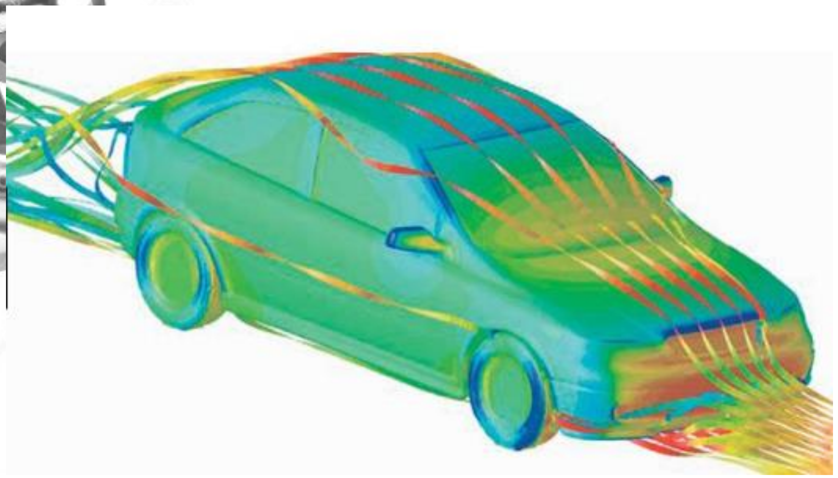
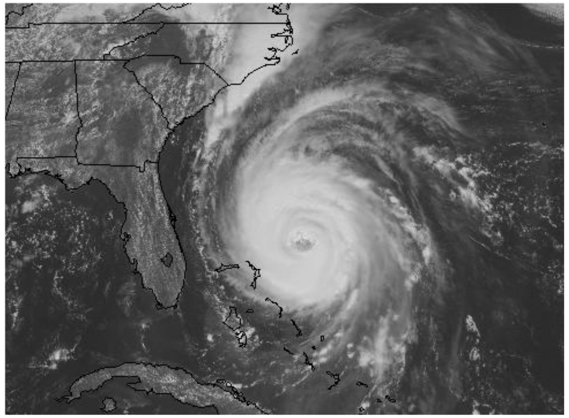
유변학

흐름과 유체

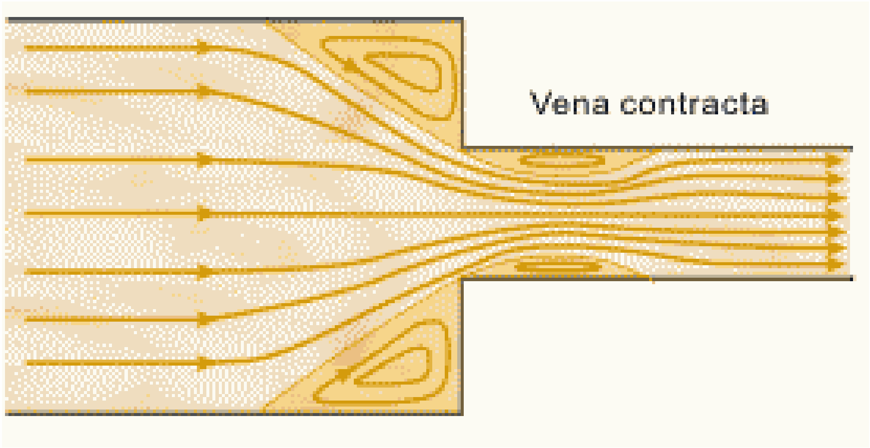
흐름(flow)

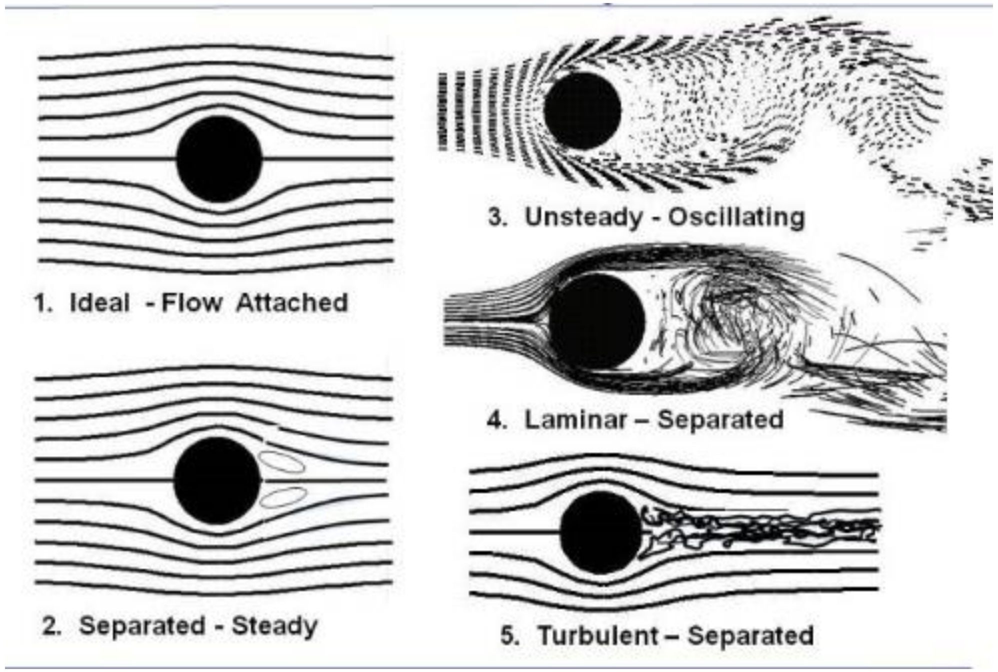


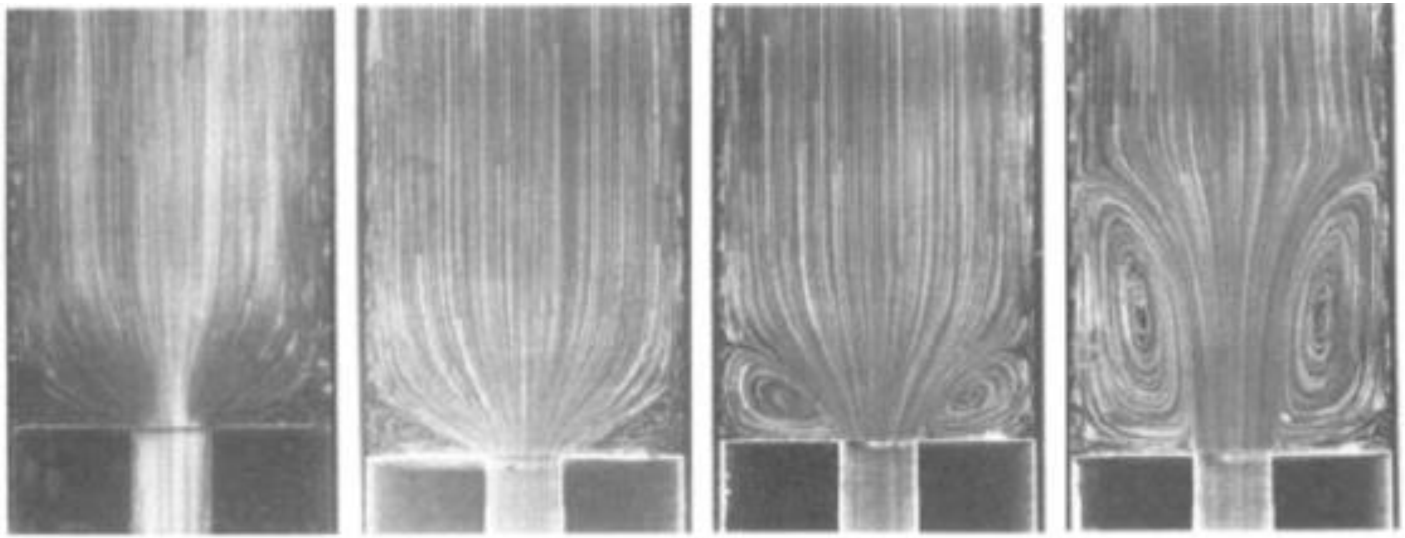





NASA Dryden Flight Research Center Photo Collection
http://www.dfrc.nasa.gov/gallery/photo/index.html
NASA Photo: EC99-44921-1 Date: 1999

X-33 artist concept - 1999


Vena contracta


1. Ideal - Flow Attached
2. Separated - Steady
3. Unsteady - Oscillating
4. Laminar – Separated
5. Turbulent – Separated



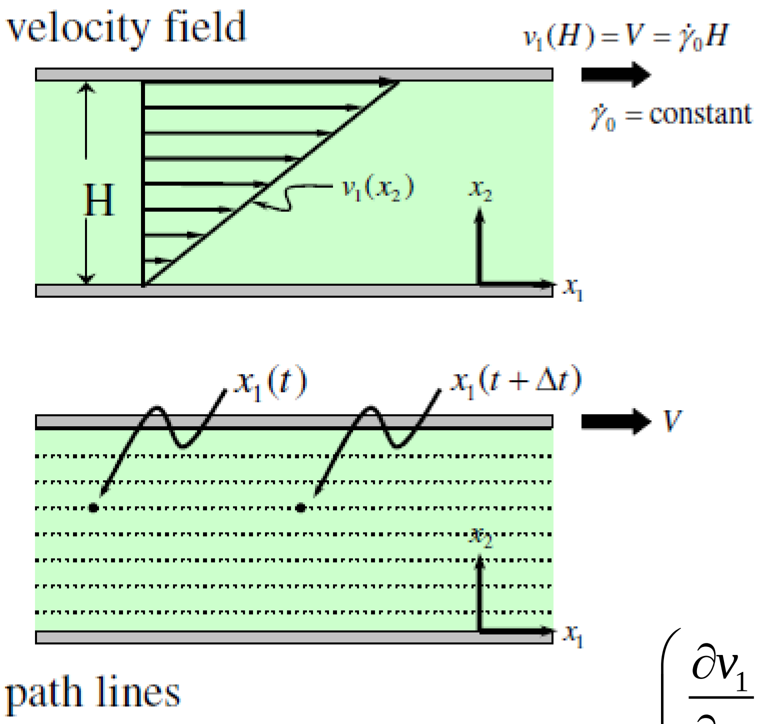
$\lambda\dot{\gamma} = 0{\cdot}63$ $\lambda\dot{\gamma} = 0{\cdot}96$ $\lambda\dot{\gamma} = 1{\cdot}43$ $\lambda\dot{\gamma} = 1{\cdot}63$

flow

- shear flow
    - simple shear flow

- elongational flow
    - uniaxial elongational flow
    - biaxial stretching flow
    - planar elongational flow

simple shear flow



$$\mathbf{v} = \begin{pmatrix} \dot{\gamma}_{21} x_2 \\ 0 \\ 0 \end{pmatrix}$$

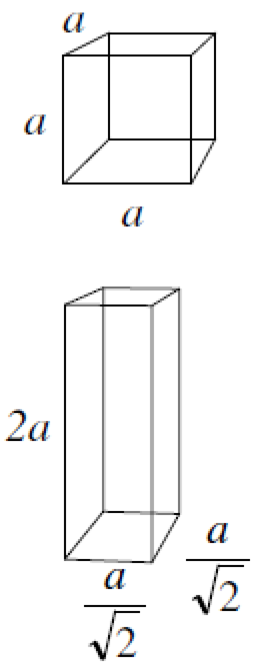
$$\dot{\boldsymbol{\gamma}} = \nabla v + (\nabla v)^T = \begin{pmatrix} \frac{\partial v_1}{\partial x_1} & \frac{\partial v_2}{\partial x_1} & \frac{\partial v_3}{\partial x_1} \\ \frac{\partial v_1}{\partial x_2} & \frac{\partial v_2}{\partial x_2} & \frac{\partial v_3}{\partial x_2} \\ \frac{\partial v_1}{\partial x_3} & \frac{\partial v_2}{\partial x_3} & \frac{\partial v_3}{\partial x_3} \end{pmatrix} + \begin{pmatrix} \frac{\partial v_1}{\partial x_1} & \frac{\partial v_1}{\partial x_2} & \frac{\partial v_1}{\partial x_3} \\ \frac{\partial v_2}{\partial x_1} & \frac{\partial v_2}{\partial x_2} & \frac{\partial v_2}{\partial x_3} \\ \frac{\partial v_3}{\partial x_1} & \frac{\partial v_3}{\partial x_2} & \frac{\partial v_3}{\partial x_3} \end{pmatrix} = \begin{pmatrix} 0 & \dot{\gamma}_{21} & 0 \\ \dot{\gamma}_{21} & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

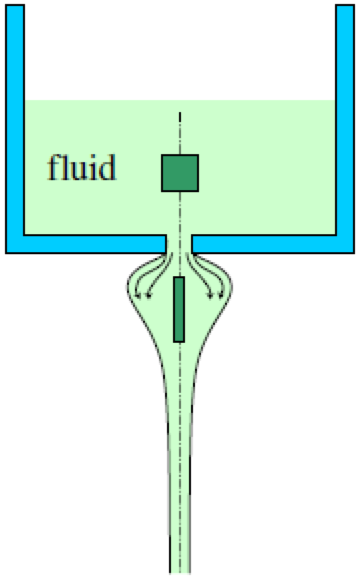
Newtonian fluid

$$\boldsymbol{\tau} = \begin{pmatrix} \tau_{11} & \tau_{12} & \tau_{13} \\ \tau_{21} & \tau_{22} & \tau_{23} \\ \tau_{31} & \tau_{32} & \tau_{33} \end{pmatrix} = -\mu\dot{\boldsymbol{\gamma}} = -\mu\begin{pmatrix} 0 & \dot{\gamma}_{21} & 0 \\ \dot{\gamma}_{21} & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

$$\tau_{21} = \tau_{12} = -\mu\dot{\gamma}_{21} = -\mu\frac{\partial v_1}{\partial x_2}$$

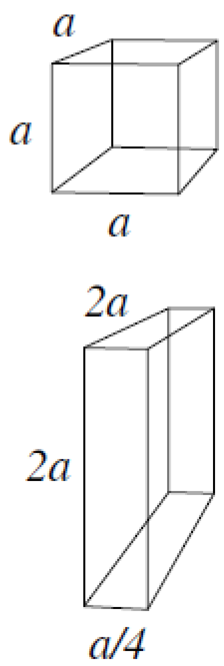
uniaxial elongational flow

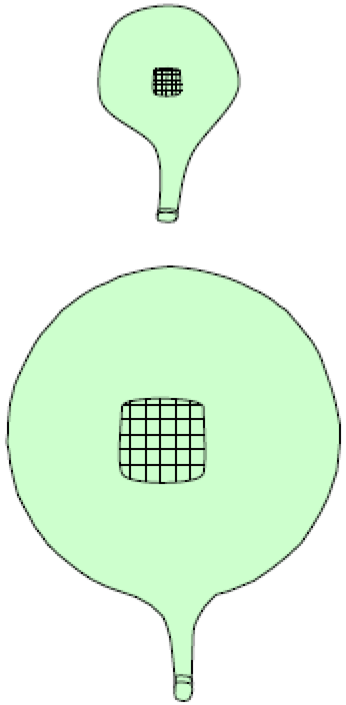


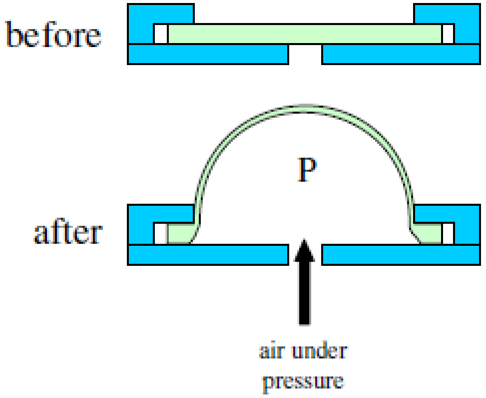


$$\underline{v} \equiv \begin{pmatrix} -\frac{\dot{\varepsilon}(t)}{2} x_1 \\ -\frac{\dot{\varepsilon}(t)}{2} x_2 \\ \dot{\varepsilon}(t) x_3 \end{pmatrix}_{123} \qquad \dot{\varepsilon}(t) > 0$$

biaxial stretching flow

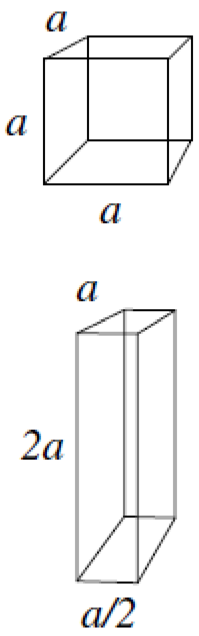


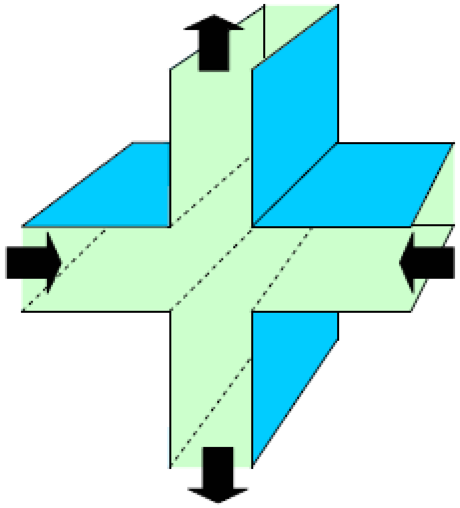




$$\underline{v} \equiv \begin{pmatrix} -\frac{\dot{\varepsilon}(t)}{2} x_1 \\ -\frac{\dot{\varepsilon}(t)}{2} x_2 \\ \dot{\varepsilon}(t) x_3 \end{pmatrix}_{123} \qquad \dot{\varepsilon}(t) < 0$$

planar elongational flow





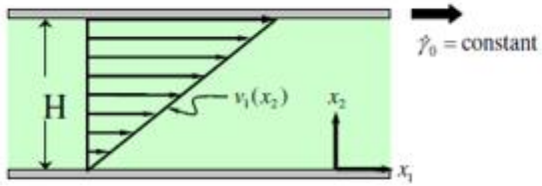
$$\underline{v} \equiv \begin{pmatrix} -\dot{\varepsilon}(t)x_1 \\ 0 \\ \dot{\varepsilon}(t)x_3 \end{pmatrix}_{123} \quad \dot{\varepsilon}(t) > 0$$

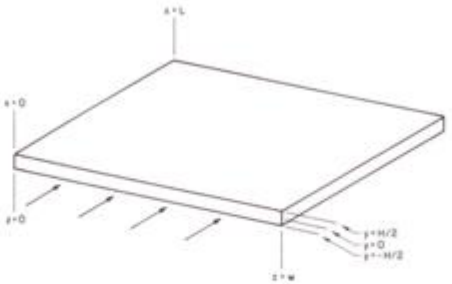
$$\underline{v} = \begin{pmatrix} -\frac{1}{2}\dot{\varepsilon}(t)(1+b)x_1 \\ -\frac{1}{2}\dot{\varepsilon}(t)(1-b)x_2 \\ \dot{\varepsilon}(t)x_3 \end{pmatrix}_{123}$$

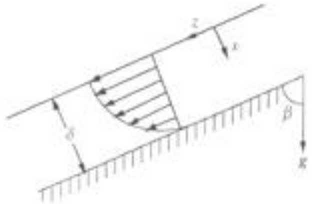
Elongational flow: b=0, $\dot{\varepsilon}(t) > 0$

Biaxial stretching: b=0, $\dot{\varepsilon}(t) < 0$

Planar elongation: b=1, $\dot{\varepsilon}(t) > 0$

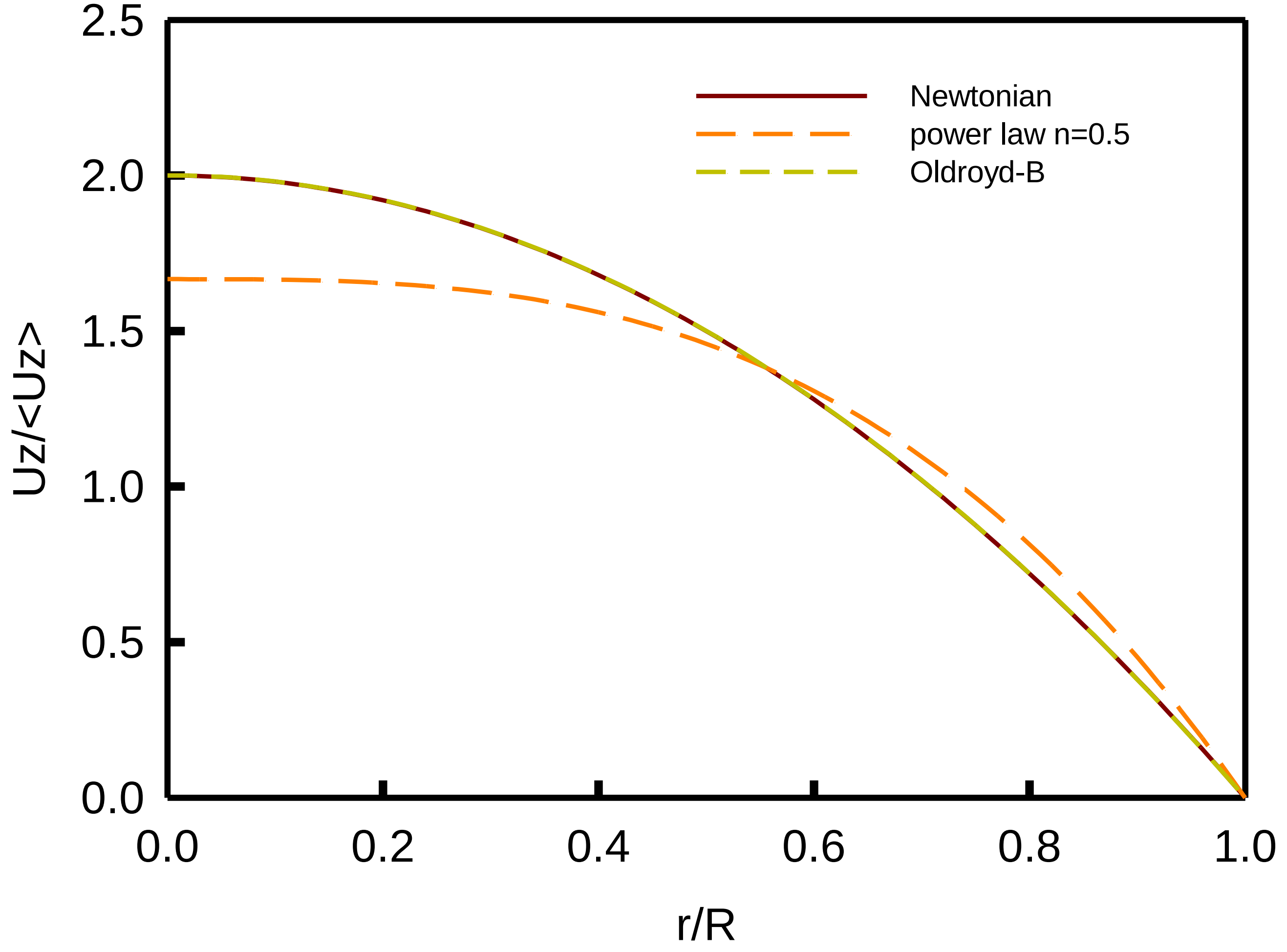




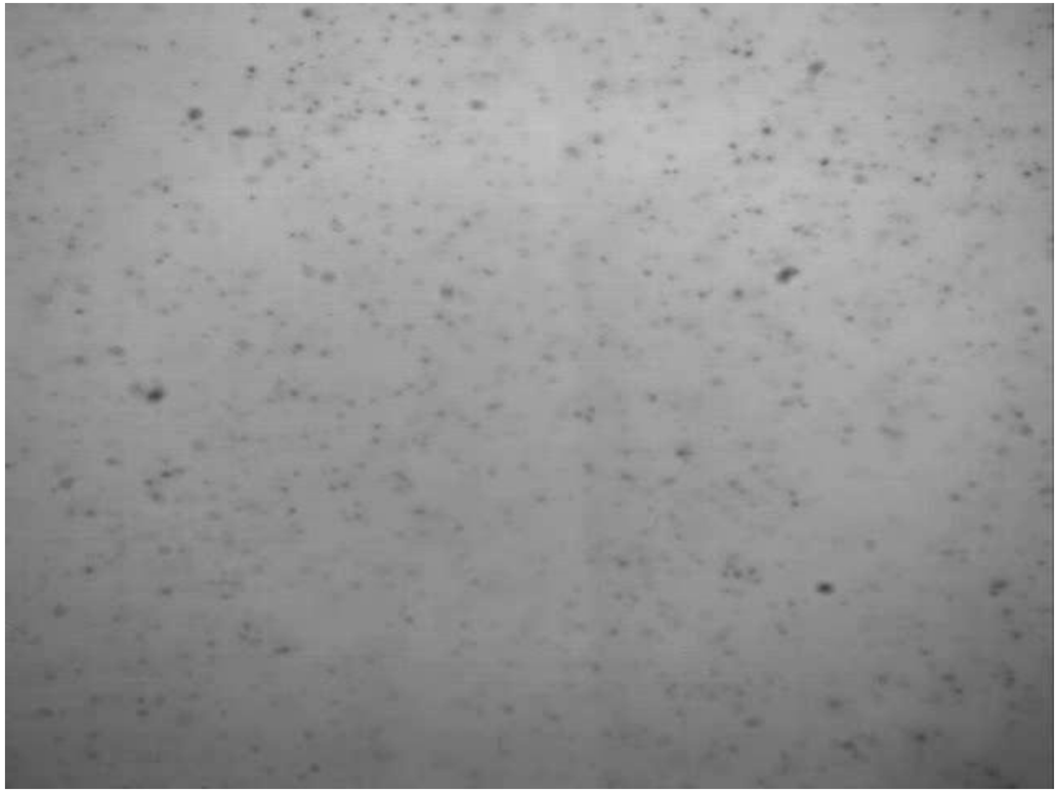


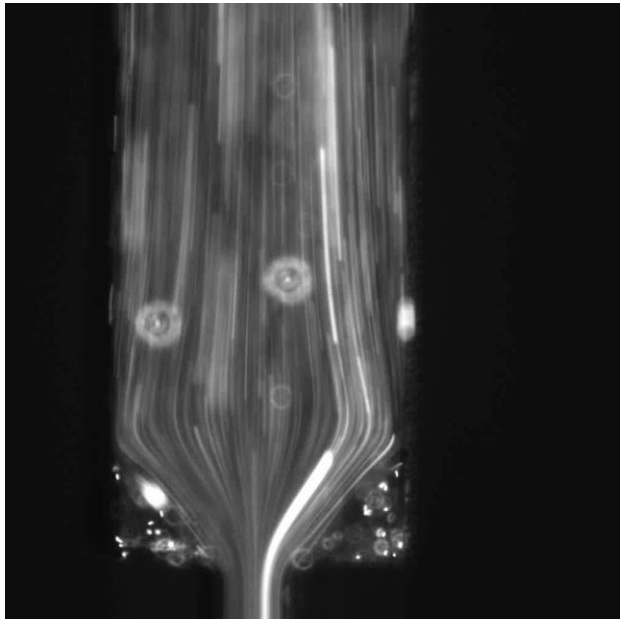
	뉴톤유체	power-law유체
a) 위판을 당겨준 평판유동	$v_1 = \frac{V}{H} x_2$	$v_1 = \frac{V}{H} x_2$
b) 압력에 의한 평판유동	$v_x = \frac{\lvert\Delta P\rvert h^2}{2\eta L}\left(1-\left(\frac{y}{H}\right)^2\right)$	$v_x = \frac{nh}{n+1}\left(\frac{H\lvert\Delta P\rvert}{mL}\right)^{1/n}\left(1-\left(\frac{\lvert y\rvert}{H}\right)^{\frac{(n+1)}{n}}\right)$
c) 기울어진 사면에서의 유동	$v_z = \frac{\rho g \delta^2 \sin\theta}{2\eta}\left(1-\left(\frac{x}{\delta}\right)^2\right)$	$v_z = \frac{n\delta}{n+1}\left(\frac{\rho g}{m}\sin\theta\right)^{1/n}\delta^{(1+n)/n}\left(1-\left(\frac{y}{\delta}\right)^{(1+n)/n}\right)$
d) 파이프에서의 유동	$v_z = \frac{\lvert\Delta P\rvert R^2}{4\eta L}\left(1-\left(\frac{r}{R}\right)^2\right)$	$u_z = \frac{nR}{n+1}\left(\frac{R\lvert\Delta P\rvert}{2mL}\right)^{1/n}\left(1-\left(\frac{r}{R}\right)^{\frac{n+1}{n}}\right)$

* ρ: 유체의 밀도, $\dot{\gamma}$: 유체의 점도, g: 중력가속도

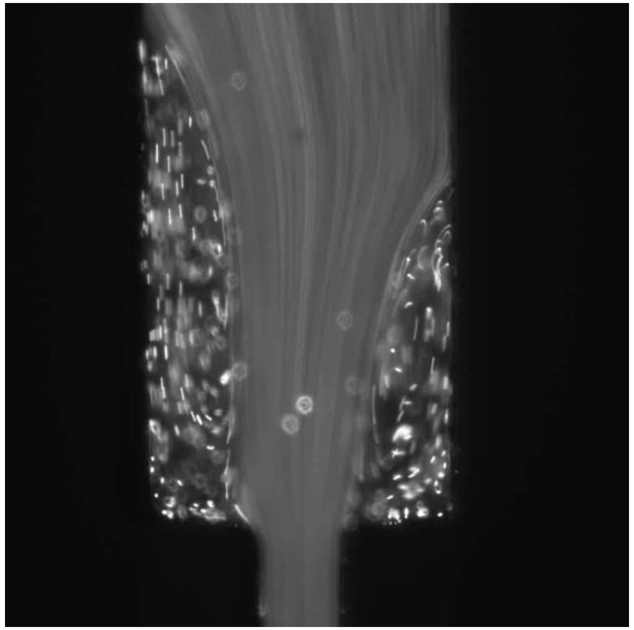

2.5
2.0
1.5
1.0
0.5
0.0
Uz/<Uz>
0.0
0.2
0.4
0.6
0.8
1.0
r/R
Newtonian
power law n=0.5
Oldroyd-B

55vol% well-dispersed alumina suspension at 0.3 /s

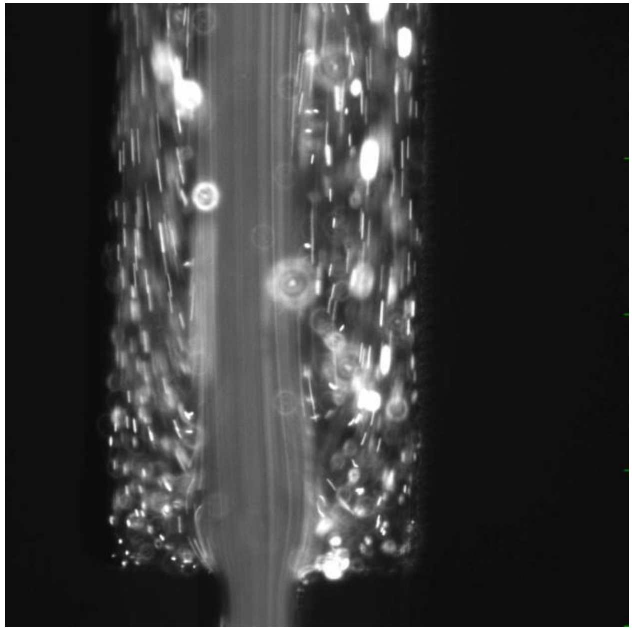




5M 0.7wt% PEO
Wi = 79



5M 1.0wt% PEO
Wi = 130

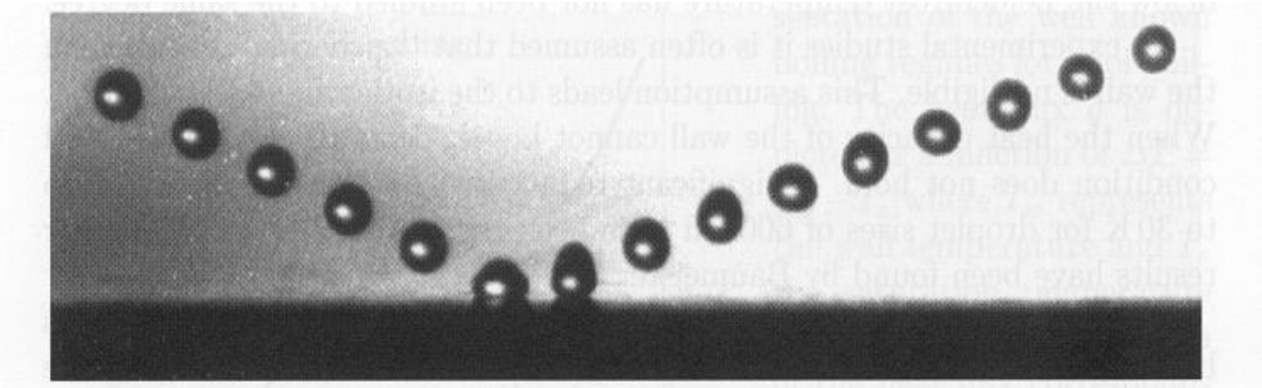


5M 0.7wt% PEO
Wi = 145

유체(fluid)

유변학

- 물질 (복잡유체)의 유동과 변형에 관한 학문
- 고체/액체
- 탄성/점성
- 후크의 법칙/ 뉴톤의 법칙



막대오름 현상

$$= \begin{pmatrix} T_{11} & T_{12} & T_{13} \\ T_{21} & T_{22} & T_{23} \\ T_{31} & T_{32} & T_{33} \end{pmatrix}$$

샴푸

녹말용액에서 걷기

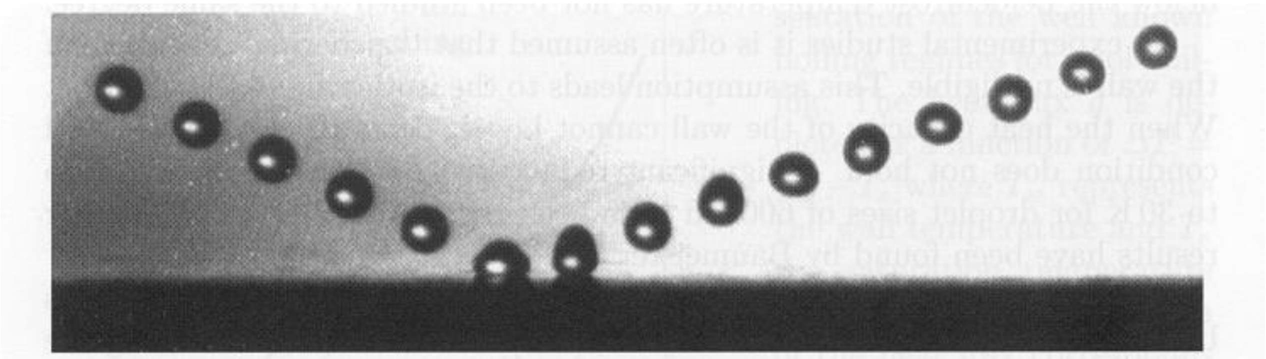
빅뱅이론

점탄성

- 구약성서 사사기:
  "The mountains flowed before the Lord“
  “주님 앞에서 산이 진동하였다 '

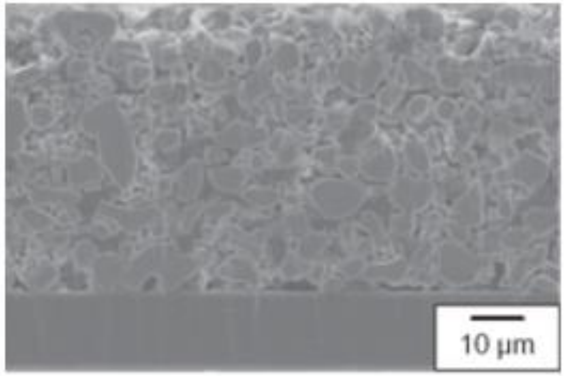
- Deborah 수, De = 물질의 특성시간 / 공정의 특성시간

$$De = \lambda / t$$

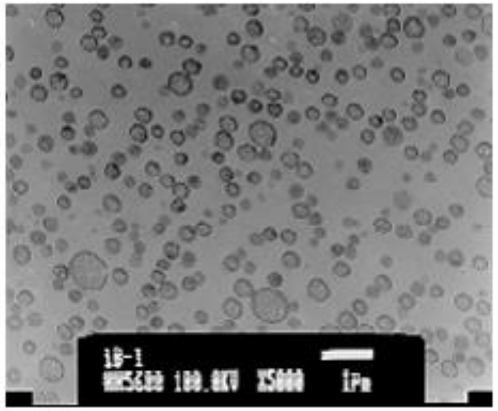




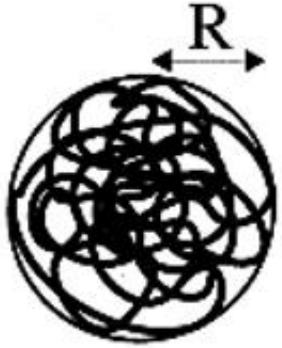
(a) 샴푸



(b) 배터리 전극

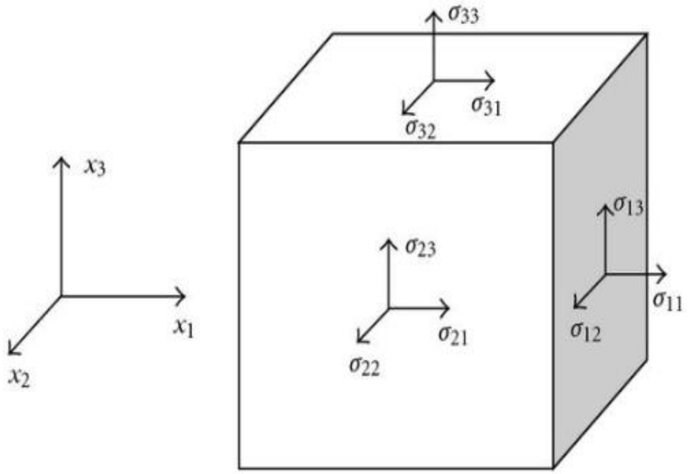


(c) ABS 수지



(d) 고분자

응력(stress): 단위면적 당 작용하는 힘



$$\underline{\underline{\tau}} = \begin{pmatrix} \tau_{11} & \tau_{12} & \tau_{13} \\ \tau_{21} & \tau_{22} & \tau_{23} \\ \tau_{31} & \tau_{32} & \tau_{33} \end{pmatrix}_{123}$$

What is measured is the total stress, $\underline{\underline{\Pi}}$:

$$\underline{\underline{\Pi}} = \begin{pmatrix} p+\tau_{11} & \tau_{12} & \tau_{13} \\ \tau_{21} & p+\tau_{22} & \tau_{23} \\ \tau_{31} & \tau_{32} & p+\tau_{33} \end{pmatrix}_{123}$$

First normal stress difference

$$N_1 \equiv \Pi_{11} - \Pi_{22} = \tau_{11} - \tau_{22}$$

Second normal stress difference

$$N_2 \equiv \Pi_{22} - \Pi_{33} = \tau_{22} - \tau_{33}$$

In shear flow, three stress quantities are measured

$$\tau_{21}, N_1, N_2$$

In elongational flow, two stress quantities are measured

$$\tau_{33} - \tau_{11}, \tau_{22} - \tau_{11}$$

SHEAR:

$$\underline{\underline{\tau}} = \begin{pmatrix} \tau_{11} & \tau_{12} & 0 \\ \tau_{21} & \tau_{22} & 0 \\ 0 & 0 & \tau_{33} \end{pmatrix}_{123}$$

ELONGATION:

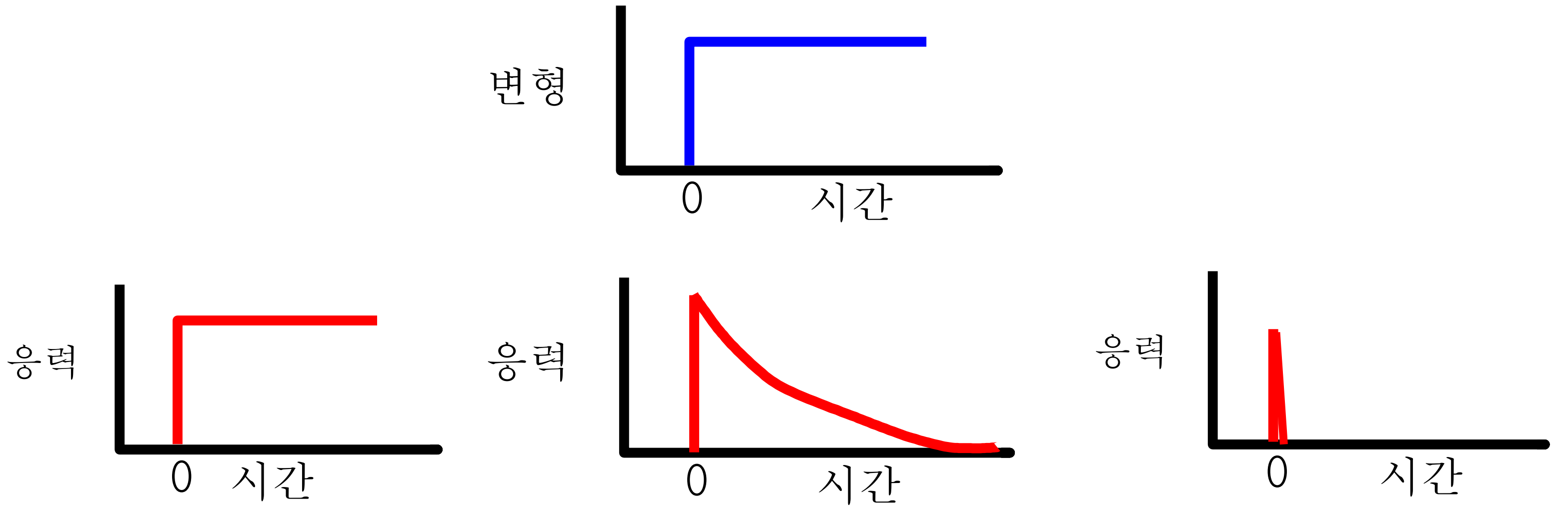
$$\underline{\underline{\tau}} = \begin{pmatrix} \tau_{11} & 0 & 0 \\ 0 & \tau_{22} & 0 \\ 0 & 0 & \tau_{33} \end{pmatrix}_{123}$$

물질의 완화특성

고체 -------------------- 액체

이상고체 ----- 대부분의 물질 ----- 이상액체

탄성 ----- 점탄성 ----- 점성



물질의 완화특성

고체 ------------------- 액체

이상고체 ----- 대부분의 물질 ----- 이상액체

탄성 ----- **점탄성** ----- 점성

$$\tau = G\gamma$$

$$\tau = \eta\dot{\gamma}$$

$$\tau_p + We\left(\frac{\partial \tau_p}{\partial t} + u \cdot \nabla \tau_p - (\nabla u)^T \cdot \tau_p - \tau_p \cdot \nabla u\right) = \beta\left(\nabla u + (\nabla u)^T\right)$$