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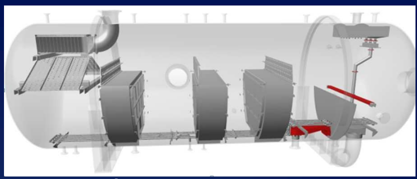

3-Phase Separation: Identifying and Addressing Issues Before They Happen

Presenter: Luis Caires. Director Product development- Liquids.
Cameron- Process Systems

SPE International

CAMERON
A Schlumberger Company

What is a 3 phase separator?

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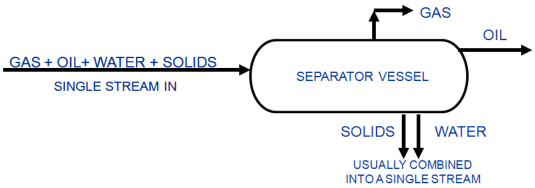
Process equipment used for the bulk separation of gas, oil and water from a multiphase flow stream. The separation is gravity based.

Please don't forget the solids even if you don't want to call it a 4 phase separator
You may also want it to catch slugs and then you call it slug catcher



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How can a Separator fail?

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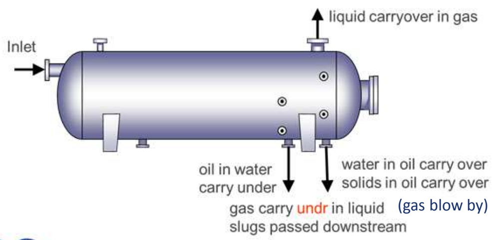
a separator fails when it doesn't do what it was supposed to do



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Some consequences of separator failure

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- Liquid in gas carryover can
  - damage compressors downstream
  - waste valuable liquids
  - plug or overload pretreatment equipment downstream
  - Increase operating cost
- Oil in water carry under can
  - overload produced water treatment plant
  - waste valuable product
  - lead to oil coated solids more difficult to dispose of
  - Increase PWT plant operating cost
- Solids in oil carryover can
  - impair emulsion separation downstream
  - create accumulations in electrostatic components
  - potential off spec oil

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Some consequences of separator failure

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- Water in oil carryover can
  - increase thermal requirements downstream
  - increase load to downstream separations
  - lead to off spec oil
  - waste valuable chemicals
  - Increase operating cost
- Gas carry under or gas blow by can
  - Damage pumping equipment downstream
  - create hazardous conditions upon gas release
  - entrain the other liquid phase
- Passing slugs downstream can
  - overload separation equipment downstream
  - lead to off spec oil or water downstream

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HOW TO PREVENT THIS FROM HAPPENING?

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- Get clarity about the separation need
- **Design the separator according to the need**
- Build the separator according to the design
- Install the separator according to the designer installation instructions
- Operate the separator as intended by the design
- Maintain the separator as per proper maintenance practices
- Monitor separation performance
- Monitor deviations from intended operational envelope to re assess the separation need
- Take action, modifications retrofit debottlenecking operating mode as appropriate

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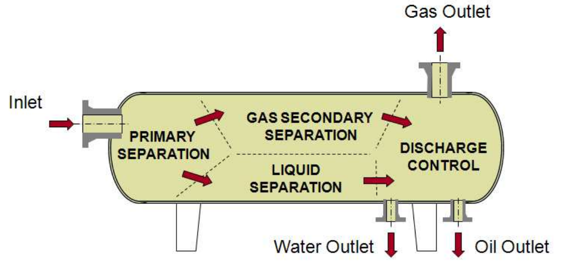
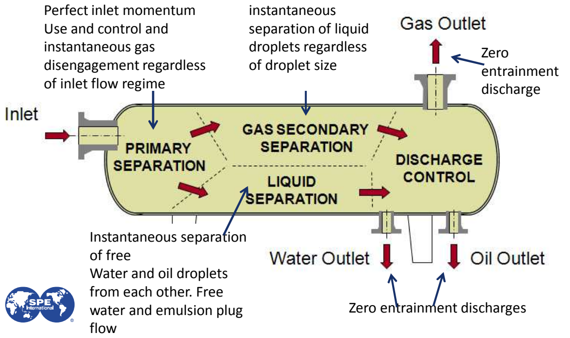
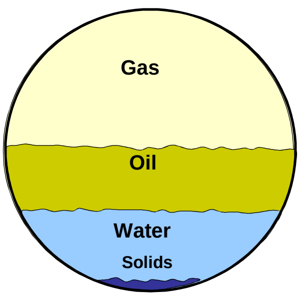
Basic anatomy of a 3 phase separator



Things that happen in a 3 phase ideal (or magic) separator



Cross section of the ideal separator



Magic is broken because…

- **Gas is not released instantly**, this can induce foaming in viscous fluids and gas carry under
- **Inlet flow regime matters** since it defines the initial severity of the inter-dispersion of the phases to be separated
- **Inlet momentum and kinetic energy cause droplet breakup** as local velocities exceed those of the critical Weber number as well as gas bubble entrainment
- **Droplet disengagement is not instantaneous**, and depending on their size they may be entrained
- **There is no plug flow** and fluid close to the center of the vessel moves faster than the rest and therefore has a lower residence time and experiences higher local turbulence
- **Rotation of the flow** near and acceleration approaching exit nozzles can induce vortices that entrain gas or liquids to the wrong place

But things are controlled by laws…

- Droplet size and breakup limited by **critical Weber's number**
- Interface instability ruled by **Kelvin-Helmholtz instability**
- Drop settling ruled by **Stoke's law** or derivatives like Newton's law
- Local turbulence quantified by **local Reynolds Number**

Turbulence $Re = DV\rho / \mu$

Interfacial instability $U_{g,cr} = \sqrt{\frac{2\sqrt{\rho_{liq}\sigma g}}{\rho_{gas}}}$

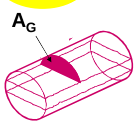
Droplet breakup $We = \rho V^2 l/\sigma$

Droplet settling velocity $v = 1.73[gD(\rho_L - \rho_G)/\rho_G]^{1/2}$

Droplet rate of fall Newton's law (Stokes derivative)

NEWTON'S LAW: $v = 1.73[gD(\rho_L - \rho_G)/\rho_G]^{1/2}$

$A_G = \frac{F_G}{v_G}$



v = droplet falling velocity-ft/sec

D = droplet diameter-ft

g = gravity constant-32.2 ft/sec^2

ρ_L = liquid density-lb/ft^3

ρ_G = gas density-lb/ft^3

Sauder Brown equation for gas phase sizing (Newton derivative)

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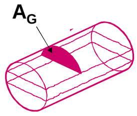
NEWTON'S LAW ⇨ SAUDER-BROWN EQUATION

$A_G = \frac{F_G}{v_G}$ ⇨ $v_G = K\sqrt{(\rho_L - \rho_G)/\rho_G}$

A_G



v_G = gas velocity-ft/sec

K = superficial velocity factor-ft/sec

ρ_L = liquid density-lb/ft^3

ρ_G = gas density-lb/ft^3

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Stokes Law (for laminar flow, not for field conditions)

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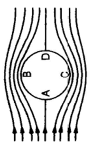

$$\mathrm{ma} = \frac{1}{2}\mathrm{C_D A}\rho_{gas}\mathrm{u}^2$$

$$\mathrm{C_D} = \frac{24}{Re} = \frac{24\,\mu}{\rho_{gas} uD} \qquad Re \ll 1$$

$$\mathrm{m} = (\rho_l - \rho_g)\mathrm{V} = (\rho_l - \rho_g)\frac{4}{3}\pi r^3 = (\rho_l - \rho_g)\frac{1}{6}\pi D^3$$

$$(\rho_l - \rho_g)\frac{1}{6}\pi D^3 a = \frac{1}{2}\frac{24\,\mu}{\rho_{gas} uD}\frac{\pi}{4}D^2\rho_{gas}u^2$$

$$(\rho_l - \rho_g)\frac{1}{6}D^2 a = 3\,\mu\, u$$

$$u = \frac{(\rho_l - \rho_g)D^2 a}{18\,\mu}$$

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K value

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$$u = k\sqrt{\frac{(\rho_l - \rho_g)}{\rho_g}}$$

$$(\rho_l - \rho_g)Va = \frac{1}{2}C_D A\rho_g u^2$$

$$(\rho_l - \rho_g)\frac{1}{6}\pi D^3 a = \frac{1}{2}C_D A\rho_g u^2$$

$$(\rho_l - \rho_g)\frac{1}{3}\pi D^3 a = C_D\frac{1}{4}\pi D^2\rho_g u^2$$

$$(\rho_l - \rho_g)\frac{4}{3}Da = C_D\rho_g u^2$$

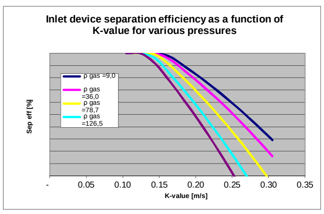
$$u = \sqrt{\frac{4Da}{3C_D}}\sqrt{\frac{(\rho_l - \rho_g)}{\rho_g}}$$

$$k = \sqrt{\frac{4Da}{3C_D}}$$

The k-value indicate the same droplet size performance at different pressures

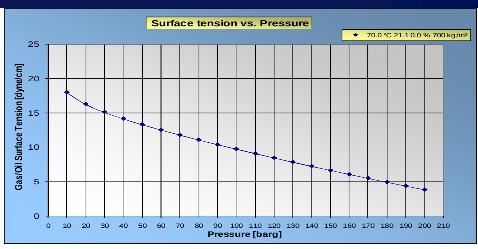
The k-value will be a good scaling factor for separators

We see however some deviation at high pressure



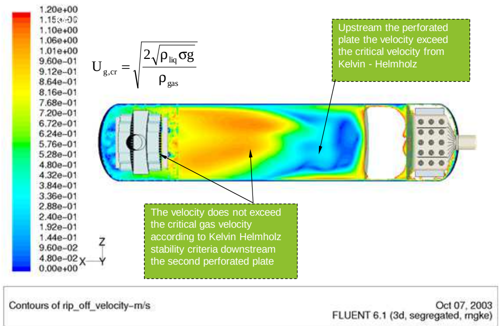
Weber's number

Effect of surface tension on demister performance as measured



Air water 72 dyne/cm
Liquid carry over with 10 dyne/cm is 250 times higher than for air water
At 4 dyne/cm the liquid carry over is 1000 times higher than for air water
Surface tension will generally decrease with increasing pressure making the separation more difficult at high pressure

Kelvin Helmholtz instability



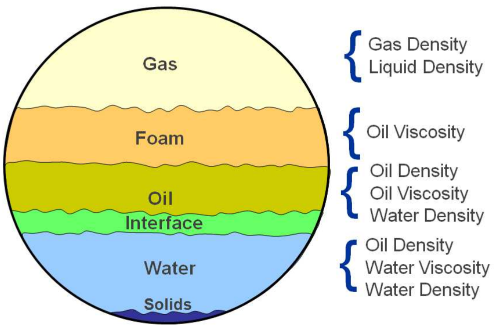
Design separator according to the need

- **Make the proper space allocation for the different phases and their larger than ideal interfaces**
- **Select and use the correct set of internals to address the issues foreseeable from the proper analysis of the separation need**

Design separator according to the need

- Predicting absolute BS&W and water quality out from the separator is difficult.
- The main issue is the optimum utilization of the available separator volume
- The following questions will affect the separator design and will be addressed in this presentation.
  - How is the flow in a three phase separator?
  - Which parameters affects the separation performance of the vessel?
  - How does gas entrainment in the liquid affect the separation performance of the vessel?
  - How will slugs / flow variations affect the separation performance of the vessel?
  - How to choose the optimum inlet design and type?
  - How to design of the gas section to minimize liquid carry over?

Gravity Separator – 6 Components space allocation

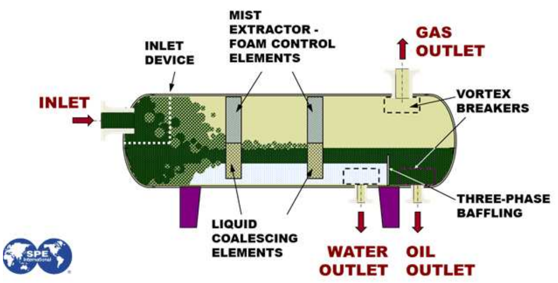


Gravity Separator – 6 Components space allocation

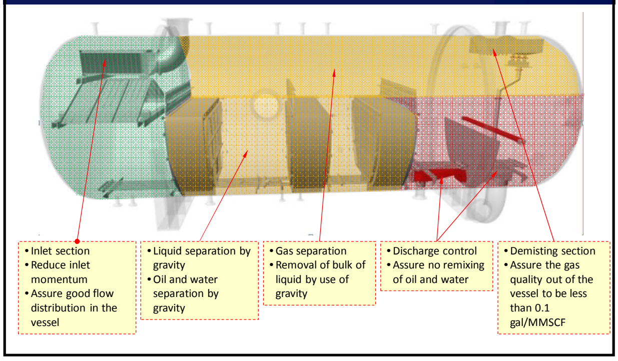
- Gas cross section
  typically decided by K factor considerations
- Oil and water space typically set by residence time consideration based on experience (*be careful though since interface area does matter*)
- Solids space defined by solids accumulation rate mass balance and sand jetting frequency commonly very small volume within the water space in a quiescent zone to avoid entrainment to the oil phase. Many times it is just ignored
- Foam space based on experience or correlations typically defined by an expected foam height above the oil phase
- Oil water interface space based on experience and rarely on a coalescence model typically defined by an expected thickness between the water and the oil phases

Basic anatomy of a 3 phase separator II

INTERNALS IN A GENERIC HORIZONTAL SEPARATOR



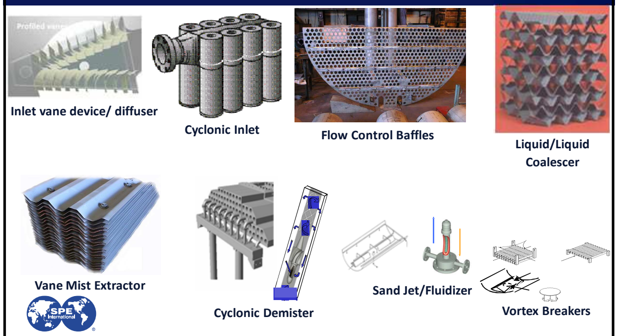
Basic anatomy of a 3 phase separator III



Functions of a Separator and Associated Zones

Separation zone	Problem	Device function
Inlet separation zone	Foaming Slugging Flow Distribution	Inlet devices such as cyclones and vane distribution packs aid to reduce foam, absorb inlet momentum, and promote even flow distribution.
Secondary separation zone	Mist removal Re-entrainment	Mist extractors used to remove fine droplets .
Liquid separation zone	Oil-water separation Re-entrainment	Coalescing media used to enhance retention time thus increase oil-water separation efficiency.
Discharge separation zone	Re-entrainment	Vortex breakers and baffling devices utilized to minimize re-entrainment.

Separation technologies



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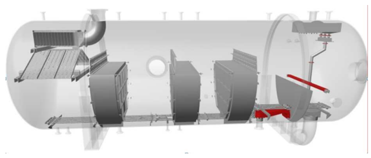
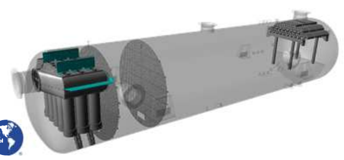
Inlet devices that will help reduce the problems with gas

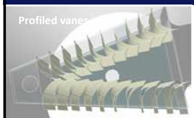


Inlet vanes

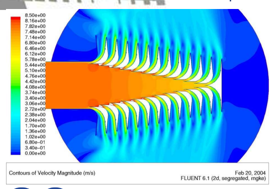


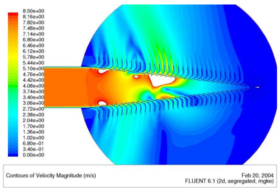
Cyclones extending only into the oil layer

Inlet vane device/diffuser



Bent plates or Profiled vanes
Provide uniform gas distribution within operating range
Profiled vanes provides a more effective retardation of the gas velocity and more capacity by keeping boundary layer attached to the profile





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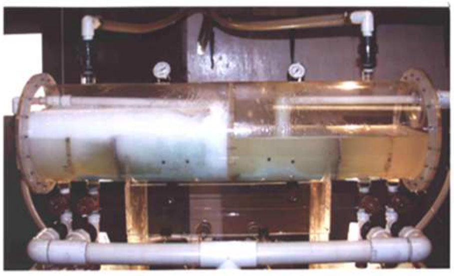
Cyclonic inlet vs. splash plate



Splash plate side **Cyclonic device side**

Cyclonic inlet devices

Eliminate Foam – use the energy from the fluid momentum to create G-force
Higher or Lower g-forces options keeping performance depending on available space or difficulty to break the foam
Mechanical robust design to handle slugging forces

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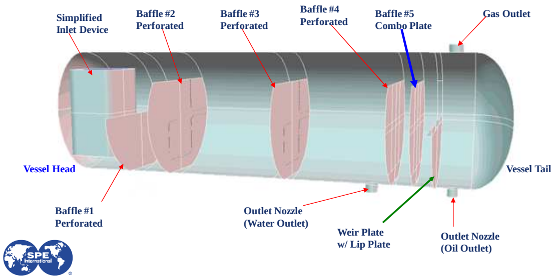
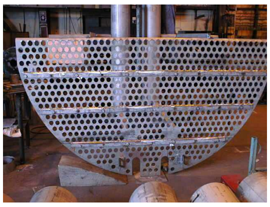
Internal baffles for large FWKO



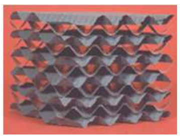
Perforated plates

- Design based on pressure drop – must be sufficient to manage the flow
- Consider hole size for type of service
- Consider hole size for uniform flow
- Use for flow control in both directions

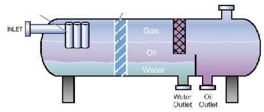


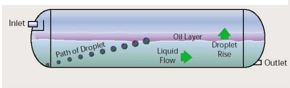
Liquid/liquid coalescing media

- Improve liquid - liquid separation
- Improve gas - liquid separation
- Reduce foam
- Used in horizontal separators
- Open matrix resists plugging
- Continuous element eliminates flow disruptions
- Reduces turbulence and droplet or gas bubble travel distance

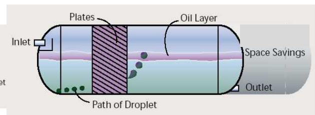


Liquid/liquid coalescing media





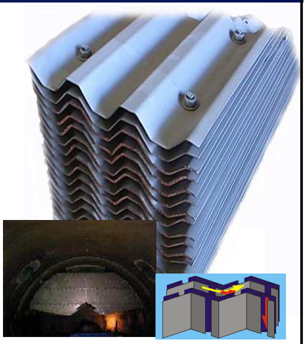
Droplet Path without Coalescer



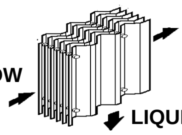
Droplet Path with Coalescer

Demisting vanes

- Improves gas - liquid separation
- Droplet rate of fall related to $D^{1/2}$
- Used in horizontal or vertical separators
- 98% efficient down to 10 microns
- Tortuous path - inertial separation
- Excellent for crude oil service
- Vanes are used for operating pressure below 1000 psig

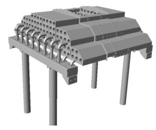


Demisting vanes

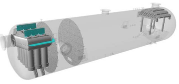


Demisting cyclones

- Features:
  Used as polishing stage in both primary separators and scrubbers
  Axial flow cyclones which use centrifugal forces to separate liquid droplets from a gas stream



- Benefits:
  High separation efficiency
  Double side packing in horizontal separators is recommended
  Enables more cyclones to be installed
  Yield more efficient bulk separation in the separator settling compartment
  High liquid handling capacity



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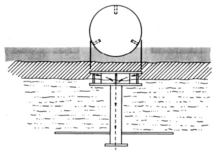
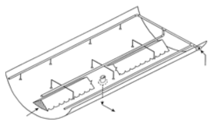
Solids removal drain and jetting systems

Interface Sludge Drain
Operated As Required



Sand Jet (Mud Wash) System
Scheduled or Continuous Operation

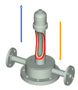


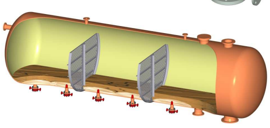
Solids removal fluidizer

Fluidizer - compact and efficient device used to generate flowing slurry from the bottom of a tank or vessel. Designed to transport all sizes of solids found settled in oil and gas production systems

Fluidizer Operating Principles:

- Use controlled injection of water
- Broad but shallow zone of fluidized sand slurry is generated close to the bottom of the vessel.
- No vortex - keep disturbance localized in the area containing the deposited solids.
- Slurry flows towards the fluidizer through an internal flow passage and is discharged from the fluidizer outlet



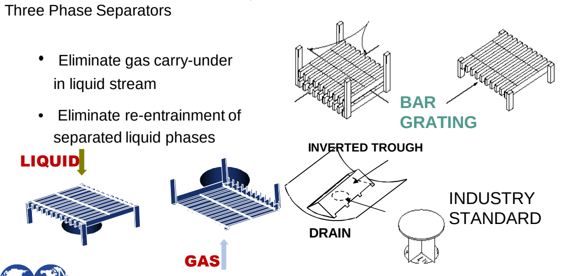


Typical Installation in Horizontal Vessel

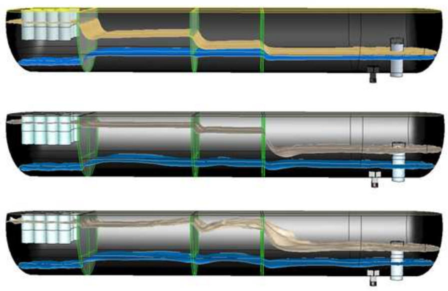
Vortex breakers

Vortex Breakers Prevent Gross Carryover Due to Re-Entrainment in Two and Three Phase Separators

- Eliminate gas carry-under in liquid stream
- Eliminate re-entrainment of separated liquid phases

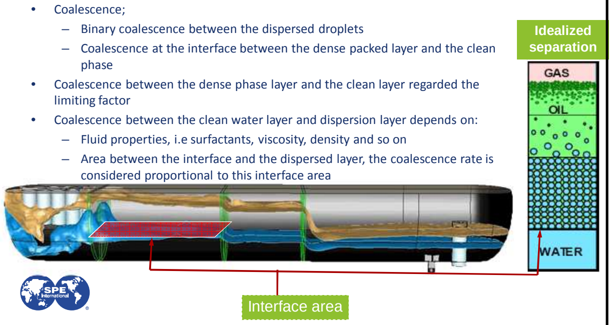


Examples/ situations



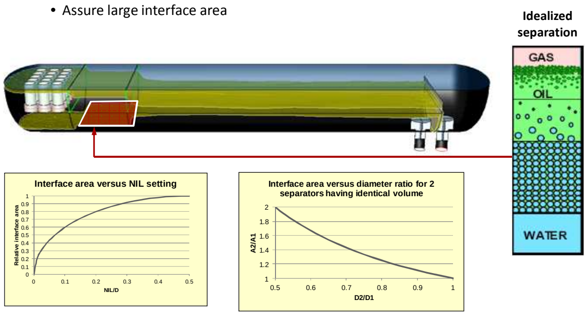
Key factors in liquid/liquid separation

- Settling of the dispersed droplets
- Coalescence;
  - Binary coalescence between the dispersed droplets
  - Coalescence at the interface between the dense packed layer and the clean phase
- Coalescence between the dense phase layer and the clean layer regarded the limiting factor
- Coalescence between the clean water layer and dispersion layer depends on:
  - Fluid properties, i.e surfactants, viscosity, density and so on
  - Area between the interface and the dispersed layer, the coalescence rate is considered proportional to this interface area

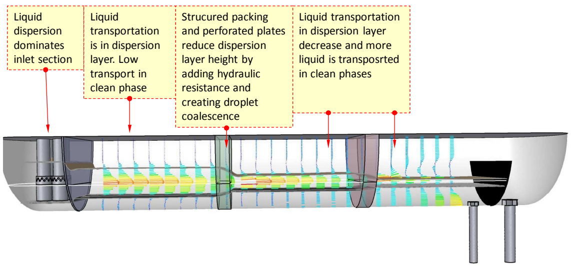


Liquid traffic in the separator/ dispersion band

- Limiting factor is coalescence into water
- Assure large interface area

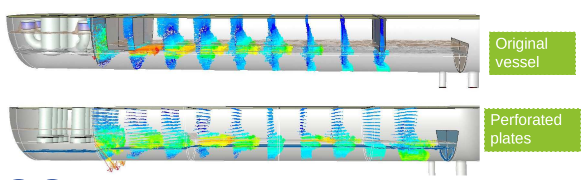


Liquid side of an separator using resistance

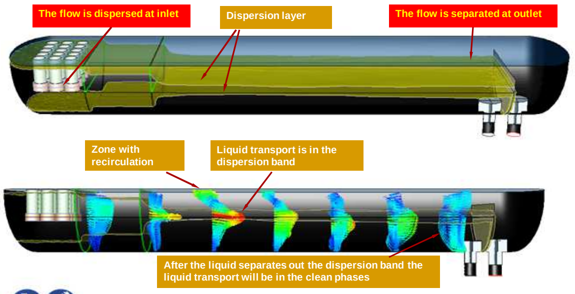


Flow resistance and flow pattern improvement

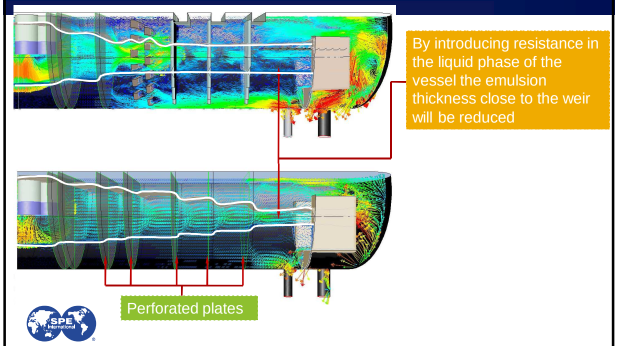
- The flow in the vessel will be dispersed in the inlet and separated in the outlet of the vessel.
  - In order to utilize the vessel volume one should use properly spaced perforated plates in the vessel
  - Even better is using coalescing media



Flow distribution

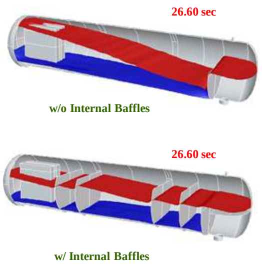


Flow distribution



CFD and multi physics in solving baffling problems -sloshing

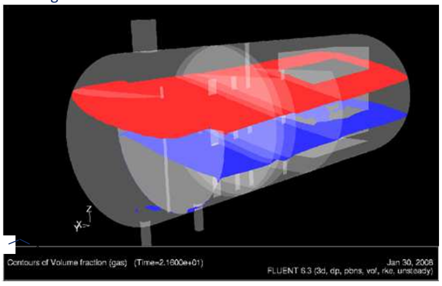
- A powerful computer tool with “visualization” capabilities
- Predict fluid dynamics, heat and mass transfer, and chemical reactions
- Provides detailed insight and better understanding of designs



CFD and multi physics in solving baffling problems -sloshing

Webinars

- Oil-water interface rises above the weir height.
- Right side experience higher roll motion.



Proper baffling non optimal open area

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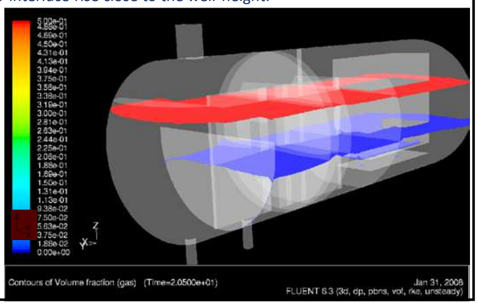
- No water spilled over the weir.
- But oil-water interface rise close to the weir height.



Proper baffling and open area

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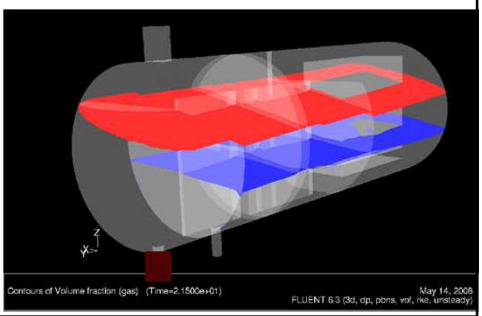
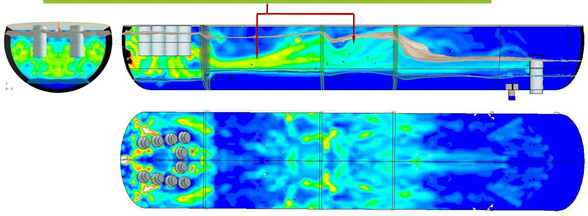
The oil-water interface is better controlled with X% open baffle



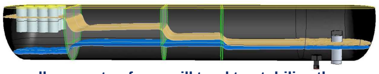
Gas in the liquid phase will generally stabilize the dispersion.

The gas flow lifts the dispersion layer and hinder separation
Small gas bubbles are considered worse than large



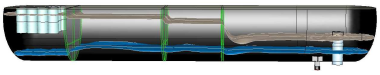
Countours showing gas concentration in vessel

Effect of gas in the liquid phase



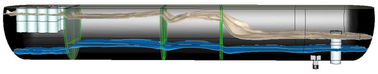
GVF = 0 vol%

Even small amounts of gas will tend to stabilize the dispersion



GVF = 0.05 vol%

D_b = 1000 microns

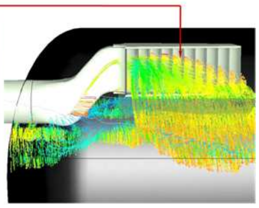


GVF = 1 vol%

D_b= 1000 microns

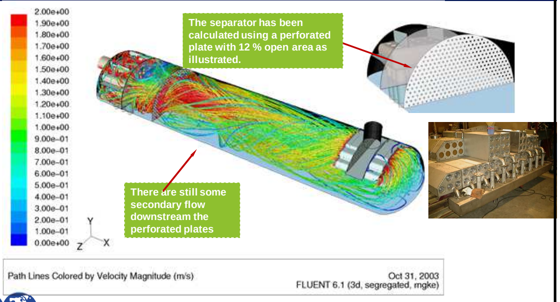
Preventing gas stabilization of the dispersion layer

- Gas deep in the separator may stabilize the dispersion
  - Introduce the liquid higher in the vessel so the gas exceed at the top of the vessel with a shorter separation distance
  - Alternatively use a vane inlet that will assure that the liquid is put on top of the liquid layer



Correcting gas flow pattern

Webinars



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Correcting gas flow pattern

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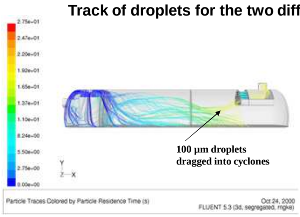
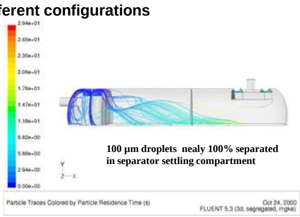
Single vs. double side packing of axial flow cyclones

Track of droplets for the two different configurations





Double side packing in horizontal separators is reccomended

- Enable more cyclones to be installed
- Increases distance to HHLL
- Yield more efficient bulk separation in the separator settling compartment

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Correcting gas flow pattern

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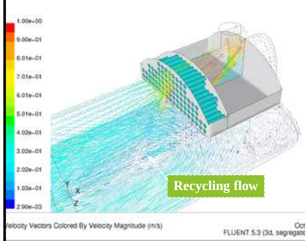
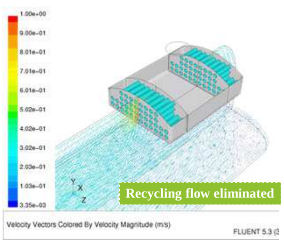
Velocity vector showing flow path in the two options





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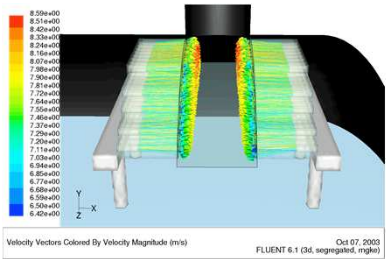
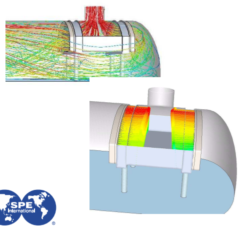
Correcting gas flow pattern

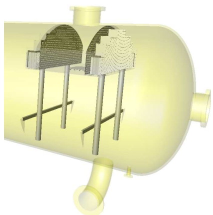
Pressure resistance across axial flow cyclones ensures a uniform flow distribution



Correcting gas flow pattern

- Dual side packing is also recommended for vane packs
- Improved flow versus V-bank layout
- Better utilization of separator volume than vanepack oriented forwards in the separator vessel.



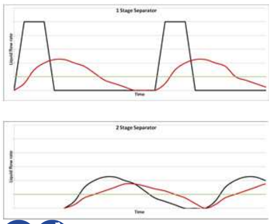


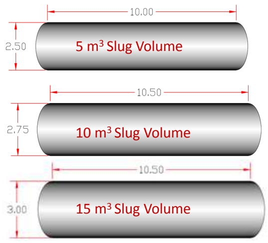
Slugging considerations

- Be aware of the flow pattern in three phase vessels
  - Use perforated plates or other type of resistance for optimized volume utilization
- *Understand the coalescence mechanism in the separator*
  - *Large L/D and NIL close to the center of the vessel improves separation*
- Plan for flow surges
  - Slug should fit between NIL and NLL
  - Volume is the only way to suppress liquid slugs
  - Internals need to withstand the mechanical load
- Choose an inlet sections that will aid separation
  - Inlet cyclones may give reduced separation performance due to gas carry under
  - Splash plate inlets will shatter droplets
- Do not sub optimize vessel
  - Weir should be variable for flexible operations
  - Maximize the number of cyclones in the vessel, they have no turndown issue
  - Vessel nozzles should be based on vessel capacity
  - Liquid nozzles should be large to assure no erosion velocity

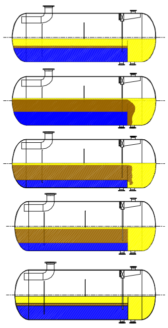
Liquid surges need volume to be dampened

- Even when you have a regulation system that is fast enough the flow surges will continue to the next stage

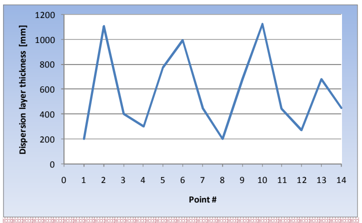




Liquid flow surges will affect separation performance



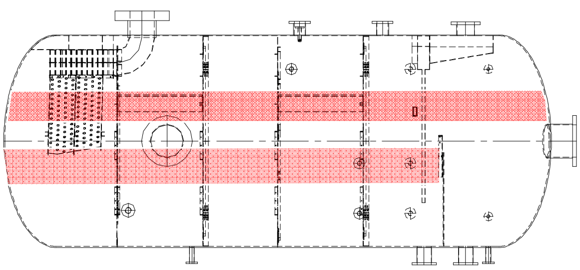
- Flow dynamics will reduce the separation performance if the distance from the NIL to the weir is not sufficient to contain the slug



The thickness of the emulsion bands as measured at different times at constant flow rate

The emulsion thickness varies from 200 mm to 1100 mm.

Liquid slugs should be fitted between weir and NIL



Maximize distance between NIL and weir

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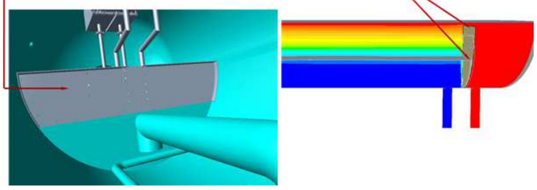
- Unstable flow into a three phase vessel will give poor separation performance.
  - The distance between the weir and the water interface should be maximised



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Future technologies density difference not sufficient alone

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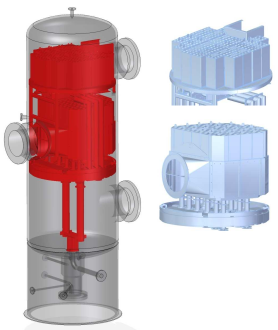
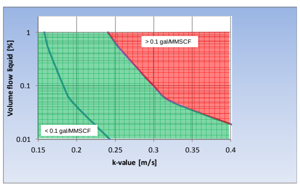
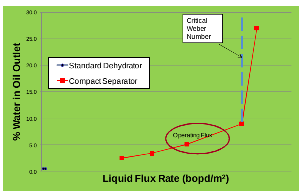




Future technologies density difference not sufficient alone

Webinars



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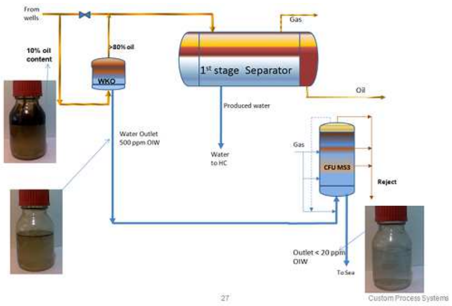
Electrostatic coalescence for separators operating in oil continuous streams

Future technologies density difference not sufficient alone



Challenges

- Predictable water quality based on correlations or semi empirical models
- Predictable oil quality based on correlations or semi empirical models
- Removal of solid fines that may stabilize the emulsion
- New technology for separation will rely on more than density difference between the phases for separation
  - Electrostatic coalescence for separators
  - Compact flotation for water continuous flows

Q&A

- **YOUR TURN**