Pall Corporation

Droplet Stability and Coalescence

A problem for the Twenty-Eighth Annual Workshop on Mathematical Problems in Industry

At the University of Delaware

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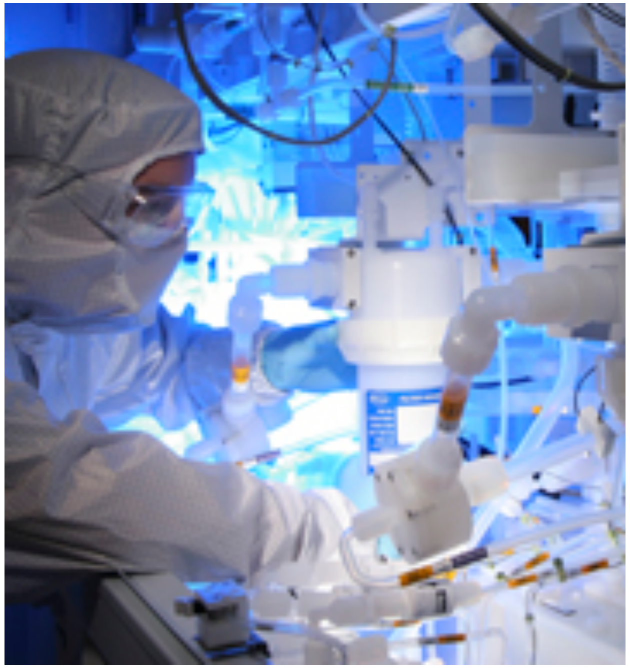
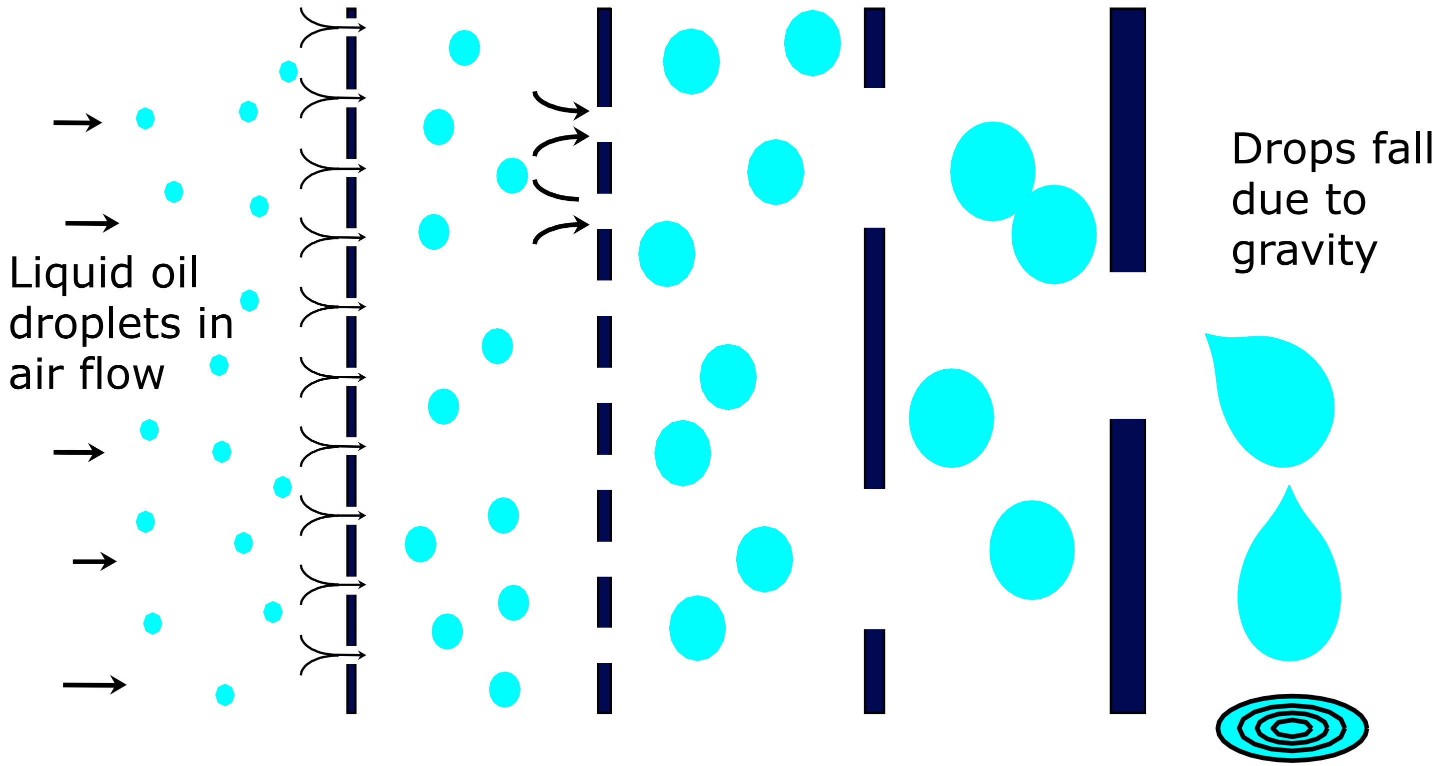
About Pall Corporation

- Leader in Filtration, Separation and Purification
- Scientific, technology and advanced engineering company
- Founded in 1946
- Global Footprint
- Over 10,000 Employees
- $2.7B Annual Revenue year ending Aug. 2011



Coalescence: Two or more droplets merge

- Random collisions can cause coalescence
- A coalescer forces droplet interaction in a fibrous structure
- Schematic example:

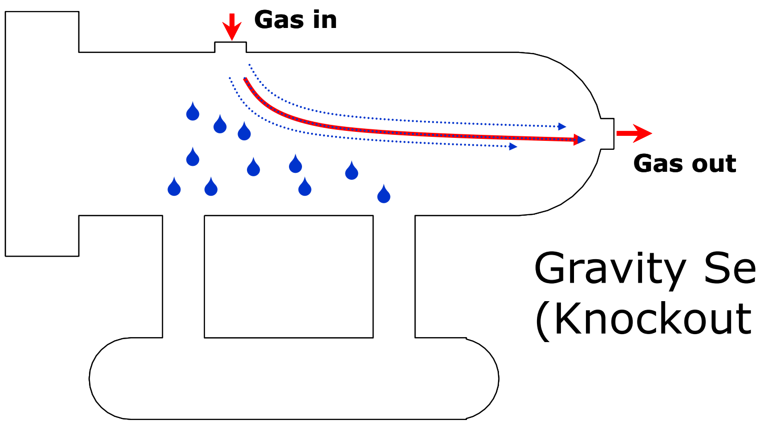


Big equipment means small improvements are important

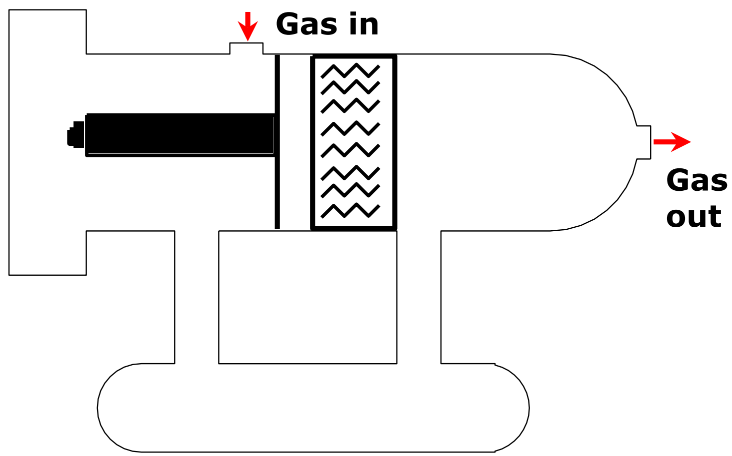
North Sea off-shore gas field.
Removal of salt-containing produced water before export compressor

Middle East gas treating plant.
Removal of amine from sweet gas downstream of contactor, protection of glycol unit

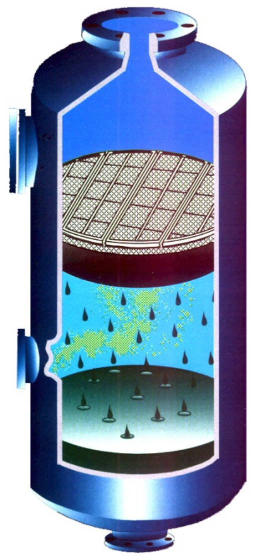
Other types of liquid / gas separators



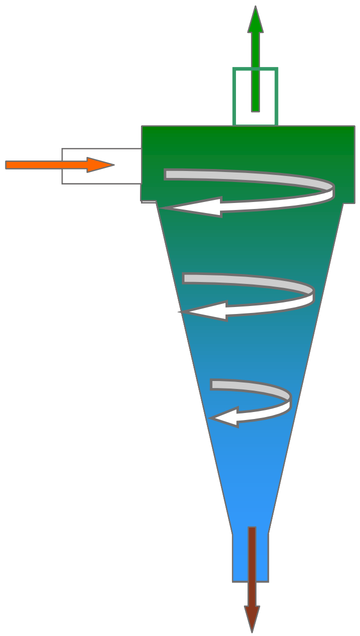
Gravity Separator (Knockout Drum)



Filter Vane Separator

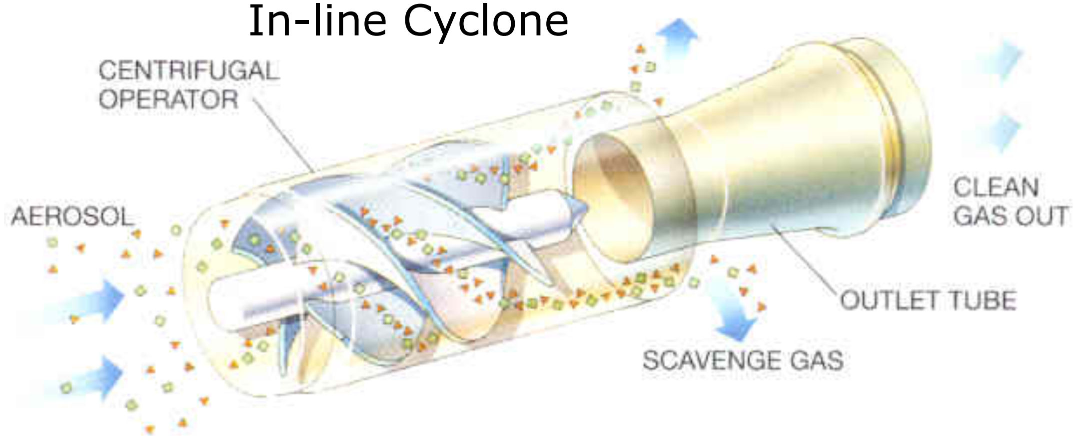


Mist Eliminator

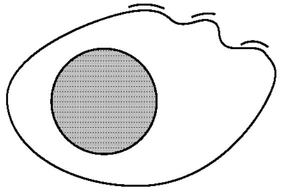


Standard Cyclone

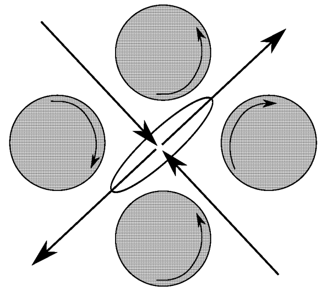
In-line Cyclone



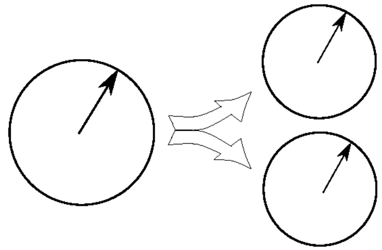
Brief (and very select) history of droplet analysis



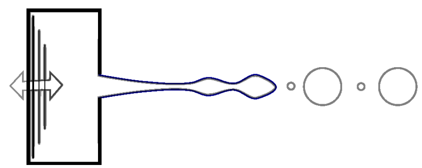
- **1932,** H. Lamb, “Hydrodynamics, 6th edition”
  - Inertia versus gravity for waves and tides



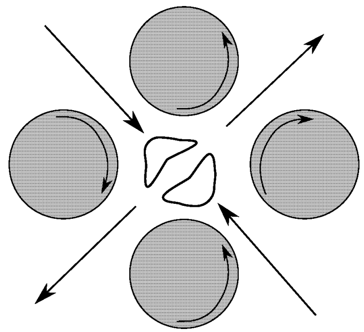
- **1934,** G. I. Taylor, “The Formation of Emulsions in Definable Fields of Flow”
  - Viscosity versus surface energy
  - Emulsions and energy to make small droplets



- **1960,** R. Shinnar & J. M. Church, “Predicting Particle Size in Agitated Dispersions”
  - Surface energy versus turbulence
  - Estimate stable droplet size in turbulent flow



- **1994,** J. Eggers & T. F. Dupont, “Drop formation in a one-dimensional approximation of the Navier-Stokes equation”
  - Surface energy, inertia and viscosity
  - Ink jet printing jet stability and drop size

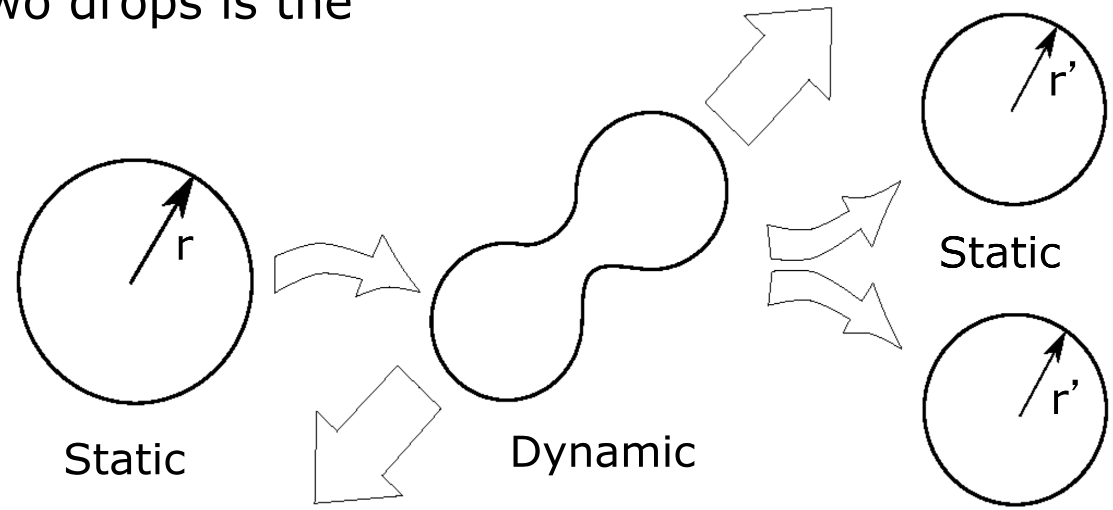


- **2006,** F. Baldessari & L. G. Leal, “Effect of overall drop deformation on flow-induced coalescence at low capillary numbers
  - Coalescence of viscous droplets in shear flow

Problem 1: What makes an inviscid drop be stable?

- Reasonable starting point:
  - Radius: r = 0.1 to 10 cm
  - Constant density: ρ = 1.0 gm/c.c.
  - Surface tension: σ = 70 dyne/cm
  - Neglect viscosity and evaporation

- Minimum energy to make two drops is the change in surface energy
- Is this a useful criterion?

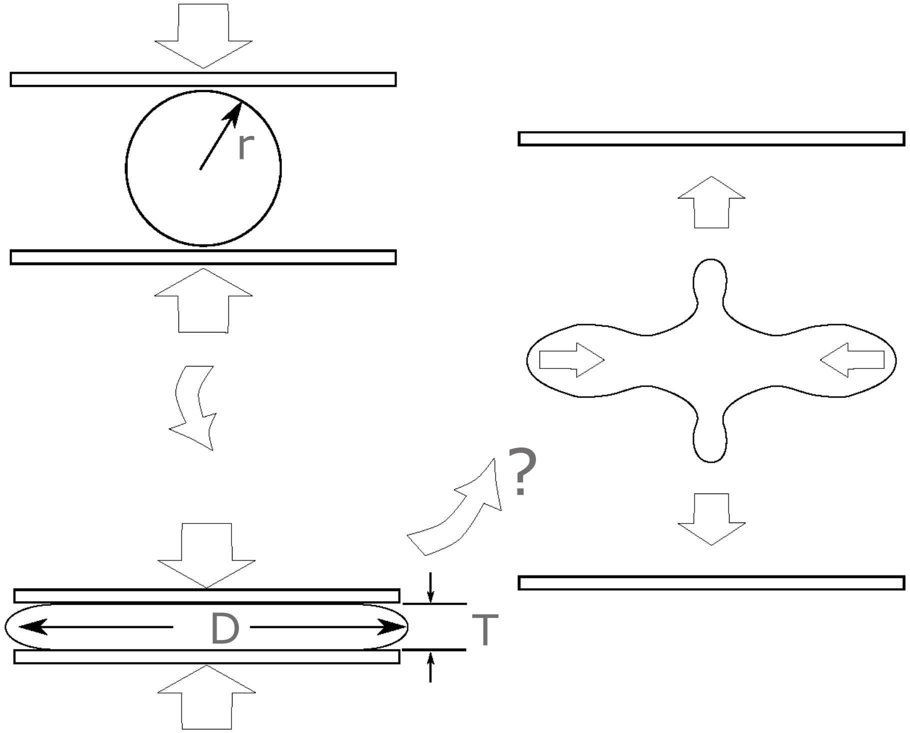


- Volume conservation:
  - $r' = r / 2^{1/3}$

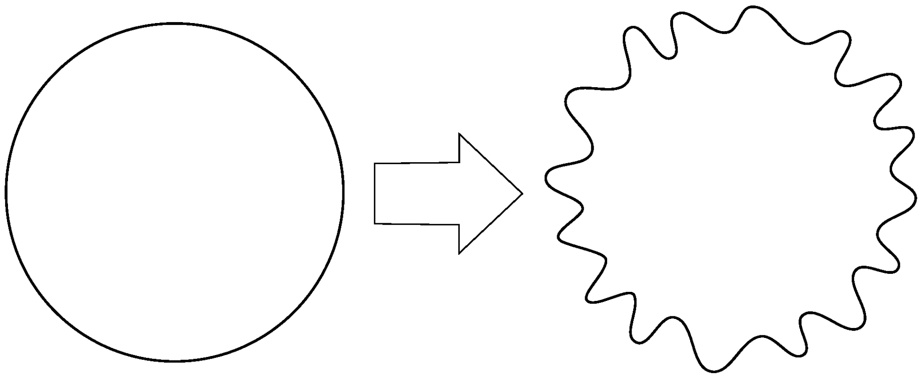
- Change in surface energy:
  - $\Delta E = 4\pi\sigma\,(2r'^{\,2} - r^2) = 1.04\pi\sigma\, r^2$
  - Area increase = 25%

Surface area extremes

- Flatten droplet with parallel, non wetting plates
  - 25% increased area: T/2r ~0.49
  - Is this enough to expect instability?

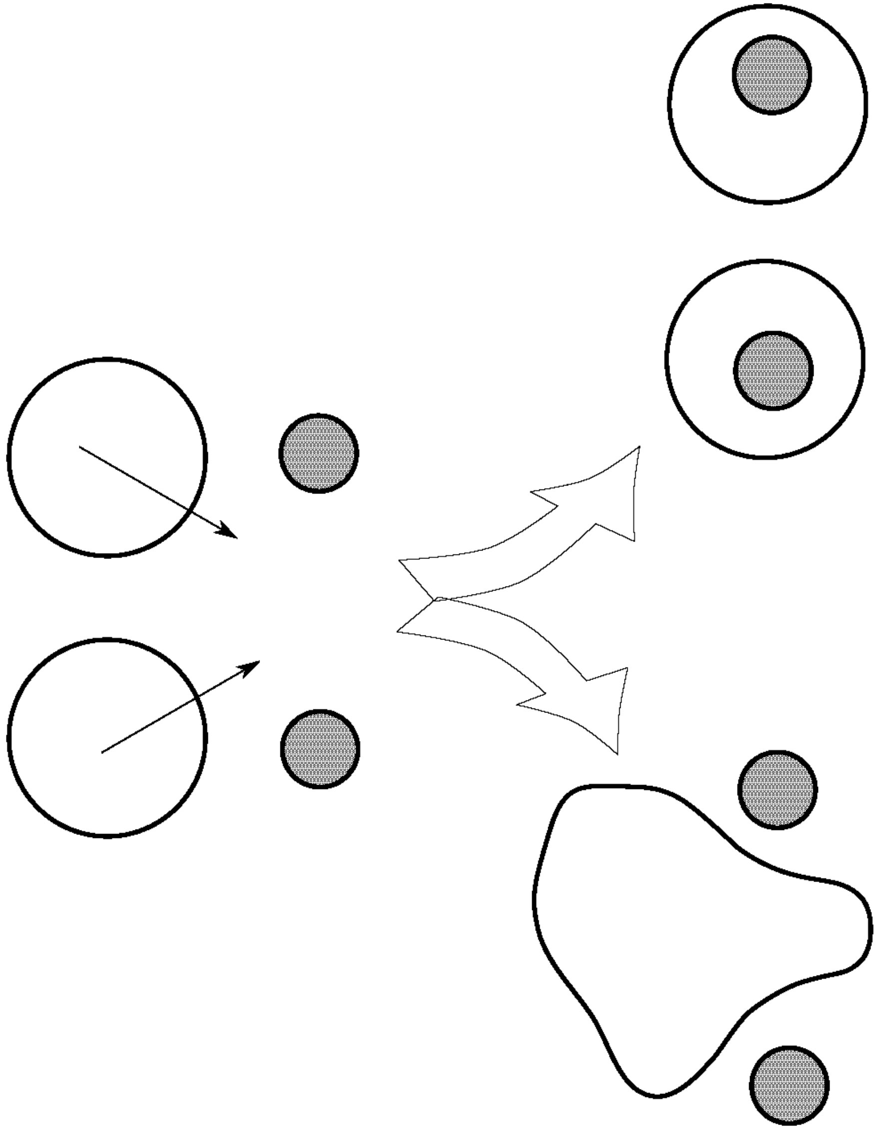


- Short wavelength pressure fluctuations
  - Large area increase with small change in aspect ratio
  - What are the resonances?



Problem 2: Lubrication layer, phobic and phylic fibers

- (In case problem 1 is too easy!)
- Lubrication layer tends to keep droplets separate and separate from fibers
- Droplets wet and stick to phylic fibers
- Phobic fibers push droplets together
- What are the criteria that predict coalescence?



Thank you.

And now the fun begins!