



FUNDAMENTALS – 2022

SEPARATION

Part I: Theory & Design –
Clay Jones, PE, Trimeric Corporation

Part II: Operational Issues –
Darryl Mamrosh, PE, Trimeric Corporation

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PART I: THEORY & DESIGN



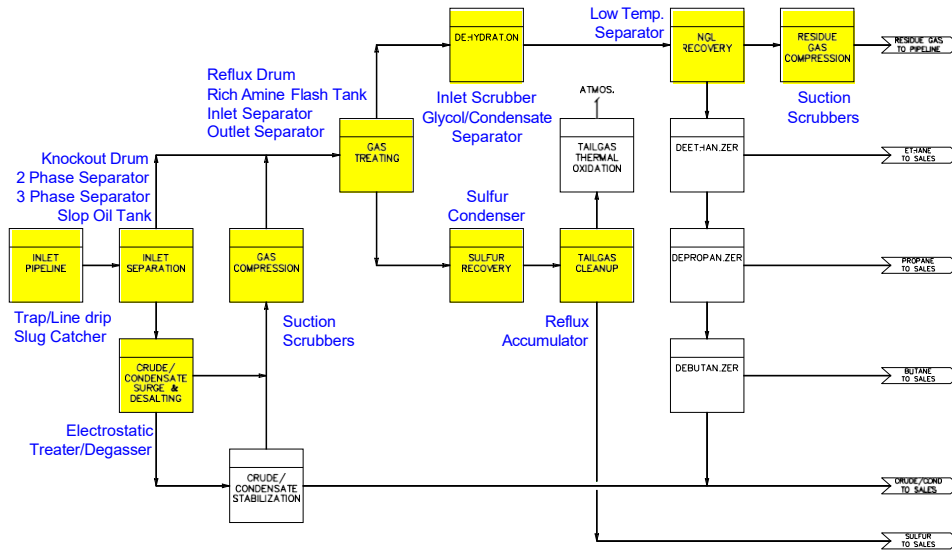
- Overall Introduction to 2022 Fundamentals
 - What will and will not be covered - *This will be about physical separation only*
 - Presented in two part – Part I Theory & Design, Part II Operational Issues
- Context for separation - Where and Why we do it
- Separating liquid from gas
- Separating two liquids from each other
- Separator internals
- The Future of separator design (Is Now!)

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SEPARATION APPLICATIONS



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Why do we do separation?

- Prevent damage to downstream equipment
- Basic to the functioning of a process – think distillation, absorption, stripping, liq. degassing, liq.–liq. extraction
- impossible to *process* gas and liquid at the same time
- Ultimately, we want liquid and gas products



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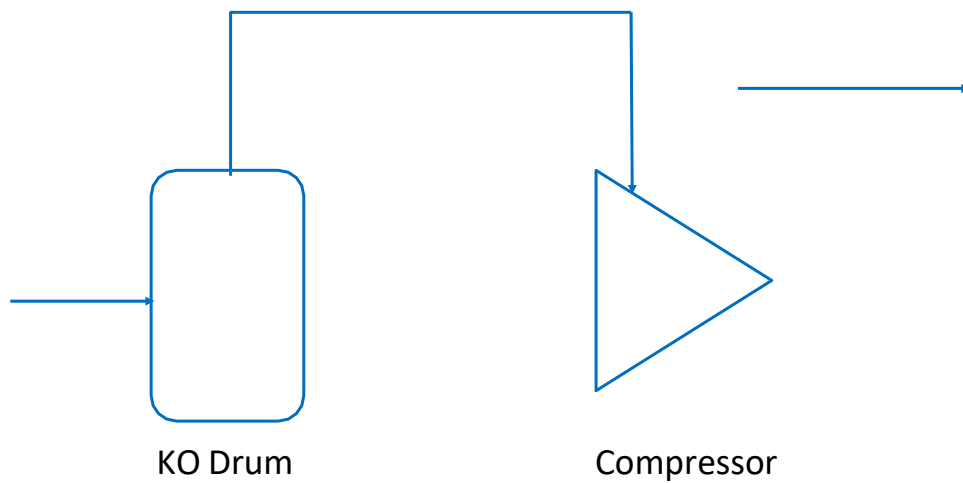


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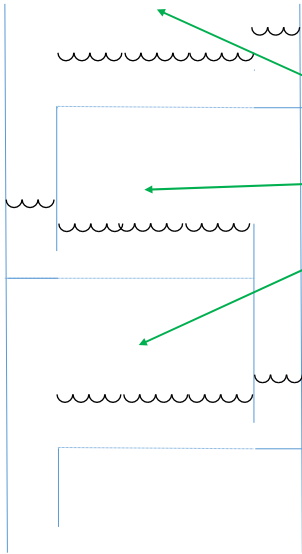
Prevent liquid from damaging a compressor



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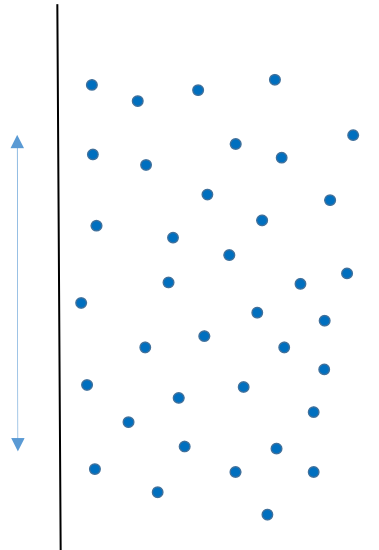


Need to separate liquid from gas (vapor) rising up a distillation or absorption column

Liquid-Liquid Extraction

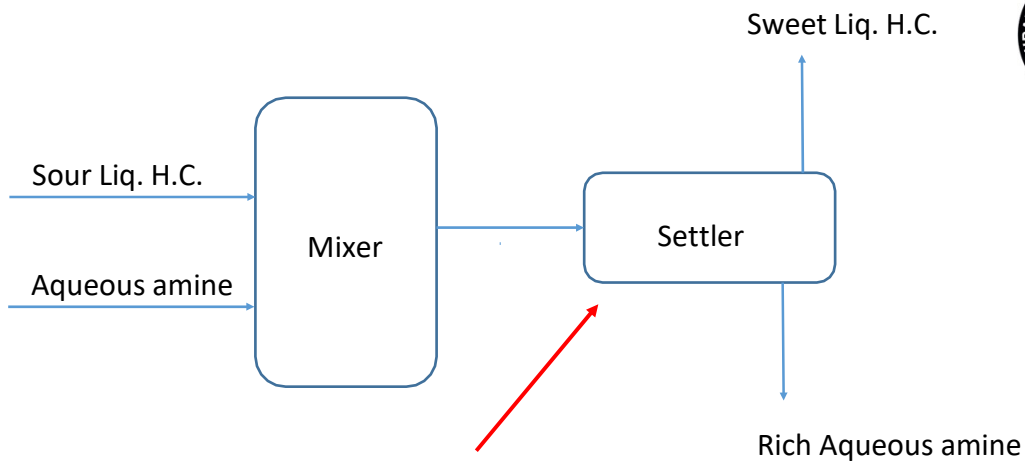
- Liquid hydrocarbon treating
- Solvent recovery
- Extraction processes

- We are going to be interested in how fast droplets rise or fall



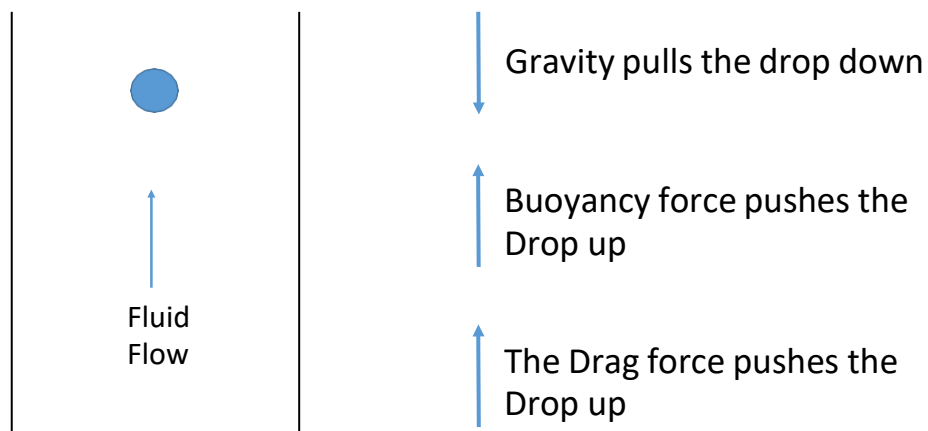
Droplets may be rising or falling





How do we ensure good (adequate) separation in the settler?

Physics of gravity separation



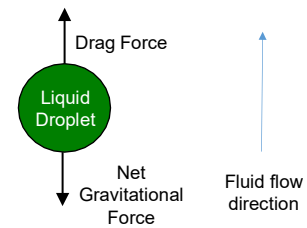
Free Settling or Terminal Velocity

- **Net Gravitational Force**

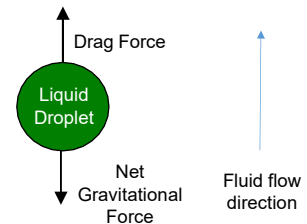
- Gravitational force = Weight of droplet – Weight of fluid it displaces (buoyancy)

- $F_G = Vol_p \rho_l - Vol_p \rho_g = Vol_p (\rho_l - \rho_g) = \frac{4}{3} \pi \frac{D_p^3}{8} (\rho_l - \rho_g)$

- $F_G = \frac{\pi D_p^3 (\rho_l - \rho_g)}{6}$



Free Settling or Terminal Velocity



$$F_D = C_D A_p \rho_g \left(\frac{V_t^2}{2g} \right) = C_D \pi D_p^2 \rho_g \left(\frac{V_t^2}{8g} \right)$$

$$\frac{\pi D_p^3 (\rho_l - \rho_g)}{6} = C_D \pi D_p^2 \rho_g \left(\frac{V_t^2}{8g} \right)$$

$$V_t = \sqrt{\frac{4g D_p (\rho_l - \rho_g)}{3 C_D \rho_g}}$$

Eqn. 1

area x density x velocity²
 (m²) (kg/m³) (m²/sec²)
 kg m/sec² ≡ Newton or Force

Coefficient of Drag - C_D

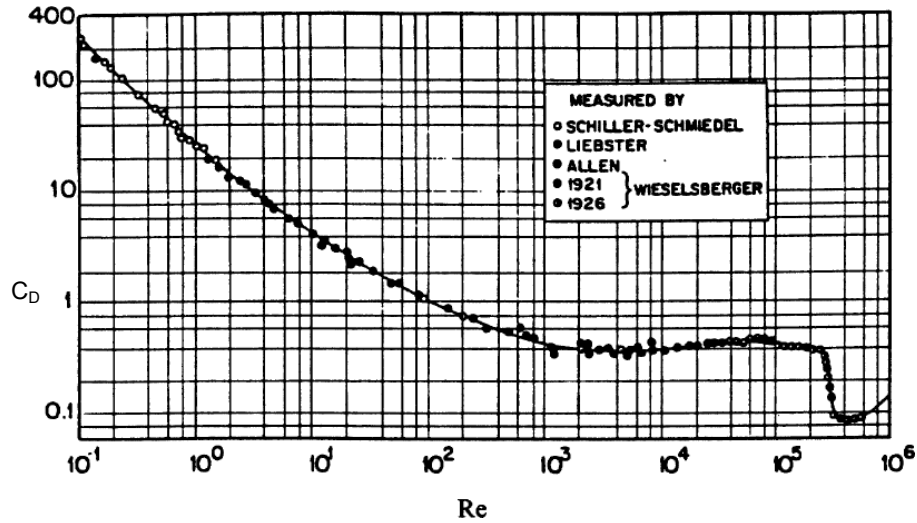


Figure courtesy of Dullien, F.A.L., *Introduction to Industrial Gas Cleaning*, Academic Press, Inc, 1989, p.12.

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Newton's Law

- $500 < Re < 200,000$; $D_p > 1000$ microns (10^{-6} meters)

- $C_D = 0.44$

$$V_t = 1.74 \sqrt{\frac{gD_p(\rho_l - \rho_g)}{\rho_g}} \quad \left((4/3 \times .44)^{1/2} = 1.74 \right)$$

- **Not** related to units

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Intermediate Range

- $2 < Re < 500$; $100 < D_p < 1000$ microns (10^{-6} meters)

$$C_D = \frac{24}{Re} + \frac{3}{\sqrt{Re}} + 0.34 \quad \leftarrow \text{Eqn. 2}$$

- Or $C_d \sim [(24/Re)^{1/2} + .5407]^2$ Ref. Bird, Stewart & Lightfoot
- For Re of 250 Δ in $C_d \sim 13\%$
- Solve Iteratively for V_t

Iteration for V_t

- Assume a value for C_D
- Substitute C_D into equation 1, Calculate V_t
- Calculate $Re = D_p \rho V_t / \mu$
- Substitute Re into equation 2, Calculate a new C_D
- Substitute new C_D into equation 1
- ITERATE TO CONVERGENCE

Stokes' Law

- Reynolds Number

$$\text{Re} = \frac{D_p V_t \rho_g}{\mu}$$

- Stokes Law

- $\text{Re} < 2$ Note Bird et al say $\text{Re} < 0.1$
- $3 \text{ micron} < D_p < 100 \text{ micron}$

$$C_D = \frac{24}{\text{Re}} \quad \text{Substitute into eqn 1 and solve for } V_t$$

$$V_t = \frac{g D_p^2 (\rho_l - \rho_g)}{18 \mu}$$

Separating Liquids from Gas

- When the gravity and drag forces are equal the drop will be stationary inside the vessel
- The designer needs to set the gas velocity such that the gravity force is larger (just larger) than the drag force

Separating Liquids from Gas

- Some things to consider...
- How much liquid must be removed?
- What size of droplet must be removed?
- What is the best configuration, Horizontal or Vertical?

Design

- References:
 - GPSA Engineering Data Book, Section 7. (Esp 14th ed)
 - 2018 LRGCC Proceedings – Separation Fundamentals

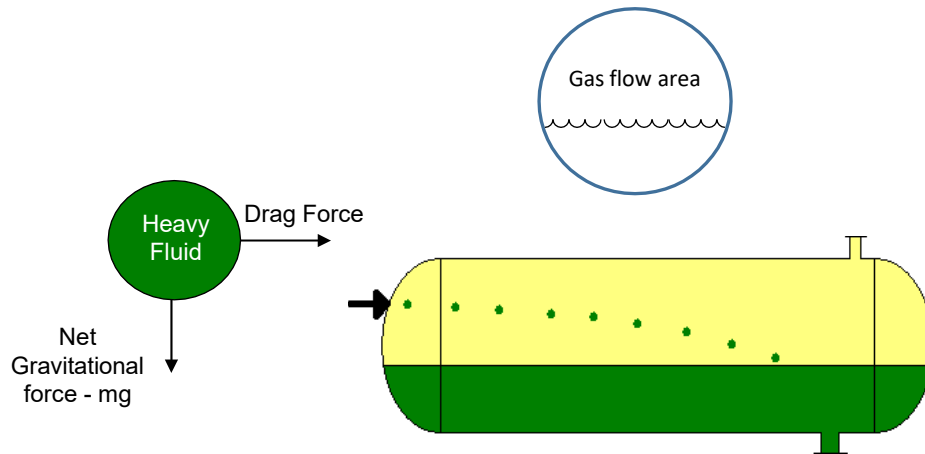
Design

- Input data required
 - Flowrates
 - Temperature
 - Pressure
 - Composition
 - Flow characteristics (maximums and minimums)
 - Separation Specifications
 - Max allowable content of minimum particle size

Design

- Given: flowrate, composition, temperature and pressure – calculate volumetric flow of gas
- $PV = ZnRT$ $\rho = P \times MW / ZRT$
- Z from charts or equations of state
- From calculated terminal velocity and volumetric gas flow calculate flow *area* required $A = \text{Volume rate} / V_t$
- Vessel diameter = $(4 A / \pi)^{1/2}$ For vertical vessels
- For horizontal vessels account for fraction of circle occupied by liquid

What is the fraction of the vessel where gas flows?

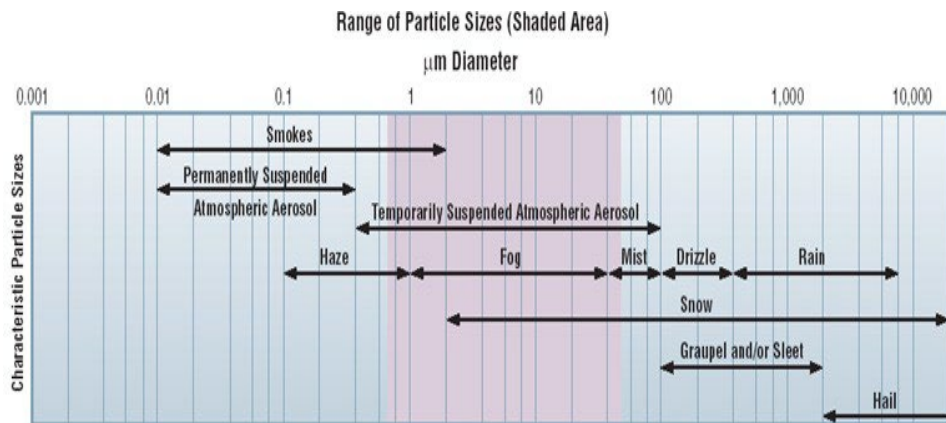


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Particle Characteristics



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Particle sizes to remove

APPLICATION	PARTICLE DIA. MICRON
Secondary separation in high gas/liquid streams	500
Flare or vent scrubbers without mist eliminators	300 – 500
Secondary separation in low gas/liquid streams	100
Mist elimination	10
Requiring chemical or electrostatic removal	<0.1

Efficiency

- A measure of how well a separator is performing or is required to perform
- Must be expressed in terms of
 - Particle size
 - Percent removal
- *Example* – A scrubber must remove **99.9%** of liquid particles greater than **100** microns.

Practical Settling Velocity Calculations

- Experience has show that for a given application an empirical factor can be substituted into equation 1 to replace $(4 g D_p / 3 C_d)^{1/2}$
- Remember that the V_t depends on what is chosen as an acceptable droplet size. Larger droplets will definitely be removed
- There will come a point where removing ever smaller droplets by gravity separation becomes uneconomical if not impractical

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Souders-Brown Equation

$$V_t = K \sqrt{\frac{(\rho_l - \rho_g)}{\rho_g}}$$

SEPARATOR TYPE	K, ft/sec
Horizontal (H = 10 ft.)	0.40 - 0.50
Horizontal (H = L ft.)	$0.45(L/10)^{0.56}$
Vertical (H = 5 ft.)	0.12 - 0.24
Vertical (H = 10 ft.)	0.18 - 0.35
Spherical	0.20 - 0.35
Wire Mesh Mist Eliminator	0.35
Vertical Scrubber	0.35
Wet Steam	0.25
Vapors under vacuum	0.2
Salt & Caustic evaporators	0.15
Separators w/o Demister	multiply K by 0.5
Glycol & Amine systems	multiply K by 0.6 - 0.8
Compressor Suction Scrub	multiply K by 0.7 - 0.8

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Souders – Brown Published in 1934

- What has change in the last 84 years is our understanding and experience as to what values of K work, work well, work very well, in different applications

Liquid capacity

- Based on
 - Liquid Degassing Requirements
 - Process Control Stability
 - Surge Volume
- Usually expressed as retention time
- Dimensions and layout of vessel depend on orientation - Horizontal or Vertical

Typical Retention Times –2 Phase

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

API 12J Retention Times for Gas-Oil Separators

Oil Gravity	Liquid Retention Time, min
> 35	1
20 – 35	1 to 2
10 – 20	2 to 4

Many will say 30 minutes

Vertical Separators

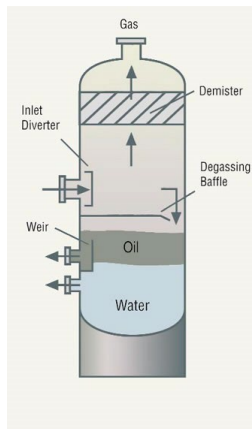


Figure courtesy of NATCO Group

- **Advantages**
 - Absolute level does not affect separation efficiency
 - Better for streams containing solids
 - Less chance of liquid re-entrainment
 - Smaller footprint
- **Disadvantages**
 - Smaller interface area for liq./liq. separation
 - Access platform / ladders may be required

Horizontal – Single Barrel

• Advantages

- Larger interface area for degassing & liq./liq. separation
- Better at handling foam
- Easier to hook-up, service and skid mount.

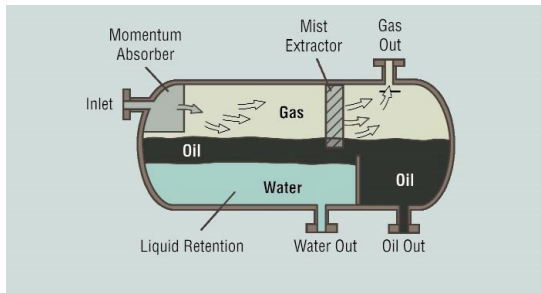


Figure courtesy of NATCO Group

• Disadvantages

- Absolute level is critical to separation efficiency
- Slower response to level control
- Not as good at handling solids



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Comparison

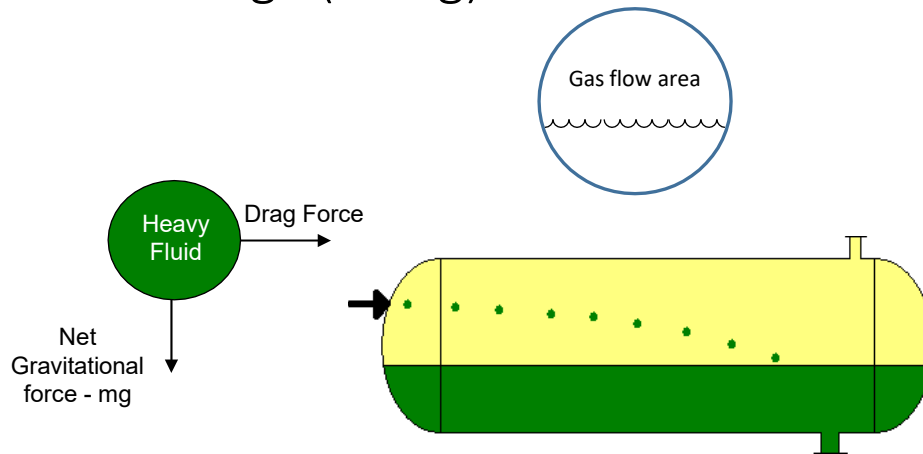
FEATURE	VERTICAL	HORIZONTAL
Removal of solids	✓	
Equipment size and capital cost		✓
Liquid surge capacity	✓	
Liquid/Liquid separation		✓
Accommodate foaming		✓
Installation footprint	✓	
Greater lag time between NLL and HLSD	✓	
Liquid degassing		✓
Very high gas to liquid ratio	✓	
Moderately high gas to liquid ratio		✓
Low gas to liquid ratio	✓	
Less liquid re-entrainment potential	✓	
Slug flow	✓	
Three phase separation		✓
Shipping height		✓

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In a horizontal separator either the gas or liquid dictate the design (sizing)



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Temperature & Pressure Effects

- High temperature decreases gas gravity more than liquid – helps separation
- High temperature decreases viscosity – helps separation
- High pressure increases gas gravity more than liquid – hinders separation
- High temperature and high pressure increase solubility – hinders separation

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Separating two Liquids from each other

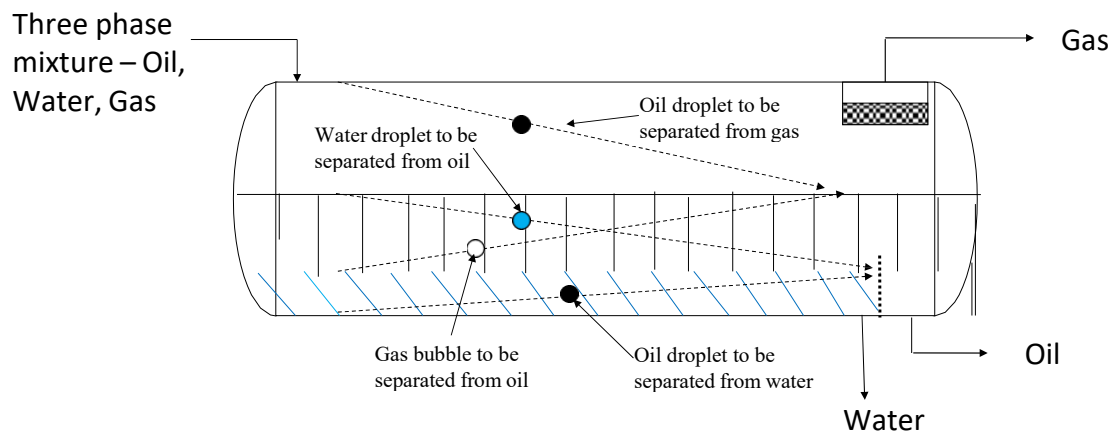
- Often done in three phase separators
- In liquid – gas separations the density difference is $\sim 20 - 40$ times
- In liquid – liquid separation the density difference is $\sim 1.05 - 1.4$ times
- Stokes' law almost always applies
 - For the drop sizes we are concerned about
- Water or aqueous phase falling through H.C. ("oil")
- Hydrocarbon phase rising through aqueous phase or water

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Droplet & Bubble Separation



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Usefulness of Stokes' Law

- Liquid volume is usually set by:
 - a residence time criteria
 - a surge volume requirement
- If separation is inadequate it can be useful to calculate the time for a drop (bubble) to reach its target phase and compare this to the travel time in the vessel
 - What does the velocity profile look like

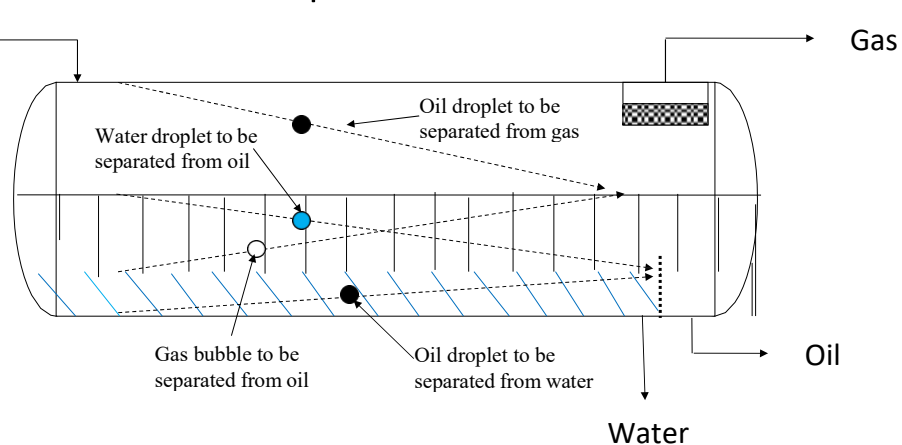
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Droplet & Bubble Separation

Three phase mixture – Oil, Water, Gas



Assuming a flat velocity profile the transit time across the vessel for any phase is the (volumetric flow / cross sectional area available for that phase) / effective length

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Guidelines for liquid residence time

Typical Retention Times for Liquid-Liquid Separation

Type of Separation	Retention Time, minutes
Hydrocarbon/Water Separators ⁷ Above 35° API hydrocarbon Below 35° API hydrocarbon 100°F and above 80°F 60°F	3 – 5
	5 – 10
	10 – 20
	20 – 30
Ethylene Glycol/Hydrocarbon ⁸ Separators (Cold Separators)	20 – 60
Amine/Hydrocarbon Separators ⁹	20 – 30
Coalescer, Hydrocarbon/Water Separators ⁹ 100°F and above 80°F 60°F	5 – 10
	10 – 20
	20 – 30
	30 – 45
Caustic/Heavy Gasoline	30 – 90

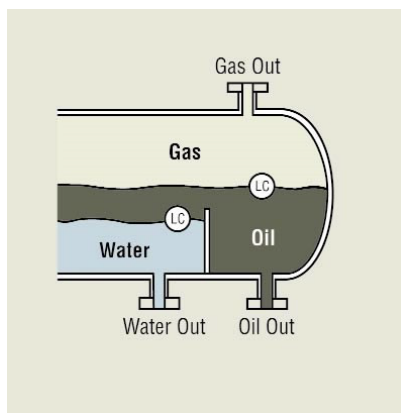
Tables courtesy of GPSA Engineering Data Book, Vol 1, 2004.

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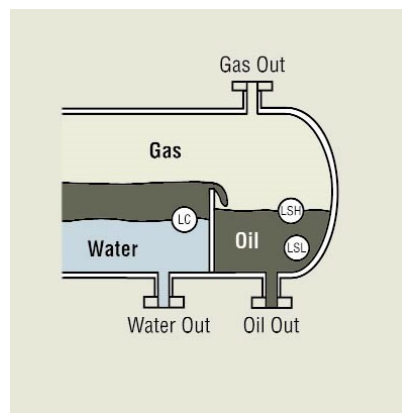
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3 Phase Separation



Fixed Weir



Spillover Weir

Figures courtesy of NATCO Group

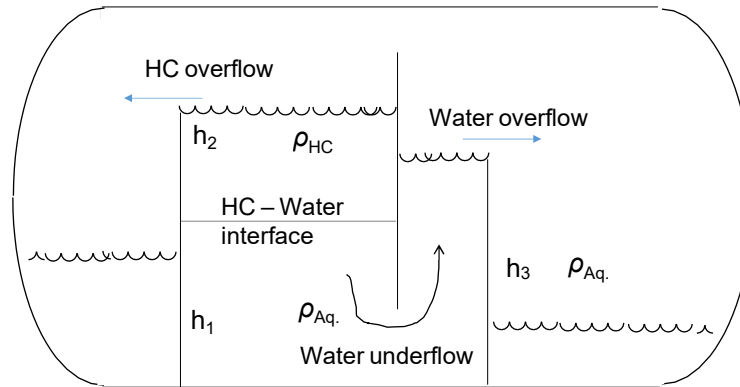
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Three Phase Separators

Hydrostatic Force Balance



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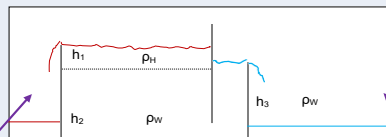
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$$h_3 = 8.25 \quad \rho_{HC} = 0.836$$

$$h_1 + h_2 = 8.50 \quad \rho_W = 1.04$$

$$A = h_3 \times \rho_W = 8.58$$

$$B = h_1 + h_2 = 8.50$$



Hydrocarbon side

Aqueous side

ρ_{HC}	ρ_W	A
1	1	B

$$h_1 \times \rho_{HC} + h_2 \times \rho_W = 8.25$$

$$h_1 + h_2 = 8.5$$

$$h_1 = 1.275$$

$$h_2 = 7.225$$

Level calculator for three phase separator

$$ad-bc = -0.204$$

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Vessel internals

- Inlet devices
- Separation aid devices (things in the middle)
- Outlet devices

- The proper selection of these is critical to achieving the desired separation ***economically***

- There are many proprietary designs available

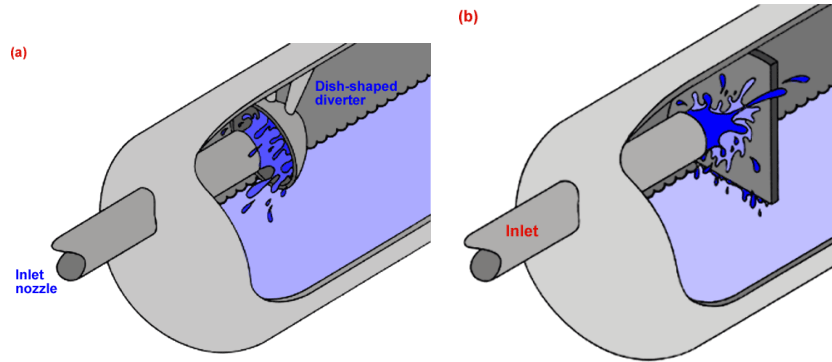
Inlet devices

- The most *cost effective* of all inlet devices is the one least frequently installed

- Simply increase the inlet line by one pipe size, ten pipe diameters before the vessel inlet

- The goal is to slow everything down so gravity can do its thing – a larger pipe size is the least expensive step in that direction

Inlet Diverters – Deflector Plate / Baffle



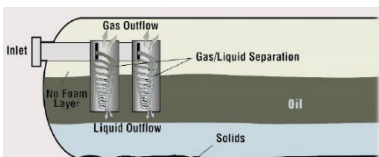
Figures from www.IPIMS.com
 "Separation of Produced Fluids" training module.

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Inlet Diverters – Cyclonic



Porta-Test Revolution™ installed as Separator inlet device
 Natco's Porta-Test Revolution™



G-Sep™ CCI – Inlet Cyclone
 - 6-body design with top inlet connection

AKPS' G-SEP™ CCI

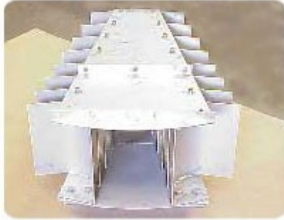
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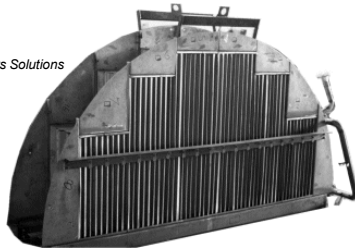
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Inlet Diverters – Vane

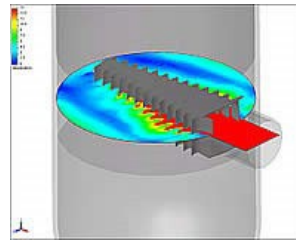
CDS Evenflow™ Vane Inlet



Picture courtesy of Akers Solutions



Shell Schoepentoeter™



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Stilling Wells



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Things in the middle

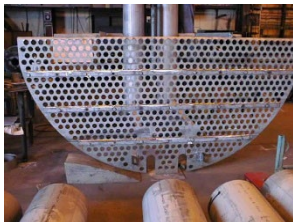
- The goal of this equipment is to
 - 1) Ensure the flow profile is what we would like it to be – Uniform
 - 2) In liquid – liquid separation shorten the time a drop needs to rise / fall to reach a collection point (“home base”)

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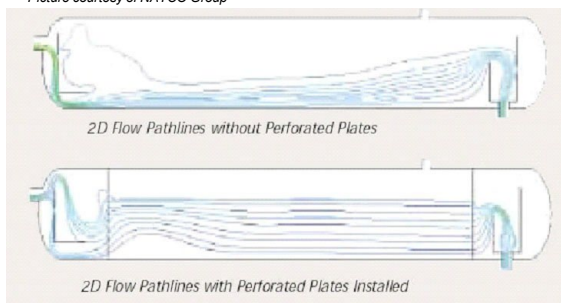
Perforated Baffles



Picture courtesy of NATCO Group



Picture courtesy of Akers Solutions



Picture courtesy of CDS Separation Technology

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Wave Breakers

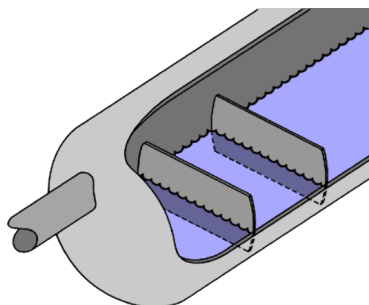
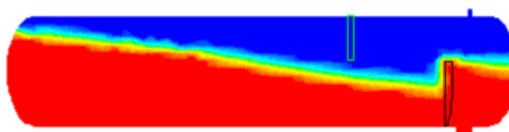


Figure from www.IPIMS.com
"Separation of Produced Fluids" training module.

Vessel without Internal Baffles



Vessel with Engineered Internal Baffles

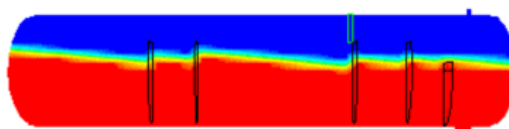


Figure courtesy of NATCO Group

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Coalescing / Defoaming Plates

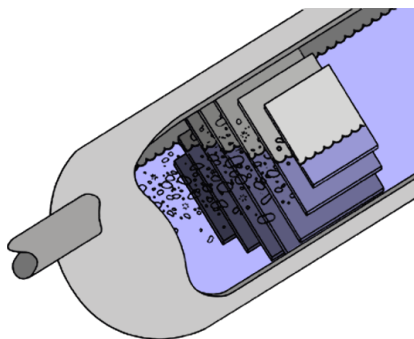


Figure from www.IPIMS.com
"Separation of Produced Fluids" training module.



Picture courtesy of
Akers Solutions

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Sand Jets and Drains

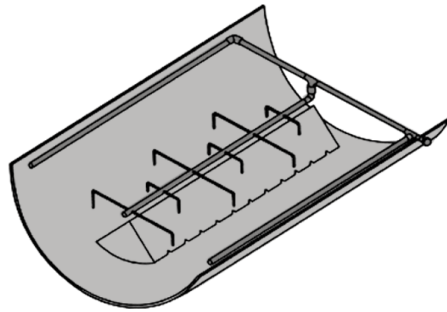


Figure from www.IPIMS.com
"Separation of Produced Fluids" training module.



Picture courtesy of CDS
Separation Technology

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Outlet devices

- The goal is coalescence of 'small' drops to make bigger drops; then let Souders-Brown do the rest
- There are three broad types
 - Mesh pads
 - Vane packs
 - Cyclonic devices

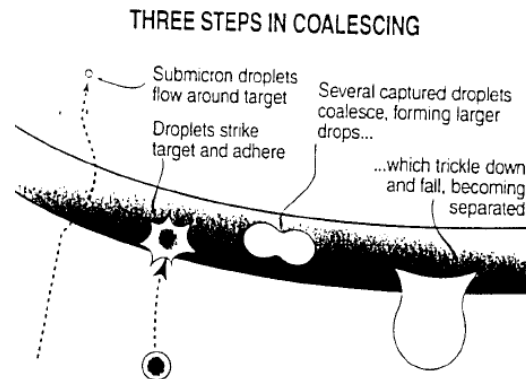
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Coalescing

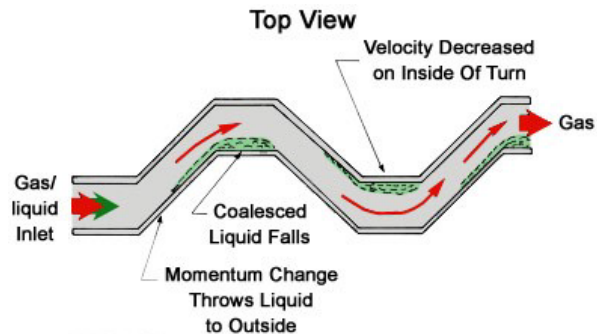
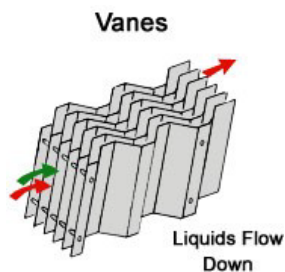
- Purpose – To combine many droplets into fewer droplets of greater diameter
- Low surface tension and high viscosity hinder coalescing



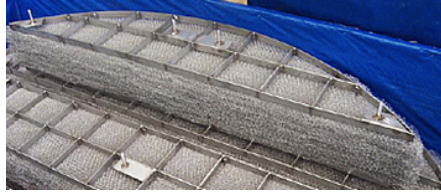
- 1) Collection of Individual Droplets
- 2) Combining of Several Small Droplets into Larger Ones
- 3) Rise/Fall of the Enlarged Droplets by Gravity

Figure by ACS Separations and Mass Transfer Products

Momentum



Mist Extractors - Mesh



Pictures courtesy of www.pentanechem.com



Picture courtesy of www.supremesupplycompany.com

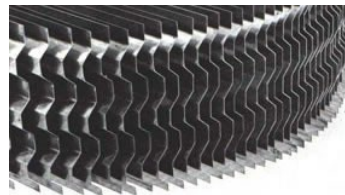
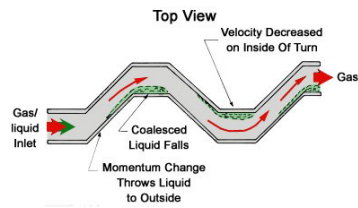
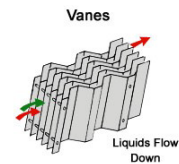
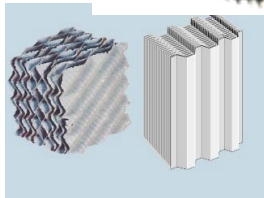
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Mist Extractors - Vane

Figures from www.IPIMS.com "Separation of Produced Fluids" training module.



Picture courtesy of www.supremesupplycompany.com

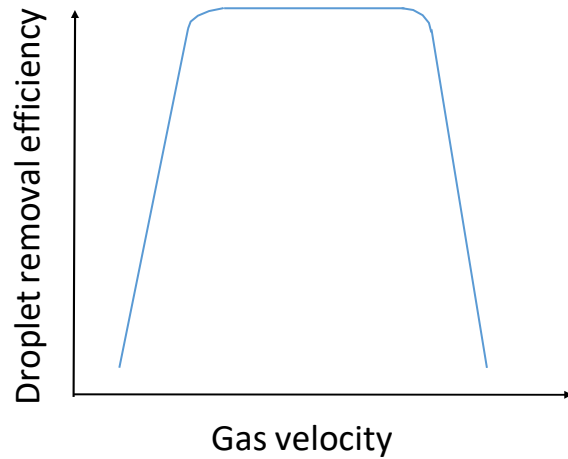
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Mesh pads and vane packs have a design range

- At low velocity small droplets lack momentum and flow around mesh elements
- At high velocity re-entrainment occurs



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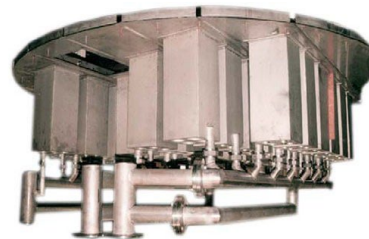
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Mist Extractors - Centrifugal



Shell Swirtube™
Picture courtesy of Sulzer Chemtech



Cyclone mist eliminator assembly with mounting deck and liquid drain piping for a vertical vessel.

Picture courtesy of CDS Separation Technology.



Cyclone mist eliminator assembly is designed for retrofitting a horizontal vessel, including housing and liquid collection piping.

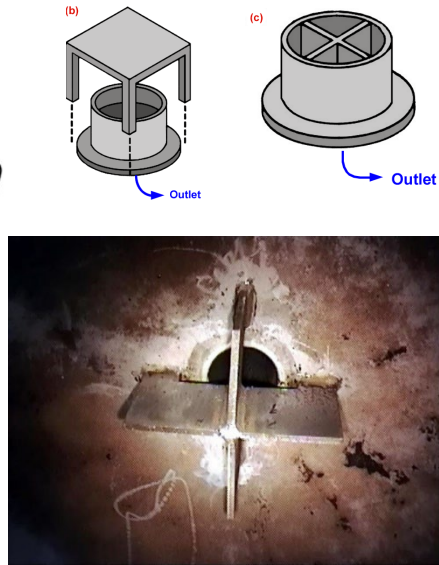
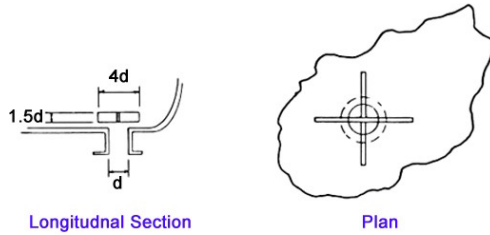
Picture courtesy of CDS Separation Technology.

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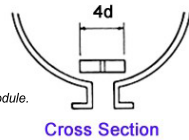
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Vortex Breaker



Figures from www.IPIMS.com
 "Separation of Produced Fluids" training module.

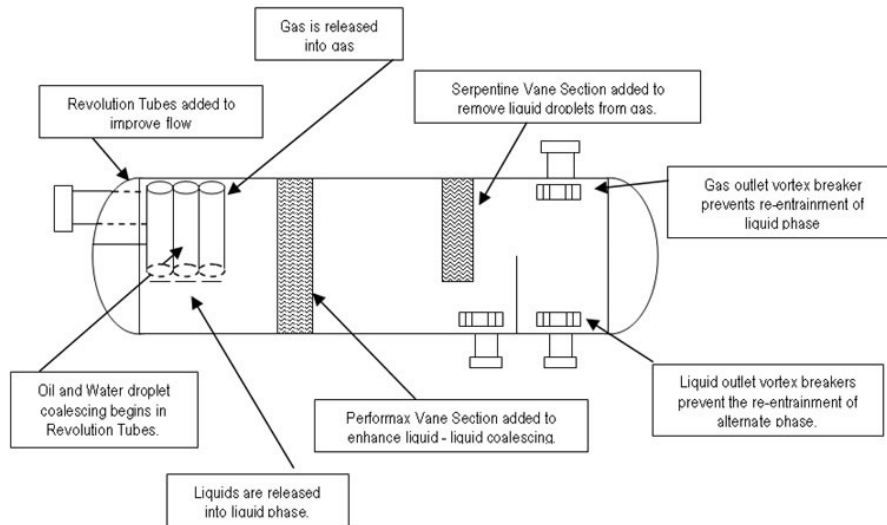


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Putting It All Together



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Beyond Souders - Brown

- With the advent of Computational Fluid Dynamics CFD it is possible calculate the flow patterns within a vessel

Acknowledgement

- All those listed in the slides
- No slide should be constructed as a recommendations of a particular vendor of type of equipment

PART II: OPERATIONAL ISSUES



1. Reasons for poor performance
2. Consequences of Poor Separation
3. Examples of Separator Problems – Symptoms, Causes, & Solutions
4. Retrofit to solve problems
5. Conclusions

PART II: OPERATIONAL ISSUES



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Reasons for Poor Performance

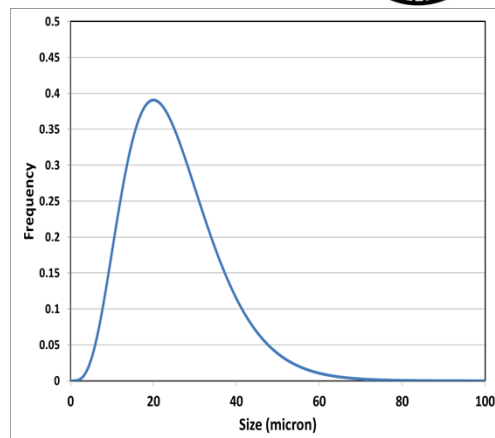
BUT FIRST: WHAT IS POOR (AND GOOD) PERFORMANCE?

- What is the expectation for the separator?
 - **Don't expect** quantitative separation of phases
 - **Expect:**
 - Removal of *X%* of liquid droplets smaller than *Y micron*
 - Removal of *Z %* of entrained liquids
 - To achieve a certain amount of liquid in outlet gas: *T gallon liquid per MMCF*
- Two quantitative expectations sometimes seen:
 - 0.1 gal/MMSCF in outlet gas
 - 99.5% removal of 10 μm particles



Reasons for Poor Performance

- Knowing everything about liquids entrained in a gas is difficult
 - Amount of each phase
 - Composition of each phase
 - Particle size distribution (PSD)
- Sampling usually disturbs P & T and disrupts balance
- In-line PSD not commonly done



Reasons for Poor Performance



- Lack of input data for rigorous design calculations
- The phase separation efficiency of a well-designed separator may not be known
- Observable problems usually define a poorly-performing separator

However:

- Standard design practices give satisfactory results

Reasons for Poor Performance



SUBSTANDARD DESIGN: Size of vessel

- Poorly defined process design conditions
- Small vessel diameter
 - Gas velocity too high to allow droplets to fall
- Short vessel height (vertical)
 - Not enough liquid residence time to degas
 - Not enough vapor residence time to allow L-V separation

Reasons for Poor Performance



SUBSTANDARD DESIGN: Inlet Equipment

- Inlet Nozzle: too small
 - Small Nozzles → high velocity
 - Jetting of gas into surfaces can cause re-entrainment
 - Very high velocities → smaller droplets
 - Deflectors
 - Useful to direct liquid flow towards the bottom of vessel
- Designing inlet nozzles conservatively = good value for improved performance

Reasons for Poor Performance



SUBSTANDARD DESIGN: Internals

- Demisters: Gas velocity out of range (high or low)
 - High: liquid re-entrained into gas, high pressure drop
 - Low: Inefficient removal because droplets don't hit media

Reasons for Poor Performance



UNEXPECTED CONDITIONS

- Solids entrained in feed
 - Accumulation in sump: reduces liquid residence time, plugging of outlets
 - Plugging of demister: high dP and loss of removal efficiency
- Very small droplet size (aerosol, fog)
 - Can be caused by unusual upstream conditions,
 - Can be caused by known chemistry
 - Vessel, internals design may not remove smallest
Question: Do they need to?
- Formation of liquid-liquid emulsions

Reasons for Poor Performance



UNEXPECTED CONDITIONS (continued)

- Dissolved solids in liquid feeds
 - Evaporating liquids on demisters → solids deposits → demister plugging
- Incompatible liquids and internals
 - Gasket failure
 - Corrosion

Reasons for Poor Performance



Picture courtesy of www.supremesupplycompany.com

Reasons for Poor Performance



Reasons for Poor Performance



INCONSISTENT CONDITIONS

- Very large variability gas flow rate
 - Very large variability in liquid content
 - Slug catchers are designed for this
- ➔ Size vessels for highest reasonable expected flow

Reasons for Poor Performance



DOWNSTREAM OR UPSTREAM PROBLEMS

- Downstream cooling/condensation in pipes
 - Can be blamed on separator
 - Upstream operations upsets
 - Cause short term conditions outside of design range
 - Changing process conditions over time
 - Pressure, temperature
 - Composition
 - Flow rate
- ➔ Important in Oil & Gas world

Reasons for Poor Performance



UNREALISTIC EXPECTATIONS

- Separators are physical devices
 - Do not affect equilibrium
- **Separation of phases is limited to their mutual solubility**
 - *Air-water separator*: some oxygen will be always be dissolved in the water and some water will always be dissolved in the air
- Look at VLE information at your composition, temperature, and pressure
 - Simulation software
 - Henry's Law for low-solubility gases

PART II: OPERATIONAL ISSUES



1. Reasons for poor performance
2. **Consequences of Poor Separation**
3. Examples of Separator Problems – Symptoms, Causes, & Solutions
4. Retrofit to solve problems
5. Conclusions

Consequences of Poor Separation



EQUIPMENT PROBLEMS

- Liquid carry-over with gas:
Compressor wear/failure
- Vapor carry-under with liquid:
Pump cavitation/failure
- Corrosion
- Physical damage of separator
internals



Consequences of Poor Separation



OPERATING PROBLEMS

- Plugging
- Pressure drop
- Excessive load on downstream operations
- Capacity limitations due to reduced component
separation efficiency

Consequences of Poor Separation



PRODUCT QUALITY

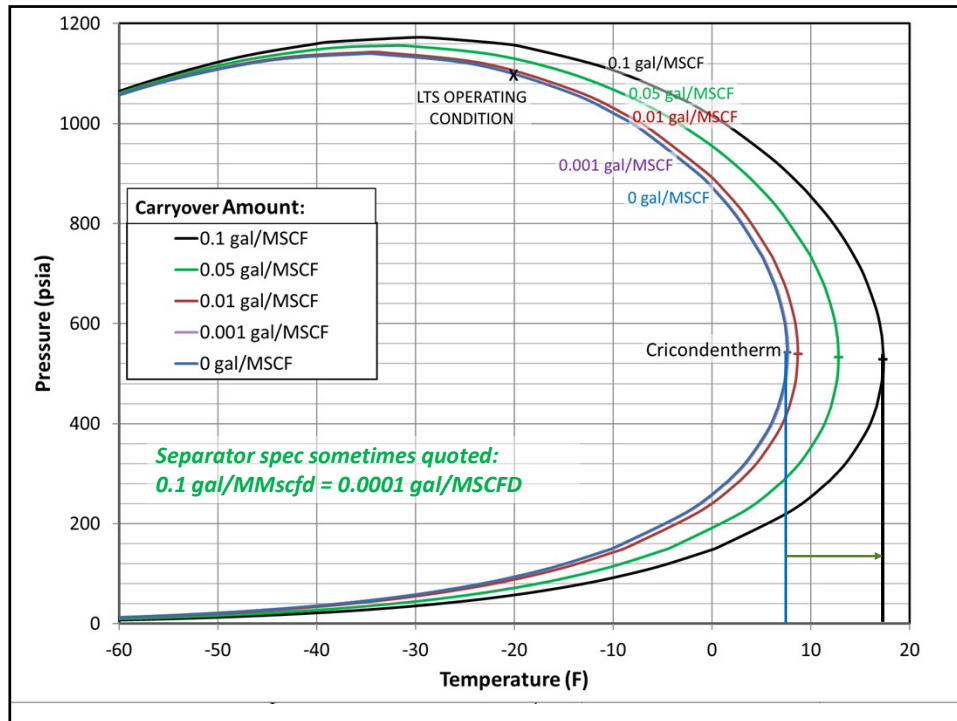
- Natural gas may have a dew point specification, and want to avoid condensation in long pipelines
 - Low temperature separation processes may be used to reduce heavies in gas
 - Liquid carryover from cold separator directly affects the product gas dew point

Consequences of Poor Separation

EXAMPLE



- Example rich gas cooled to -20 F and V-L separated
- Remixed some of the liquid back into the gas to simulate carryover
- Looked at impact on phase envelope



Consequences of Poor Separation Example



Lesson of this example:

- Allowing significant carryover from an LTS results in potential dew point problems with product gas
- The LTS is not the place to cut corners since it can waste expensive refrigeration capacity

PART II: OPERATIONAL ISSUES



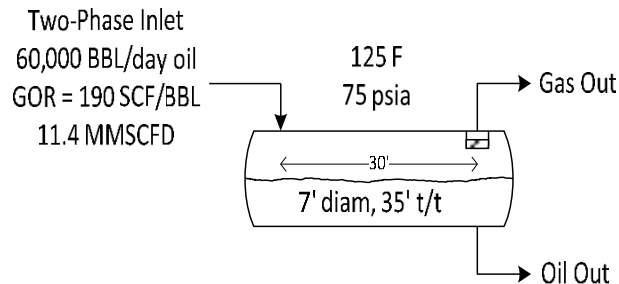
1. Reasons for poor performance
2. Consequences of Poor Separation
3. **EXAMPLES of Separator Problems – Symptoms, Causes, & Solutions**
4. Retrofit to solve problems
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Examples of Separator Problems – Symptoms, Causes, and Solutions



- Examples of process plant problems associated with separators
- Based on true stories, with changes to data and some details

Example 1: Excessive Carryover



- Production separator
- Excessive oil carryover observed in downstream gas equipment

Example 1: Excessive Carryover



Troubleshooting

Souders-Brown Equation to evaluate for current conditions:

$$v = K \left(\frac{\rho_l - \rho_g}{\rho_g} \right)^{1/2}$$

$$\rho_l = 53 \text{ lb/ft}^3, \rho_g = 0.29 \text{ lb/ft}^3$$

Design Parameter, K:

$$K = 0.45 * (L/10)^{0.56} \approx 0.8 \text{ ft/s}$$

(Large L > 10 ft horizontal with ME)

Use K = 0.4 ft/s as a conservative-bias assumption



Example 1: Excessive Carryover

$$v_{\text{allowable}} = 0.4 \frac{\text{ft}}{\text{s}} \left(\frac{53 - 0.29}{0.29} \right)^{0.5} = 5.4 \frac{\text{ft}}{\text{s}}$$

Calculate the actual gas velocity

Remember to use actual gas flow rate, not standard!

$$Z = 0.97, P = 75 \text{ psia}, T = 125 \text{ F}$$

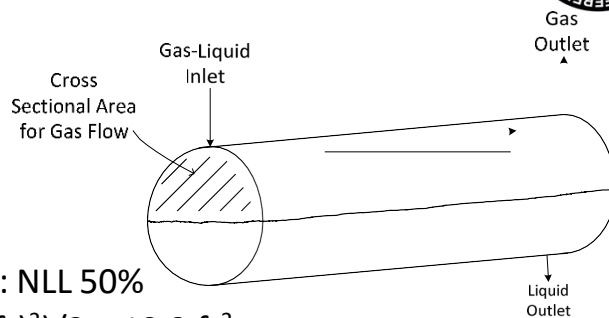
$$Q = 11.4 \text{ MMSCFD} * 0.97 * (125+460 \text{ R}) / (60+460 \text{ R}) * 14.7 \text{ psia} / 75 \text{ psia}$$

$$Q = 2.4 \text{ MMACFD} * 1\text{e}6/\text{MM} * (1 \text{ day}/24 \text{ hr}) * (1 \text{ hr}/60 \text{ min}) * (1 \text{ min}/60 \text{ sec})$$

$$Q = 28.2 \text{ ft}^3/\text{sec}$$



Example 1: Excessive Carryover



- $v_{\text{actual}} = Q / A$
- Vessel design: NLL 50%
- $A = (\pi/4 * (7 \text{ ft})^2)/2 = 19.2 \text{ ft}^2$
- $v_{\text{actual}} = 28.2 \text{ ft}^3/\text{s} / 19.2 \text{ ft}^2 = 1.5 \text{ ft/s}$
- Compare with $v_{\text{allowable}} = 5.4 \text{ ft/s}$
→ design should be conservative

Example 1: Excessive Carryover



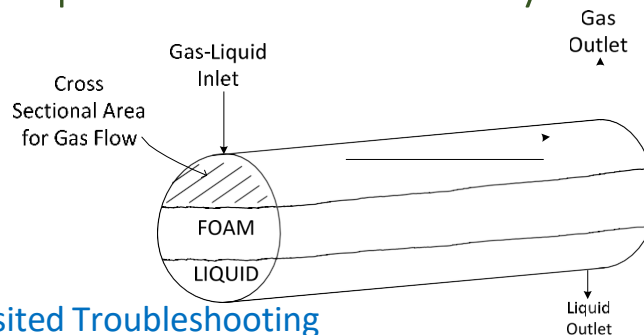
Troubleshooting continues...

- Foaming suspected
 - Infer from taking samples at different points in gas area
 - Gamma Scanning
- Anti-foam applied continuously and the problem is solved

Longer term: don't want to continuously add anti-foam, so revisit

- Cost of anti-foam
- Downstream impact of silicone

Example 1: Excessive Carryover



Revisited Troubleshooting

- Tried lowering liquid level: ~ 50% to 35%
- Result: no substantial carryover with antifoam turned off.
- Still indication that foam was present in vessel.

Example 1: Excessive Carryover



Why did this work?

- S-B equation: the space above the liquid/foam only is available for gas flow
- Foaming: actual cross-sectional area for gas much smaller than design
- Anti-foam application allowed the vessel to run as designed
- Lowering the liquid level also lowered the foam level, allowing the vessel to run as designed

Example 1: Excessive Carryover



- Be cautious lowering liquid level
 - Reduce residence time for liquid degassing
 - Less control flexibility



Photo: J Lundeen



Example 1: Excessive Carryover

Check liquid residence time (τ)

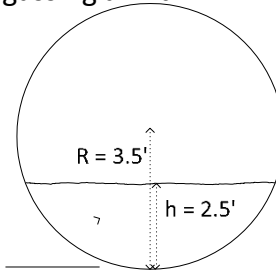
- At 50% level:

$$\tau = V / Q_{\text{oil}} = \left(\frac{\pi}{4}(7ft)^2/2\right)(30ft) / (3.9 \text{ ft}^3/\text{s}) = 2.5 \text{ min}$$

- 2.5 min is plenty of residence time for degassing a mid-weight oil

- Reduce liquid level to 35%

- $T = 12.3 \text{ ft}^2 * 30 \text{ ft} / 3.9 \text{ ft}^3/\text{s} = 1.6 \text{ min}$
- This is likely still good for degassing



$$\text{Area} = R^2 \cos^{-1}((R-h)/R) - (R-h)(2Rh-h^2)^{0.5}$$



Example 1: Excessive Carryover

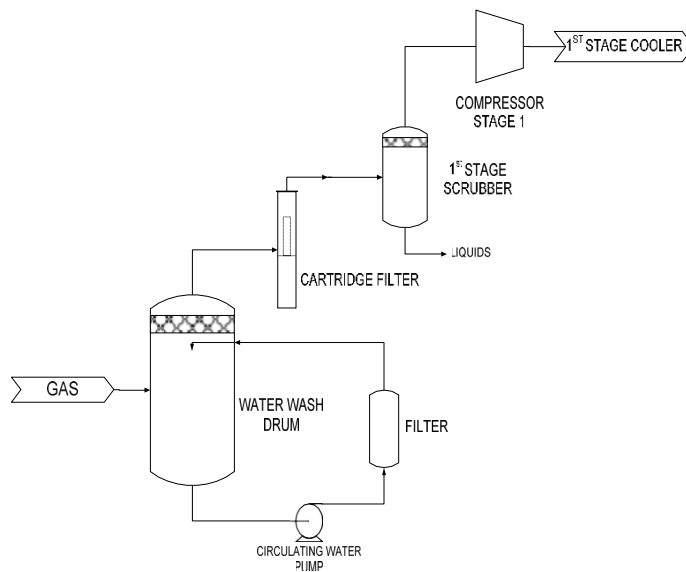
Lessons Learned

- Calculate the area for gas flow carefully
 - Static foam takes up volume
- Check liquid residence time when changing level

Example 2: Reciprocating Compressor Failure



- Hydrogen recompression in chemical process
- Large reciprocating compressor debottlenecked to increase capacity by 25%
 - Originally designed for higher flow rate but hobbled due to frequent mechanical failures
 - Project improved foundations, pulsation dampeners, and pipe routing to allow for full capacity



Example 2: Reciprocating Compressor Failure



- After 4 months of runtime, new rings and rider bands on 1st stage unusually worn down and needed to be replaced
 - High vibrations on 1st stage cylinders and rod drop alarms
 - Hone out one cylinder liner
 - Found inconsistencies in material quality reports on ring and rider band material, [blamed manufacturer](#)



Photo: J Lundeen

Example 2: Reciprocating Compressor Failure



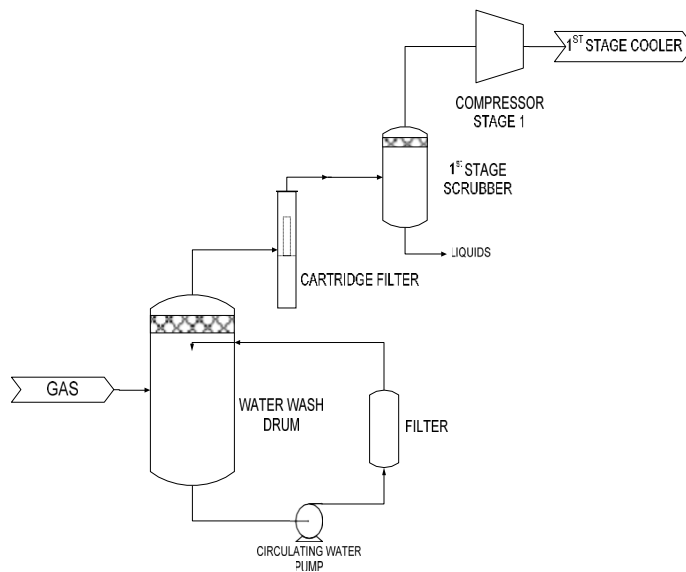
- Approximately 4 months later suffered a second failure
 - 2nd stage piston cracked, again lost significant amounts of ring and rider band material
 - Sludge found in discharge valves
- Sludge: high amounts of iron oxide in addition to expected components of wear parts and lubrication



Example 2: Reciprocating Compressor Failure

Troubleshooting continues

- Historical research: Old plant, gas collection network constructed of various materials over the decades
- Some carbon steel: wet service with chlorides & oxygen
 - Water Wash Drum installed in 1990s to knock down rust
 - Before recent failure operators reported opaque water in water wash system that cleared up after a few days
- After 2nd compressor failure, engineering witnessed replacement of cartridge filters
 - Completely saturated with water
 - Operators reported “marbles” sound in piping when taking filter housings in/out of service



Example 2: Reciprocating Compressor Failure



- Isolated and entered water wash tower for inspection
 - Found 8' diameter demister pad over 90% blocked by iron oxide cake
 - Severe channeling through center of demister pad
- Replaced demister pad, no further issues
- *Compressor 1st stage scrubber level remained at 0% throughout incidences (design not checked)*



Example 2: Reciprocating Compressor Failure



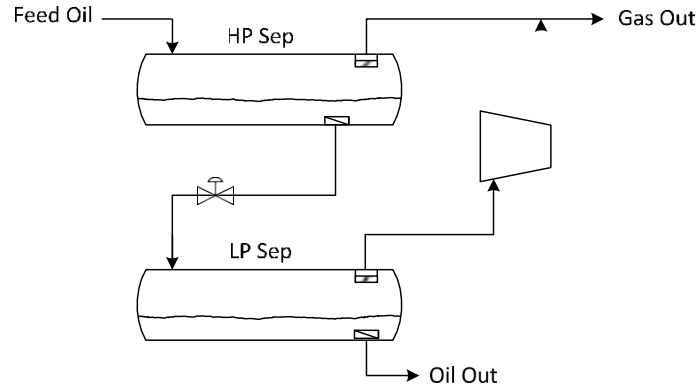
Lessons Learned

- When changing conditions check scrubber sizing
- Pay attention to differential pressure across separators with demisters
- Pay attention to observations of operations

Example 3: Overloaded Compressor



Interstage gas compressor chronically tripped (high current to drive)



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Example 3: Overloaded Compressor



What caused this?

- Higher gas flow rate than design from LP separator
 - Verified by flow meter
- No obvious problems
 - Liquid in HP Sep was at design level
 - Vortex breaker present at liquid outlet

Why the high gas flow from LP separator?

- Samples of oil from HP separator show large amounts of gas
 - More than equilibrium amount
- Gas carry-under was proposed as a cause
- Liquid level was increased
 - Gas velocity at higher liquid level was okay
- With longer liquid residence time, problem was resolved

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Example 3: Overloaded Compressor

Degassing of liquids (gas carry-under)

- Usually secondary concern: designing for avoiding liquid carryover in gas, and reasonable liquid level → usually plenty of liquid res time to degas
- 1-2 minutes is usually enough for most cases.
- Rule of thumb from API 12J (G-L two phase)
 - API gravity > 35: at least 1 min
 - API gravity in the 10 to 20 range: at least 2 to 4 min
- GPSA Data Book
 - 2 minutes for light hydrocarbons
 - Up to 15 minutes for foaming or viscous liquids



Example 3: Overloaded Compressor

Degassing of liquids

- Stokes' Law applied to separation of gas bubbles from liquid
- The terminal velocity of a gas bubble in a liquid:

$$v_t \propto \frac{D^2(\rho_g - \rho_l)}{\mu_l}$$

- Terminal velocity for a bubble: ~50x less for 15 API compared to 30 API

Typical Viscosity of Crude Oil	
	Viscosity
API	(cp)
15	500
30	9
45	2.5

Example 3: Overloaded Compressor



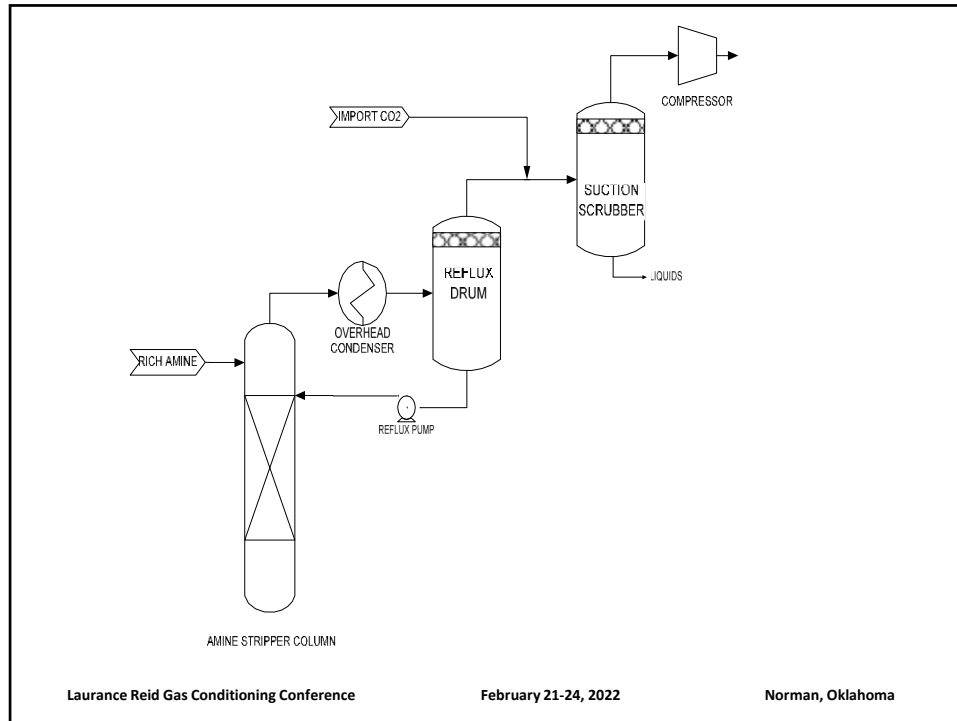
Lesson Learned

- Pay attention to liquid properties
- Use literature guidance

Example 4: Centrifugal Compressor Failure



- Amine unit for CO₂ removal from syngas
- CO₂ Acid Gas from amine regenerator is recovered
- 4 stage centrifugal compressor for CO₂ Acid Gas
 - Imported CO₂ mixed with amine unit CO₂
- Historically, amine residue found on CO₂ compressor inlet guide vanes and 1st stage compression wheel
 - Worse as throughput increased through the years
 - Unplanned CO₂ compressor shut downs, excessive maintenance



Example 4: Centrifugal Compressor Failure



- Investigated potential sources
 - Import CO₂ purity
 - Reflux Drum: sized for adequate removal of liquids
 - Compressor scrubber sized adequately
 - No pocketing of piping from Reflux Drum to Suction Scrubber or from Compressor KO Drum to 1st stage of CO₂ Compressor
 - Distance from Compressor KO Drum to 1st stage of CO₂ Compressor minimized
- Upgraded internals in Reflux Drum & Scrubber
 - Improved inlet diverters and demister pads
 - Problems persisted

Example 4: Centrifugal Compressor Failure

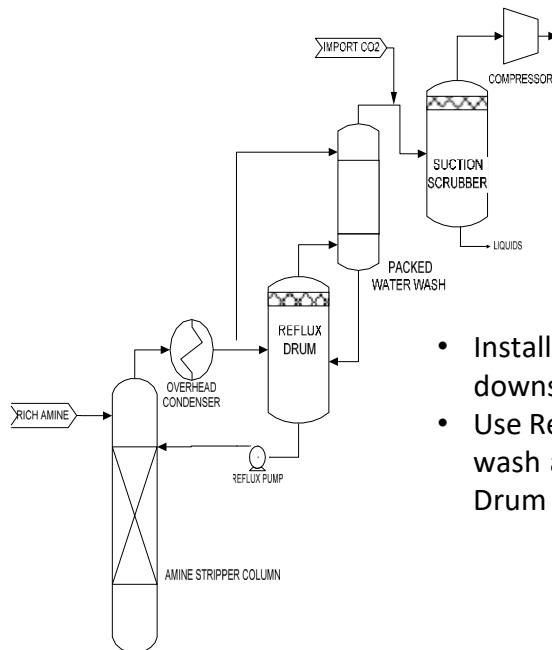


- Investigated VLE of amine with CO₂
 - Unlikely that amine was condensing out of gas stream
 - Condensation of amine would be with a much larger amount of water
- Rich amine enters above packing via gallery tray
 - No rich flash drum
 - Pressure reduction valve is directly at column entry
 - Hypothesis: Rich amine atomizing due to ~400 psi dP, and carrying through to compressor

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- Installed water wash column downstream of Reflux Drum
- Use Reflux Drum water for wash and return to Reflux Drum

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Example 4: Centrifugal Compressor Failure

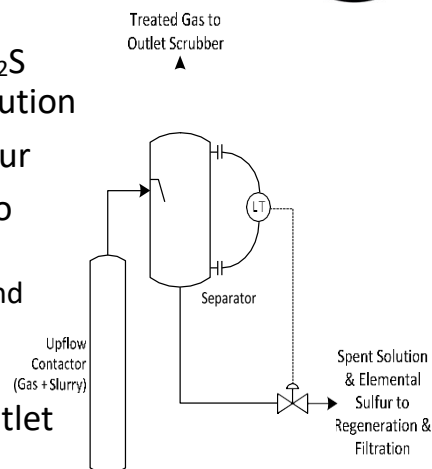
Lesson Learned

- High energy operations (e.g., large pressure drops) can create surface area (small particles)
- If separator isn't operating per design, look at design assumptions
- Most designs aren't meant to remove the smallest particles



Example 5: Solids

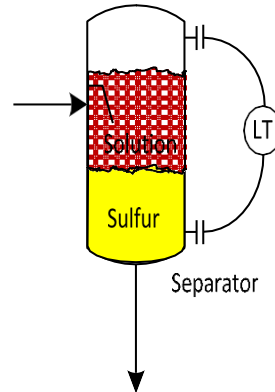
- High pressure natural gas H_2S treatment with aqueous solution
- Formation of elemental sulfur
- Level in Separator difficult to control, highly variable
 - But usually maintained around setpoint
- Massive carryover of liquid indicated by collection in outlet scrubber





Example 5: Solids

- Collection of solids can block level transmitters, totally or partially, giving false liquid level readings
- Requires cleanout
- Design
 - Extended remote diaphragms
 - Blowout nozzles



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3. Examples of Separator Problems – Symptoms, Causes, & Solutions
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5. Conclusions



Retrofit to Solve Problems

- Change operating practice
 - Smooth control of upstream operations: reduce variability range of feed
 - Smooth control of separator liquid level
- Consider/improve upstream and downstream
 - Is the separator really the problem? Insulate/HT downstream to avoid condensation
 - Is the upstream process creating a difficult feed?



Retrofit to Solve Problems

- Add/Change internals
 - Add a more efficient mist extractor
 - Increase/decrease the mist extractor area
 - Add baffles to stabilize level
 - Add vortex breakers
 - Add/improve inlet diverters



Photo: D Mamrosh



Retrofit to Solve Problems

- Add another unit operation before or after
 - Before: Slug catcher to deal with intermittent large liquid volumes
 - After: Coalescing filter, Fiber bed ME, etc., to take out more liquid mist
- Modify separator vessel
 - Larger nozzles (& associated piping)
 - Boot



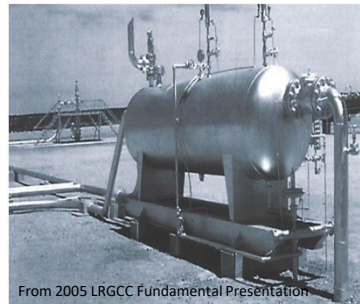
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Conclusions

- Just a few examples were given here, mostly confined to G-L separation in typical oil & gas applications
- The examples hopefully illustrate some typical problems that might be encountered



From 2005 LRGCC Fundamental Presentation



Conclusions

- See previous papers and presentations on separators in previous years LRGCC proceedings, including:
 - 2005 Fundamentals
 - 2009 Fundamentals: Section on separations in offshore environment *Compact Options*
 - 2013 Fundamentals: Filtration and carbon treatment, coalescers
 - Many other papers...

Acknowledgements

- Authors and presenters of previous Separator Fundamentals session, from which some of this material was drawn
- Colleagues for donating their war stories