M6
LIQUID BLENDING
YIELD STRESS MATERIALS

Yield Stress Fluids

- Important class of fluids for industry.

- Fluid must experience certain shear stress before it will move:

$$\tau = \tau_Y + \mu_\infty \dot{\gamma} \qquad \mu_A = \frac{\tau_Y + \mu_\infty \dot{\gamma}}{\dot{\gamma}}$$

$$\tau = \tau_Y + K\dot{\gamma}^n \qquad \mu_A = \frac{\tau_Y + K\dot{\gamma}^n}{\dot{\gamma}}$$

- Typical yield stress is 10 - 50 Pa:
  - At low shear rates, apparent viscosity is very high.

Shear Stress - Shear Rate Models

- These models are simply “fits” of data to a model.
- No physical basis.
- A yield stress fluid may be considered a shear-thinning fluid with very low *n*.
- A shear-thinning fluid may be considered a yield stress fluid with a low yield stress.
- Need to design mixers that work and yield stress model allows us to do this.

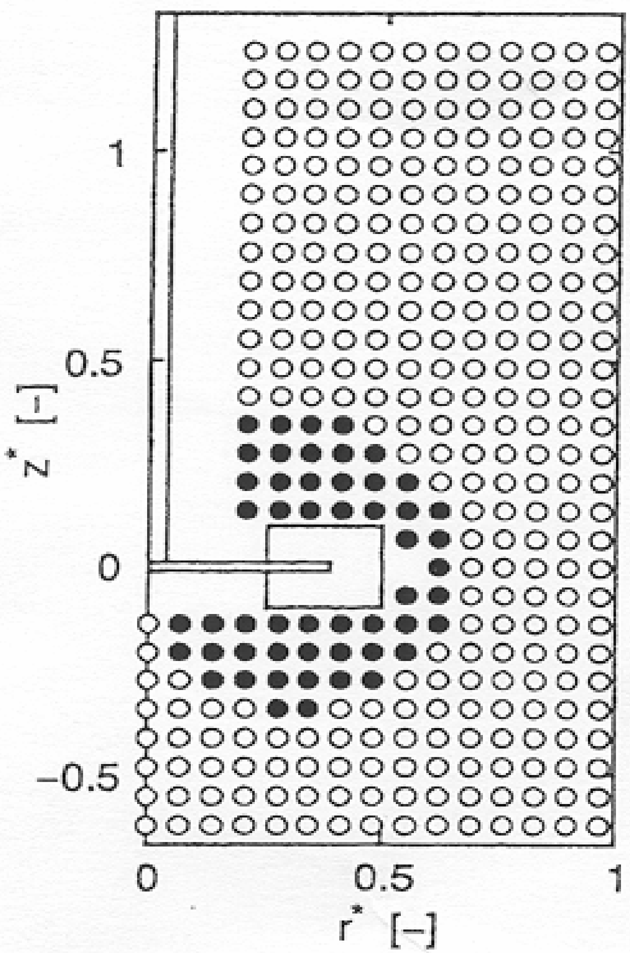
Observations

- A “cavern” of moving fluid is created around the impeller.
- A the boundary, the shear stress generated by the impeller is equal to the fluid’s yield stress.
- As impeller speed increases, cavern size increases.
- Until cavern reaches wall:

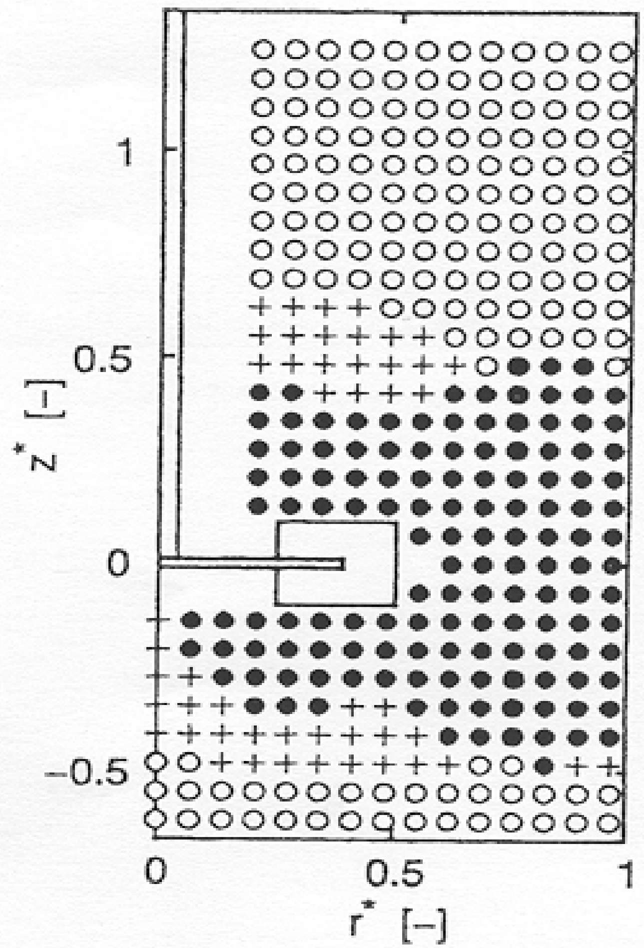
$$H_C = xD_C$$

- Once cavern reaches wall, cavern grows axially.

Hirata & Aoshima, ChERD,



(a) Re=28 (1.1rps)



(b) Re=183 (3.4rps)

Streak Photography - Nienow

Impeller Blade

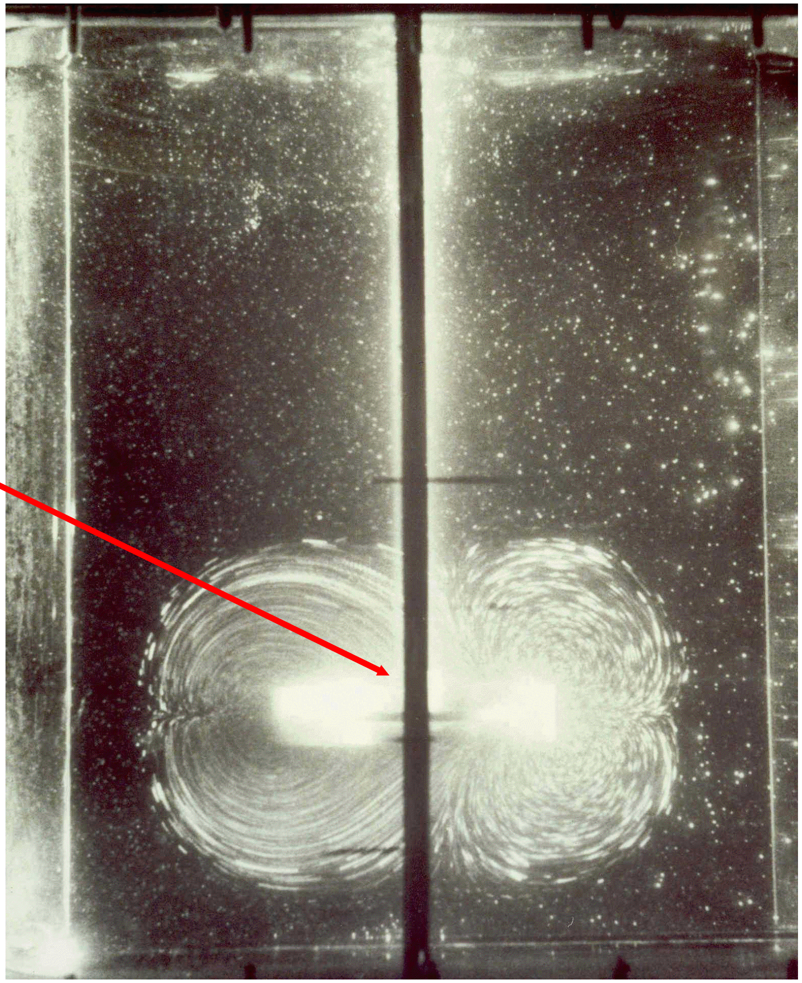
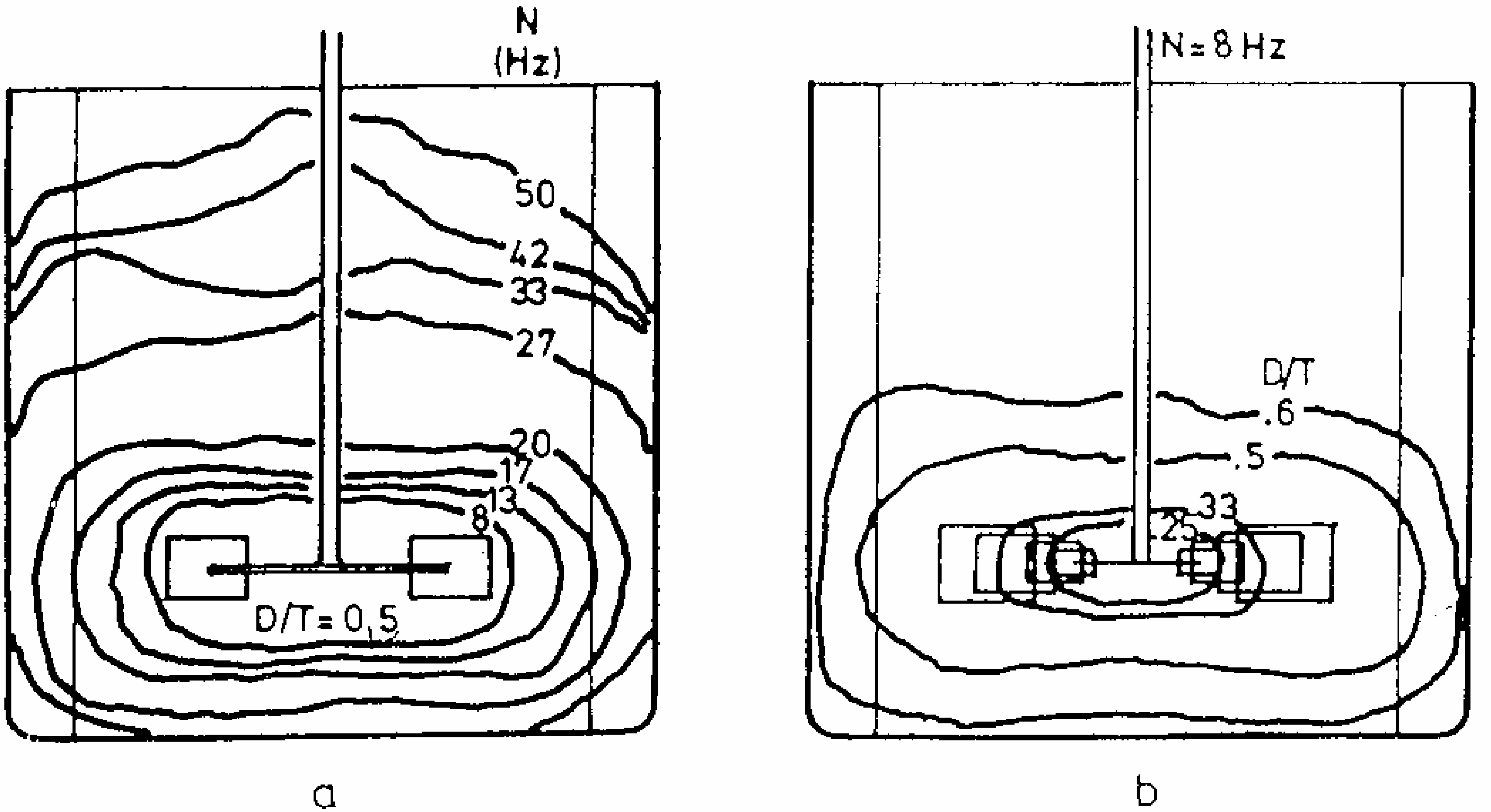


Figure 7. The effect of (a) impeller speed
(b) impeller diameter on cavern size.



Cavern Diameter

- Prediction of Cavern Diameter:

$$\left(\frac{D_C}{D}\right)^3 = \frac{1.32}{\pi^2} Po Re_Y$$

$$Re_Y = \frac{\rho N^2 D^2}{\tau_Y}$$

- Minimum speed when cavern reaches vessel wall:

$$D_C = T$$

$$N_C = \sqrt{\frac{\pi^2}{1.32}\left(\frac{T}{D}\right)^3 \frac{\tau_Y}{Po \rho D^2}}$$

Growth of Cavern

- Once cavern reaches vessel wall, it grows axially:

$$\frac{H_C}{T} = x\frac{N}{N_C}$$

- Need to compare power and speed of single impeller design versus multiple impellers (intersecting caverns).

- Value of *x* dependent on impeller type:
  - Rushton turbine: $x = 0.40$
  - Paddle: $x = 0.45$
  - Pitched blade turbine: $x = 0.55$
  - Propeller: $x = 0.75$

Shear-thinning vs. Yield stress Correlations

- For yield stress fluids, when cavern reaches wall:

$$\left(\frac{T}{D}\right)^3 \propto \frac{Po\rho N^2 D^2}{\tau_Y}$$

$$\frac{Po\rho N^2 D^5}{T^3} \propto \tau_Y \rightarrow \frac{Tq}{T^3}$$

- For shear-thinning fluids:

$$\tau_W \propto \frac{Tq}{T^3}$$

YIELD STRESS

- Correlations work amazing well
- Often used for design and prediction
- Scale up is simple even without rheology

CAVERNS AND JETS

- Momentum sets reach of jet
- Work by Battelle on PJMs for WTP Bechtel
- Show caverns and stagnant zones

MOBILIZATION

- Radius of cleaning increases with time
- Is this a time dependent rheology effect?
- Is this an erosion effect?
- Kinetic are usually so fast in mixing they are neglected.
- Time dependent rheology (thixotrophy) requires very complicated models and is studied by only a small group