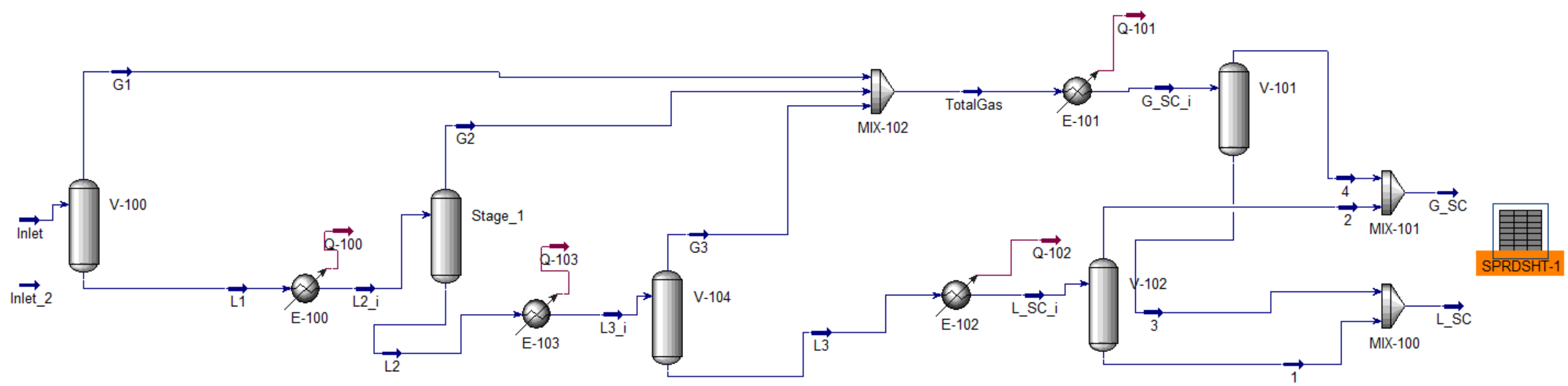
NTNU – Trondheim
Norwegian University of
Science and Technology

Production Technology

Field Processing and Systems

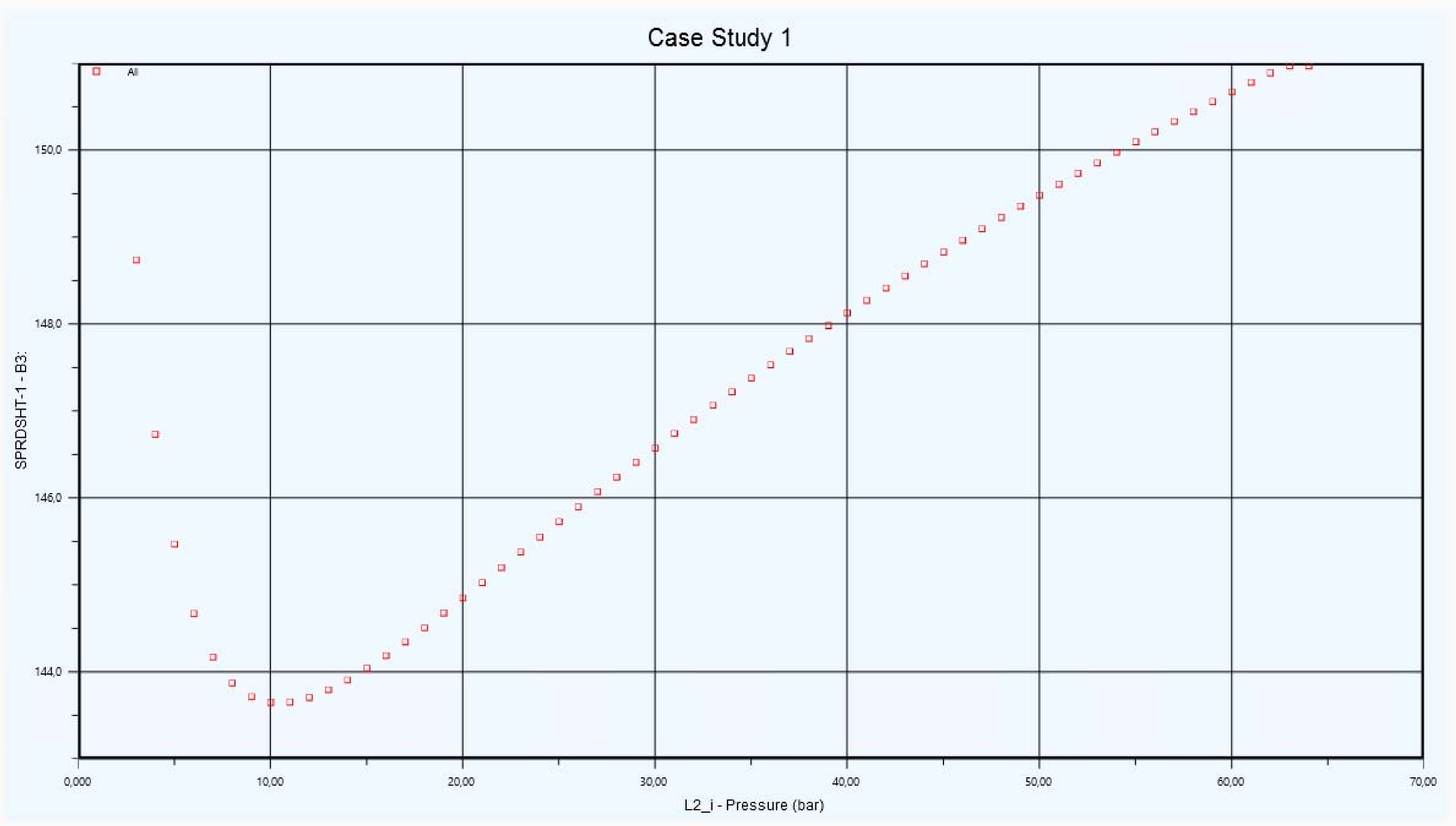
Postdoc Mariana Díaz
01 /22/2019

Summary



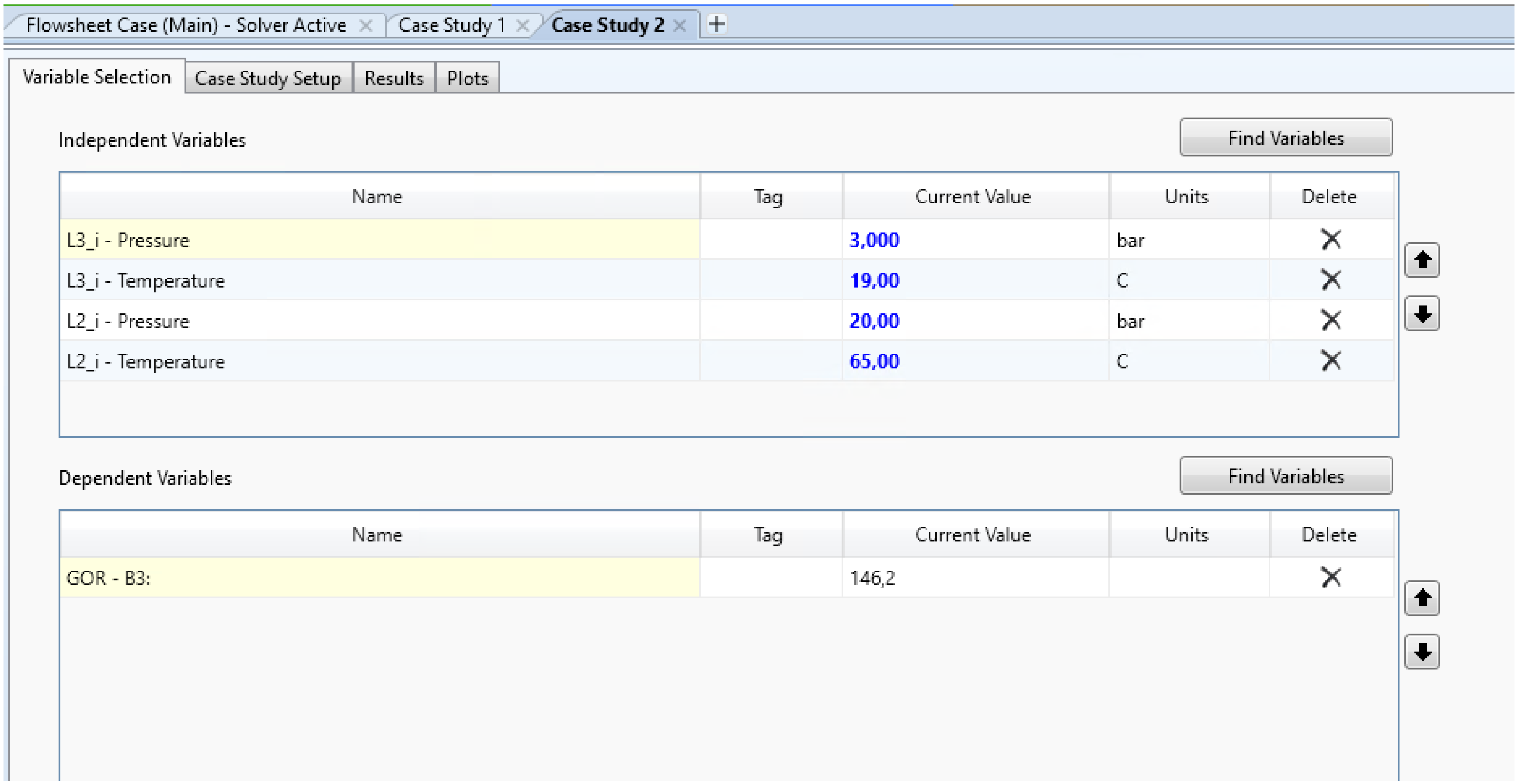
Postdoc Mariana Díaz

Summary



Postdoc Mariana Díaz

Multivariable Case Studies

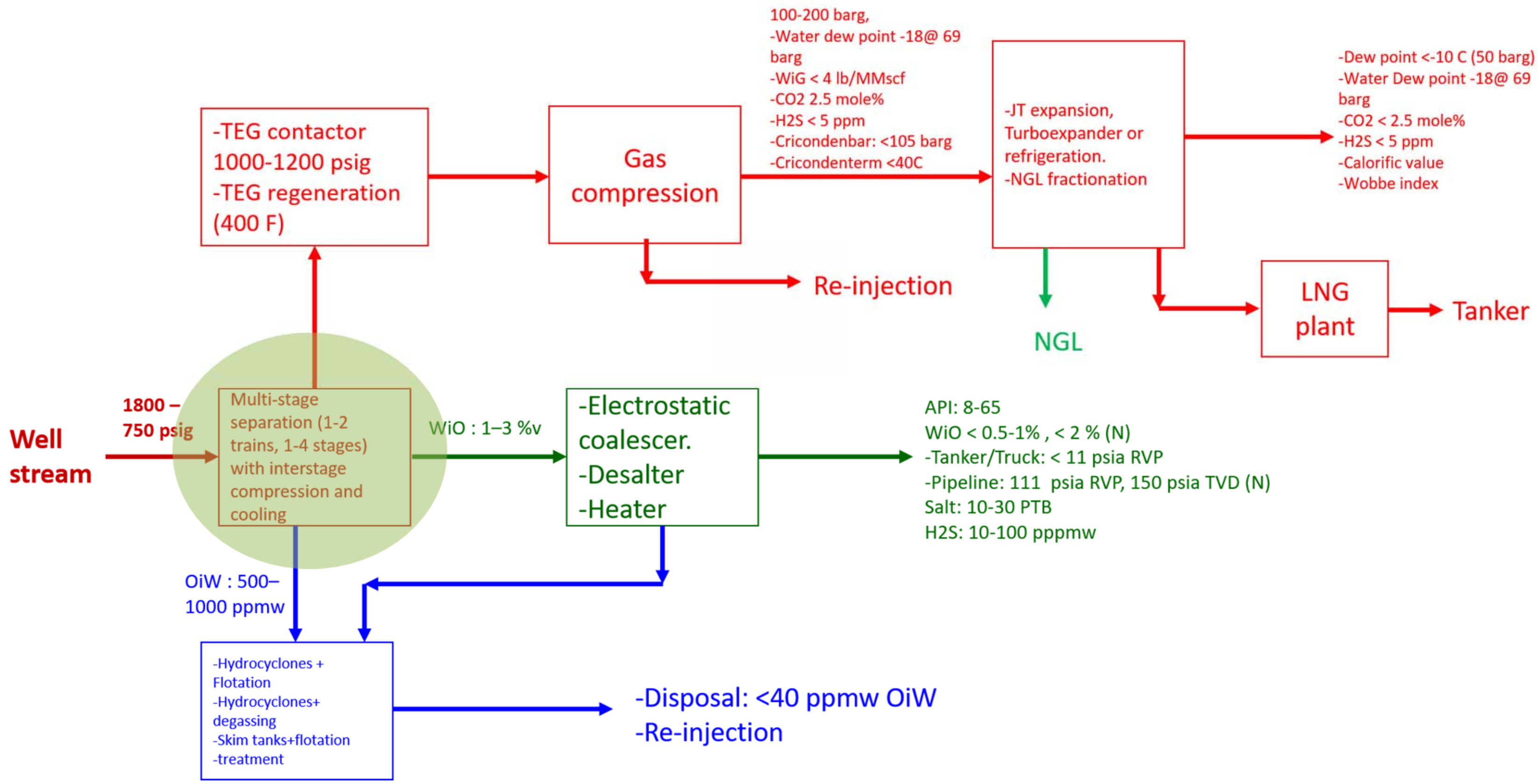


Postdoc Mariana Díaz

SEPARATION

Postdoc Mariana Díaz

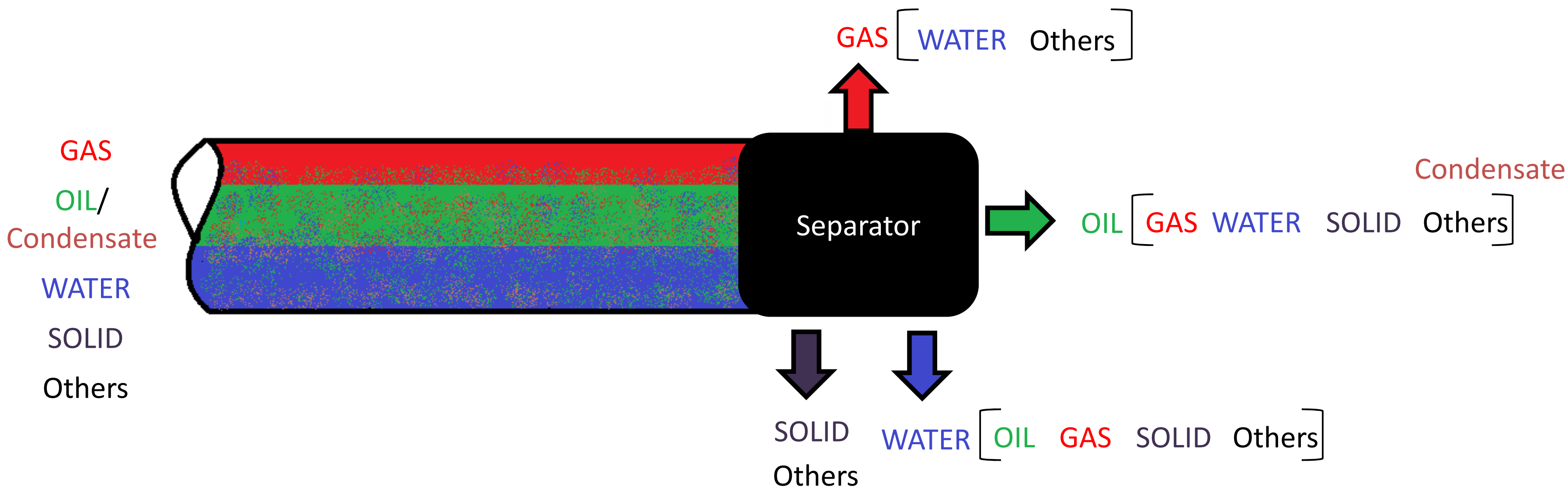
Processing Block Diagram



Stanko Milan (2018)

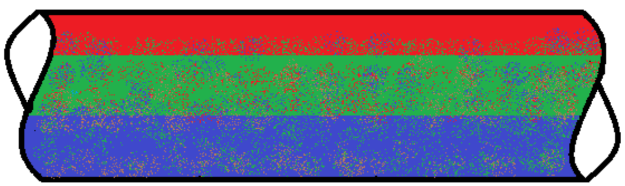
Postdoc Mariana Díaz

Separation in Oil and Gas Production



Postdoc Mariana Díaz

Characteristics of the flow stream



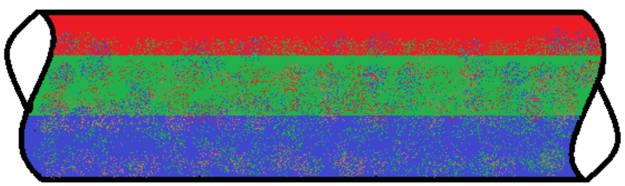
- **Type of fluids/phases**

Type of wells

- Dry gas: Gas, Water
- Gas condensate: Condensate, Water
- Crude oil: OIL, Gas, Water, Solid

Postdoc Mariana Díaz

Characteristics of the flow stream



- **Flow mixture**

Heterogeneous mixtures

Homogeneous mixtures

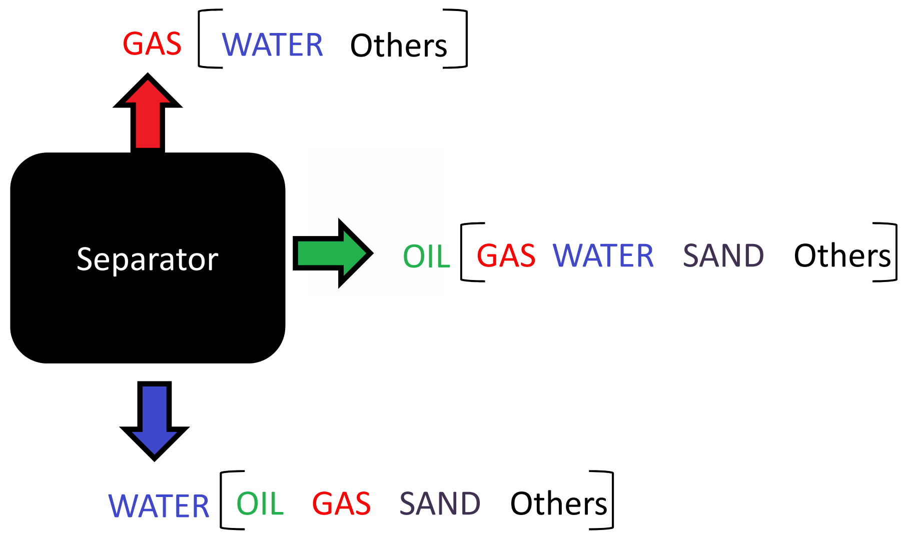
- Emulsion
- Foam

- **Separation variables**

Pressure
Temperature
Density
Composition

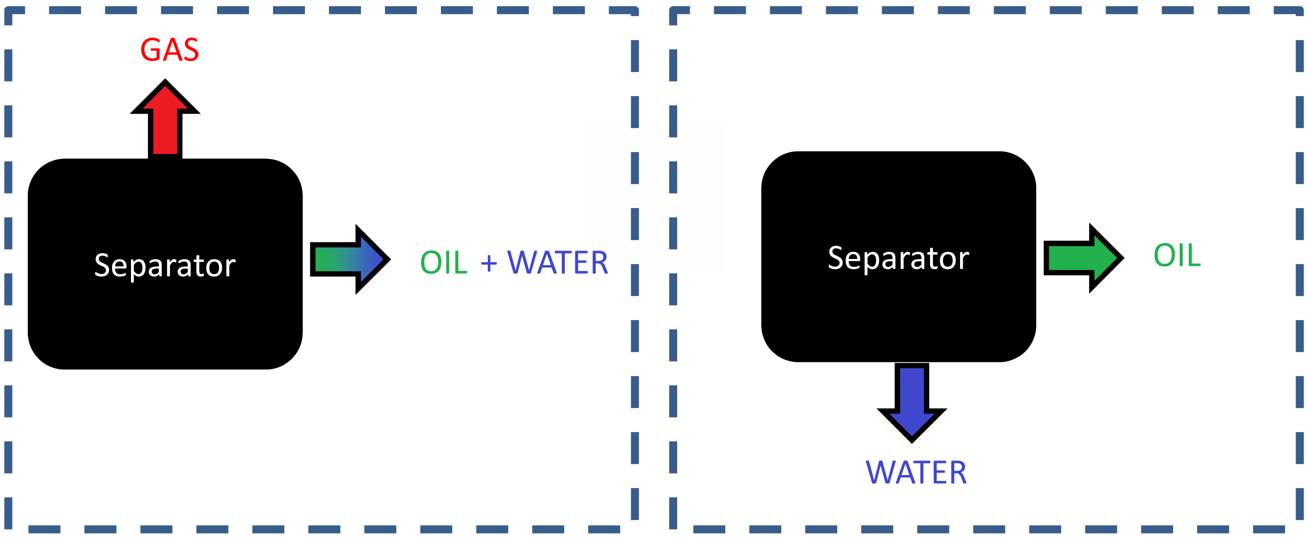
Postdoc Mariana Díaz

Three phase separation



Postdoc Mariana Díaz

Two phase separation



Gas – Liquid Separation

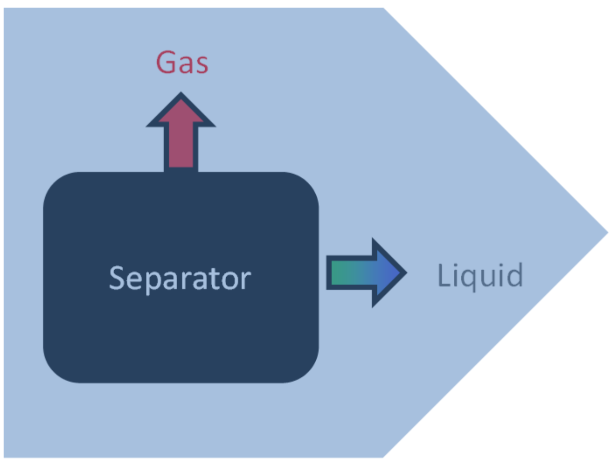
Liquid – Liquid Separation

Postdoc Mariana Díaz

Factor affecting separation

- Gas and liquid flow rate
- Operating and design pressure and temperature
- Slugging or surging
- Physical properties (density, compressibility,…)
- Presence of impurities (paraffin, san, scale,…)
- Foaming tendencies of the oil
- Corrosive tendencies of the liquids or gas

Gas-Liquid Separation



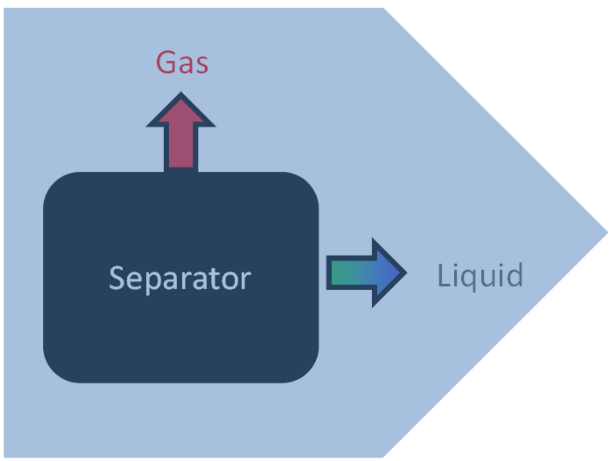
- Gravity tank separators
- Scrubber
- Slug Catcher
- Cyclonic

Gravity tank separators, Scrubber, Slug Catcher → Gravity Forces

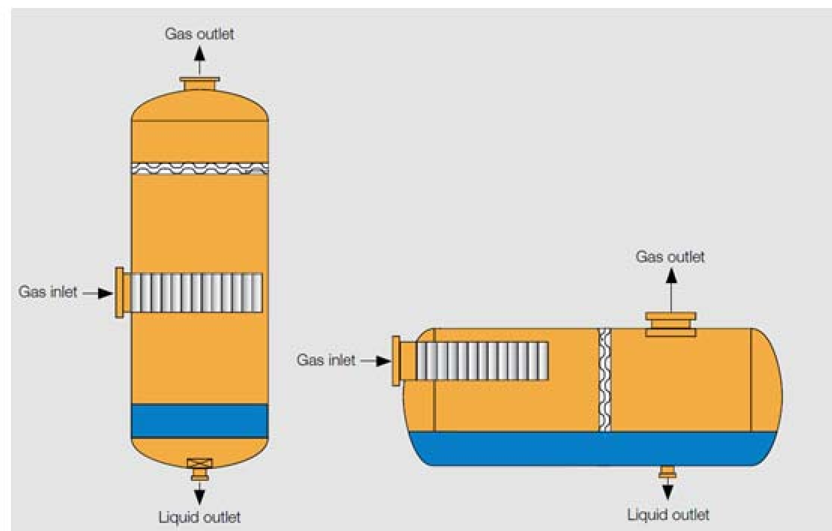
Cyclonic → Centrifugal Forces

Postdoc Mariana Díaz

Gas-Liquid Separation

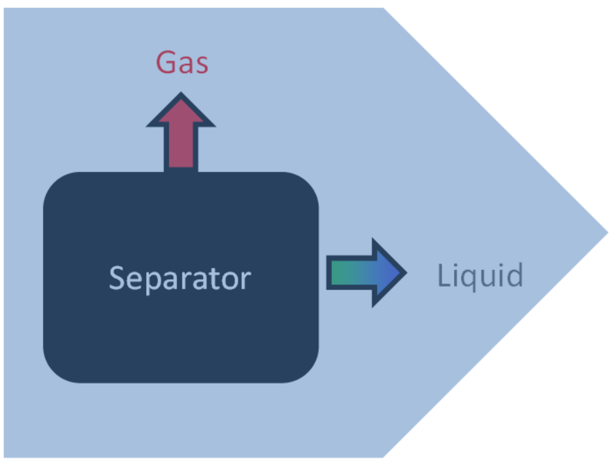


- **Gravity tank separators**
- Scrubber
- Slug Catcher
- Cyclonic

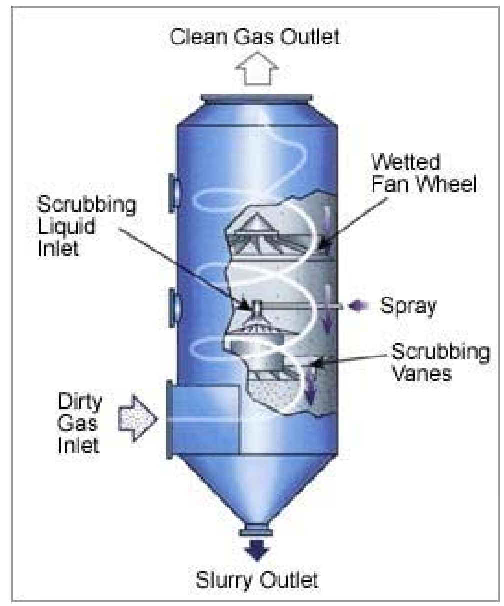


Postdoc Mariana Díaz

Gas-Liquid Separation

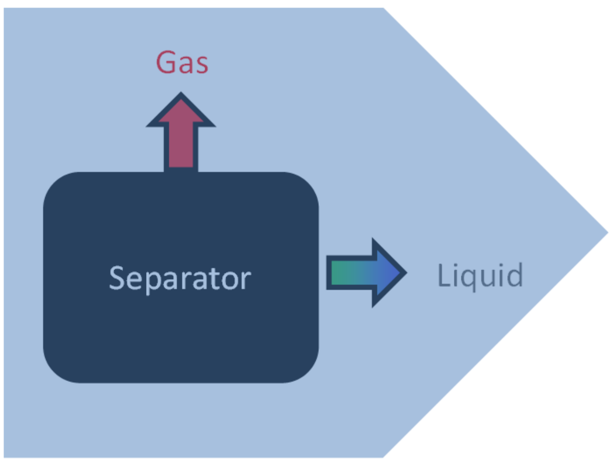


- Gravity tank separators
- **Scrubber**
- Slug Catcher
- Cyclonic

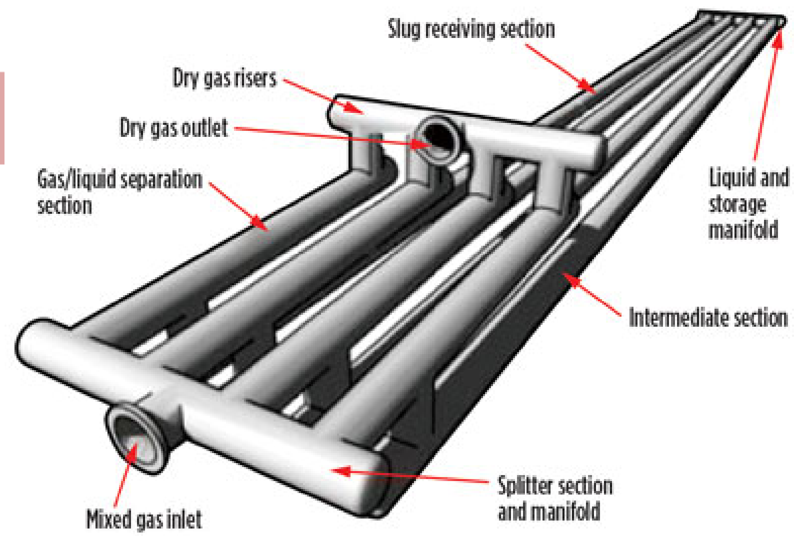


Postdoc Mariana Díaz

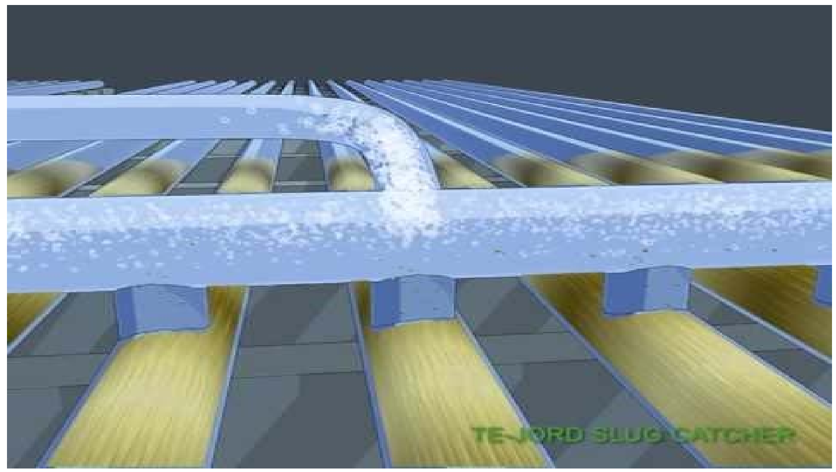
Gas-Liquid Separation



- Gravity tank separators
- Scrubber
- **Slug Catcher**
- Cyclonic

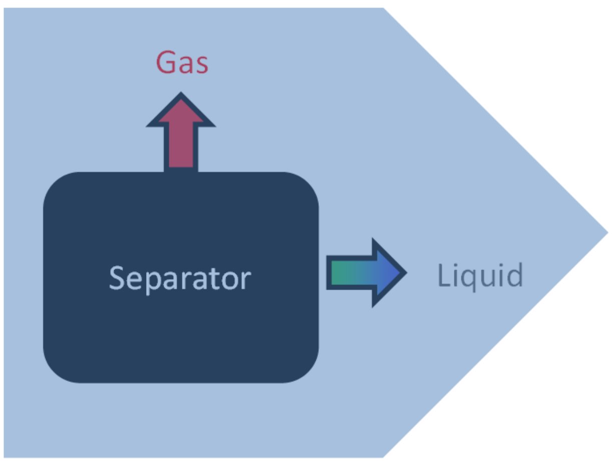


Postdoc Mariana Díaz

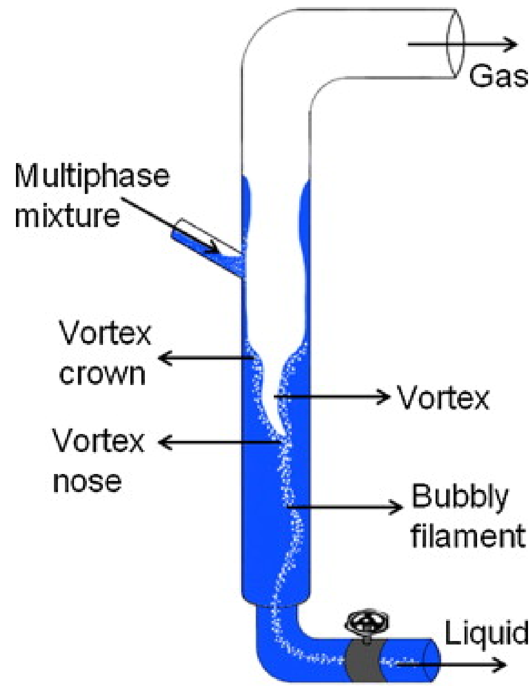


Postdoc Mariana Díaz

Gas-Liquid Separation

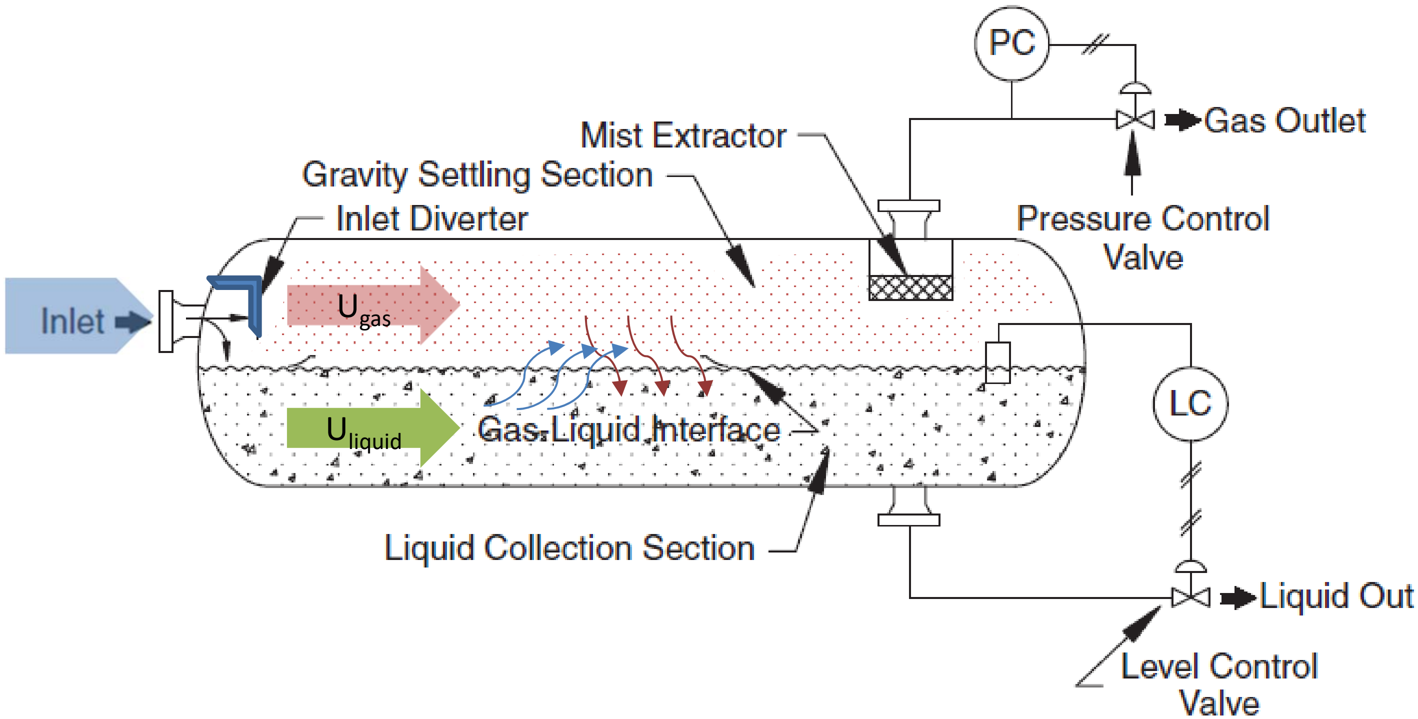


- Gravity tank separators
- Scrubber
- Slug Catcher
- **Cyclonic**



Postdoc Mariana Díaz

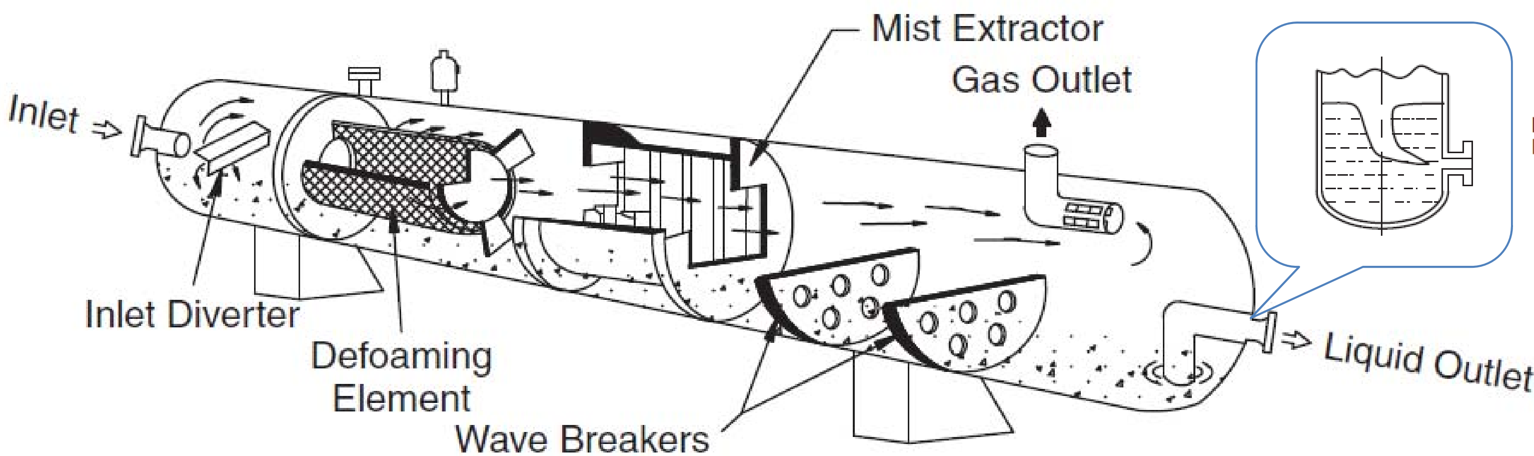
Gravity tank separator



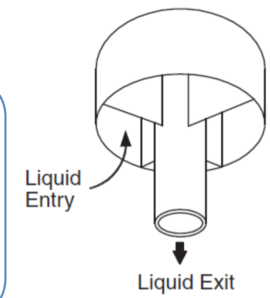
(Stewart and Arnold, 2008)

Gravity tank separator

Internal elements



Vortex breaker

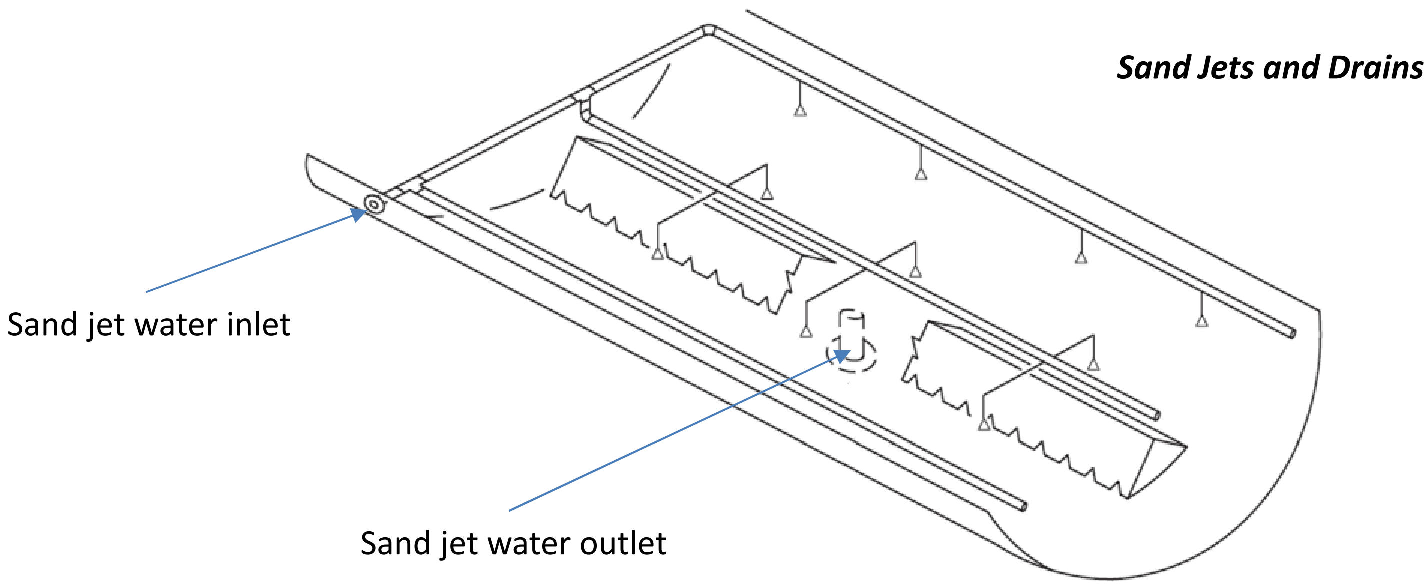


(Stewart and Arnold, 2008)

Postdoc Mariana Díaz

Gravity tank separator

Internal elements

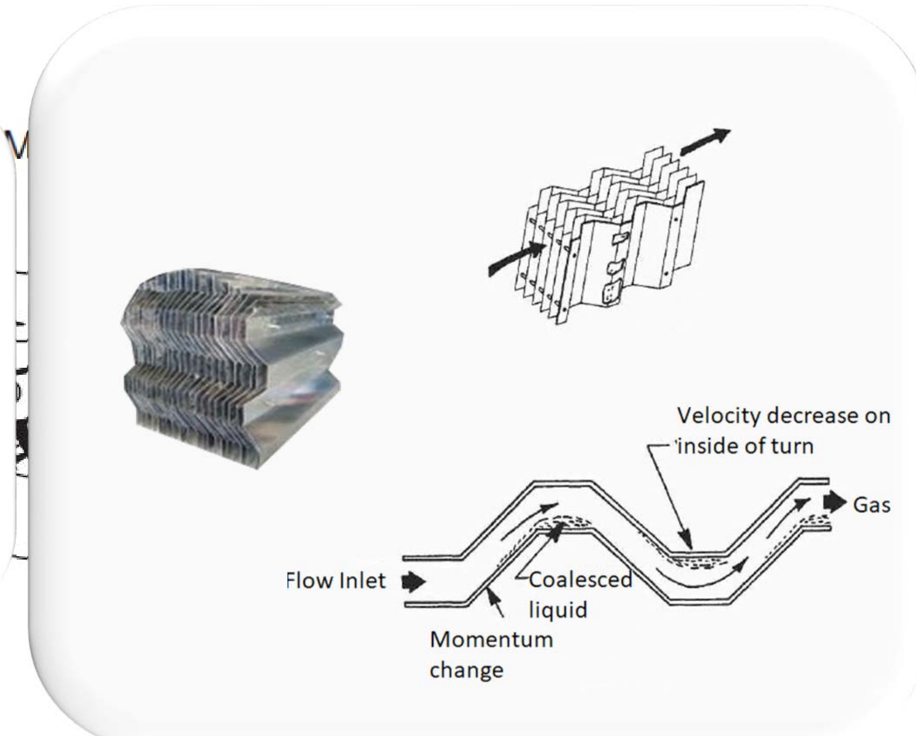


(Stewart and Arnold, 2008)

Postdoc Mariana Díaz

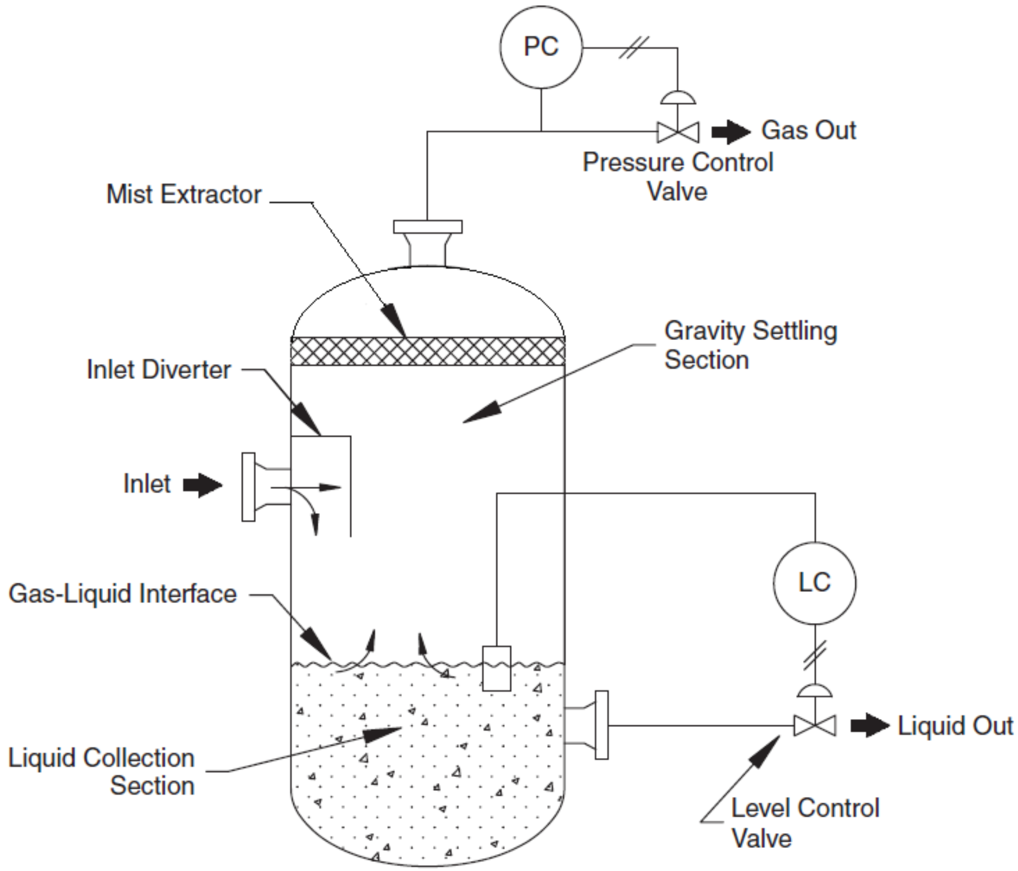
Gravity tank separator

Internal elements



Postdoc Mariana Díaz

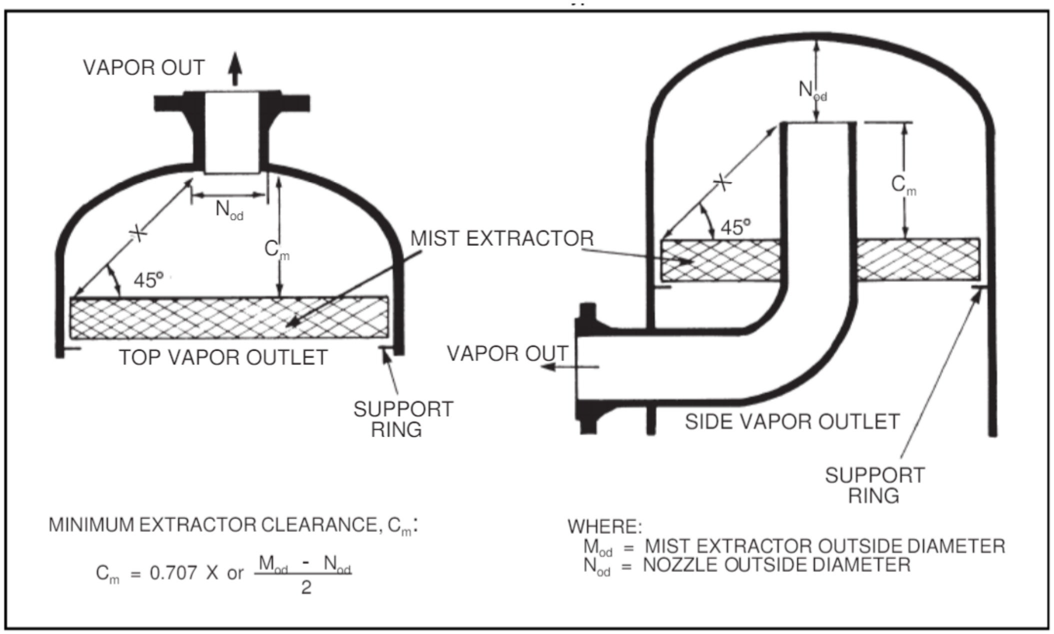
Vertical Tank



(Stewart and Arnold, 2008)

Postdoc Mariana Díaz

Mist Extraction

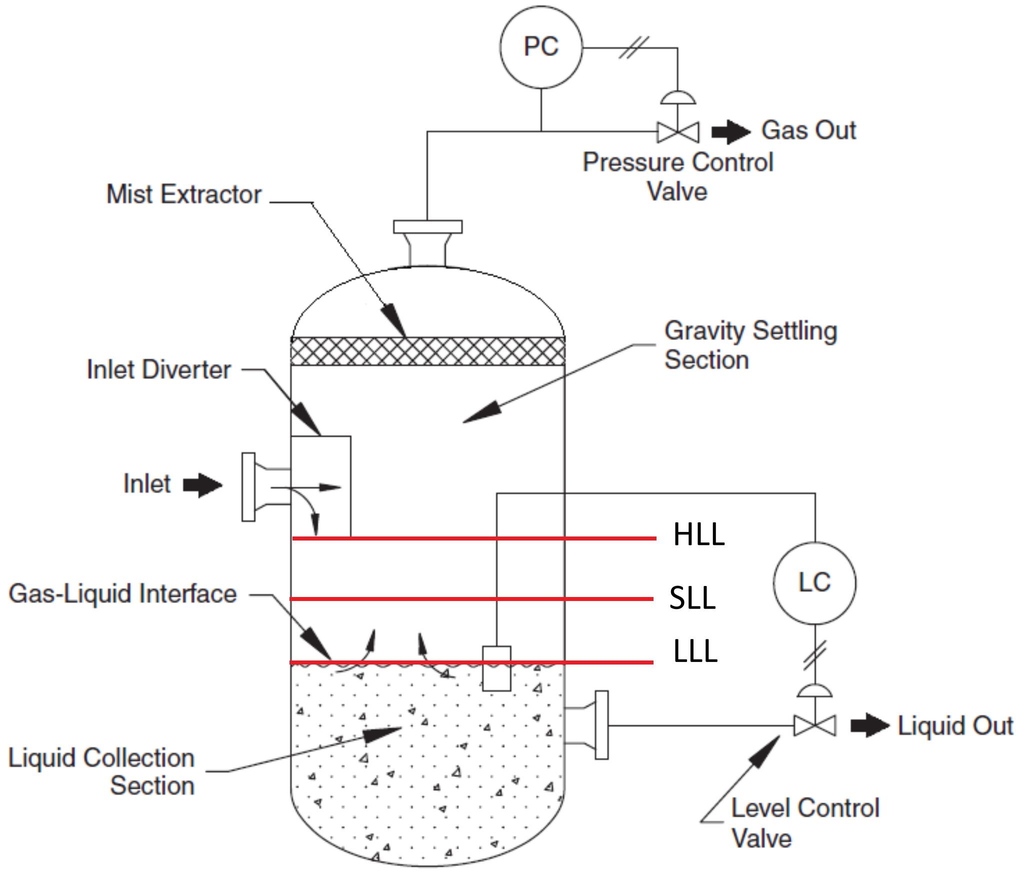


Droplet removal efficiency: 99 to 99.5% removal of 3-10 micron

GSAP (2004)

Postdoc Mariana Díaz

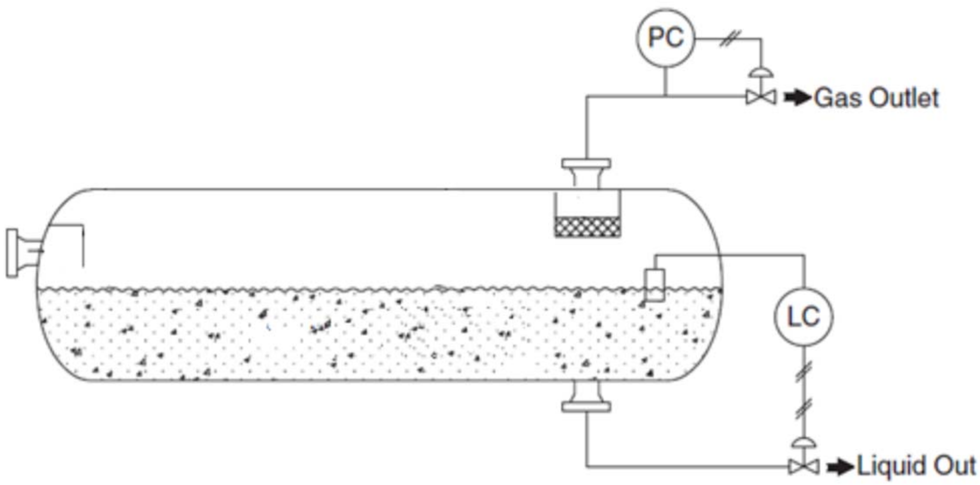
Control system

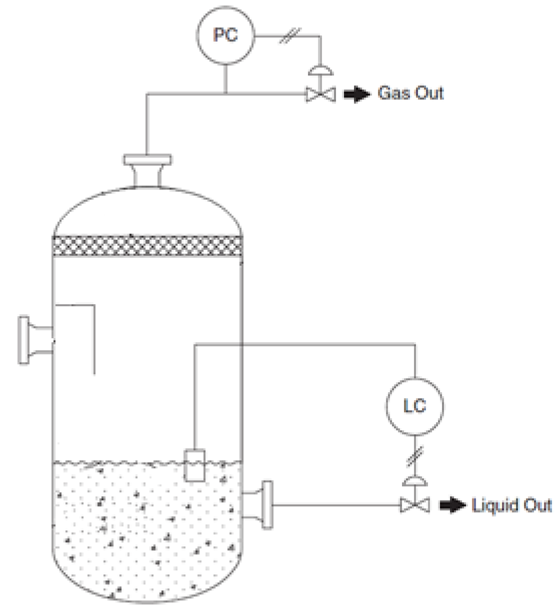


(Stewart and Arnold, 2008)

Postdoc Mariana Díaz

Horizontal vs Vertical





Postdoc Mariana Díaz

Horizontal vs Vertical

Horizontal

+
- Smaller than vertical tanks for a given gas-liquid flow rate
- Commonly used for high gas-liquid ratios and foaming crude
- The interface are is large in horizontal than verticals so it is easier for the gas com out of the liquid and reach the vapor space

−
- They are not so good as vertical for solid handling
- Can have less liquid surge than vertical vessels
- surges in horizontal vessels could create internal waves, which could activate the high-level sensor prematurely
- Harder to clean

Vertical

+
- Commonly used for low to intermediate gas-liquid ratio.
- Suited for production containing solids and sediments
- Save space
- Less tendency for re-evaporation of liquid into the gas

−
- Wall might need to thicker due to the distribution of supports
- some relief valves and controls systems may be difficult to service without special ladders and platforms

*High gas-liquid ration, a vertical separator is a scrubber

Postdoc Mariana Díaz

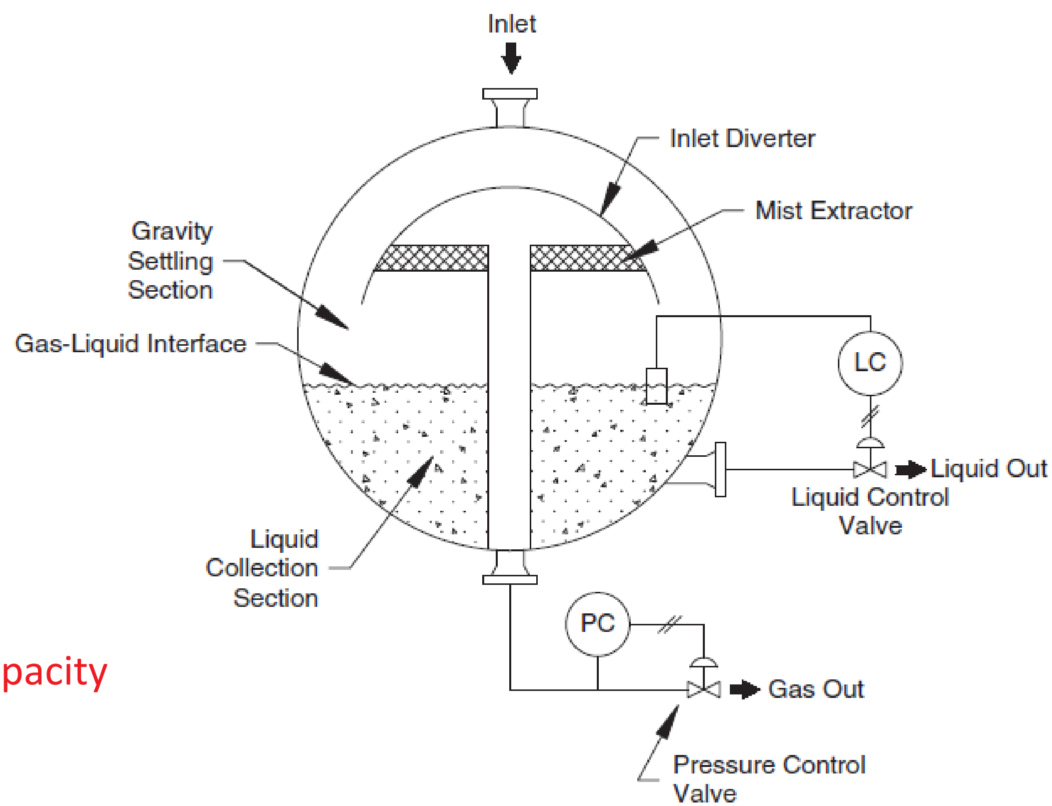
Spherical Separator

+

- Very efficient pressure containers
- Very compact

−

- Very difficult to operate and size
- They have limited liquid surge capacity
- Difficult to fabricate
- Limited liquid settling section
- Liquid level control is critical



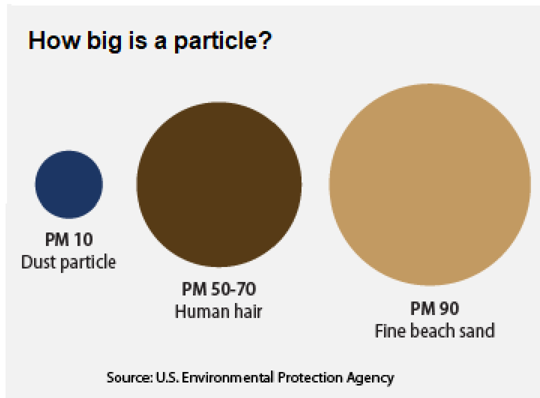
(Stewart and Arnold, 2008)

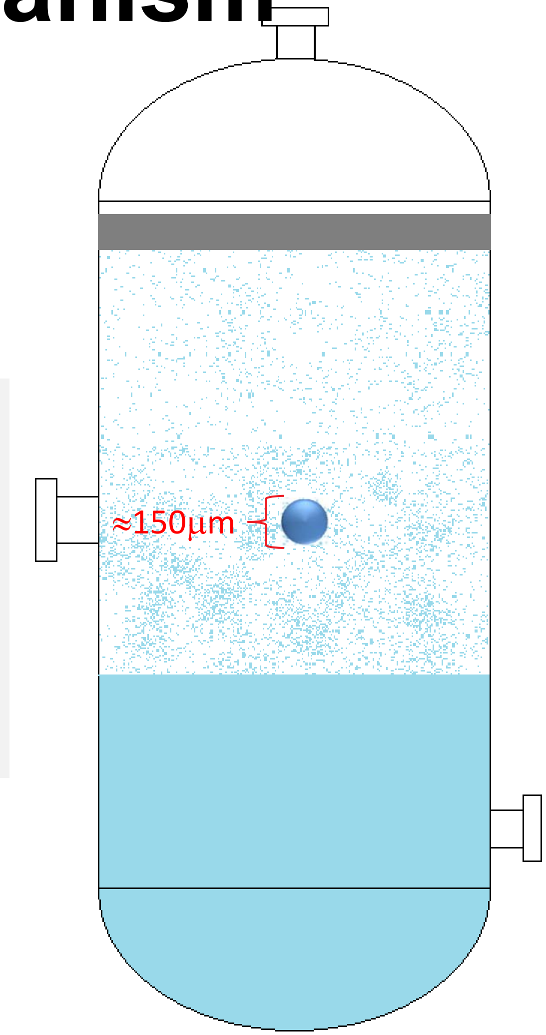
Postdoc Mariana Díaz

Bubble and Droplet Mechanism

Postdoc Mariana Díaz

Bubble and Droplet Mechanism





Postdoc Mariana Díaz

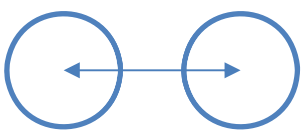
Bubble and Droplet Mechanism

Continuous **vs** disperse flow

Continuous phase

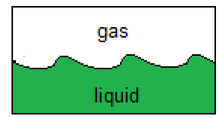
Disperse phase

Isolated particles

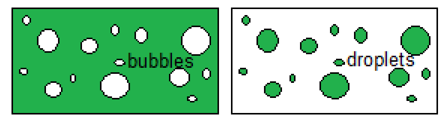


Particle-Particle interaction

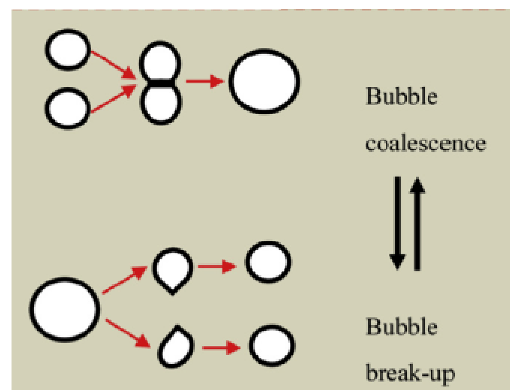
- Momentum
- Heat transfer



a) Separated two-phase flow



b) Dispersed two-phase flow

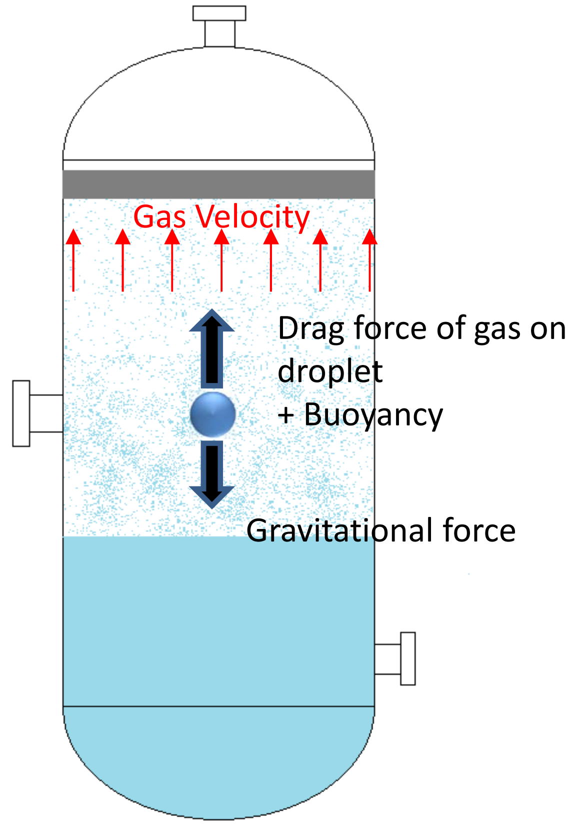


(Xu et al., 2015)

Postdoc Mariana Díaz

Bubble and Droplet Mechanism

Gravitational forces > Drag force of gas on droplet + Buoyancy



Terminal Velocity (Vt)

$$F_g = F_d + F_b$$

Weight

Drag

Buoyancy

Postdoc Mariana Díaz

Bubble and Droplet Mechanism

Terminal Velocity (Vt)

$$F_g = F_d + F_b$$

$$F_g = M_P g = \frac{\pi D_P^3}{6} \rho_P g$$

$$F_d = C_d A_P \underbrace{\frac{1}{2} \rho_f V_t^2}_{\text{Dynamic pressure}}$$

$$F_b = Vol_P \rho_f g = \frac{\pi D_P^3}{6} \rho_f g$$

$$V_t = \sqrt{\frac{4 D_P g (\rho_P - \rho_f)}{3 C_d \rho_f}}$$

Postdoc Mariana Díaz

Bubble and Droplet Mechanism

$$V_t = \sqrt{\frac{4\,D_P\,g\,(\rho_P - \rho_f)}{3\,C_d\,\rho_f}}$$

1. Droplet settling theory
   - Trial and error solution
   - Graphical solution
2. Souders-Brown approach

$$K_{SB} = \sqrt{\frac{4\,D_P\,g}{3\,C_d}} = V_t\sqrt{\frac{\rho_f}{(\rho_P - \rho_f)}}$$

f(mist extractor, separator geometry, flow rates, fluid properties)

Postdoc Mariana Díaz

Bubble and Droplet Mechanism

1. Droplet settling theory

$$V_t = \sqrt{\frac{4\, D_P\, g\, (\rho_P - \rho_f)}{3\, C_d\, \rho_f}}$$

→ *Trial and error solution*

$$C_d = f(Re)$$

→ *Correlations and plots*

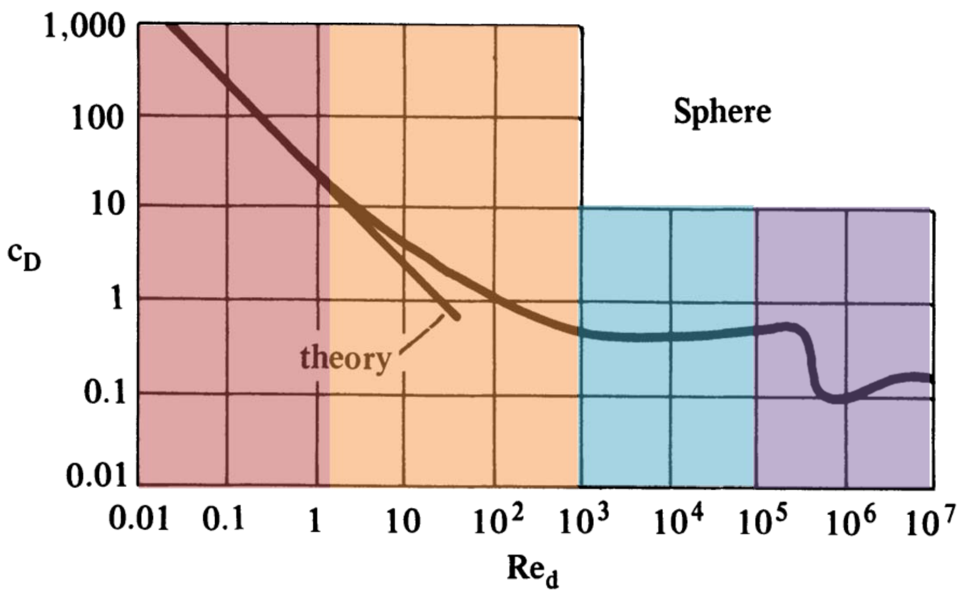
$$Re = \frac{D_P V_t \rho_f}{\mu_f}$$

Postdoc Mariana Díaz

Bubble and Droplet Mechanism

1. Droplet settling theory

$$C_d = f(Re)$$



$C_d = \dfrac{24}{Re}$	$Re < 2$	Stokes drag coefficient
$C_d = \dfrac{24}{Re}(1 + 0.15Re^{0.687})$	$2 < Re < 10^3$	
$C_d = 0.44$	$10^3 < Re < 10^5$	
$C_d = 0.1$	$10^5 < Re < 10^6$	

(P.P Wegener, 1997)
(Richardson et al., 2002)

Postdoc Mariana Díaz

Bubble and Droplet Mechanism

1. Droplet settling theory

Trial and error solution

Assuming $C_d^* =$

$$V_t = \sqrt{\frac{4\, D_P\, g\, (\rho_P - \rho_f)}{3\, C_d\, \rho_f}}$$

$$Re = \frac{D_P V_t \rho_f}{\mu_f}$$

$$C_d = \frac{24}{Re} \qquad Re < 2 \qquad \text{Stokes drag coefficient}$$

$$C_d = \frac{24}{Re} + (1 + 0.15 Re^{0.687}) \qquad 2 < Re < 10^3$$

$$C_d = 0.44 \qquad 10^3 < Re < 10^5$$

$$C_d = 0.1 \qquad 10^5 < Re < 10^6$$

$$tol \geq |C_d^* - C_d|$$

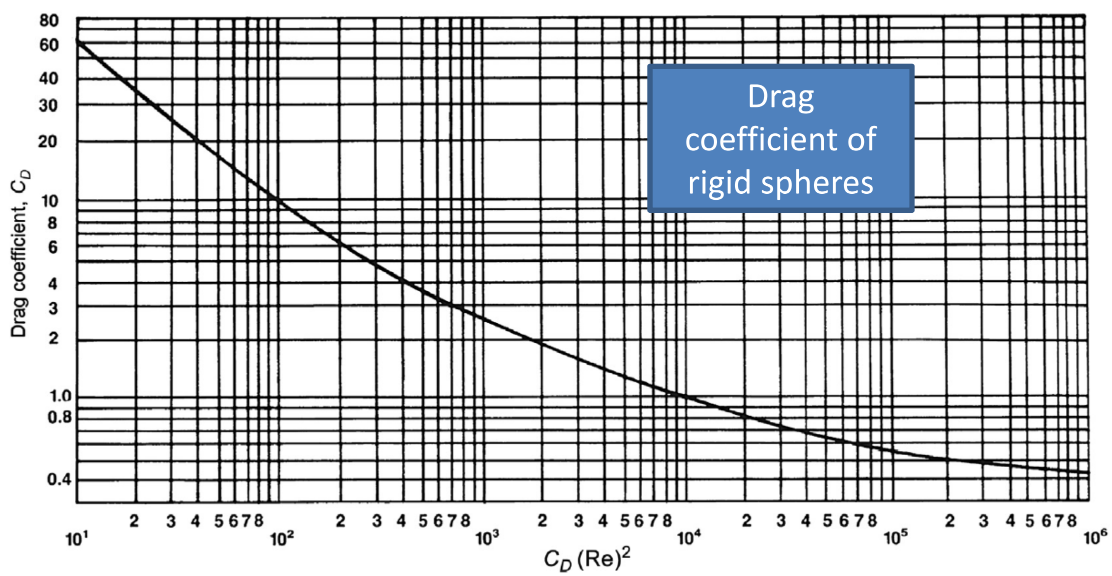
$V_t =$

Postdoc Mariana Díaz

Bubble and Droplet Mechanism

1. Droplet settling theory

Correlations and plots



$$C_D Re^2 = \frac{1.31 * 10^7 \rho_f D_p^3 (\rho_p - \rho_f)}{\mu^2}$$

$$V_t = \sqrt{\frac{4\, D_P\, g\, (\rho_P - \rho_f)}{3\, C_d\, \rho_f}}$$

$$Re = \frac{D_P V_t \rho_f}{\mu_f}$$

$\rho \ldots kg/m^3$

$\mu \ldots mPa\ s$

$D \ldots m$

(Bahadori, A. 2014)

Postdoc Mariana Díaz

Bubble and Droplet Mechanism

$\rho \ldots kg/m^3$

$\mu \ldots mPa\ s$

$D \ldots m$

1.2 Droplet settling theory *Gravity Settling Laws*

$C_d = \frac{24}{Re}$

- **Stokes Law** $Re < 2$

  $K_{CR}(Re = 2) = 0.033$

$V_t = \frac{1000 g D_p^2 (\rho_p - \rho_f)}{18\mu}$

$C_d = \frac{18.5}{Re^{0.6}}$

- **Intermediate Law** $2 < Re < 500$

  $K_{CR}(Re = 500) = 0.435$

$V_t = \frac{2.94 g^{0.71} D_p^{1.14} (\rho_p - \rho_f)^{0.71}}{\rho_f^{0.29} \mu^{0.43}}$

$C_d = 0.44$

- **Newton's Law** $500 < Re < 2 * 10^5$

  $K_{CR}(Re = 2e5) = 23.64$

$V_t = 1.74 \sqrt{\frac{D_P\ g\ (\rho_P - \rho_f)}{\rho_f}}$

$$D_p = K_{CR} \left[\frac{\mu^2}{g \rho_f (\rho_p - \rho_f)} \right]^{0.33}$$

$K_{CR} \ldots proportional\ constant$

(Bahadori, A. 2014)

Postdoc Mariana Díaz

Bubble and Droplet Mechanism

2. Souders-Brown approach

$$K_{SB} = \sqrt{\frac{4\ D_P\ g}{3\ C_d}} = V_t \sqrt{\frac{\rho_f}{(\rho_P - \rho_f)}} \longrightarrow V_t = K_{SB} \sqrt{\frac{(\rho_P - \rho_f)}{\rho_f}}$$

API 12J recommended range of K_{SB} for vertical and horizontal separators assuming the vessel is equipped with a wire-mesh mist extractor

Type	Height or length (m)	Typical K_{SB} range (m/s)
Vertical	1.52	0.037-0.073
	≥3.05	0.055-0.107
Horizontal	3.05	0.122 to 0.152
	Others lengths	$(0.122\ to\ 0.152)*(L/3.05)^{0.56}$

NORSOK P-100: $K_{SB} = 0.137 * \left(\frac{L}{6}\right)^{0.58}$

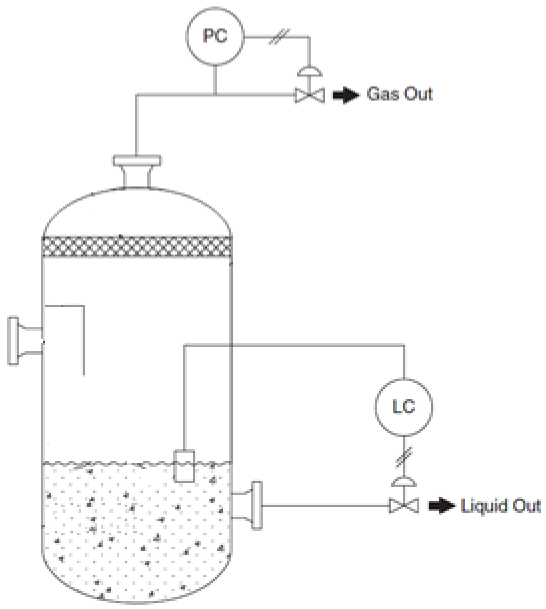
(John M. Campbell, A. 2015)

Postdoc Mariana Díaz

Separator sizing

Postdoc Mariana Díaz

Separator sizing



1. Vapor Capacity → Cross-sectional area
2. Liquid Capacity → Residence time to “de-gas”
3. Operability → Ability to deal with solids, liquid slugs, turn-down, etc.

↓

Lsem/Dv

Postdoc Mariana Díaz

Vertical separator sizing

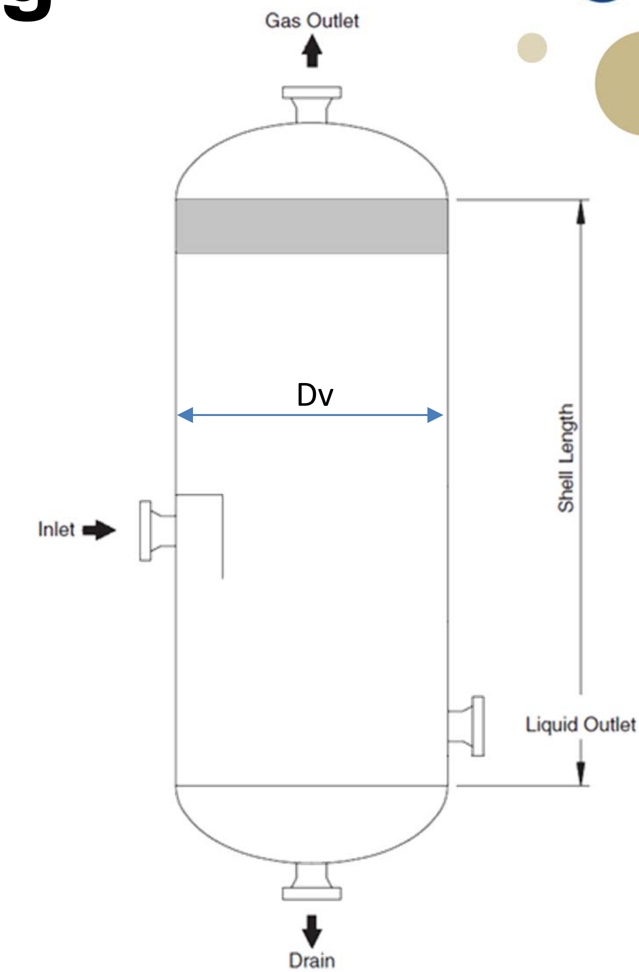
1. **Vapor Capacity**

$Q_g = V_t A_v$ (Actual Conditions)

$Q_g^{s.c} = Q_g \left(\frac{P}{P_{s.c}}\right)\left(\frac{T_{s.c}}{T}\right)\frac{1}{z}$ (s.c. = standard conditions)

15 C
1 atm (1.01325 bara)

Calculate V_t → Calculate A_v → Calculate D_v **Minimum value*



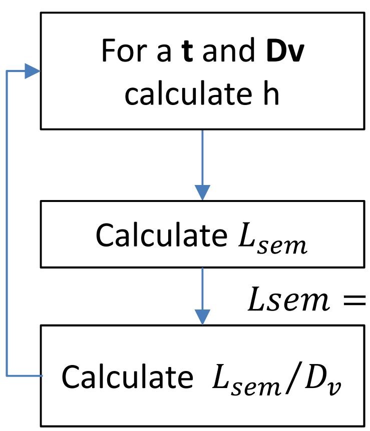
(Stewart and Arnold, 2008)

Postdoc Mariana Díaz

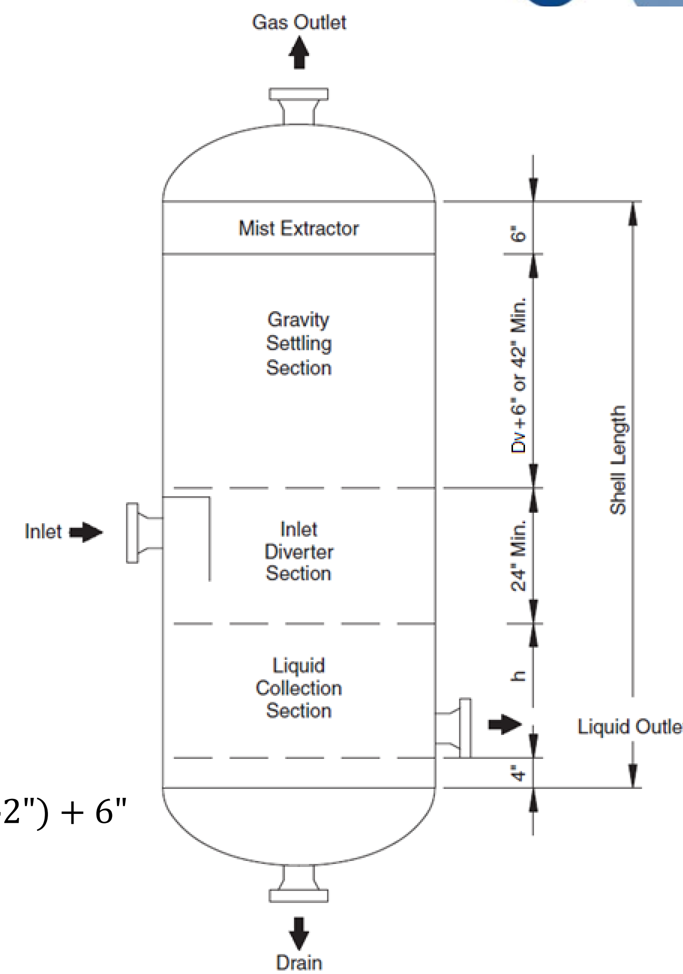
Vertical separator sizing

1. Vapor Capacity
2. **Liquid Capacity**

$$t\,Q_l = h\,A_v \longrightarrow h = \frac{t\,Q_l\,4}{\pi\,D_v^2} \qquad t\ \ldots retention\ time$$



$$Lsem = 4" + \max(h;36") + max(2*ID;24) + \max(D_V+6;42") + 6"$$



(Stewart and Arnold, 2008)

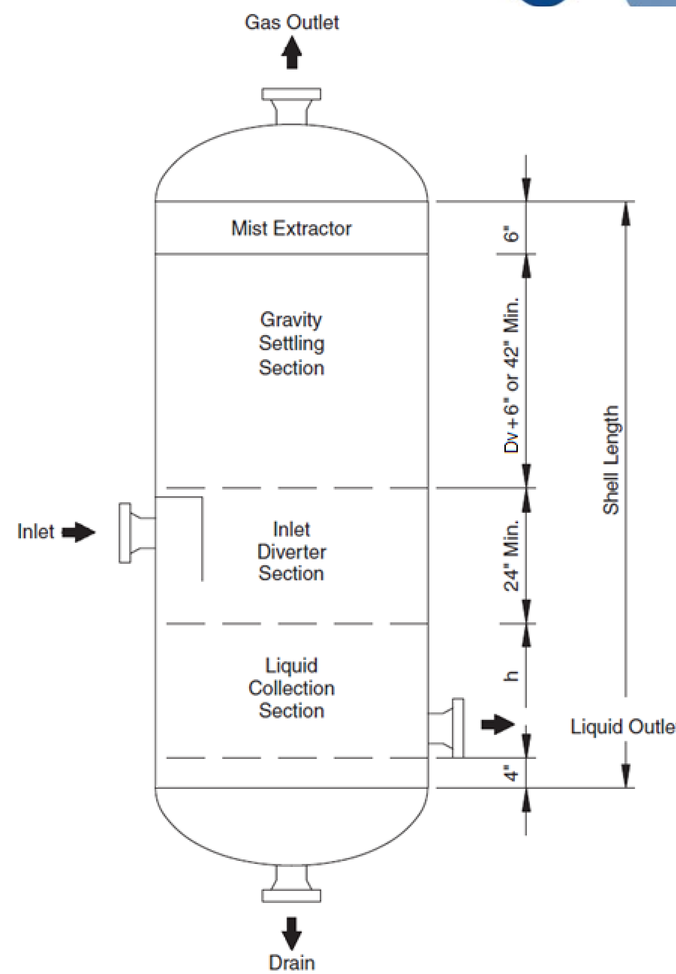
Postdoc Mariana Díaz

Vertical separator sizing

1. Vapor Capacity
2. Liquid Capacity
3. **Operability**

Adjust Lsem

Adjust Retention time



(Stewart and Arnold, 2008)

Postdoc Mariana Díaz

Design criteria

For the gravity settling section → Droplet size $\approx 140 - 150\mu m$

Vent scrubbers → Droplet size $\approx 300 - 500\mu m$

Retention time in most application → 30 s and 3 min →

Retention Time for Two-Phase Separators

°API Gravity	Retention Time (Minutes)
35+	0.5 to 1
30	2
25	3
20+	4+

1. If foam exists, increase above retention times by a factor of 2 to 4.
2. If high CO_2 exists, use a minimum of 5-minute retention time.

Horizontal Liquid volume → 50% full liquid

L/D relation

→ Vertical Separator are normally L/D = 2 to 4

Horizontal Separator are normally L/D = 2.5 to 5

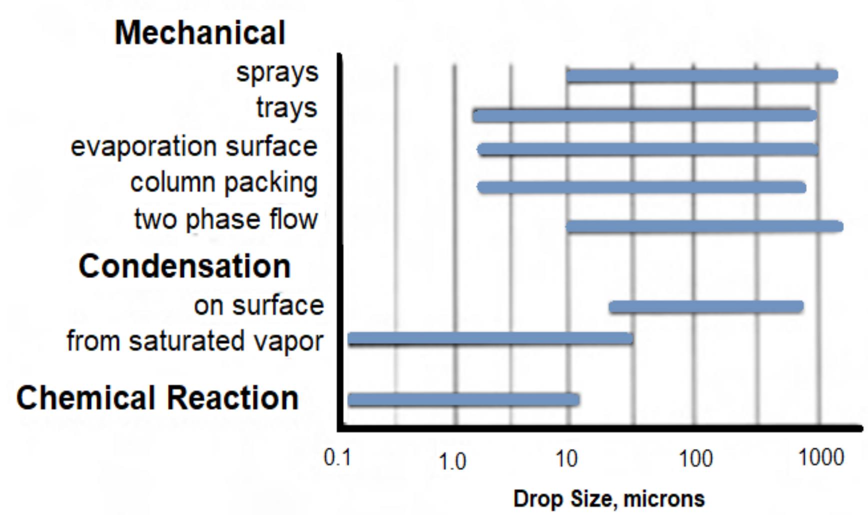
Design criteria

Other factors

Typical Retention Times for Gas/Liquid Separator

Application	Retention Time, minutes
Natural Gas – Condensate separation	2 – 4
Fractionator Feed Tank	10 – 15
Reflux Accumulator	5 – 10
Fractionation Column Sump	2
Amine Flash Tank	5 – 10
Refrigeration Surge Tank	5
Refrigeration Economizer	3
Heat Medium Oil Surge Tank	5 – 10

Typical particle size distribution ranges from entrainment caused by various mechanisms



Postdoc Mariana Díaz