ENGINEERING STANDARD

FOR

PROCESS REQUIREMENTS OF VESSELS,

REACTORS AND SEPARATORS

CONTENTS :

APPENDICES:

0. INTRODUCTION

"Process Design of Towers, Vessels, Reactors, and Agitated Vessels", are broad and contain various subjects of paramount importance. Therefore, a process Engineering Standard Specification is prepared to cover this subject, and includes the following Standards:

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

This Engineering Standard Specification covers:

"PROCESS REQUIREMENTS OF VESSELS, REACTORS, AND SEPARATORS"

1. SCOPE

This Engineering Standard Specification covers minimum process requirement of separators, vessels and reactors used in OGP production plants. An amendment is made to IPS-E-PR-895, "Process Design of Gas (Vapor)-Liquid Separators", and IPS-E-PR-880, "Process Design of Solid-Liquid Separators".

2. REFERENCES

Throughout this Standard the following standards and codes are referred to. The editions of these standards and codes that are in effect at the time of publication of this Standard shall, to the extent specified herein, form a part of this Standard. The applicability of changes in standards and codes that occur after the date of this Standard shall be mutually agreed upon by the Company and the Vendor/Consultant.

IPS   (IRANIAN PETROLEUM STANDARDS)

IPS-E-PR-200	"Basic Engineering Design Data"
IPS-E-PR-360	"Process Design of Liquid and Gas Transfer and Storage"
IPS-E-PR-700	"Process Design of Crude Oil Electrostatic Desalters"
IPS-E-PR-880	"Process Design of Gas (Vapor)-Liquid Separators"
IPS-E-PR-895	"Process Design of Solid-Liquid Separators"
IPS-G-ME-150	"Towers, Reactors, Pressure Vessels & Internals"

ASME   (AMERICAN SOCIETY OF MECHANICAL ENGINEERS)

ASME Section VIII, Div. 1   "Boiler and Pressure Vessel, Code"

BSI   (BRITISH STANDARDS INSTITUTION)

BS 5500 Cat. 1 & 2

IPC   (THE INSTITUTE OF PETROLEUM CONSTRUCTORS, CALGARY CANADA)

Technical Bulletin for	"Multicyclone Separators"
Technical Bulletin for	"Crude Oil Separators"

NACE   (NATIONAL ASSOCIATION OF CORROSION ENGINEERS)

NACE Standard MR-01-75   "Material Requirements-Sulphide Stress Cracking Resistant Material for Oilfield Equipment", Latest Revision

3. DEFINITIONS AND TERMINOLOGY

The following is a glossary of terms used in this Standard Specification. In addition reference is made to Sections 3 of IPS-E-PR-880 and IPS-E-PR-895.

3.1 Coalescers

A mechanical process vessel with wetable, high-surface area packing on which liquid droplets consolidate for gravity separation from a second phase (for example gas or immiscible liquid).

3.2 Control Volume

Is a certain liquid volume necessary for control purposes and for maintaining the velocity limit requirement for degassing and to counter foam in separators.

3.3 Conventional Gas-Liquid Separator

In this Standard, the term "Conventional Gas-Liquid Separator" is referred to vertical or horizontal separators in which gas and liquid are separated by means of gravity settling with or without a mist eliminating device.

3.4 Critical Diameter

"Critical diameter" or "cut point", is the diameter of particles, that particles larger than which will be eliminated in a sedimentation centrifuge.

3.5 Disengaging Height

The height provided between under the wire-mesh pad and liquid level of a vapor-liquid separator.

3.6 Fabric Filter

Commonly termed "bag filters" or "baghouses", are collectors in which dust is removed from the gas stream by passing the dust-laden gas through a fabric of some type.

3.7 Filter Medium

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

3.8 Filtrate

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

3.9 Flash Tank

A vessel used to separate the gas evolved from liquid flashed from a higher pressure to a lower pressure.

3.10 Hold-Up Time

A time period during which the amount of liquid separated in a gas-liquid separator is actually in the vessel for the purpose of control or vapor separation.

3.11 Knock-Out

A separator used for a bulk separation of gas and liquid, particularly when the liquid volume fraction is high.

3.12 Line Drip

A device typically used in pipelines with very high gas-to-liquid ratios to remove only free liquid from a gas stream, and not necessarily all the liquid.

3.13 Mesh

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

$$Mesh = 25 / (w + d)$$ (Eq. 1)

(See Clause 4 for Symbols and Abbreviations.)

3.14 Mist Extractor

Is a device installed in the top of scrubbers, separators, tray or packed vessels, etc. to remove liquid droplets entrained in a flowing gas stream.

3.15 Open Area

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

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

(See Clause 4 for Symbols and Abbreviations.)

3.16 Overflow

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

3.17 Septum

(See Clause 3.7.)

3.18 Scrubber

Is a type of separator which has been designed to handle flow streams with unusually high gas-to-liquid ratios.

3.19 Slug Catcher

A particular separator design able to absorb sustained in-flow of large liquid volumes at irregular intervals.

3.20 Target Efficiency

Is the fraction of particles or droplets in the entraining fluid of a separator, moving past an object in the fluid, which impinge on the object.

3.21 Terminal Velocity or Drop-Out Velocity

Is the velocity at which a particle or droplet will fall under the action of gravity, when drag force just balance gravitational force and the particle (or droplet) continues to fall at constant velocity.

3.22 Underflow

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

3.23 Vapor Space

The volume of a vapor liquid separator above the liquid level.

4. SYMBOLS AND ABBREVIATIONS

API	American Petroleum Institute.
ASME	American Society of Mechanical Engineers.
BSI	British Standards Institution.
C_D	Drag Coefficient, (dimensionless).
d	Interval.
d_1	Nozzle diameter, in (m).
d_2	Diameter of the gas outlet nozzle, in (m).
d_3	Diameter of the liquid outlet nozzle, in (m).
D_p	Diameter of droplet, in (m).
d_p	Double pocket vanes.
DN	Diameter Nominal, in (mm).
EOR	End Of Run.
Eq.	Equation.
F_o	The whole area of a woven wire filter, in (mm²).
FWKO	Free Water Knock-Out.
g	Acceleration of gravity, in (m/s²).
GOR	Gas/Oil Ratio.
H_l	Height of liquid space, in (m).
HLL	Highest Liquid Level.
IE	Ion Exchange.
Inf	Infinity.
IP	Institute of Petroleum.
IPS	Iranian Petroleum Standards.
K	Entrainment Coefficient, in (m/s).
L	Distance between the inlet nozzle and outlet nozzle, in (m).
$M_G + M_L$	Mass of gas and liquid in the mixture, in (kg).
Mod	Moderate.
NLL	Normal Liquid Level.
n_p	No-Pocket vanes.
OD	Outside Diameter, in (mm).
OGP	Oil, Gas and Petrochemical.
ppm	parts per million.
$Q_G + Q_L$	Volume of gas and liquid in the mixture, in (m³).
Q_{max}	Liquid handling capacity as droplets.
S_h	Specific gravity (relative density) of the heaviers, (dimensionless).
S_1	Specific gravity (relative density) of the lighters, (dimensionless).
SOR	Start Of Run.
S_P	Single-Pocket vanes.
TCA	Total Corrosion Allowance.
TGU	Thermal Gas-Oil Unit.
U_t	Terminal velocity of the heavier fine particles, in (m/s).

V	Very.
V_G	Gas superficial velocity, in (m/s).
V_h	Horizontal liquid velocity, in (m/s).
$V_{m,in}$	Velocity of the mixture in the inlet nozzle, in (m/s).
VBU	Visbreaker Unit.
yr	Year.
w	Width of woven wire opening, in (mm).
ρ_G (rho)	Gas density, in (kg/m³).
ρ_h (rho)	Density of droplet, in (kg/cm³).
ρ_L (rho)	Density of liquid, in (kg/m³).
ρ_i (rho)	Density of the continuous phase, in (kg/m³).
ρ_m (rho)	Mean density of mixture, in (kg/m³).
ρ_v (rho)	Vapor density, in (kg/m³).
μ (mu)	Particle size, in microns or micrometers (μm).
μ (mu)	Viscosity (dynamic) of continuous phase, in [cP = mPa.s].
λ (lambda)	Gas handling maximum capacity.

5. UNITS

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

6. SEPARATORS

6.1 Gas-Liquid Separators

6.1.1 General

Process design of gas (vapor)-liquid separators should be based on IPS-E-PR-880, "Process Design of Gas (Vapor)-Liquid Separators" and should be amended with the following selection and design criteria:

  a) **Selection criteria**

    a.1) **General**

    The followings outline various criteria and features which play a role in separators performance and selection. Table A.1 in Appendix A summarizes the relative performance of various types of separators.

    a.2) **Orientation**

    In general, a vertical vessel is preferred for gas/liquid separation for the following reasons:

        - when the gas/liquid ratio is high;
        - a smaller plan area is required (critical on offshore platforms);
        - easier solids removal;
        - liquid removal efficiency does not vary with liquid level;
        - vessel volume is generally smaller.

    However, a horizontal vessel should be chosen if:

        - large volume of total fluid is available;
        - large amount of dissolved gas is available;
        - large liquid slugs have to be accommodated;

- there is restricted head room;
- a low downward liquid velocity is required (for degassing purposes, foam breakdown or in case of a difficult liquid/liquid separation).

a.3) Components

Following the gas/liquid flow path through the separator, the following parameters should be identified:

- Feed inlet

This comprises the upstream piping, inlet nozzle, and the inlet devices (if any).

- The diameter of the inlet nozzle is a function of the feed flow rate and pressure.

- Information on the nature of the feed (foaming tendency, feeds with solids, wax or cocking tendency) are given in Clauses B.1 and B.2 in Appendix B.

- The criterion for the nozzle sizing is that the momentum of the feed shall not exceed prescribed levels. The maximum allowable inlet momentum can be increased by applying inlet devices.

- The momentum criteria are given in Appendix C.

- The function of the inlet device is to initiate the gas/liquid separation and to distribute the gas flow evenly in the gas compartment of the vessel.

- Commonly used inlet devices are the half-open pipe and their specific proprietory inlet devices designed for introducing gas/liquid mixtures into a vessel or column.

- Separator internals

- In knock-out vessels the diameter should be selected sufficiently large to keep the gas velocity low at which the major portion of the droplets could be settled by gravity.

- In all other types of gas/liquid separators, internals should be considered, for selection the required duty, wire mesh, vane-pack (either horizontal or vertical flow), multicyclones axial or reversed flow, filter candles, etc. should be studied.

- Gas and liquid outlets

After completion of the gas/liquid separation process the two phases will leave the vessel via the gas and liquid outlet respectively. The nozzle sizing criteria are given in Appendix C.

- Gas handling capacity

The separator shall be large enough to handle the gas flow rate under the most severe process conditions. The highest envisaged gas flow rate should be determined by including a margin for surging, uncertainties in basic data. This margin is typically between 15 and 50%, depending on the application. For the recommended margin see Appendix D.

- Selection strategy

To facilitate the choice of a separator for a given application, the performance characteristics of various separators are summarized in Appendix A, Table A.1.

1) Gas handling capacity:

- max. capacity (gas load factor);
- turndown ratio.

2) Liquid removal efficiency:

- overall;
- with respect to fine mist;
- with respect to the possible flooding above the maximal load factor (which will affect the sharpness of the efficiency decline above the maximum capacity).

3) Liquid handling capacity:

- slugs;
- droplets.

4) Fouling tolerance:

- sand;
- sticky material.

5) Pressure drop:

The following selection strategy is suggested:

First define the mandatory requirements which the separator shall satisfy. With the aid of Table A.1 in Appendix A, a number of separators can then be ruled out. Check, using the Clause a.2), whether there are limitations which will rule out horizontal or vertical vessels.

b) Design criteria

b.1) General

Unless explicitly stated otherwise, both the maximum gas and liquid flow rates should contain a design margin or surge factor as defined in Appendix D. Table A.1 to Appendix A, summarizes the performance data which can enable a comparison of the various separators.

b.2) Vertical and horizontal separators

Specific indication to process application, characteristics, recommended and non-recommended use of various vertical/horizontal separators used in OGP production plants are given hereunder for design consideration:

- Vertical Knock-Out Drum

Application:

- Bulk separation of gas and liquid.

Characteristics:

- unlimited turndown;
- high slug handling capacity;
- liquid removal efficiency typically 80-90% (ranging from low to high liquid load).

- Warning: Liquid removal efficiency for mist is very poor

- very low pressure drop;
- insensitive to fouling.

Recommended use:

- vessels where internals have to be kept to a minimum (e.g., flare knock-out drums);
- fouling service e.g., wax, sand, asphaltenes;
- foaming service.

Non-recommended use:

- where efficient demisting of gas is required.

Typical process applications:

- vent and flare stack knock-out drums;
- production separator;
- bulk separator (e.g., upstream of gas coolers);
- flash vessel.

- Horizontal Knock-Out Drum

Application:

- Bulk separation of gas and liquid.

Characteristics:

- can handle large liquid fractions;
- unlimited turndown;
- very high slug handling capacity;
- liquid removal efficiency typically 80-90% (ranging from low to high liquid load).

- Warning: Liquid removal efficiency for mist is very poor

- insensitive to fouling;
- very low pressure drop.

Recommended use:

- vessels where internals have to be kept to a minimum and where there are height limitations;

- slug catchers;

- fouling service, e.g., wax, sand, asphaltenes;

- for foaming or very viscous liquids.

Non-recommended use:

- where efficient demisting of gas is required.

Typical process applications:

- vent and flare stack knock-out drums;
- production separator-low GOR;
- bulk separator;
- slug catcher.

- Vertical Wire Mesh Demister

Application:

- demisting of gas.

Characteristics:

- high turndown ratio;
- high slug handling capacity;
- liquid removal efficiency > 98%;
- sensitive to fouling;
- low pressure drop.

Recommended use:

- for demisting service with a moderate liquid load;
- where slug handling capacity may be required.

Non-recommended use:

- fouling service (wax, asphaltenes, sand, hydrates);

- for viscous liquids where degassing requirement determines vessel diameter;

- for compressor suction scrubbers unless precautions are taken to prevent the possibility of loose wire cuttings entering the compressor or plugging of the demister mat increasing suction pressure drop.

Typical process applications:

- production/test separator:

  - moderate GOR;
  - non-fouling;

- inlet/outlet scrubbers for glycol contactors;
- inlet scrubbers for gas export pipelines;
- for small diameter and/or low pressure vessels, where extra costs of vane of SMS internals cannot be justified.

- Horizontal Wire Mesh Demister

Application:

- demisting of gas where a high liquid handling capacity is required.

Characteristics:

- high turndown ratio;
- very high slug handling capacity;
- liquid removal efficiency > 98%;
- sensitive to fouling;
- low pressure drop.

Recommended use:

- typically for demisting service with a high liquid load and low GOR;
- applied where slug handling capacity may be required;
- for viscous liquids where liquid degassing requirement determines vessel diameter;
- in situations where head room is restricted;
- for foaming liquids.

- Vertical Vane-Type Demister

Application:

- demisting of gas.

Characteristics:

- liquid removal efficiency > 96%;
- moderate turndown ratio;
- suitable for slightly fouling service (if without double-pocket vanes);
- robust design;
- sensitive to liquid slugs (in-line separator cannot handle slugs).

Recommended use:

- typically for demisting service;
- in-line separator to be used only with relatively low flow parameter ($\phi_{feed} < 0.01$);
- two-stage separator to be used if $\phi_{feed} \geq 0.01$;
- attractive for slightly fouling service (if without double-pocket vanes);
- may be used where demister mats may become plugged, i.e., waxy crudes.

Non-recommended use:

- heavy fouling service (heavy wax, asphaltenes, sand, hydrates);

- for viscous liquids where degassing requirement determines vessel diameter;

- the in-line vertical flow vane pack separator shall not be used where liquid slugging may occur or where $\phi_{feed} \geq 0.01$;

- if pressure exceeds 100 bar (abs), due to the consequent sharp decline in liquid removal efficiency.

Typical process applications:

- compressor suction scrubbers-where vane packs are preferred to demister mats since their construction is more robust;

- demisting vessels with slightly fouling service.

- Horizontal Vane-Type Demister

Application:

- demisting of gas where a high liquid handling capacity is required.

Characteristics:

- liquid removal efficiency > 96%;
- moderate turndown ratio;
- suitable for slightly fouling service (if without double-pocket vanes);
- high slug handling capacity;
- robust design.

Non-recommended use:

- heavy fouling service (heavy wax, asphaltenes, sand, hydrates);
- if pressure exceeds 100 bar (abs).

Typical process applications:

- production separator where GOR is low and the service is slightly fouling.

- Cyclone

Application:

- demisting of gas in fouling service.

Characteristics:

- liquid removal efficiency > 96%;
- insensitive to fouling;
- limited turndown ratio;
- high pressure drop.

Recommended use:

- typically for use in a fouling (e.g., coke-formation) environment and where a high demisting efficiency is still required.

Non-recommended use:

- if high pressure drop can not be tolerated.

Typical process application:

- in oil refineries: Thermal Gas-Oil Unit (TGU);
  Visbreaker Unit (VBU);

- in chemical plants: Thermoplastic Rubber Plants.

- Vertical Multicyclone Separator

Application:

- demisting and dedusting of gas in slightly fouling service and high pressure.

Characteristics:

- liquid removal efficiency > 93%;
- suitable for slightly fouling service (e.g., low sand loading);
- high pressure drop;
- compact separator;
- sensitive to high liquid loading or slugs.

Recommended use:

- typically for use in a slightly fouling environment where the gas pressure is higher than 100 bar (abs) and a compact separator is required.

Non-recommended use:

- low gas pressure;
- heavy fouling service (high sand loading will cause erosion);
- high liquid loading;
- slug;
- when high liquid removal efficiency is required.

Typical process application:

- wellhead separators;
- primary scrubbers under slightly fouling service and when the liquid loading is low;
- compressor suction scrubbers if sand is present in the feed.

- Filter Separator

Application:

- after-cleaning (liquid and solids) of already demisted gas when a very high liquid removal efficiency is required.

Characteristics:

- liquid removal efficiency > 99%;
- very high pressure drop;
- sensitive to high liquid loading or slugs;
- sensitive to fouling by sticky material.

Recommended use:

- typically as a second-line gas/liquid separator to after-clean the gas stream exiting from the first-line gas/liquid separator.

- use filter candles with the flow from OUT to IN where solids are present.

- use filter candles with the flow from IN to OUT where ultimate efficiency is required and NO solids are present.

Non-recommended use:

- heavy fouling (sticky material) service;
- high liquid loading;
- slugs.

Typical process application:

- last demisting stage of natural gas prior to despatch for sale.

6.2 Solid-Liquid Separators

6.2.1 General

The process design of solid-liquid separators should be based on the IPS-E-PR-895, "Process Design of Solid-Liquid Separators" and the following is covered as an amendment to IPS-E-PR-895 above.

6.2.2 Multicyclone scrubbers/separators

6.2.2.1 Application

High efficiency separation of solids & liquids. For detailed applications see Table E.2*.

6.2.2.2 Introduction

The multicyclone gas separator/scrubber offers an economical way to remove solid and liquid particles from a gas stream.

6.2.2.3 Advantages:

- On high pressure applications, the reduced diameter of the multicyclone is smaller than the vane type and markedly smaller than the demister type. This means thinner walls, reduced space, and most importantly reduced costs (especially on larger flow rates).

- The multicyclone is able to handle and remove solid particles whereas the vane and demister type principally do not.

Note:

The vane and demister type separators will remove small solids suspended in liquid.

- Like the wire mesh demister and vane type the multicyclone separator is a high capacity separator designed to operate with a low pressure drop.

* Table E.1 also represents a separator type selection guide for other types of separators for any reference.

- The multicyclone is self cleaning and needs only a periodic blowdown for removal of collected material.

- It is high efficient over a wide range of operating conditions.

6.2.2.4 Removal efficiency

See Fig. E.1* of Appendix E. Generally, the efficiency of the separator is dependent on the following factors:

- Particle size.
- Distribution of particles.
- Liquid loading.

6.2.2.5 Liquid efficiency

The outlet gas shall contain less than $1 \text{ m}^3/74.81 \times 10^6 \text{ m}^3$ liquids to gas through the scrubber (based on a liquid to gas ratio of less than or equal to 5%). In addition, based on the same inlet assumption, all liquid particles 5 microns (μm) and larger shall be removed.

6.2.2.6 Solids

Based on an assumed solid loading of 22.88 g/m^3. The multicyclone separator will generally remove 100% of 8 microns (μm) and larger solid particles (see Fig. E.1 of Appendix E).

6.2.2.7 Operation

Fig. E.2 of Appendix E shows the general detail of multicyclone scrubber/separator.

6.2.2.8 Material specifications and construction

Multicyclone scrubbers are designed and manufactured in accordance with the main international codes, ASME VIII Div. 1, BS-5500 Cat. 1 & 2, etc. Materials of construction are as customers specification, from standard carbon steel to stainless steel, and other steel alloys. Cyclone tubes are manufactured as standard from high alloy cast steel.

6.3 Liquid-Liquid Separators

6.3.1 General

For liquid-liquid separators the following requirements and criteria should be considered:

a) The vessels should be sized in such a way that the settling time for each liquid phase from the other is less than it's residence time in the vessel itself.

b) Settling velocity for the dispersed droplets is calculated using Stocke's, Newton's or an intermediate law, according to the field of application.

c) A maximum settling value of 250 mm/min shall be considered for light hydrocarbons. It should be verified that the hold-up time necessary for any phase for settling satisfies process hold-up requirements.

6.3.1.1 For normal liquid droplet separation, droplet diameters ranging from 500 to 1000 microns (μm) are assumed as a guide for the design for vertical separators, and droplet diameter of about 100 microns are assumed as a guide for the design of horizontal separators. Terminal velocity, design calculation is given in Appendix F of this Standard Specification.

* Fig. E.1 also represents gas separator types and their performance for reference.

6.3.1.2 Vertical separator

a) Liquid velocities

The terminal velocity U_t of any droplet moving in a medium can be calculated form Stockes' law.
The settling rate of each phase from the other phase should be calculated to decide which phase is limiting.

b) Construction

Typical construction of vertical liquid-liquid separators are shown in Appendix F, Fig. F.1. Feed nozzles shall be so arranged that the liquid-liquid interface may not be disturbed.

6.3.1.3 Horizontal separator

a) Liquid velocity

The liquid velocity can be determined by the equation given below, where D_p is assumed to be 100 microns:

$$\frac{L}{V_h} \geq \frac{H_l}{U_t} \qquad\qquad \textbf{(Eq. 3)}$$

b) Construction

Typical construction of horizontal liquid-liquid separator, are shown in Appendix F, Figs. F.2 and F.3.

6.3.2 Crude oil separator

6.3.2.1 Process design of crude oil separator shall be in accordance with requirements and criteria setforth in IPS-E-PR-880 and the followings:

a) Sizing

a.1) In three-phase separators the following main functions should be considered:

i) Provision of enough residence time for the liquid so that degassing can occur.

ii) Provision of enough free cross sectional area above the liquid so that the gas velocity is low enough to allow liquid particles to be separated.

iii) Provision of enough residence time for the liquid/liquid separation to occur.

a.2) A separator should be either liquid or gas controlling, the gas/oil will determine which. Liquid residence time for a two-phase separator will depend on the rate of vapor break out from the liquid.

In this regard the following is recommended:

Minimum for light gravity crudes (greater than 35 API)	2 mins.
20-35 API	4 mins.
15-20 API	6 mins.

a.3) When degassing water a residence time of only 1 minute is required. Residence time for a three phase separator is recommended 3 minutes minimum. This can be more depending on inlet temperature, API gravity, inlet oil quality, and final oil quality required.

a.4) Special considerations

- Special considerations should be given to the sizing of separators under the following conditions:

- Degassing of very light > 40 API dry oil.
- Degassing and dehydration of waxy crude.
- Handling of foaming crude.

b) Other special separators

- Free water knock outs are usually specified downstream of the degassing or first stage separator. They are normally employed to remove large amounts of water from oil streams i.e., 70% to 90% water.

The free water knock out is essentially a separator for which the sizing completely controlled on liquid/liquid separation rather than gas.

The inlet fluid enters and impinges on an inlet diverter as with a standard separator.

c) Free water knock-out special considerations

- The free water knock-out, as its name implies, is designed to remove free water, not emulsions from oil.

The use of demulsifying chemicals is usually a must to aid with separation, and even then outlet quality depends on the extent and tightness of the emulsion.

- As a guide, the following typical outlet ppm qualities of oil in water and water in oil emulsions will give an indication of achievable separation (see IPS-E-PR-700, "Process Design of Crude Oil Electrostatic Desalters"):

Oil in Water Emulsion

Heavy crude ,	< 30 API	-150 ppm outlet
Medium crude,	30 API to 45 API	-100 ppm outlet
Light crude,	> 45 API	- 50 ppm outlet

Water in Oil Emulsion

Heavy crude,	< 30 API	-5/6%
Medium crude,	30 API to 45 API	-3/5%
Light crude,	> 45 API	-2/3%

- The FWKO is usually sized on a residence time between 15 and 30 minutes.

7. VESSELS AND REACTORS

7.1 General

7.1.1 The process design requirements, criteria and philosophy of vessels and reactors are covered to some extent in the IPS-E-PR-880, IPS-E-PR-895 and under Section 6 of this Standard Specification relating to different horizontal and vertical separation vessels but subject to their accomplishment as setforth in the scope. So, under this Section 7, the intention is made to cover the process design specification, requirement and criteria for pressure vessels, used widely in OGP production plants.

7.1.2 For mechanical design of towers, reactors, pressure vessels and internals reference is made to Engineering and Material Standard IPS-G-ME-150, "Towers, Reactors, Pressure Vessels & Internals".

7.2 Code, Regulations and Standards

7.2.1 All design and construction shall be in accordance with the latest edition of ASME Section VIII, Division 1, "Boiler and Pressure Vessel Code".

7.2.2 All pressure vessels shall be inspected and "U" stamped in accordance with ASME Code and also in accordance with other applicable Codes subject to Company's approval. Applicable Registry Certificates shall be provided for each vessel.

7.2.3 Where applicable, the requirement, criteria and design specification of Engineering Standard, IPS-E-PR-360, "Process Design of Liquid and Gas Transfer and Storage" should be considered.

7.2.4 In all cases where more than one code or standard applies to the same conditions, the most stringent shall be followed.

7.3 Design

7.3.1 Pressure and temperature

7.3.1.1 The design pressure shall be 350 kPa or 10%, whichever is greater, in excess of the maximum working pressure, except in special cases approved by the Company or when the Company specifies the design pressure. In addition, where process fluid static head or other appropriate loads significantly increase the internal pressure, the design pressure shall be increased accordingly for the vessel section concerned.

7.3.1.2 Vessels not designed for full vacuum to meet normal operating conditions but which may be subjected to partial vacuum when contents are being emptied or during steaming out, shall be suitable for partial vacuum. As a minimum, vessel shall be designed for 50 kPa (ga) external pressure using ASME Code.

Where the above restrictions create excessive cost, vessels may be provided with an automatic vacuum relief, subject to written approval by the Company.

Vessels shall be designed so that each part subject to pressure will have strength equivalent to the new and cold working pressure of the shell and heads or integral external piping connections, whichever is lower.

The maximum allowable working pressure stamped on the nameplate shall be calculated for the "as built" vessel and shall be limited by the lesser of the shell, head or flange rating.

The design temperature shall be at least 15°C above the maximum working temperature. For cold service, the design temperature shall be 6°C below the minimum operating temperature unless otherwise specified.

7.4 Corrosion

7.4.1 The minimum corrosion allowance shall be 1.6 mm for sweet service and 3.2 mm for sour service, unless specified otherwise.

7.4.2 No corrosion allowance shall be provided in high alloy vessels.

7.4.3 Corrosion allowance shall be cladding or lining thickness for alloy clad or lined vessels.

7.4.4 Unless otherwise specified, vessel corrosion allowance shall be provided to all exposed surfaces of non-removable internal parts and half this amount to surface of removable parts (except demister wire, column packing, etc.).

7.5 Design Load

7.5.1 Loadings

Loadings to be considered in designing a vessel shall be per the ASME Code Section VIII and shall include cyclic conditions and erection loadings.

7.5.2 Additional loadings

Vessels containing circulating suspensions of solids in fluids (fluid-solids processes) shall be subjected to additional horizontal loadings.

7.5.3 During erection, start-up, or operation

During erection, start-up, or operation, all applicable loads shall be considered as acting simultaneously, including either wind or earthquake, whichever governs.

7.5.4 During hydrostatic testing

During hydrostatic testing, wind load (wind pressure) equivalent to 58 km/h (16 m/s) wind speed shall be considered acting simultaneously with the hydrostatic test load.

7.6 Materials

7.6.1 Materials shall be per ASME Code Section VIII or as specified on the Vessel Data Sheet. Proposals to use any other materials shall be submitted to purchaser for approval by Owner's Engineer.

7.6.2 Material production shall be by the electric furnace, basic oxygen, or open hearth processes.

7.6.3 Proposals to use materials having a specified maximum tensile strength greater than 620 MPa at room temperature shall be submitted to purchaser for approval by the Company.

7.6.4 For vessels in hydrogen service, external welded attachments, and at least a 450 mm course of all skirts, shall be of the same nominal chemistry as the material used for the vessel. Proposals to use alternative materials shall be submitted to purchaser for approval by the Company.

7.6.5 All carbon steel and low alloy material used in sour service shall comply with, but not be limited to the requirements of NACE Standard MR-01-75, (Material Requirements-Sulphilde Stress Cracking Resistant Material for Oilfield Equipment, latest Revision).

7.7 Documentation

A manufacturer's data report shall be furnished, and shall contain the same information as required by form U-1 of the ASME Code Section VIII, Division 1. If the vessel is constructed for use at a location where the ASME Code is not mandatory (if approved by the Company), it shall be noted on the form that the vessel does not carry an ASME Code symbol.

7.8 Internals

7.8.1 All gas scrubbers, contactors and separators shall be provided with 316 Stainless Steel wire mesh mist eliminator(s) of 150 mm minimum thickness, adequately supported and fastened to prevent displacement under surge conditions.

7.8.2 All demister pads shall be fabricated in sections to permit their removal through manways, where applicable.

7.8.3 The following criteria should be considered in vessels, tower's internal design:

a) The minimum thickness of removable tray plates shall be 2 mm. Any corrosion allowance specified for the tray parts under consideration shall be added to this thickness. Active devices may be less than 2 mm thick for process reasons.

b) Each tray shall be designed for an upward pressure differential and shall be specified in the data sheet.

c) Valve type proprietary tray designs shall have been tested by Fractional Research Incorporated and shall be of a type approved by the Company.

Trays with the capped perforated areas are not acceptable.

d) Thickness

d.1) Minimum thickness for 13 Cr. Monel and 18/8 Stainless Steel assemblies shall be as follows:

Tray and related components	2 mm
Support ring, Downcomer bars	6 mm when alloy 10 mm when
and Parts welded to vessel	Carbon Steel
Other Parts	3 mm

d.2) Minimum thickness for Carbon Steel assemblies shall be as follows:

Tray and related components	2 mm
Support rings, Downcomer bars and	10 mm
Parts welded to vessel	
Other Parts	3 mm

e) Corrosion Allowance

e.1) No corrosion allowance is required for Monel or Stainless Steel assemblies.

e.2) The corrosion allowance for all surfaces of floor beams trusses or other support members of Carbon Steel assemblies shall be 1 mm minimum.

f) Loading

f.1) The design live load for tray assemblies at operating temperatures shall be based on a liquid height of 50 mm above weirs at a density of 800 kg/m³, with a minimum of 100 kg per square meter. For areas under downcomers design live load shall be 100 kg per square meter.

f.2) For maintenance purposes, all assemblies shall be designed for a concentrated load   of 135 kg at any point.

7.8.4 Trays in columns 900 mm inside diameter and greater shall incorporate manways.

7.8.5 All internal manways shall be designed to be opened from either side of the tray and shall be gasketed to prevent leakage of liquids.

7.8.6 Tray spacing is recommended to be 610 mm.

7.8.7 Trays shall be bolted to support rings and not welded to the vessel wall and shall be in bolted sections to facilitate their removal through vessel manways.

7.8.8 For columns less than 900 mm inside diameter, cartridge trays shall be employed and vessel break flanges shall be provided to facilitate tray package removal.

7.8.9 Impingement plates attached to shell or baffles shall be provided where severe erosion may occur, such as opposite inlet connections. These and all internal supports shall be attached with full fillet seal welds.

7.8.10 Vortex breakers shall be provided on liquid bottom outlet nozzles from vessels as follows:

  a) pump suction connection;
  b) vessels where two liquid phases may be present.

7.9 Miscellaneous Requirements

7.9.1 All nozzles over DN 40 (1-½") shall be flanged. Connections DN 40 (1-½") and smaller may be made with forged steel couplings. Such connections shall be limited to vessels for which the design pressure and temperature is less than 42 bar(ga) (600 psig) and 232°C (450°F) respectively. Couplings shall be 420 bar(ga) (6000 psig) rating for DN 40 (1-½") and smaller connections. Couplings shall not be used in lined portions of alloy lined vessels, on bottom heads of vertical vessels. Threaded fittings or tapped holes are not permitted. The minimum size of nozzles shall be DN 25 (1"), except that for alloy lined nozzles the minimum size is DN 40 (1-½"). For vessels in hydrogen service minimum size connection shall be DN 25 (1") and all connections shall be flanged.

7.9.2 All vessels 900 mm inside diameter (ID) or greater shall be provided with at least one 450 mm inside diameter manhole opening. Davits or hinges shall be provided for handling manhole covers.

7.9.3 Vessels less than 900 mm inside diameter shall be provided with two 168.3 mm outside diameter (OD) hand holes unless otherwise specified.

7.9.4 Vessel vents and drains shall be independent of the normal process flow lines and shall be in accordance with the Clause 6.5.5.1.10 of IPS-E-PR-200, "Basic Engineering Design Data".

Drain connections shall be flushed with the bottom of the vessel. These and internal siphon drains shall as a minimum be Schedule 160 pipe.

7.9.5 Provide one(1) manway in single cross-flow trays, two(2) manways in double cross-flow trays, removable from above and below. Manways shall be as close to tray centerline as possible and as nearly aligned as practicable.

7.9.6 All trays are equipped with one manway top and bottom removable for each liquid flow as per 7.9.5 above, except where the free space between tray and beams are less than 400 mm. In this case manways are to be provided on both sides of beams.

7.9.7 Specification sheets of reactors shall contain but not be limited to, the following information:

  a) Capacity.
  b) Space velocity (normal and design conditions).
  c) Conversion per pass (normal and design conditions).
  d) Design-temperature and pressure.
  e) Recycling (normal and design conditions).
  f) Reactor pressure drop (SOR & EOR).
  g) Reactor bed design and bed life.
  h) Catalyst and it's characteristics.
  i) Reactor inlet & outlet conditions (normal and design conditions).

j) Reactor bed temperature profile, etc. (normal and design conditions).

k) Reactor lining.

l) Corrosion allowance.

m) Process fluid complete physical properties (normal and design conditions).

n) Operating and design conditions.

o) Stress relieving and insulation.

p) Materials of construction.

q) Stress relieving.

r) Insulation requirements.

s) Type of trays.

t) Tray numbers and details for columns.

u) Pedestal height.

v) Details of special internals such as pans, distributors, etc.

w) Mist eliminators, supports, mesh or packing, etc.

x) Basic recommendation for spares for commissioning and 2 years operation.

y) Instrumentation requirements.

7.9.8 Internals for fixed bed reactors

7.9.8.1 Table G.1 of Appendix G lists the basic practices and standards which may be used as an acceptable typical material for fixed bed reactor internals.

7.9.8.2 Design requirements are as follows:

a) Vessel internals which contribute to the total reactor height shall be designed for minimum height. Similar parts shall be interchangeable where possible.

b) All internals, except shrouds, shall be removable with vertical thermowells in place, and shall be designed to pass through the nearest manhole above their level.

c) All removable internals shall be designed to permit installation and removal from the top side.

d) Screens shall be attached on top of grids and catalyst support hardware to prevent inerts and catalyst from:

    1) Falling through holes or slot openings.

    2) Blocking clearances in support hardware that are required for thermal expansion.

7.9.8.3 Loads are as below:

a) Reactor internals shall be designed to support their own mass plus specified design live loads. For trays and decks, this design shall be based on a corroded thickness of 1.5 mm.

b) Maximum deviation from the horizontal for liquid distributor trays under loaded conditions shall not exceed 1/900 of the reactor diameter.

c) Maintenance loads

Support members as defined in Table G.2 of Appendix G shall be designed for a concentrated live load of 135 kg at any point based on the allowable stress. This design shall be based on the corroded thickness of the support members; i.e., total thickness excluding corrosion allowance.

7.9.8.4 Minimum metal thickness and corrosion allowance as:

a) For internals fabricated from sheet, plate, or strip; and for internal piping, the minimum acceptable total metal thickness (including corrosion allowance) is given in Table G.2 of Appendix G for the specified Corrosion Design Category and Vessel Shell Corrosion Allowance (or Metal Lining or Cladding Thickness). Unless otherwise specified, Corrosion Design Category "10 yr" shall be used.

b) Supporting members formed as an integral part of the tray deck shall have the same total thickness as the tray.

c) The Total Corrosion Allowance (TCA) to be added to the design thickness of support members (major beams, supporting, etc.) is given in Table G.2 of Appendix G for the specified Corrosion Design Category and Vessel Shell Corrosion Allowance (or Metal Lining or Cladding Thickness).

7.9.8.5 Distributor trays, quench decks, splash decks, and bed support grids as:

a) The nominal diameter of trays, decks, and grids shall be determined to the nearest 5 mm (¼ inch) per the following:

Diameter = Vessel ID - [1% Vessel ID + 19 mm (¾ inch)]

b) A minimum of 19 mm (¾ inch) overlap under the most adverse operating conditions shall be provided between the support ring and the OD of trays, decks, and grids.

c) Bolt hole spacing around the edge of tray, deck, or grid sections shall not exceed 177 mm.

d) Access through grids, decks, and trays shall be provided either by split construction or by use of manways, as follows:

1) Manways shall provide a minimum rectangular opening of 380 × 460 mm except as provided in Sub-par. d.2.

2) Access through liquid distributor trays shall be at least 600 mm wide, and of sufficient length to permit catalyst leveling and arrangement of the inert ball layer at the top of each bed by a man lying on the tray. Assume a maximum reach 900 mm from the edge of any opening.

7.9.8.6 Internal pipes and thermowells

- Thermowells shall be designed to resist collapse due to pressure in the fully corroded condition.

- Clearance between thermowell and thermowell nozzle shall be minimized.

- Side entering thermowells shall be structurally supported within the vessel.

- Internal distribution pipes shall have flanged and gasketed connections and shall have their ends blanked.

- Expansion guides shall be provided for vertical thermowell installation.

- Tray guides shall be provided to minimize liquid leakage at points where thermowells or catalyst dump tubes pass through trays. Highest Liquid Level (HLL) will be specified.

APPENDICES

APPENDIX A
TABLE A.1 - PERFORMANCE COMPARISON OF VARIOUS SEPARATORS

| | KO DRUM | | WIRE MESH DEMISTER | | VANE-TYPE DEMISTER | | | CYCLONE | VERTICAL MULTI-CYCLONE SEPARA-TOR | FILTER SEPARA-TOR |
| | Vertical | Horizontal | Vertical | Horizontal | Vertical | | Horizontal | | | |
					in-line	two-stage	two-stage			
Gas handling max capacity (λ) turndown (max/min)	Low Inf.	Low Inf.	Mod. 4	Mod. 4	High 3	High 3	High 3	V. High 2	V. High 2	Low Inf.
Liquid removed efficiency overall, % with respect to fine mist flooding above λ_{max} *	80 - 90 V. Low No	80 - 90 V. Low No	> 98 High Yes	> 98 High Yes	> 96 Low	> 96 Low	> 96 Low	> 96 Low No	> 93 Low Yes	> 99 V. High Yes
					Yes, unless dp vanes are used					
Liquid handling capacity as slugs as droplets (Q_{max})	High High	V. High High	High High	V. High High	V. Low Low	High Mod.	High Mod.	High High	Low Low	Low Low
Fouling tolerance Sand Sticky material	High High	High High	Low V. Low	Low V. Low	V. Low if d_p, Low if S_p Mod. if n_p.			High High	High Low	High Low
Pressure drop	V. Low	V. Low	Low	Low	Low	Low	Low	High	High	V. High

d_p = double-pocket vanes
s_p = single-pocket vanes
n_p = no-pocket vanes
Inf. = Infinity
Mod. = Moderate
V. = Very

* This will cause a sharp decrease in efficiency.

APPENDIX B
NATURE OF THE FEED

B.1 Foaming Tendency

For foaming to occur it is necessary for gas bubbles to be formed, and for the drainage of the liquid films surrounding the bubbles to be 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 of 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, 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.

Note that foaming is more likely to be a problem at high liquid loads, when flow in the inlet pipe is in the froth or intermittent flow regimes.

Installation of internals to combat foam is normally not effective and may even be counterproductive.

Foaming in the vessel is minimized 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.

B.2 Feeds with Solids, Wax or Coking Tendency

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 water spray and drain.

When 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 are low. Also, narrow openings will tend to become plugged.

Coke will also accumulate on surfaces where the velocities are low, and will tend to form on any surfaces which are not continuously wetted.

Knock-out drums are recommended for waxy feeds and cyclones for coking feeds. Multicyclone separators and filter separators can handle solids as long as they are not sticky.

Vane pack separators may be used provided the service is only slightly fouling and the vane structure is sufficiently open.

Demister mats shall not be used because of the danger of plugging.

APPENDIX C
SIZING OF THE FEED AND OUTLET NOZZLES

The sizing of the nozzles shall be based on the ACTUAL flow rates (i.e., EXCLUDING the appropriate design margin).

C.1 Feed Inlet Nozzle

The internal nozzle diameter, d_1, may be taken equal to that of the feed pipe, but also a momentum criterion (dependent on the inlet device, if any) shall be satisfied:

If no inlet device is used:

$$\rho_m \cdot V^2_{m,in} \leq 1000 \qquad\qquad Pa \qquad\qquad\qquad \textbf{(Eq. C.1)}$$

Where:

ρ_m is mean density of the mixture in the feed pipe

$$= (M_G + M_L)/(Q_G + Q_L); \qquad\qquad\qquad \textbf{(Eq. C.2)}$$

and

$V_{m,in}$ is velocity of the mixture in the inlet nozzle

$$= (Q_G + Q_L)/(\pi d_1^2 / 4). \qquad\qquad\qquad \textbf{(Eq. C.3)}$$

If a half-open pipe is used as inlet device:

$$\rho_m \cdot V^2_{m,in} \leq 1500 \qquad\qquad Pa \qquad\qquad\qquad \textbf{(Eq. C.4)}$$

If a specific inlet proprietary device is used, the respective $\rho_m \cdot V_{m,in}$ value should be specified.

C.2 Gas Outlet Nozzle

The diameter of the gas outlet nozzle, d_2, should normally be taken equal to that of the outlet pipe, but the following criterion shall be satisfied:

$$\rho_G \cdot V^2_{G,out} \leq 3750 \qquad\qquad Pa \qquad\qquad\qquad \textbf{(Eq. C.5)}$$

In High Vacuum Units where a precondenser is used in overhead systems, this criterion may result in a high outlet velocity, leading to a pressure drop which is too high.

In that case it is recommended to size the gas outlet nozzle such that the pressure drop requirements between column and downstream system are met.

C.3 Liquid Outlet Nozzle

The diameter of the liquid outlet nozzle, d_3, shall be chosen such that the liquid velocity does not exceed 1 m/s. The minimum diameter is 0.05 m (2 inch). The nozzle shall be equipped with a vortex breaker.

APPENDIX D
DESIGN MARGINS FOR SEPARATOR

To determine the highest envisaged volumetric load factor for vessel design the following design margins (surge factor) are recommended:

D.1 In Exploration and Production:

D.1.1 Offshore service

Separator handling natural-flowing production from:

		Design Margin
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

D.1.2 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

D.2 In Manufacturing Oil, Gas and in Chemicals Manufacturing:

The design margin ranges typically from 1.15 to 1.25.

APPENDIX E
TABLE E.1 - SEPARATOR TYPE SELECTION GUIDE

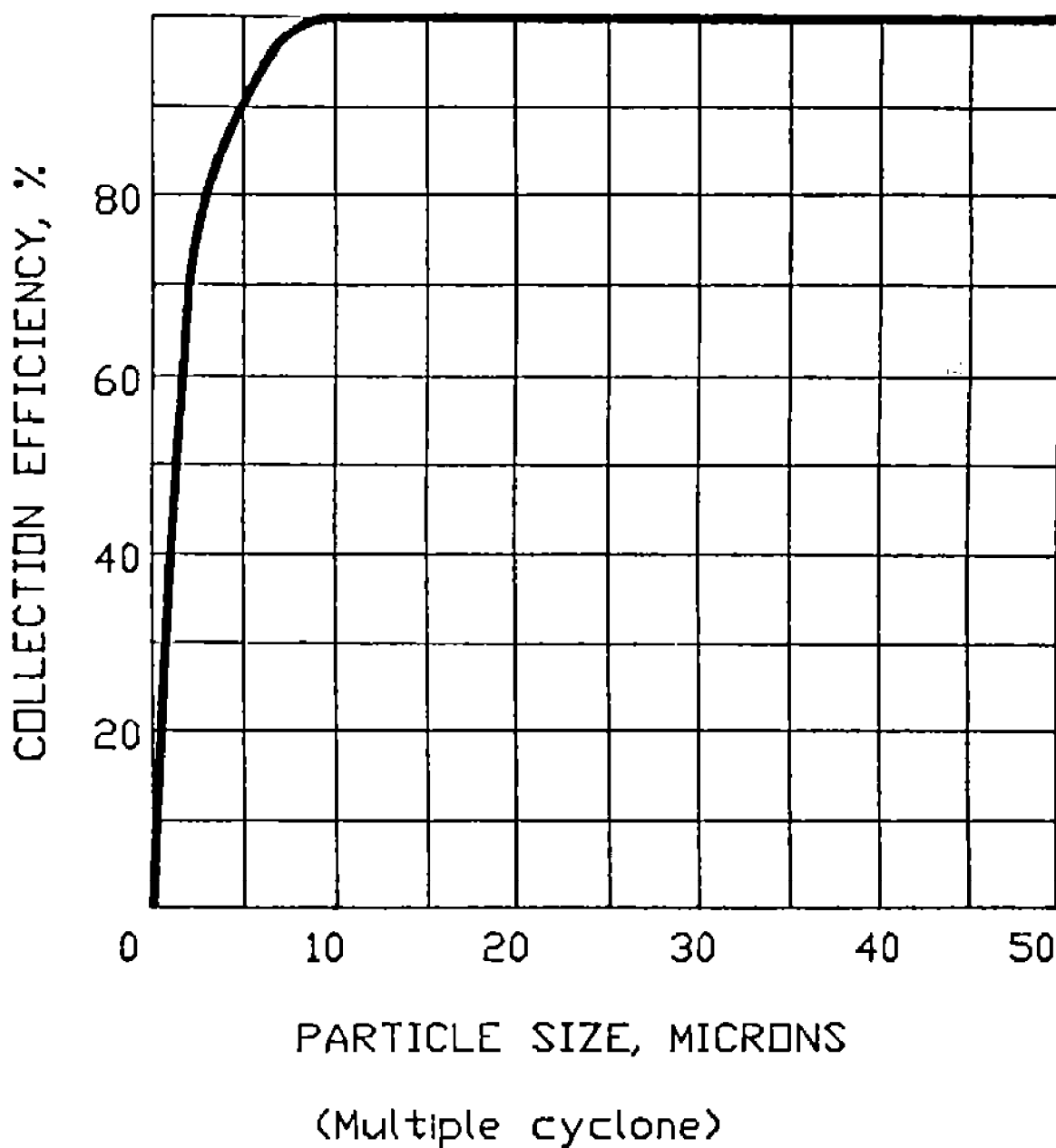| APPLICATION	Vertical Separator with Vane	Demister	Inline Vane	Cyclone	SEPARATOR TYPE		
					Multi-cyclone	Filter	Filter Separator
Gas Transmission:							
Station Scrubber	×	×			×		×
Fuel Gas	×				×	×	×
City Gates/Metering	×	×			×	×	×
Pressure Reduction	×	×	×		×		×
Compressor Station	×	×	×		×		
Process:							
Glycol Dehydrators		×	×	×	×		
Amine Contactors		×	×	×	×		
Compressors			×		×		×
Gathering	×	×		×			
Pressure Reduction	×	×	×		×		×
Wellhead	×				×		

TABLE E.2 - GAS SEPARATOR TYPES ALONG WITH TYPICAL SEPARATION PERFORMANCE

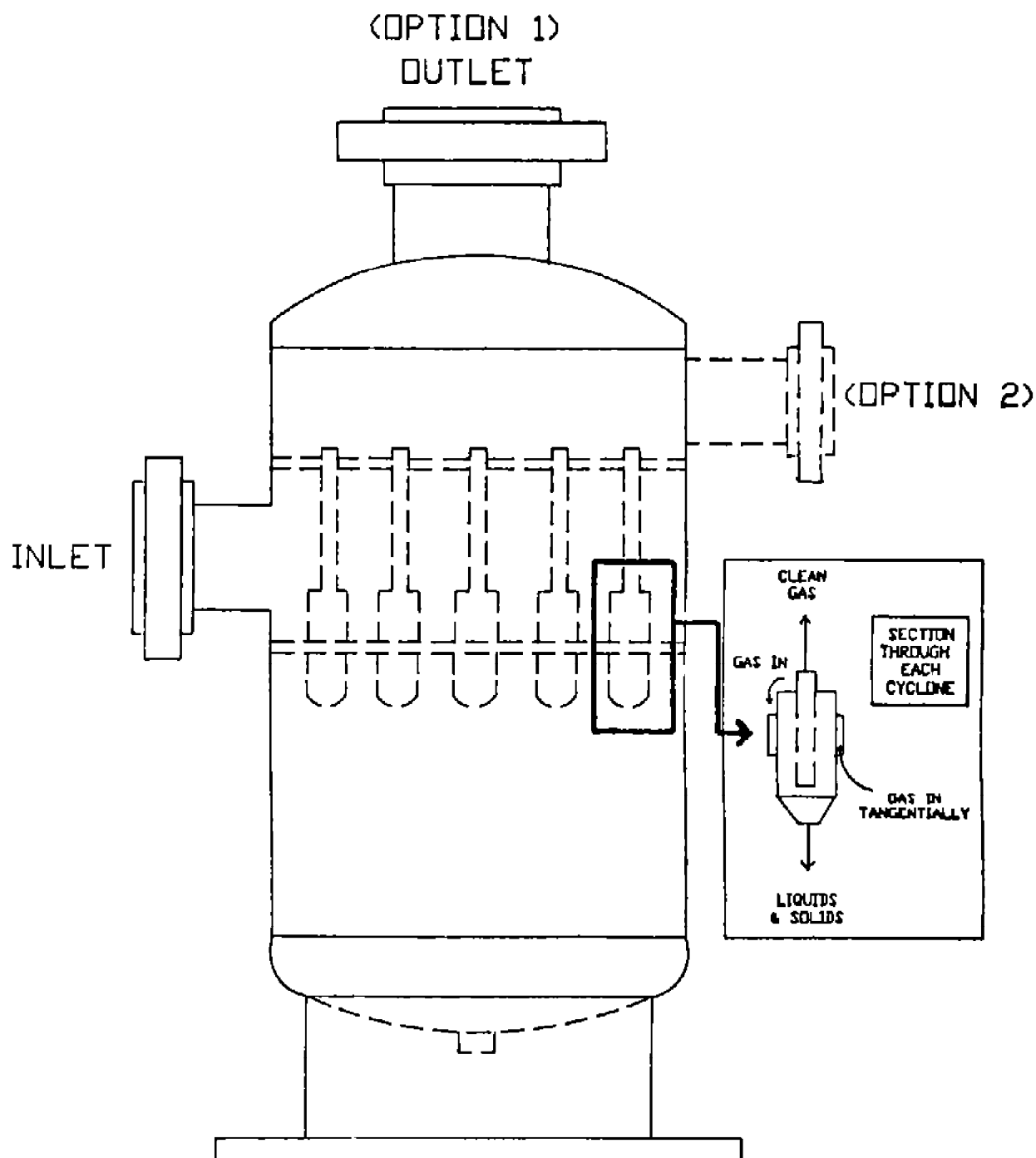| SEPARATOR TYPE	SLUG HANDLING CAPACITY	SOLID REMOVAL EFFICIENCY IF ANY	LIQUID REMOVAL EFFICIENCY
Multicyclone scrubbers	Yes	100% 8μ & larger 99% 5 - 8μ	100% 5μ & larger
Vertical gas separator with vane	Yes	No	100% 8μ & larger
In-line vane	No	No	100% 8μ & larger
Vertical separator with wire mesh demister	Yes	No	98% 8μ & larger
Filter separators with vane	Yes	100% 3μ & larger 99% 0.5 - 3μ	100% 3μ & larger
Dry gas filters	No	100% 10μ & larger 99% 1 - 3μ	

μ = **microns (μm)**

APPENDIX E (continued)

PARTICLE SIZE, MICRONS

(Multiple cyclone)

EFFICIENCY CURVE FOR MULTI-CYCLONE SEPARATOR SOLID PARTICLE REMOVAL
Fig. E.1

(to be continued)

APPENDIX E (continued)

(OPTION 1)
OUTLET

(OPTION 2)

INLET

CLEAN
GAS

GAS IN

SECTION
THROUGH
EACH
CYCLONE

GAS IN
TANGENTIALLY

LIQUIDS
& SOLIDS

SKETCH OF MULTI-CYCLONE SCRUBBER/SEPARATOR
Fig. E.2

APPENDIX F

TYPICAL EQUATIONS, WHICH CAN BE USED FOR TERMINAL VELOCITY CALCULATION

F.1 Terminal Velocity of a Spherical Fine Particle Settling under the Influence of Gravity

The terminal velocity of a spherical fine particle settling under the influence of gravity can be determined by Stockes' law.

$$U_t = \left[\frac{4 \, g.D_p}{3 \, C_D} \cdot \frac{\rho_L - \rho_v}{\rho_v} \right]^{1/2} \tag{Eq. F.1}$$

$$U_t = K \frac{\rho_l - \rho_v}{\rho_v} \tag{Eq. F.2}$$

Where:

U_t is terminal velocity, in (m/s);
g is acceleration of gravity, in (m/s²);
D_p is diameter of fine particle, in (m);
C_D is drag coefficient;
ρ_L *(rho)*   is density of liquid, in (kg/m³);
or
ρ_l
ρ_v *(rho)*   is density of vapor, in (kg/m³);
k is entrainment coefficient, in (m/s).

Based on the theory and experimental results, C_D can be expressed approximately as follows. It should be noted that C_D is given as a function of Reynolds number, Re only, where the velocity is he relative velocity of the fine particle to its surrounding fluid.

$C_D = 24/Re$ for Re < 2	(Stocks' law)	(Eq. F.3)
$C_D = 10/\sqrt{Re}$ for 2 < Re < 500	(Allen's law)	(Eq. F.4)
$C_D = 0.44$ for Re > 500	(Newton's law)	(Eq. F.5)

Substituting these for C_D in Eq. F.1.

$$U_t = \frac{g.D_p^2(\rho_L - \rho_v)}{18 \, \P} \qquad \text{(Re < 2)} \tag{Eq. F.6}$$

$$U_t = \left[\frac{4}{225} \frac{(\rho_L - \rho_v)^2 \, g^2}{\P . \rho_v} \right]^{\frac{1}{3}} D_p \qquad \text{(2 < Re < 500)} \tag{Eq. F.7}$$

$$U_t = \left[3g . D_p \frac{\rho_L - \rho_v}{\rho_v} \right]^{1/2} \qquad \text{(Re > 500)} \tag{Eq. F.8}$$

(to be continued)

APPENDIX F (continued)

F.2 Application to Vertical Vapor-Liquid Separator

F.2.1 The value "k" in Eq. F.2 is used for design of usual vapor-liquid separators.

F.2.2 Several types of wire-mesh demisters are manufactured. The most widely used ones are given in Appendix F, Table F.1:

TABLE F.1 - TYPICAL IDENTIFICATION OF WIRE MESH TYPES

Density (kg/m³)	Surface Area (Note 1) (m²/m³)	Void Fraction —	Wire Diameter (mm)	MANUFACTURE'S TYPE					APPLICATION
				York	Divment	Metex	Nihon Mesh	Naniwa Special Mesh	
192	36	0.977	0.275	421	4210	Xtradense Standard	SL	3311	High efficiency, Relatively clean, Moderate Velocity, use in 100 mm pad
144 (Note 2)	279	0.982	0.275 (Note 3)	431	4310	Nu-standard	N	3383	Standard efficiency, General purpose, use in 100 mm pad
128	459	0.984	0.15	326	3260	—	SN	—	Fine mist removal, use in 100 mm - 150 mm pad
80	151	0.990	0.275 (Note 3)	931	9310	Hl-throughput	H	3346	High through-put or low density, For service containing solids or "dirty" material, use in 150 mm pad
219	902	0.972	5 strand each 0.122	—	—	—	T	4060	Very high efficiency, 250 mm and 300 mm recommended for special applications such as fine mists , oil vapor mist

Notes:

1) If the mesh is made of nickel, monel or copper, multiply the density values by 1.13, referenced stainless steel.

2) Normally, 144 kg/m³.

3) Some manufacturer fabricates with 0.254 mm wire.

APPENDIX F (continued)

F.2.3 "K" Value for wire mesh demisters, based on disengaging height (height between bottom of mesh, and liquid surface) of 300 mm minimum should be considered as following Table F.2:

TABLE F.2 - "K" VALUE FOR WIRE MESH DEMISTERS

SERVICE CONDITION	"K" VALUE	MESH TYPE
- Clean Fluids, Moderate Liquid Load, fits 90% of process situations	0.35 to 0.36 0.35 0.25	- Standard - High efficiency - Very high efficiency
- High Viscosity, Dirty Suspended Solids	0.40	- Low density or Herringbone, High Throughput
- Vacuum Operations • 50 mm Hg (abs.) • 400 mm Hg (abs.) • Corrosive Chemicals	 0.20 0.27 0.21	- Standard or - High efficiency - Plastic Coated Wire, or Plastic strand

F.2.4 For variation of "K" Values with disengaging height see recommended values as hereunder in Table F.3:

TABLE F.3 - VARIATION OF "K" VALUES WITH DISENGAGING HEIGHT

DESENGAGING HEIGHT ABOVE MESH, (mm)	ALLOWABLE "K" VALUE
75	0.12
100	0.15
125	0.19
150	0.22
175	0.25
200	0.29
225	0.32
250	0.35
275	0.38
300	0.40
325	0.42
350	0.43

F.2.5 It is required that disengaging heights should be 460 mm, minimum in cases where wire mesh is provided. This height must be corrected for the vapor velocity in each individual case.

Provision of baffles must be considered. The reason for this is that the duty of vapor liquid separation in the disengaging zone can be reduced by directing the liquid flow downwards. Also, consideration has been given to avoid the unfavorable effects on wire mesh pad due to the conning of feed stream in cases where no baffle is provided. The same thought has been followed even in cases where no wire mesh is provided.

APPENDIX F (continued)

F.3 Application of These Equations to Vertical Liquid-Liquid Separators

F.3.1 Using Allen's and Stocks' equations, the terminal velocity of the heavier particles can be calculated. Typical application of these equations to the separation of water from oil is given in the following Tables F.4 and F.5.

TABLE F.4 D_P = 400 - 500 microns

PHYSICAL PROPERTIES		OIL FRACTION	MAXIMUM LIQUID VELOCITY
Relative Density (Sp. Gr.)	μ (cP)		m/s
0.70	0.5	Naphtha	0.3
0.80	1.5	Kerosene	0.015
0.85	5.0	Gas-Oil	0.003
0.90	10.0	Vac. Gas-Oil	0.0015

TABLE F.5 D_P = 1,000 microns (1 mm)

PHYSICAL PROPERTIES		OIL FRACTION	MAXIMUM LIQUID VELOCITY
Relative Density (Sp. Gr.)	μ (cP)		m/s
0.70	0.5	Naphtha	0.8
0.80	1.5	Kerosene	0.04
0.85	5.0	Gas-Oil	0.02
0.90	10.0	Vac. Gas-Oil	0.005

F.4 Horizontal Separators

The following equation is based on Stocks' equation described in Appendix F:

$$U_t = g. D_p{}^2 (\rho_h - \rho_L) / 18\mu \qquad \text{(Eq. F.9)}$$

Where:

|	
g	is acceleration of gravity, in (9.8 m/s²);
D_p	is diameter of the heavier particle, in (m);
ρ_h *(rho)*	is density of the lighter fraction, in (kg/m³);
ρ_L *(rho)*	is density of the heavier fraction, in (kg/m³);
μ *(mu)*	is viscosity of the lighter fraction, in (kg/m.s).

Substituting 9.8 m/s² for g and 100 microns for D_p, converting the densities to relative densities (specific gravities), and expressing the viscosity in centipoise:

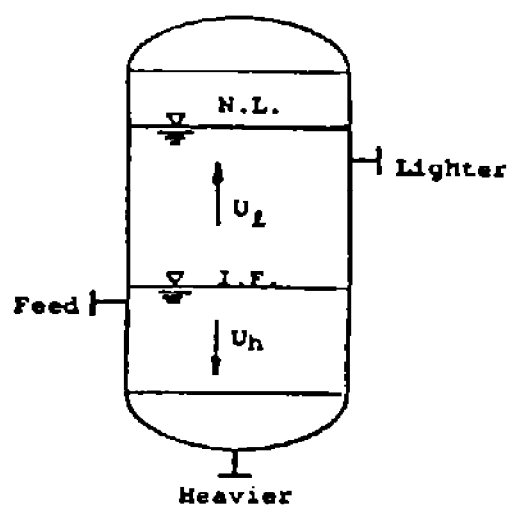$$U_t = \frac{g. D_p^2 (°_h \quad °_l)}{18\P} \qquad \text{(Eq. F.10)}$$

$$= 5.45 \times 10^{-3} \frac{S_h - S_l}{\mu} \qquad (m/s) \qquad \text{(Eq. F.11)}$$

(to be continued)

APPENDIX F (continued)
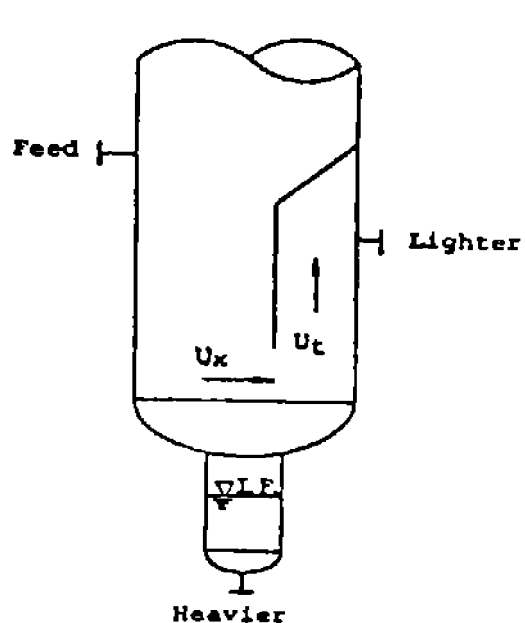
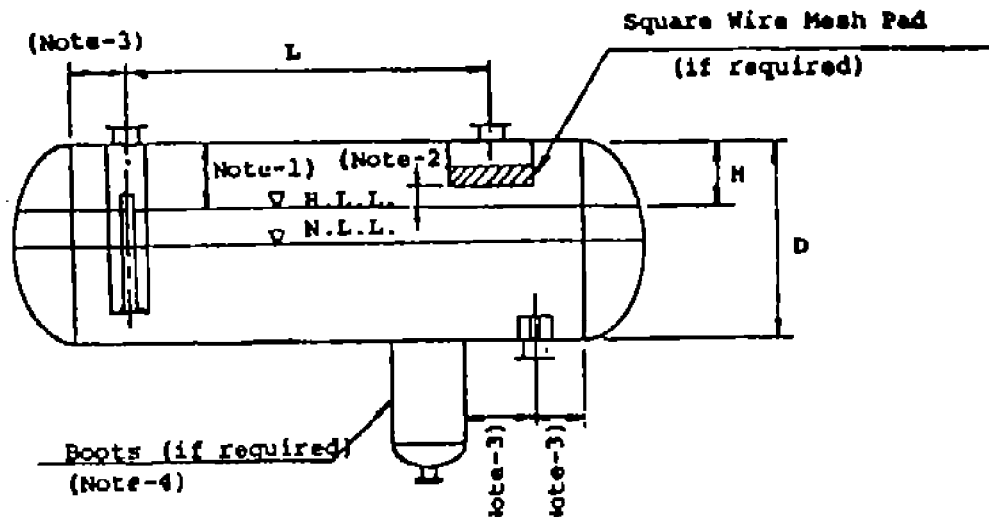U_x is assumed to be equal to terminal velocity U_t, i.e., $U_x = U_t$.

U_h or U_l, whichever is the larger, is made equal to the terminal velocity U_t.

VERTICAL LIQUID-LIQUID SEPARATOR
Fig. F.1

(to be continued)

APPENDIX F (continued)

HORIZONTAL SEPARATOR
Fig. F.2

Notes:

1) 20% of drum diameter of 300 mm (12 inches), whichever is the greater.

2) Minimum 150 mm (6 inches).

3) Minimum.

4)

    a) Boots shall be sized for a minimum residence time of five minutes as a guideline and their diameters shall be the same as the commercial pipe sizes as far as possible. The height-diameter ratio shall be 2:1-5:1.

    b) Boot diameters shall be 250 mm φ minimum, because of good operability.

    c) Maximum boot diameters shall be $^1/_3$ of the drum inside diameter.
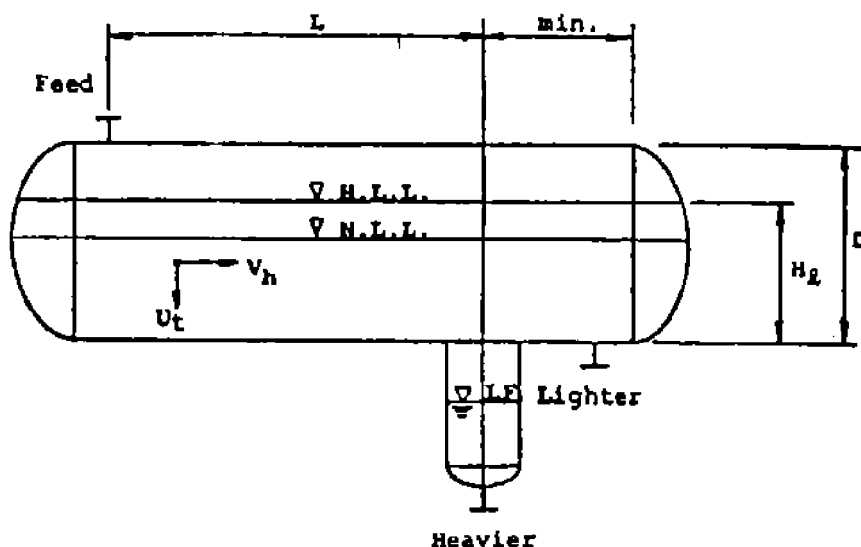
HORIZONTAL LIQUID-LIQUID SEPARATOR
Fig. F.3

APPENDIX G

ACCEPTABLE GRADES AND SPECIFICATION FOR A NUMBER OF STANDARD INTERNAL MATERIALS

Acceptable grades and specification for a number of standard internal materials are listed below:

TABLE G.1 - TYPICAL MATERIALS

MATERIALS	ASTM STANDARDS				
	PLATE	SHEET	STRIP	BARS	BOLTS & NUTS
Carbon Steel	**A283, A285, A36**	**A414, A569**	**A570**	**A675**	**A307, GrB**
Low and Intermediate Alloy Steels C-1/2 Mo	A204	As specified for High Alloy Steels			
1-1/4 Cr-1/2 Mo through 5 Cr-1/2 Mo	A387				
High Alloy Steels					A193 B6, and A194 Gr6F (with Selenium), or Gr8
12 Cr: welded components	A176 and A240, Types 405 and 410S			A276 Type 405	
12 Cr: non-welded components	A176 and A240, Types 405 and 410S			A276 Type 405 or 410	
18 Cr 8 Ni: Types 304, 316, 321, 347	A167 and A240			A276	A193 B8 and A194 Gr8
Non-Ferrous Nickel copper (Monel)	B127			B164	B164
Titanium	B265 Gr2			B348 Gr2	B348 Gr4

* Vendor's proposals to use materials, or thickness alternative to those specified shall be submitted to purchaser for approval by the Company.

** When materials are not specified, Vendor's proposals shall be submitted to purchaser for approval by the Company.

APPENDIX G (continued)

TABLE G.2 - METAL THICKNESS OF INTERNALS, mm (inch)[6, 7, 8]

	VESSEL MATERIALS [1]		CORROSION DESIGN CATEGORY	VESSEL SHELL CORROSION ALLOWANCE, mm OR METAL LINING OR CLADDING THICKNESS, mm					
	Shell (interior surface)	Internals		0.25	0.8	1.6	3.0	4.5	6.0
Non-Supporting Members, such as: Trays, Decks, Integral Minor Beams, Liquid Redistributor	CS	CS	10 yr	—	—	2.0	3.5	4.5	5.5
			15 yr			2.8	4.5	5.5	5.5
			5 yr			2.0	4.5	← 2.0 Alloy →	
	CS	Alloy	All	—	—	←——————2.0——————————→			
	Alloy	Alloy[5]	10 yr	2.0	2.0	2.8	3.5	4.5	Notes (2), (4)
			15 yr			2.8	4.5	5.5	
			5 yr			2.0	4.5		
Tray Accessories such as: Bubble caps, Chimneys, Weirs, Baffles	CS	CS	10 yr	—	—	1.6	2.8	3.5	5.5
			15 yr			1.6	3.5	4.5	5.5
			5 yr			1.6	3.5	4.5	5.5
	CS	Alloy	All	—	—	←———1.6———————→			
	Alloy	Alloy[5]	10 yr	1.6	1.6	1.6	2.8	4.5	5.5
			15 yr	1.6	1.6	1.6	2.8	4.5	5.5
			5 yr	1.6	1.6	1.6	3.5	4.5	Notes (3), (4)
Internal Piping (non-pressure)	CS	CS	All	—	—	← Schd STD →		←—— Schd XS —→	
	CS	Alloy		—	—	← Schd 10 →			
	Alloy	Alloy[5]		← Schd 10 →		←—— Schd STD ——→			Schd XS

(to be continued)

APPENDIX G (continued)

TABLE G.3 - MINIMUM ACCEPTABLE CORROSION ALLOWANCES (TCA) FOR STRUCTURAL COMPONENTS, IN (mm)

Supporting Members such as: All Major Beams and Non-Integral Minor Beams; Inlet Distributors; Outlet Collector Rings, any Load Bearing components welded to the shell.	CS	CS	All	—	—	3.0	6.0	9.0	12.0
	CS	Alloy		—	—	← ——— 1.6 ——— →			
	Alloy	Alloy[5]		None	1.6	3.0	6.0	9.0	12.0

Notes:

1) Abbreviations used in the above table are:

    CS   designates carbon, low alloy and intermediate alloy steels;

    Alloy   designates stainless steels (300 and 400 series), Nickel alloys, Copper alloys; Aluminum alloys.

    TCA   total corrosion allowances.

2) Trays, Decks, etc. shall be at least 2.0 mm thick.

3) Tray Accessories shall be at least 1.6 mm thick.

4)* Material and Metal thickness to be specified.

5) Internals shall be of the same material as the interior surface of the vessel shell.

6) Metric conversion of metal thickness of internals (ex. Internal Piping) and Corrosion Allowance values in Table H.3 shall be as follows:

CORROSION ALLOWANCE				METAL THICKNESS					
mm	(inch)	mm	(inch)	mm	(inch)	mm	(inch)	mm	(inch)
0.25	(0.010)	1.5	(1/16)	0.25	(0.010)	2.8	(0.105)	1.6	(1/16)
0.8	(0.030)	3.0	(1/8)	0.8	(0.030)	3.5	(0.134)	3.0	(1/8)
1.5	(0.060)	4.5	(3/16)	1.6	(0.060)	4.5	(0.179)	4.5	(3/16)
		6.0	(1/4)	2.0	(0.075)	5.5	(0.224)	6.0	(1/4)
		9.0	(3/8)						
		12.0	(1/2)						

7) Vessel shell corrosion allowance for 5, 10 and 15 yr, design categories are based on the maximum values for a given range of corrosion rates.

8) Thickness specified for each vessel shell corrosion allowance are designed so that successively lower corrosion rates are used for each (5, 10, 15 yr) corrosion design category.