slug,l})/A_{H\_L,l}$

$L_{coleff,h} = (Q_h * (t_{con,h})_{spec} + V_{slug,h})/A_{H\_L,h}$

In the case of a small Q_l/Q_h ratio:

$L_{coleff,l} = (Q_l * (t_{con,l})_{spec} + V_{slug,l})/A_{H\_L,l}$

$L_{coleff,h} = (Q_h * (t_{con,h})_{spec} - \Delta V_{hd,h} + V_{slug,h})/A_{H\_L,h}$

$L_{col} = (L_{coleff,h} + L_{coleff,l} + w_{ww})/2$

w_{ww} is the distance between the two water weirs.

w_{ww} is min. 0.2 m.

$A_{H\_L,l}$ and $A_{H_L,h}$are the cross-sectional areas of the light and heavy liquid phases collection compartments respectively between LA(H) and LA(L) just downstream of the weirs.
They are half of the corresponding vessel cross-sectional areas.
These areas and also ΔV_{hd} of the largest liquid collection compartment are calculated using the relationships presented in Appendix VI.

The length of the smallest collection compartment will then also determine the location of the transversal separation plate (i.e. plate perpendicular to the vessel axis) between the collection compartments.

6. Settling compartment

$$L_{set} = L_{ves} - L_{in} - L_{col}$$

Obviously, if L_{set} is very small, or even negative (!), smaller values for L_{in} and L_{col} shall be taken.
Depending on the feed internal to be used, a smaller value for L_{in} could be selected.
Also it may be possible to relax the control time requirements which will result in a smaller value of L_{col}

The smallest droplets which can be separated off are given by the following relationships:

heavy-phase droplet:

$$d_h = \sqrt{18\eta_l(v_{dh,set} + 0.05v_{l,ax} / \{g(\rho_h - \rho_l)\}}$$

with $v_{dh,set} = \{NL - IL - 0.5H_{db}\}v_{l,ax}/L_{set}$

It has to be checked that $v_{l,ax}$ does not exceed 0.015 m/s, because this may result in a larger value of d_h than given by above formula.
$v_{l,ax}$ can be decreased by selecting a lower IL.

light-phase droplet:

$$d_l = \sqrt{18\eta_l(v_{dl,set} + 0.05v_{h,ax} / \{g(\rho_h - \rho_l)\}}$$

with $v_{dl,set} = (IL - 0.5H_{db})v_{h,ax}/L_{set}$

It has to be checked that $v_{h,ax}$ does not exceed 0.015 m/s, because this may result in a larger value of d_l than given by above formula.
$v_{h,ax}$ can be decreased by selecting a higher IL.

If the smallest droplets which can be separated off are still too large, the following actions could be considered in the following order:

a. Adjust IL, if the above limitation holds only for either the heavy or light phase.
Of course this will have consequences for the various weir heights and also possibly for L_{col}.
IL shall be at a distance of at least $0.5H_{db}$ + 0.2 m from either the lower rim of the heavy-phase underflow weir or from the upper rim of the light-phase overflow weir.

b. Install a plate pack in the settling compartment possibly in conjuction with an adjustment of IL.
In Appendix II rules and background are given for the sizing of a plate pack.
Below (under point 9) the major steps are given.

7. Check of vessel dimensions with respect to de-gassing (if required)

$$D_{ves}*(L_{in} + L_{set}) \geq \{4.5*10^7(Q_l + Q_h)\eta_l/(\rho_l - \rho_G)\}$$

8. Check of vessel dimensions with respect to de-foaming (if required)

$$D_{ves}*(L_{in} + L_{set}) \geq 7000(Q_l + Q_h)\{\eta_l/(\rho_l - \rho_G)\}^{0.27}$$

The de-gassing and de-foaming criteria (also described in DEP 31.22.05.11-Gen.) are based here on the physical properties of the light liquid and the total liquid flow rate.
In the case of this type of settler the collection compartments have not been taken into account.

9. Installation of a plate pack in the settling compartment

The performance of the existing three-phase separator can be upgraded with the installation of a plate pack.

The plate pack to be installed will extend from vessel bottom to NL and its distance from the calming baffle of the inlet compartment is 150 mm.

Below the procedure is given for assessing its performance as a function of the selected plate pack characteristics (plate spacing, angle between plates and horizontal plane and length of the plate pack) and of the flow conditions.

The following steps should be taken:

9a. Determine the part of the gross frontal plate pack area, $A_{f,gross}$, which can be accommodated in the vessel cross-sectional area between NL and (IL+0.5H_{db}) and between (IL-0.5H_{db}) and vessel bottom respectively.

$$(A_{f,gross})_l = F_{pp}A_l$$

$$(A_{f,gross})_h = F_{pp}A_h$$

F_{pp} is assumed to be the same for both areas and is typically 0.8

9b. Calculate the corresponding net free area, $A_{f,net}$, taking into account the plate thickness t_{pp}, a selected plate distance d_{pp} and the loss factor F_{loss}

$$(A_{f,net})_l = (A_{f,gross})_l*F_{loss}*d_{pp}/(t_{pp} + d_{pp})$$

$$(A_{f,net})_h = (A_{f,gross})_h*F_{loss}*d_{pp}/(t_{pp} + d_{pp})$$

F_{loss} is typically in the range of 0.9 to 0.95 and t_{pp} is typically 1 mm

9c. Check the selected d_{pp}.

The distance between the plates, d_{pp}, has to be selected such that it is sufficiently small to ensure laminar flow in the plate pack but it shall not be smaller than a given minimum distance, $d_{pp,min}$. This minimum distance is 10 mm for non-fouling conditions and 40 mm for fouling conditions.

Both the following criteria should be satisfied:

for upper part of plate pack:

$$d_{pp,min} \leq d_{pp} \leq Re_{crit}\eta_l(A_{f,net})_l/(2\rho_l Q_l)$$

for lower part of plate pack:

$$d_{pp,min} \leq d_{pp} \leq Re_{crit}\eta_h(A_{f,net})_h/(2\rho_h Q_h)$$

Re_{crit} is the critical Reynolds number above which the flow regime will no longer be laminar.

If flat plates (with front and rear contours) are used, then Re_{crit} is 850;
if corrugated plates are used then Re_{crit} is 450.

If d_{pp} is too large to ensure laminar flow, select a smaller value and repeat steps 9b and 9c.

If the above criteria still cannot be satisfied for $d_{pp} = d_{pp,min}$, then the minimum distance should be used for d_{pp}, accepting the deviation from laminar flow. It should then be realised that although turbulent flow in the plate pack will affect the separation, the separation will still be better than if no plate pack were used.

9d. Determine the angle θ of the plates with the horizontal plane (45° in non-fouling service and 60° in fouling service).

9e. Select the length of the plate pack, L_{pp}

For the length of the plate pack, L_{pp}, it is recommended that:

$L_{pp,max} = L_{set} - 0.65$ m

(distance from calming plate and collection compartments 0.15 and 0.5 m, respectively)

$L_{pp,min} = 0.3$ m

If Lset < 0.95 m, the above requirements cannot be met and compromises will be necessary, for which the Principal should be consulted.

9f. Calculate the separation performance of the plate pack

If the flow in the plate pack is laminar, the smallest droplets to be separated for both phases are given by the following relationships:

heavy-phase droplet:

$$d_h = \sqrt{18\eta_l v_{dh,set} / \{g(\rho_h - \rho_l)\}}$$

with $v_{dh,set} = v_{l,pp} d_{pp} / \{\cos\theta\ (L_{pp} - 8d_{pp})\}$

in which $v_{l,pp} = Q_l / (A_{f,net})_l$

light-phase droplet:

$$d_l = \sqrt{18\eta_h (v_{dl,set} / \{g(\rho_h - \rho_l)\}}$$

with $v_{dl,set} = v_{h,pp} d_{pp} / \{\cos\theta\ (L_{pp} - 8d_{pp})\}$

in which $v_{h,pp} = Q_h / (A_{f,net})_h$

$v_{l,pp}$ and $v_{h,pp}$ are the axial velocities in the upper and lower separation part of the plate pack.
$v_{l,ax}$ and $v_{h,ax}$ are the axial velocies in the light and heavy liquid phase upstream of the plate pack.
The term $8d_{pp}$ in the expression for $v_{dh,set}$ and $v_{dl,set}$ is a correction for the non-laminar flow in the entrance of the plate pack (see also Appendix II).

If the calculated drop sizes are still too large, a larger L_{pp} has to be selected (if still allowed by the vessel geometry) and step 9f has to be repeated.

CALCULATION EXAMPLE

From an existing horizontal vessel with an ID 1.4 m and T/T of 4 m (semi-elliptical heads: ratio 2:1) and no internals it has to be checked whether it can be converted into a three-phase separator which can handle the following process conditions:

Oil: mass flow rate is 60 t/d with a density of 750 kg/m^3 and a dynamic viscosity of 0.5 mPa.s
Water: mass flow rate is 410 t/d with a density of 990 kg/m^3 and a dynamic viscosity of 0.9 mPa.s
Gas: mass flow rate is 2 t/d with a density of 0.2 kg/m^3

- Clean service.
- Feed has no foaming tendency.
- Design margin is 1.2.

- There are no liquid slugs to be expected.
- Allowance has to be made for a dispersion band of 0.2 m in the oil/water interface.
- Only bulk separation is required.
  (If no G/L separation internals are used, then in gas cap above LZA(HH), λ_{max} = 0.07 m/s).
- Minimum control time for the two liquid phases is 180 sec (between LA(H) and LA(L).
- The vessel shall also act as a sealing vessel (to preserve vacuum conditions in upstream equipment).
- Further, both the location and size of the various nozzles may be changed.

Selection of type of three-phase separator

In view of the large water/oil ratio it has been decided to convert the vessel into a three-phase separator with a weir arrangement, calming baffle and collection compartments for the separated liquid phases as shown in the top part of Figure 4.5.

The required sealing function calls for a bottom feed inlet.

Further input

LZA(HH)	=	1.1m	(in view of the small gas load, the height of the gas cap has been taken at its minimum value of 0.3 m)
IL	=	0.6m	
h_{up}	=	0.2m	
w_{ww}	=	0.2m	

Calculations

Step1:

The selected LZA(HH) is correct since :

$LZA(HH)/D_{ves}$ = 0.786 < 0.8

D_{ves} - LZA(HH) = 0.3 m

$$A_G = 0.2419 \;>\; Q_G / \lambda_{max} \sqrt{\rho_G / (\rho_l - \rho_G)} = 0.0324 \quad m^2$$

Step 2:

Non-foaming system, therefore select NL = LZA(HH) - 0.10 = 1.00 m

Step 3:

$h_{crest,l}$ = 9.8 mm
$h_{ow,l}$ = NL - $h_{crest,l}$ = 0.990 m

$h_{crest,h}$ = 28.2 mm
$h_{ow,h}$ = IL + (NL-IL)ρ_l/ρ_h - $h_{crest,h}$ = 0.875 m

NOTE The selected value for IL is very close to the preferred location of IL (($h_{ow,l}$ + h_{up})/2 = 0.595 m)

Further checks of IL:

(IL - 0.5 H_{db})/D_{ves} = 0.357 > 0.2	OK
($h_{ow,l}$ - IL - 0.5H_{db} = 0.295 > 0.2 m	OK
IL - 0.5H_{db} - h_{up} = 0.300 > 0.2 m	OK

Step 4:

$v_{l,ax}$ = 0.27 cm/s < 1.5 cm/s	OK
$v_{h,ax}$ = 1.17 cm/s < 1.5 cm/s	OK
v_{up} = 8.53 cm/s	is relatively high

If required, by increasing h_{up} up to 0.3 m (max. value, see step 3), then v_{up} can be brought down to 4.76 cm/s

Step 5:

L_{in} = 0.7 m

It has been assumed that in both collection compartments LA(L) is at 0.2 m and LA(H) is 0.2 m below the rim of the corresponding overflow weir.

$L_{coleff,l}$ = 0.53 m

$L_{coleff,h}$ = 2.95 m

L_{col} = 1.84 m

The real lengths of the oil and water collection compartments are 0.53 and 1.64 m, respectively.

Step 6:

$L_{set} = L_{ves} - L_{in} - L_{col}$ = 1.46 m

$v_{dh,set}$ = 0.056 cm/s

d_h = 52 µm

$v_{l,ax}$ = 0.27 cm/s < 1.5 cm/s OK

$v_{dl,set}$ = 0.399 cm/s

d_l = 177 µm slightly exceeds 150 µm (criterion for bulk separation)

$v_{h,ax}$ = 1.17 cm/s < 1.5 cm/s OK

Step 7:

Check on de-gassing:

According to the criterion, the product $D_{ves} * (L_{in} + L_{set})$ shall be at least 0.206 m^2.

Since $D_{ves} * (L_{in} + L_{set}) = 1.4 * 2.160 = 3.024$ m^2 , proper de-gassing will take place.

Step 8:

Since there is no foaming tendency, check on de-foaming is not required.

Nozzle sizing (no design margin!)

Feed nozzle N1: velocity ≤ 1 m/s. Select a diameter of 0.4 m.

Gas outlet nozzle N2: $\rho_G v_G^2 \leq 3750$ Pa. Select a diameter of 0.05 m

Oil outlet nozzle N3: velocity ≤ 1 m/s. Select a diameter of 0.05 m.

Water outlet nozzle N4: velocity ≤ 1 m/s. Select a diameter of 0.1 m.

It can be concluded from the above calculations that the separator will perform well as far as the G/L separation and dewatering of the oil is concerned, but will be borderline as far as the de-oiling of the water is concerned.

Therefore it will be investigated to what extent the de-oiling performance of the settler can be upgraded by installating a plate pack in the settling compartment.

Upgrading of the separation performance by installating a plate pack

The layout of the separator fitted with a plate pack is shown in Figure 4.6.

Because of the clean service flat plates will be selected with an angle of 45° (thickness of 1 mm).
The start value for the plate spacing is 20 mm.

The maximum space available for the plate pack is 1.46 - 0.65 = 0.81 m
A length of 0.8 m has been selected.

Further input:

- F_{pp} is 0.8
- F_{loss} is 0.9
- correction of effective plate pack length for turbulence in entrance: subtract 8 times the plate spacing

In the following Table the calculations are presented following the calculation scheme as outlined in Appendix IV.3.

selection of plate spacing		d_{pp} is 20 mm start value
step 9a	$(A_{f,gross})_l$, m^2	0.325
	$(A_{f,gross})_h$, m^2	0.395
step 9b	$(A_{f,net})_l$, m^2	0.279
	$(A_{f,net})_h$, m^2	0.338
step 9c	$(d_{pp,max})_l$, mm	71
	$(d_{pp,max})_h$, mm	23
	check of d_{pp}	**OK** no turbulence proceed with step 9d
step 9d	θ, degrees (input)	45
step 9e	L_{pp}, m (input)	0.800
step 9f	$v_{l,pp}$, cm/s	0.40
	$v_{dh,set}$, cm/s	0.018
	d_h, µm	26
	$v_{h,pp}$, cm/s	1.70
	$v_{dl,set}$, cm/s	0.075
	d_l, µm	72

It can be concluded that installation of a plate pack will give a substantial improvement of de-oiling performance in particular.
The cut-off diameter of the oil droplets will be reduced from 177 to 72 µm.

V.3. SIZING OF A VERTICAL THREE-PHASE SETTLER WITH PLATE PACK

CALCULATION EXAMPLE

A three-phase separator has to be designed for the following flow conditions:

Gas: mass flow rate is 1600 t/d with a density of 2.6 kg/m^3

Oil: mass flow rate is 1500 t/d with a density of 750 kg/m^3 and a dynamic viscosity of 0.5 mPa.s

Water: mass flow rate is 800 t/d with a density of 990 kg/m^3 and a dynamic viscosity of 0.9 mPa.s

- Design margin is 1.1
- Both the G/L and L/L (in particular de-watering) separation has to be efficient (cut-off diameter of water droplets 50 µm)
- Clean service
- There is no foaming tendency
- Gas carry-under shall be avoided
- There is no dispersion band expected in the L/L interface
- There are no slugs to be expected

- Min. control time for G/L and L/L separation (between high and low level (or pre-alarm levels)) is 3 minutes
- Min. flow time between all pre-alarm and trip levels is 1 minute

In view of the high gas load, clean service and the requirement of efficient G/L and L/L separation the type of separator to be selected is a vertical separator fitted with a plate pack and a mist mat (see also Table 2.1).

Design

First the nozzles are sized according to Appendix VIII.

Subsequently the design of the vessel is carried out following the calculation scheme as outlined in (4.3).

Nozzles (do not use a design margin for the sizing of the nozzles)

N1: feed inlet (fitted with Schoepentoeter); diameter is 0.55 m
$\rho_m v_m^2$ = 5722 Pa < 6000 Pa

N2: gas outlet; diameter is 0.50 m
$\rho_G v_G^2$ = 3421 Pa < 3750 Pa

N3: oil outlet (fitted with vortex breaker); diameter is 0.20 m
v = 0.74 m/s < 1 m/s
vortex breaker halfway between LZA(LL) and $LZA(HH)_{int}$

N4: water outlet (fitted with vortex breaker); diameter is 0.15 m
v = 0.53 m/s < 1 m/s

Diameter

According to DEP 31.22.05.11-Gen, the maximum allowable gas load factor for a vertical wiremesh demister with the mist mat over the total cross-section of the separator, taking into account the specified flow conditions, is 0.101 m/s.

Round off to 0.10 m/s.

Therefore, to satisfy the gas handling criterion:
$D \geq 2.43$ m

To satisfy the de-gassing criterion:
$D \geq 1.58$ m

The gas handling determines D: D = 2.43 m

Layout of the plate pack

Select a plate pack with the following characteristics:

- plate spacing is 20 mm
- plate angle is 45°
- plate thickness is 1 mm
  (small plate angle and plate spacing permitted because of clean service; for further background see Appendix II)

It has been assumed that:

- F_{loss}= 0.9
- critical plate pack Reynolds number is 850

The following valves are calculated according to Appendix II, assuming that the Reynolds number is at its critical (maximum) value:

$(A_{f,net})_l$ = 1.797 m^2

$(A_{f,gross})_l$ = 2.097 m^2

$(A_{f,net})_h$ = 0.533 m^2

$(A_{f,gross})_h$ = $0.621\ m^2$

L_{pp} is determined by the dewatering requirement (d_h = 50 µm)

L_{pp} = 0.77 m

(A correction term of $8*d_{pp}$ has been included to compensate for the turbulence in the entry region).

This plate pack length results also in a relatively efficient de-oiling of the water:
d_l = 79 µm.

From L_{pp} and D it follows that W_{pp} < 2.03 m
Take as initial value W_{pp} = 2.00 m

$H_l = (A_{f,gross})_l/W_{pp}$ = 1.05 m; H_l/W_{pp} = 0.52

$H_h = (A_{f,gross})_h/W_{pp}$ = 0.31 m; H_h/W_{pp} = 0.16

Both heights are larger than 0.3 m
The ratio H_h/W_{pp} is lower than 0.5. This will result in a larger value of d_l than that originally calculated (79 µm). However since the de-oiling is not critical and the calculated value of d_l is low, this low H_h/W_{pp} ratio is still acceptable.
Therefore the initial choice of W_{pp} can be maintained.

Check on location of N3:

Distance of vortex breaker from $LZA(HH)_{int}$ is 0.52 m > 0.2 m; OK.

$H_{contot} = Q_h * \Sigma t_{con} /(0.25\pi\ D^2)$ = 0.68 m

$H_{pp} = H_l + H_h + H_{contot}$ = 2.04 m

T/T of separator

Following paragraph F in (4.3):

X_1 = 2.31 m (height required for G/L level control)

X_2 = 0.15 m

X_3 = 0.57 m

X_4 = 0.55 m

X_5 = 0.10 m

X_6 = 0.36 m

$H = H_{pp} + X_1 + X_2 + X_3 + X_4 + X_5 + X_6$ = 6.08 m

APPENDIX VI VESSEL GEOMETRICAL RELATIONSHIPS

CROSS-SECTION: CHORD AREA AND CHORD HEIGHT

In the calculation procedures presented in Appendices IV and V for the sizing of horizontal two-phase and three-phase separators respectively, the boundaries frequently have to be determined of the horizontal zones occupied by the various phases, using as input the respective cross-sectional areas.

The reverse calculation (calculation of the respective cross-sectional areas from the respective lower and upper boundaries) is often required as well.

In this Appendix the relationships will be given which allows calculations of this type, both graphically and via equations.

Figure VI.1 shows schematically a cross-section of a horizontal three-phase separator with diameter D.

The position of the three phases, heavy and light liquid phase and gas phase respectively, have been indicated and have as cross-sectional area A_h, A_l and A_G respectively.

The heights of the boundary are h_0 (=0), h_1, h_2 and h_3 (=D) respectively.

For a more general representation the areas and heights are made dimensionless by dividing them by the vessel cross-sectional area and the vessel diameter respectively.

$A^*_h = A_h /(\pi D^2/4)$ $A^*_l = A_l /(\pi D^2/4)$ $A^*_G = A_G /(\pi D^2/4)$

$(A^*_G + A^*_l + A^*_h = 1)$

$h^*_0 = 0$ $h^*_1 = h_1/D$ $h^*_2 = h_2/D$ $h^*_3 = 1$

A^*_h and A^*_G are now dimensionless chord areas with dimensionless chord heights, h^*_1 and $(1-h^*_2)$ respectively.

In Figure VI.2 the general relationship between a dimensionless chord area, A^* and its associated dimensionless chord height, h^*, is presented.

This graph gives directly the relationship between A^*_h and h^*_1 and between A^*_G and $(1-h^*_2)$. From this, taking into account the vessel diameter D, the relationship between the cross-sectional areas of the various phases and their boundaries in the vessel is obtained.

Relationships

Both h* and A* can be expressed in terms of φ (see also insert in Figure VI.2)

$A^* = 0.5*(\varphi - \sin\varphi)/\pi$

$h^* = 0.5*\{1 - \cos(\varphi/2)\}$

h* → A*

Since h^* can also be expressed in terms of φ, A^* can be directly calculated from h^* via:
$\varphi = 2*\arccos(1 - 2*h/D)$ and subsequently $A^* = 0.5*(\varphi - \sin\varphi)/\pi$.

A* → h*

Calculation of h* from A* requires iteration:

The iteration formula is :

$\varphi_{i+1} = \varphi_i - (2*\pi*A^* - \varphi_i + \sin\varphi_i)/(\cos\varphi_i - 1)$

The start value for φ is not critical. Even the simple start $\varphi_0 = \pi$ always gives convergence.
After convergence, h* follows then from:

$h^* = 0.5 * \{1 - \cos(\varphi/2)\}$

Volume of vessel heads

The interface level control band of horizontal L/L separators will include a part of the vessel heads.

This may also be included in the G/L control band in the liquid collection compartments of three-phase separators.

The relationship for this volume, ΔV_{hd}, as a function of the vessel diameter D and its lower and upper boundaries, h_1 and h_2 respectively, is given below.

$$\Delta V_{hd} = \alpha\pi\, D^3\{0.75*(h^*_2 - h^*_1) - (h^*_2 - 0.5)^3 + (h^*_1 - 0.5)^3\}/6$$

h^*_1 and h^*_2 are the dimensionless lower and upper boundaries respectively and are defined as:

$$h^*_1 = h_1/D$$

$$h^*_2 = h_2/D$$

α is the ratio of the short to the long axis of the vessel head

The most common semi-elliptical head has an α of 0.5

In rare cases (at very high operating pressure, for instance) a semi-spherical head is specified: α =1.

FIGURE VI.1 THE (SIMPLIFIED) CROSS-SECTION OF A HORIZONTAL THREE-PHASE SEPARATOR WITH THE POSITION AND CROSS-SECTIONAL AREAS OF THE THREE PHASES INDICATED

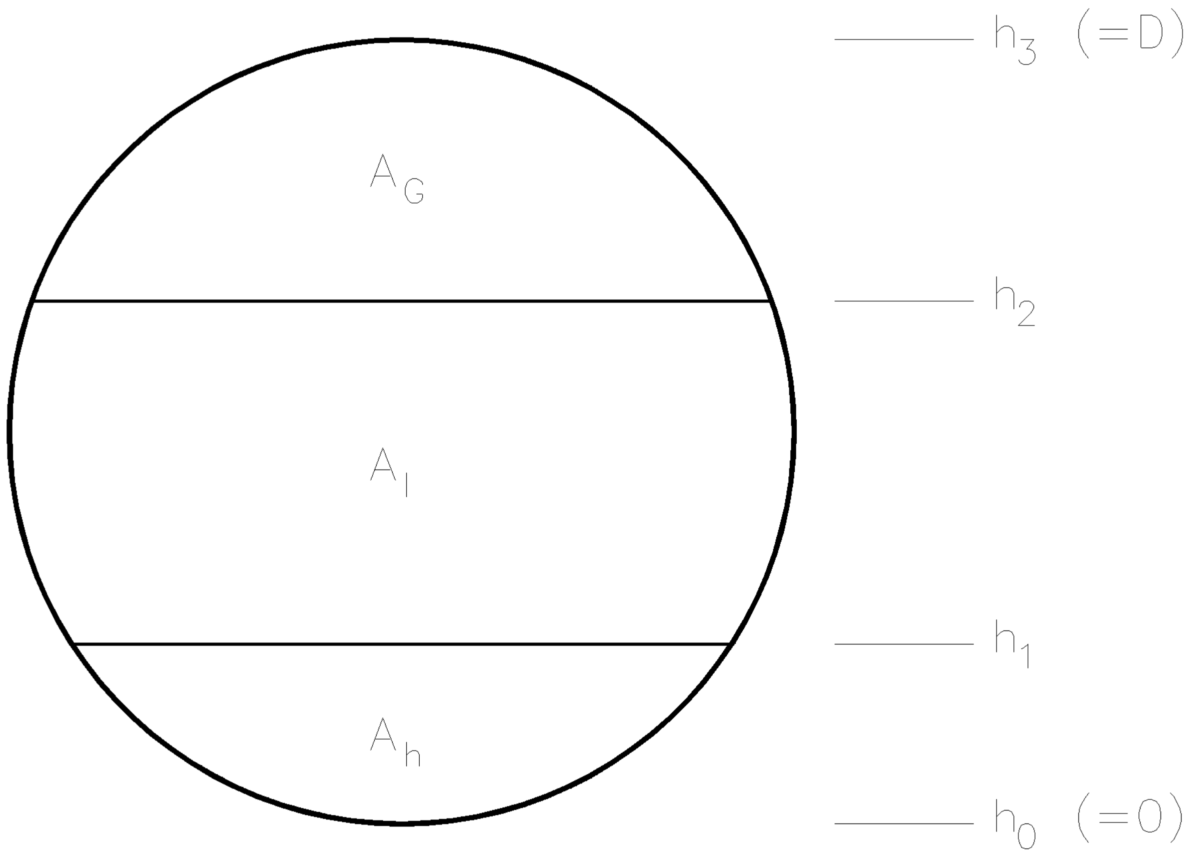
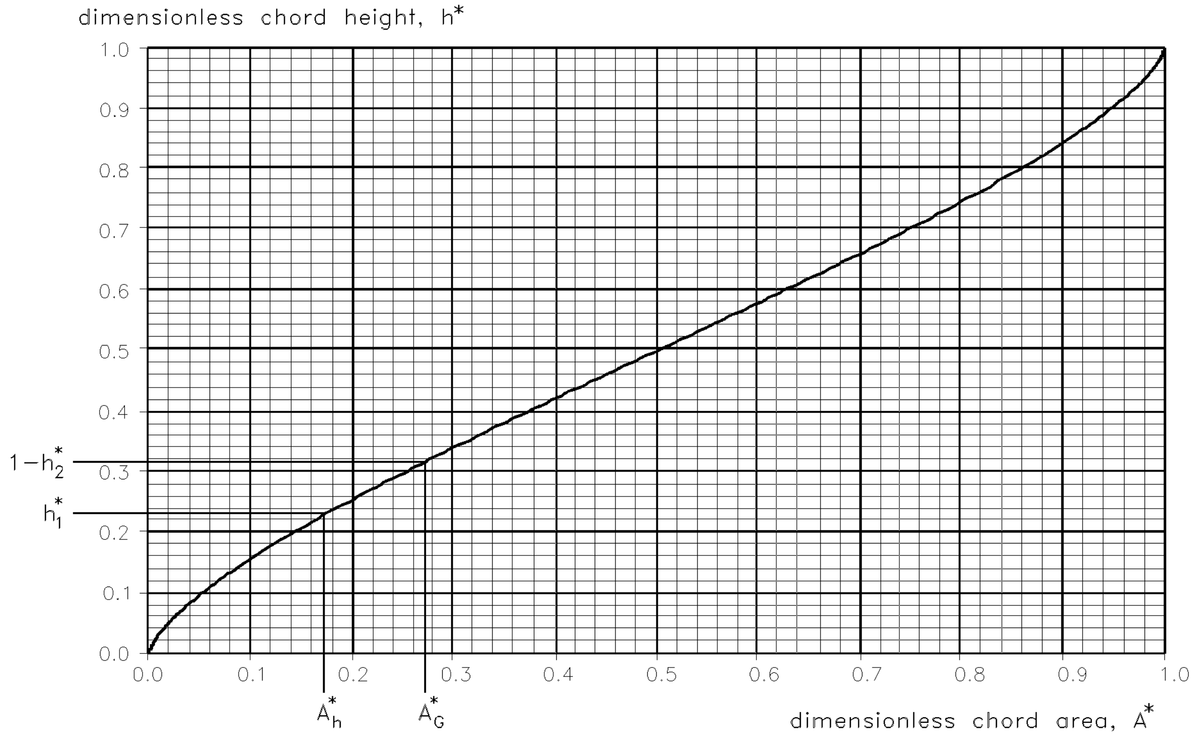
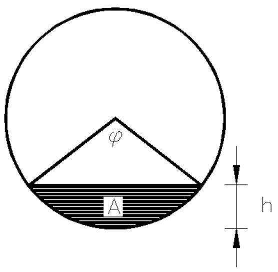


FIGURE VI.2 THE RELATIONSHIP BETWEEN THE DIMENSIONLESS CHORD AREA, A* AND DIMENSIONLESS CHORD LENGTH, H*, OF A VESSEL CROSS-SECTION





$$A^* = A/A_{ves} = 0.5*(\varphi - \sin\varphi)/\pi$$

$$h^* = h/D = 0.5*\{1-\cos(\varphi/2)\}$$

APPENDIX VII NATURE OF THE FEED IN THREE-PHASE SEPARATORS

Flow regime in the feed pipe

As in the case of a G/L separator, the feed entering a three-phase separator can be in the form of mist, stratified flow, slug flow, etc. depending on the flow rates and physical properties of the gas and liquid phases and on the feed pipe characteristics (diameter, length, vertical/horizontal).

If the liquid phases are assumed to be homogeneously mixed, they can be considered to be a single liquid phase and use can be made of available two-phase flow maps to characterise the G/L flow regime in the feed pipe.

In Figure VII.1 and VII.2 two flow maps are presented. The first flow map gives the two-phase flow regimes in a horizontal pipe and the second one those in a vertical pipe (upflow).

Strictly, the flow maps are only applicable to very long pipes with equilibrium two-phase flow. However, if the feed pipe is longer than ten pipe diameters, the flow maps still give a fair indication of the prevailing flow regime for a given set of conditions.

The transition from one flow regime to another is relatively gradual, and the boundaries shown separating the different regimes should not be interpreted as sharp changes in flow pattern.

The flow maps are generalised by using as parameters the gas and liquid Froude numbers, based on the feed pipe velocity and diameter.
The advantage of this general representation is that the flow maps are then unaffected by variations in flow conditions, physical properties and feed pipe geometry. This means that the flow maps can be used for a wide range of flow conditions, physical properties and feed pipe diameters.
If it is still considered necessary to generate a flow map for a particular set of conditions, the Principal should be consulted.

The gas and liquid Froude numbers are defined as follows:

gas Froude number: $$Fr_G = v_G \sqrt{\frac{\rho_G}{(\rho_L - \rho_G) g D}}$$

liquid Froude number: $$Fr_L = v_L \sqrt{\frac{\rho_L}{(\rho_L - \rho_G) g D}}$$

In the above formulae v_G and v_L are the superficial gas and liquid velocity respectively in the feed pipe and d_{fp} is the inside diameter of the feed pipe.

$$v_G = \frac{Q_G}{\pi d_{fp}^2 / 4}$$

$$v_L = \frac{Q_l + Q_h}{\pi d_{fp}^2 / 4}$$

and the average liquid density ρ_L is defined as:

$$\rho_L = (Q_l \rho_l + Q_h \rho_h)/(Q_l + Q_h)$$

Within the stratified-wavy and annular flow regime it is possible that droplet formation will take place in the feedpipe, resulting in a mist when these droplets are entrained into the separator.

As a rough indication, the approximate size of the largest droplets, $d_{p,max}$, formed in the feed pipe with diameter d_{fp} is given by:

$$d_{p,max}/d_{fp} = 4.5\{\sigma/(\rho_G v^2{}_G d_{fp})\}^{0.6}(\rho_G/\rho_L)^{0.4}$$

The smallest drops will generally have a diameter five to ten times smaller than $d_{p,max}$.

NOTE Much smaller droplets can be formed if the multi-phase flow has passed a sudden and significant pressure reduction (e.g. a choke with a pressure drop of more than, say, 10 bar).

Foaming tendency

For foaming to occur it is necessary that gas bubbles are formed, and that the drainage of the liquid films surrounding the bubbles is retarded. Drainage of the films is slower in highly viscous liquids, but the chief causes of foaming are surface properties which are usually unpredictable. For this reason the foaming tendency is best judged on the basis of experience in similar cases. Laboratory tests may also give an indication of the foaminess of the system.

Examples of foaming systems are some crude oils, heavy residues and absorption and extraction solvents.

Foaming in the separator may lead to carry-over of liquid (when foam reaches the gas/liquid separation internal and/or the gas outlet) or to carry-under of gas. It will also upset the level control system.

It should be noted that foaming is more likely to be a problem at high liquid loads, when flow in the inlet pipe is in a frothing or intermittent flow regime.

Installation of G/L separation internals to combat foam is not normally very effective, with the exception of cyclones.

Foaming in the vessel is minimised by decreasing the downward liquid velocity, for instance by increasing the diameter of the separator vessel.

Sometimes an antifoam agent can be injected to suppress foaming.

Feeds with solids and wax (fouling service)

Sand, rust, scale or other solids present in the feed will leave the separator together with the liquid. However, solids will also settle out in the separator and tend to accumulate. For this reason care should be taken with the location of instrument connections which could become plugged. Provision should be made for cleaning the separator during shutdowns, and if necessary during operation, by the installation of a liquid (water) spray and drain.

If solids are present in the feed, consideration should be given to reducing the inlet velocity and adding an "erosion allowance" of 1 - 2 mm extra material thickness to the inlet device (if fitted).

Wax in the feed will be deposited on any surfaces where the velocities and temperatures are low. Also, narrow openings will tend to become plugged.

Empty settlers should be used in fouling service. However, if the use of L/L and/or G/L separation internals cannot be avoided for the sake of high efficiency requirements, the selected internal should be insensitive to fouling (e.g. by using a vane pack instead of a mist mat for G/L separation or a plate pack with large plate angle or large plate spacing for L/L separation). If this is not possible, the internal shall be adequately protected by a prefilter.

FIGURE VII.1 TWO-PHASE FLOW MAP FOR HORIZONTAL FEED PIPES

Conditions:

ρ_G = 8 kg/m^3	ρ_L = 860 kg/m^3	σ = 0.03 N/m
η_G = 1.2*10^{-5} Pa.s	η_L = 1.6*10^{-4} Pa.s	d_{fp} = 0.50 m

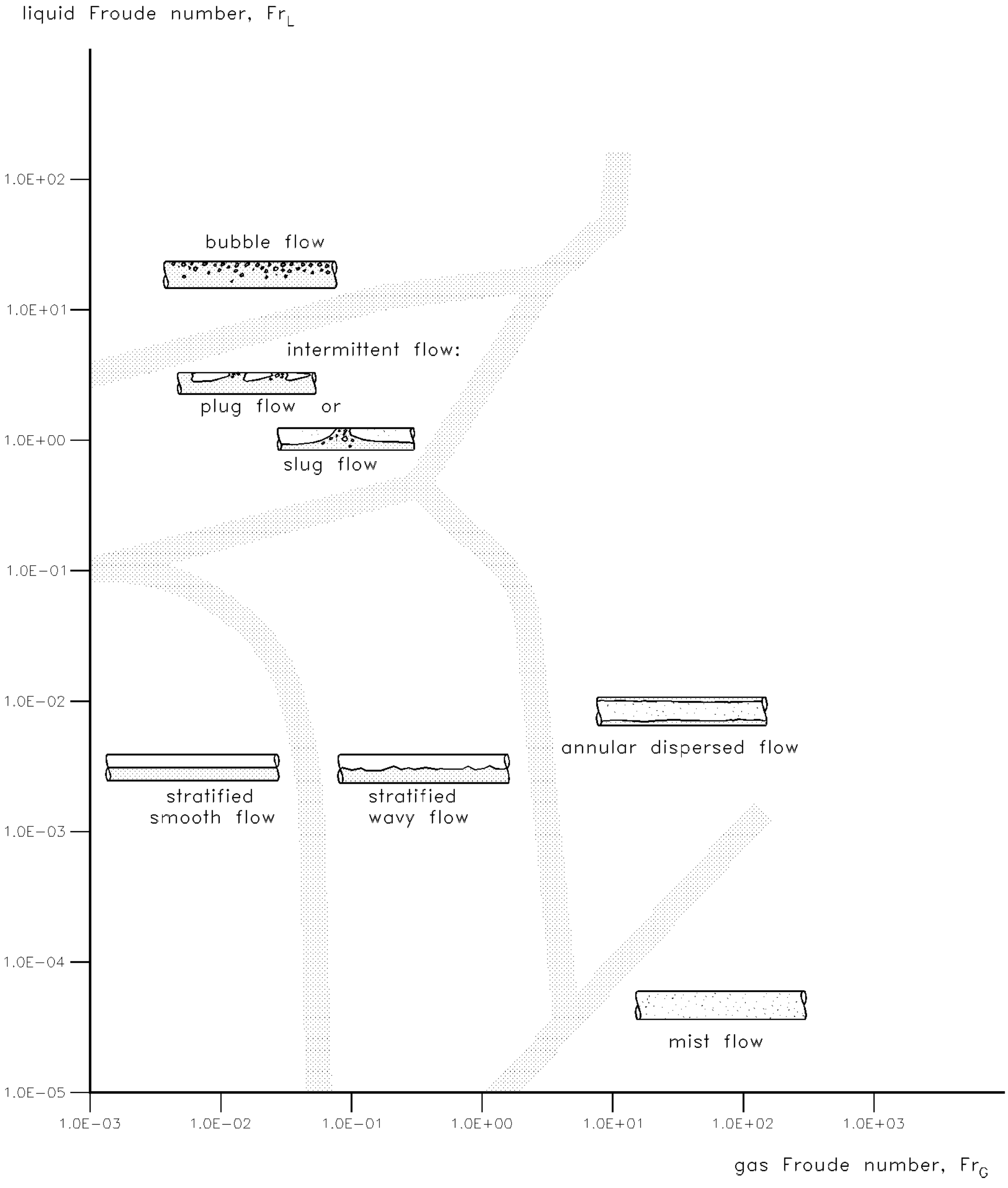
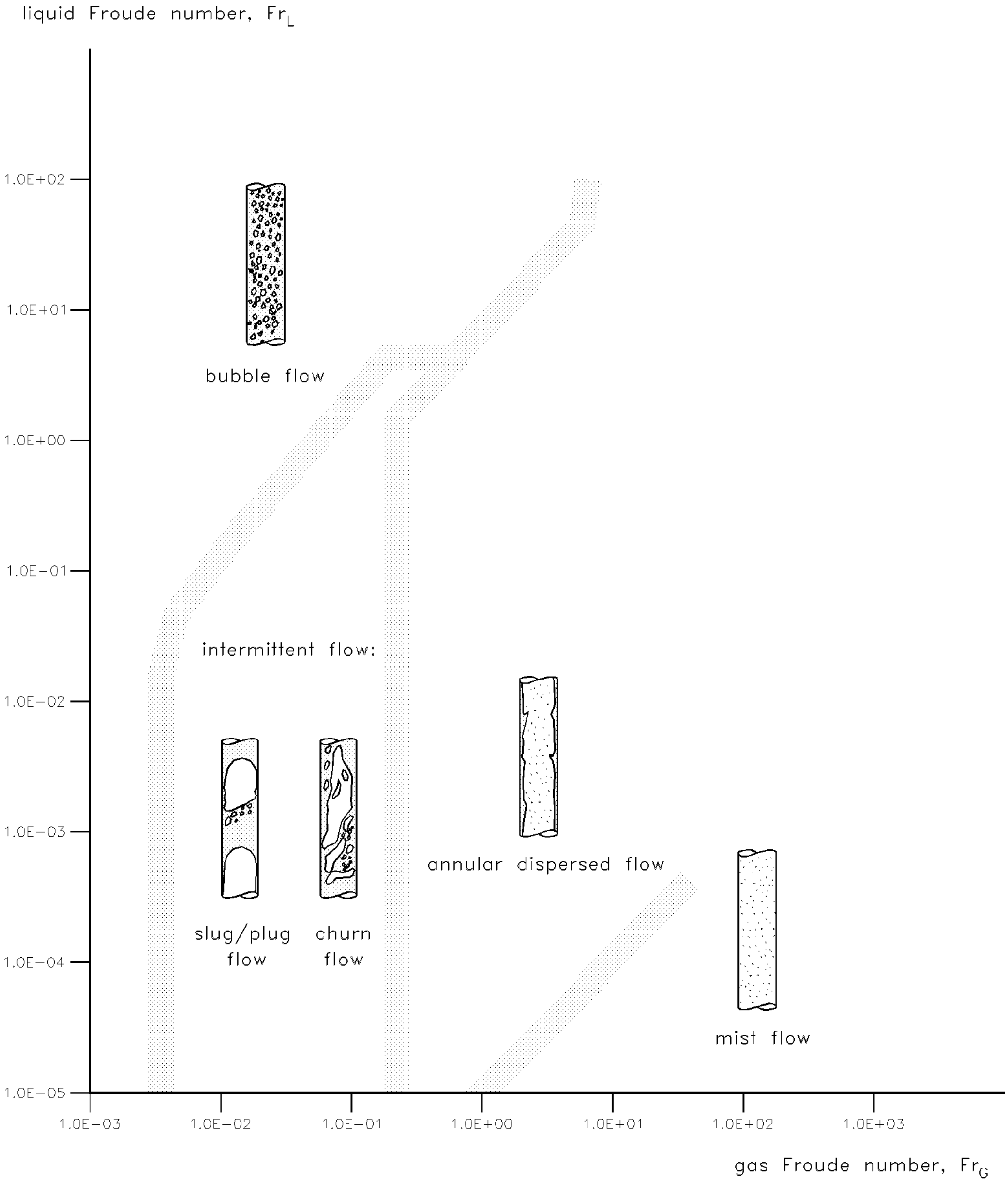


FIGURE VII.2 TWO-PHASE FLOW MAP FOR VERTICAL FEED PIPES (UPFLOW)

Conditions:

$\rho_G = 8\ kg/m^3$ $\rho_L = 860\ kg/m^3$ $\sigma = 0.03\ N/m$

$\eta_G = 1.2*10^{-5}\ Pa.s$ $\eta_L = 1.6*10^{-4}\ Pa.s$ $d_{fp} = 0.50\ m$



APPENDIX VIII SIZING OF THE FEED AND OUTLET NOZZLES

The sizing of the nozzles shall normally be based on the **ACTUAL** flow rates (i.e. **EXCLUDING** the appropriate design margin (see Appendix IX)).
(If for some reason excessive design margins are required, the Principal should be consulted).

Feed Inlet Nozzle

In L/L separators:

The inner diameter of the feed inlet nozzle should be equal to the inner diameter of the inner piping but shall also be sufficiently large so that the total liquid velocity does not exceed 1 m/s.

To promote even distribution of the feed flow into the separator, the feed nozzle should be equipped with a feed inlet device, such as an elbowed pipe or a slotted pipe (see also Figure 3.1 in (3.1) of the main text).

In G/L/L separators:

The inner diameter of the feed inlet nozzle should be equal to the inner diameter of the inner piping but shall also be sufficiently large to satisfy the relevant momentum criterion:

If **no** inlet device is used:

$$\rho_m v^2_{m,in} \leq 1000 \quad \text{Pa}$$

where ρ_m is the mean density of the mixture in the feed pipe

$$\rho_m = (Q_l\rho_l + Q_h\rho_h + Q_G\rho_G)/(Q_l + Q_h + Q_G)$$

and $v_{m,in}$ is the velocity of the mixture in the inlet nozzle

$$v_{m,in} = (Q_l + Q_h + Q_G)/(\pi\, d_1^{\,2} / 4)$$

If a **half-open pipe** is used as inlet device:

$$\rho_m v^2_{m,in} \leq 1500 \quad \text{Pa}$$

If a **Schoepentoeter** is used as inlet device:

$$\rho_m v^2_{m,in} \leq 6000 \quad \text{Pa}$$

Gas Outlet Nozzle

The diameter of the gas outlet nozzle should normally be taken as equal to that of the outlet pipe, but also the following criterion shall be satisfied:

$$\rho_G v^2_{G,out} \leq 3750 \quad \text{Pa}$$

Liquid Outlet Nozzles

The diameter of the liquid outlet nozzles shall be chosen such that the liquid velocity does not exceed 1 m/s. The minimum diameter is 50 mm (or 2 inch).

The nozzle shall be equipped with a vortex breaker in accordance with Standard Drawing S 10.010.

The vortex breaker shall be at least half a nozzle diameter away from the corresponding control level.

APPENDIX IX DESIGN MARGINS FOR SEPARATOR DESIGN

To determine the highest envisaged gas and liquid loads for vessel design, design margins (surge factors) are required:
The design margins should be supplied by the Principal.
Typical values are:

In SIEP applications:

	Design margin
1. Offshore service	
Separator handling natural-flowing production from:	
a. its own platform	1.2
b. another platform or well jacket in shallow water	1.3
c. another platform or well in deep water	1.4
Separator handling gas lifted production from:	
a. its own platform	1.4
b. another platform or well jacket	1.5
2. Onshore service	
Separator handling natural flowing production, or gas plant inlet separator in:	
a. flat or low rolling country	1.2
b. hilly country	1.3
Separator handling gas lifted production in:	
a. flat or low rolling country	1.4
b. hilly country	1.5

In SIOP and SIC applications:

The design margin ranges typically from 1.15 to 1.25.

APPENDIX X LEVEL CONTROL

In Figure X.1 the control levels are indicated both for a G/L/L settler (right part of the figure) and for an L/L settler (left part of the figure).

Going from top to bottom the criteria for the various control levels are as follows:

G/L interface

For the control of the G/L interface the hold-up times of BOTH the light and heavy liquid phases shall be taken into account.

LZA(HH) (high level trip of the G/L interface) is located at least 150 mm below the feed inlet device (and at least 0.05 vessel diameter in the case of a vertical three-phase separator fitted with a Schoepentoeter as feed inlet device).
The gas compartment of the vessel above LZA(HH) shall be sufficiently large to allow proper G/L separation. The sizing of this gas compartment is dependent on the type of G/L/L separator and is addressed in the corresponding section of this DEP.

LA(H) (high level pre-alarm of the G/L interface) is either at least 100 mm below LZA(HH) or, if required, located such that there is sufficient liquid hold-up time between the two levels for operator intervention (typically 60 seconds for action in the control room and 5 minutes for action outside the control room).
If the liquid has a foaming tendency, the distance between LA(H) and LZA(HH) has to be increased by a further 250 mm.

LA(L) (low level pre-alarm of the G/L interface) is either at least 350 mm below LA(H) or located such that there is sufficient liquid volume between the two levels for control purposes.
In Manufacturing the following general principles for hold-up times for control are applied:

1 minute on "short" circulation flows (i.e. back to inlet of vessel) PLUS

2 minutes on longer circulation flows (other upstream vessels within unit) PLUS

2 minutes on product to storage OR 3 minutes on product to other equipment/vessels OR 4 minutes on product to a furnace.

The hold-up times for control shall be specified separately for the liqht and heavy liquid phases.

If slugs are expected, they should be accommodated between NL and LA(H).
If the volume of the slug to be expected is not known, it is suggested that 2-5 seconds of flow with the maximum feed (gas + liquid) velocity and 100% liquid filling of the pipe be taken as that volume.
In general the slug size is influenced by the layout of the upstream piping. In case of doubt the Principal should be consulted for an estimate of the slug size.
In practice the total volume to be provided between LA(L) and LA(H) is the sum of the required control volume and volume of the anticipated slug.

LZA(LL) (low level trip of G/L interface)) is either at least 100 mm below LA(L) or, if required, located such that there is sufficient liquid hold-up time between the two levels for operator intervention (to be specified, but typically 60 seconds for action in the control room and 5 minutes for action outside the control room).
The distance from the vessel bottom shall be sufficient to allow proper L/L separation ("dewatering").
This minimum distance is dependent of the type of G/L/L separator and is addressed in the corresponding section of this DEP.

L/L INTERFACE

For the control of the L/L interface the hold-up time of the heavy liquid phase ALONE has to be taken into account.

$LZA(HH)_{int}$ (high level trip of L/L interface) is located such that in the liquid layer above this level adequate L/L separation ("dewatering") can take place. In horizontal L/L separators the distance of this level from the top of the vessel shall be at least 0.2 vessel diameter.
In the boot of a horizontal open three-phase settler, it is typically located 200 mm below the

bottom of the vessel.

LA(H)$_{int}$ (high level pre-alarm of L/L interface) is located either at least 100 mm below LZA(HH)$_{int}$ or, if required, such that there is sufficient liquid hold-up time between the two levels for operator intervention (typically 60 seconds for action in the control room and 5 minutes for action outside the control room).
Please note that quoted times are based on the flow rate of the heavy phase alone.
If a dispersion band width is specified, the distance between LZA(HH)$_{int}$ and LA(H)$_{int}$ has to be extended by half the band width.
If a dispersion band is expected but there is insufficient information for its width to be estimated using the formula given in Appendix I, it is suggested that 0.2 m be taken as dispersion band width.

LA(L)$_{int}$ (low level pre-alarm of L/L interface) is either at least 350 mm below LA(H)$_{int}$ or located such that there is sufficient liquid volume between these two levels for control purposes

In SIOP the following general principles for hold-up times for control are applied:

1 minute on "short" circulation flows (i.e. back to inlet of vessel) PLUS

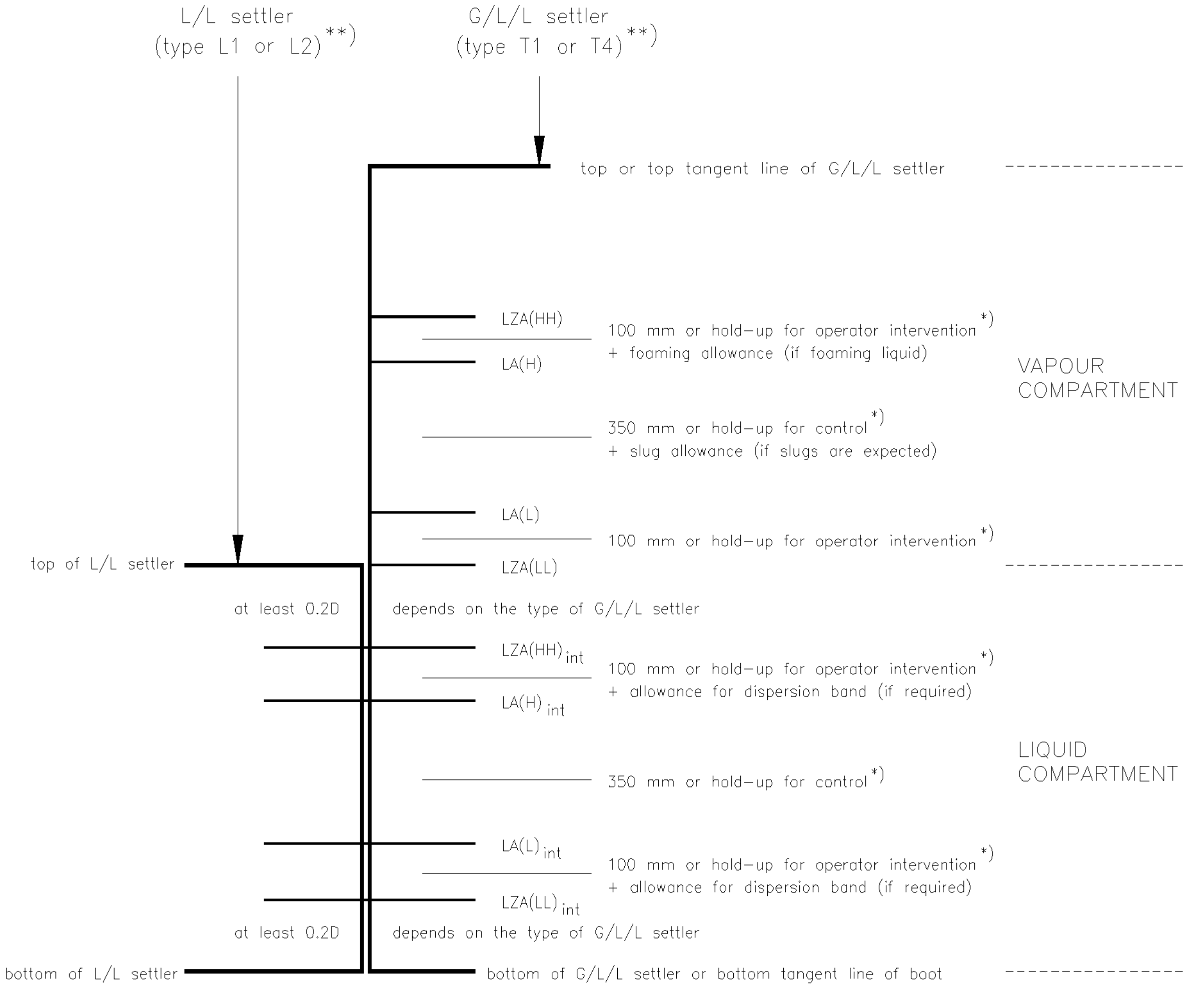
2 minutes on longer circulation flows (other upstream vessels within unit) PLUS

2 minutes on product to storage OR 3 minutes on product to other equipment/vessels OR 4 minutes on product to a furnace.

LZA(LL)$_{int}$ (low level trip of L/L interface) is either at least 100 mm below LA(L)$_{int}$ or, if required, located such that there is sufficient liquid hold-up time between the two levels for operator intervention (to be specified, but typically 60 seconds for action in the control room and 5 minutes for action outside the control room). If a dispersion band width is specified, the distance between LA(L)$_{int}$ and LZA(LL)$_{int}$ has to be extended by half the band width.
The distance to the vessel bottom shall be sufficiently large to allow a proper L/L separation ("de-oiling") in the liquid layer below LZA(LL$_{)int}$.
In horizontal L/L separators the distance of this level from the bottom of the vessel shall be at least 0.2 vessel diameter.
In the boot of a horizontal open three-phase settler it is typically located 200 mm above the bottom tangent of the boot.

NOTE In practice all the described control levels will not always be installed.
For instance, under certain non-critical circumstances it may be permissible not to install one or more trip level control.
Further, if operator action to prevent a trip is not realistically possible, the pre-alarms should be eliminated.

FIGURE X.1 CONTROL LEVELS OF G/L AND L/L INTERFACES



*) whichever leads to the largest distance
**) see Table 2.1 in (2.)