5a

ALIRAN FLUIDA

Lecture Note
Principles of Food Engineering (ITP 330)

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TUJUAN INSTRUKSIONAL

- Mahasiswa akan mengetahui dan memahami konsep dasar atas berbagai model yang menjelaskan tingkah laku dan karakteristik fluida
- Mahasiswa akan mampu menjelaskan dan memecahkan soal-soal aplikasi tentang aliran fluida (kasus industri pangan)
- Mahasiswa akan mampu menggunakan konsep aliran fluida (prinsip kontinuitas, dsb) untuk menganalisis suatu proses/soal keteknikan (kasus industri pangan) : mampu menghitung keperluan/ukuran pompa yang diperlukan untuk transportasi fluida

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ALIRAN FLUIDA

FLUIDA :
Senyawa/bahan yang dapat **mengalir** tanpa mengalami "disintegrasi" jika dikenakan tekanan kepada bahan tersebut.

FLUIDA : → GAS
→ CAIRAN
→ PADATAN

Karakteristik Aliran ··················> REOLOGI

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KENAPA BELAJAR REOLOGI?

- Bahan pangan fluida??
  - saus tomat
  - es krim
  - coklat
  - pudding/gel?
- Keperluan Disain Proses
- Evaluasi Proses
- QC
- Konsumen

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KARAKTERISTIK FLUIDA

Densitas :
massa per satuan volume

SI	:	$kg.m^{-3}$
Lainnya	:	$lb_m.ft^{-3}$
		$g.cc^{-1}$ atau $g.cm^{-3}$

Kompresabilitas :
Perubahan densitas fluida karena perubahan suhu atau tekanan
- sangat penting untuk gas
- dapat diabaikan untuk cairan

Viskositas................?

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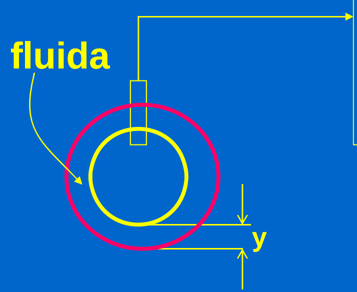
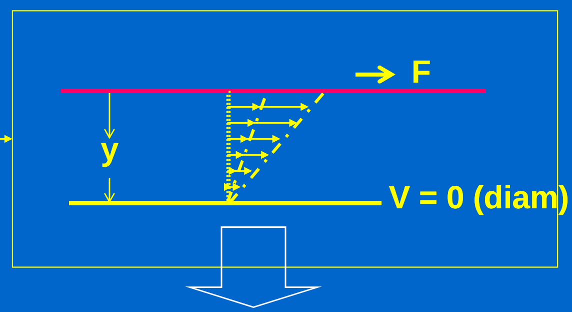
BATASAN VISKOSITAS

Perhatikan dua silinder Konsentrik :

Silinder dalam : diam
Silinder luar : bergerak/berputar
Fluida terdapat diantara dua tabung





Untuk tetap mempertahankan aliran, diperlukan gaya = F
Kemudahan mengalir? $\Delta V/\Delta y$?
V = f (F, A, sifat fluida)

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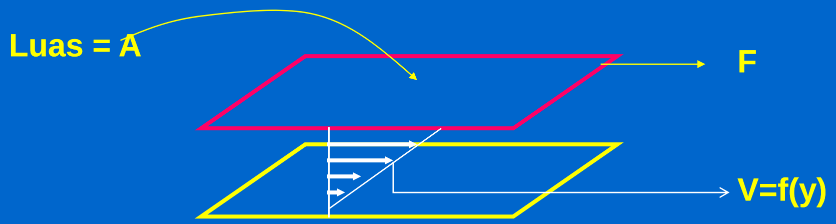
BATASAN VISKOSITAS



Kemudahan mengalir? $\Delta V/\Delta y$?
V = f (F, A, sifat fluida)

VISKOSITAS (υ)
Suatu ukuran mudah/sukarnya suatu bahan untuk mengalir
Viscosity - the property of a material which describes the resistance to flow

$$\frac{F}{A} = \mu\left(-\frac{dV}{dy}\right) = \tau$$

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Tentukan satuan Viskositas ...... μ [=]

Diketahui Hk Newton ttg viskositas

$$\frac{F}{A} = \mu\left(-\frac{dv}{dy}\right) \Longrightarrow \mu = \frac{F}{A}\left(-\frac{dv}{dy}\right)^{-1}$$

Prinsip : Fungsi ->mempunyai dimensi/satuan yg homogen

$$\mu\ [=]\ \frac{dyne}{cm^2}\left(\frac{cm\ \ /\ det}{cm}\right)^{-1}$$

$$\mu\ [=]\ \frac{g\ .\cancel{cm}.\ det^{\cancel{-2}\ -1}}{cm^{\cancel{2}}}\ .\ \cancel{det}$$

μ [=] g $cm^{-1}det^{-1}$ = poise

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Viskositas

Note : μ [=] g cm^{-1}det^{-1} = poise

1 poise = 100 cp

Contoh:

air (20^{o}C, 1 atm)	=	1.0019 cp
air (80^{o}C, 1 atm)	=	0.3548 cp
udara (20^{o}C, 1 atm)	=	0.01813 cp
C_2H_5OH (lq; 20^{o}C, 1 atm)	=	1.194 cp
H_2SO_4 (lq; 25^{o}C, 1 atm)	=	19.15 cp
glycerol (lq; 20^{o}C, 1 atm)	=	1069 cp

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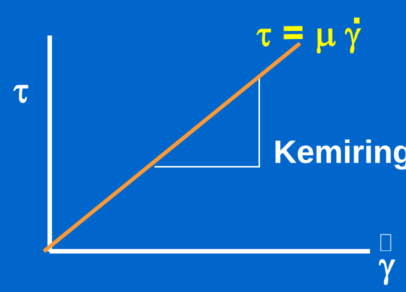
FLUIDA : NEWTONIAN & NON-NEWTONIAN

$$\frac{F}{A} = \mu\left(-\frac{dv}{dy}\right)$$: Hk. Newton

$$\tau = \mu\left(-\frac{dv}{dy}\right) \longrightarrow -\frac{dv}{dy} = \gamma$$, laju geser (*shear rate*)

τ = gaya geser



Fluida-fluida yang menganut hukum Newton:
FLUIDA NEWTONIAN

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NON-NEWTONIAN

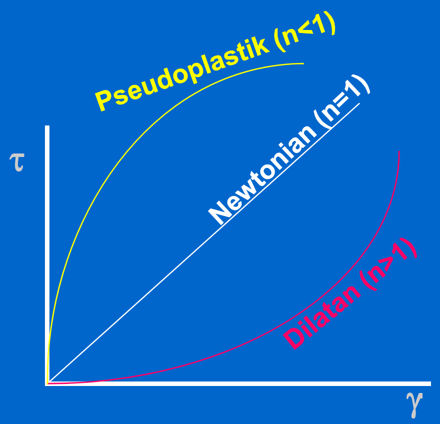
1 $\tau = K(\dot{\gamma})^n$ ……………> model “Power law”

K : Indeks tingkah laku aliran (*flow behavior index*)
n : Indeks konsistensi

A. Newtonian
$\tau = \mu(\dot{\gamma})$,
model “power law”
dgn $K=\mu$ dan $n=1$

B. Pseudoplastik
$\tau = K(\dot{\gamma})^n$, $n<1$

C. Dilatan
$\tau = K(\dot{\gamma})^n$, $n>1$



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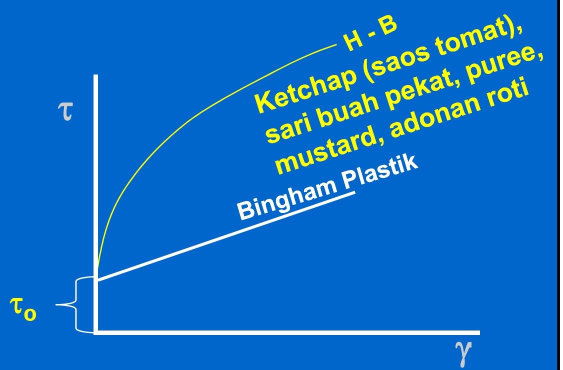
NON-NEWTONIAN

2 $\tau = \tau_o + K(\dot{\gamma})^n$ ……………> model “Herschel-Bulkley”

K : Indeks tingkah laku aliran (*flow behavior index*)
n : Indeks konsistensi
τ_o : gaya geser awal (*yield stress*)

A. Bingham plastik
$\tau = \tau_o + K(\dot{\gamma})$

B. Fluida H - B
$\tau = \tau_o + K(\dot{\gamma})^n$; $n<1$



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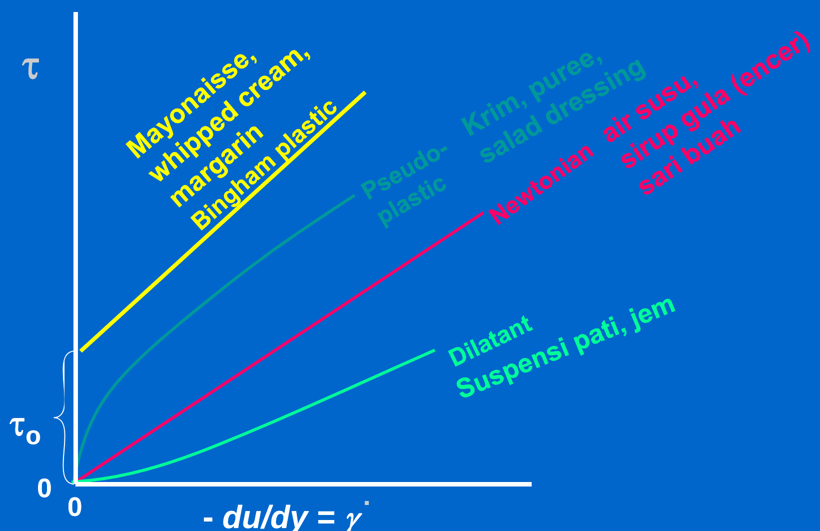
Hubungan antara gaya geser vs. laju geser (gradien kecepatan) untuk fluida newtonian dan non-newtonian



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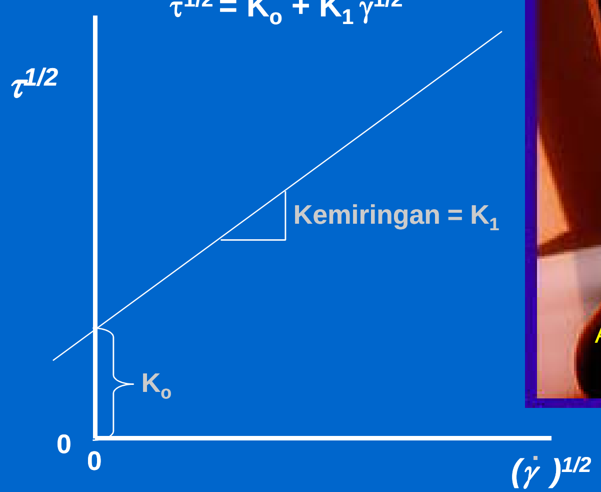
Rheologi "Melted Chocolate":

Model Casson :

$$\tau^{1/2} = K_o + K_1 \dot{\gamma}^{1/2}$$



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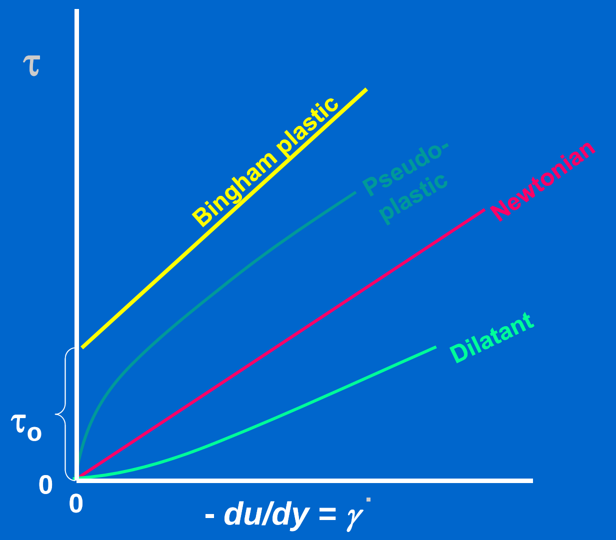
Hubungan antara gaya geser vs. laju geser (gradien kecepatan) untuk fluida newtonian dan non-newtonian



Viskositas??

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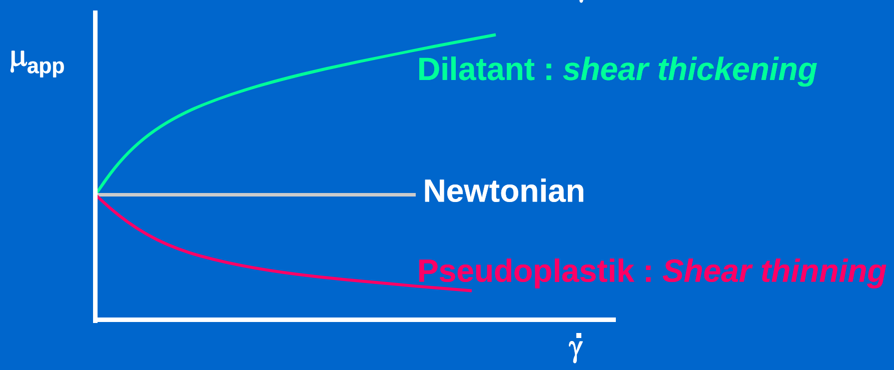
VISKOSITAS = f($\dot{\gamma}$)?

Dapat pula digunakan viskositas apparent (μ_{app})

$$\mu_{app} = \frac{\tau}{\dot{\gamma}}$$

Newtonian ⟶ $\mu_{app} = \mu$

Non-newtonian ⟶ $\mu_{app} = \frac{\tau}{\gamma} = K\gamma^{n-1}$



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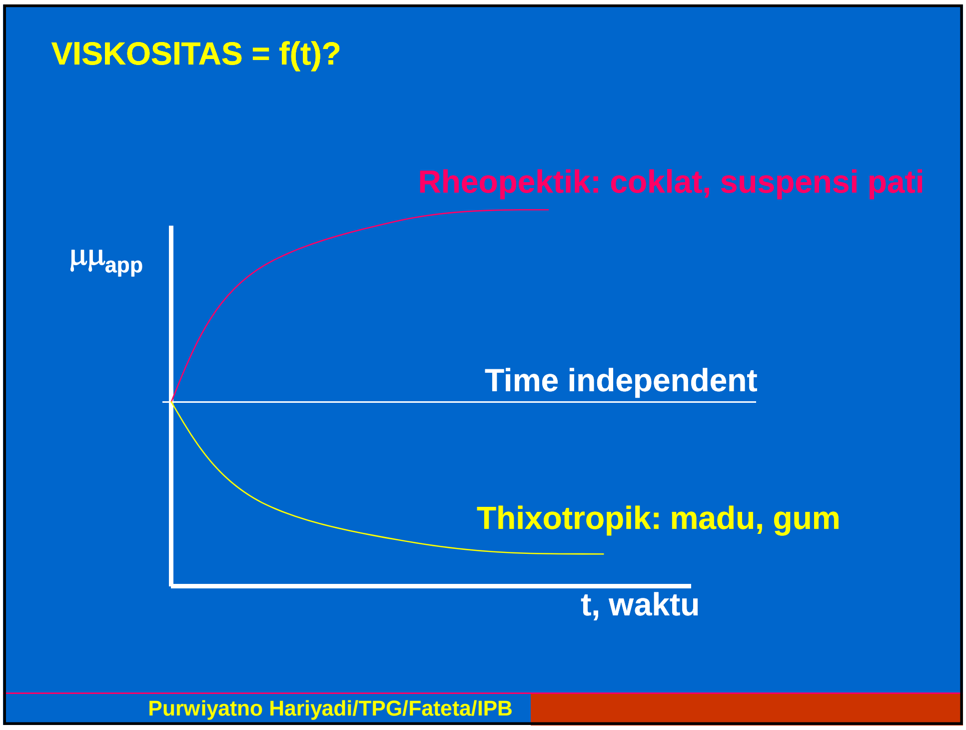
VISKOSITAS = f(t)?
Rheopektik: coklat, suspensi pati
μμapp
Time independent
Thixotropik: madu, gum
t, waktu
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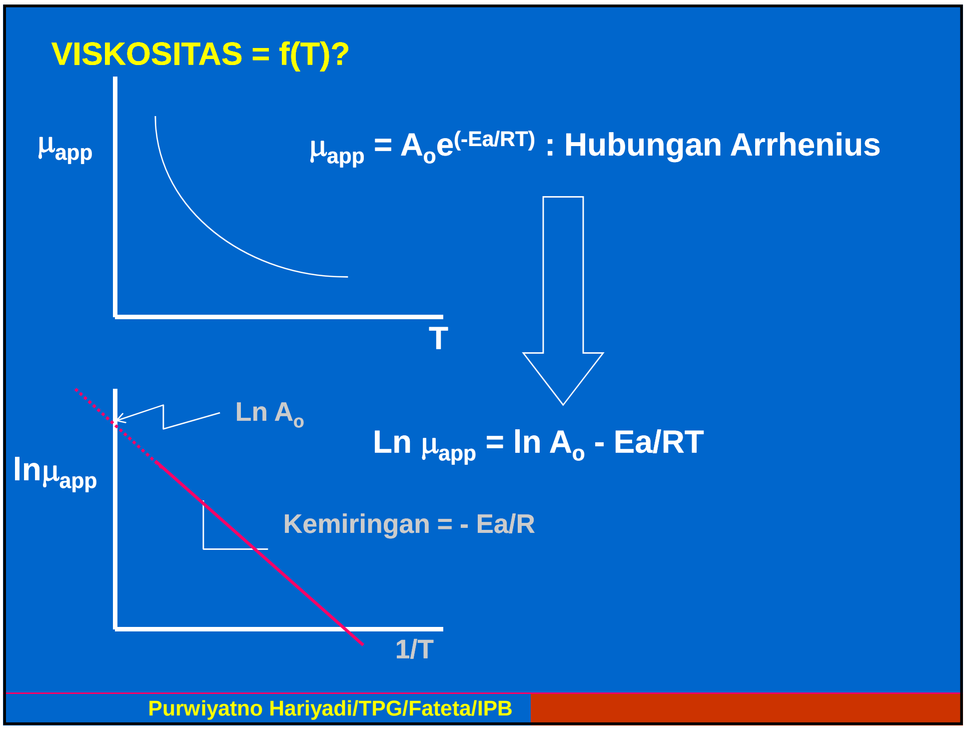
VISKOSITAS = f(T)?
μapp
μapp = Aoe(-Ea/RT) : Hubungan Arrhenius
T
Ln Ao
Ln μapp = ln Ao - Ea/RT
lnμapp
Kemiringan = - Ea/R
1/T
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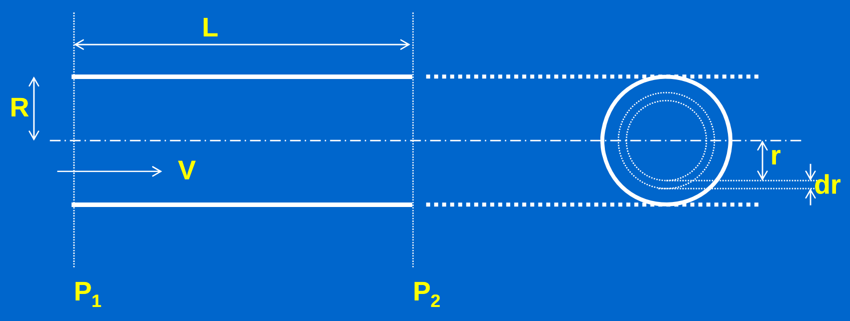
ALIRAN FLUIDA NEWTONIAN DALAM PIPA



Perhatikan : tabung silinder panjang L,
diameter R.
Fluida mengalir dengan kecepatan V
Terdapat perbedaan tekanan,
P_1 di ujung masuk pipa dan P_2 di ujung keluar, $P_1 > P_2$

Perhatikan silinder dgn jari-jari=r dan ketebalan = dr

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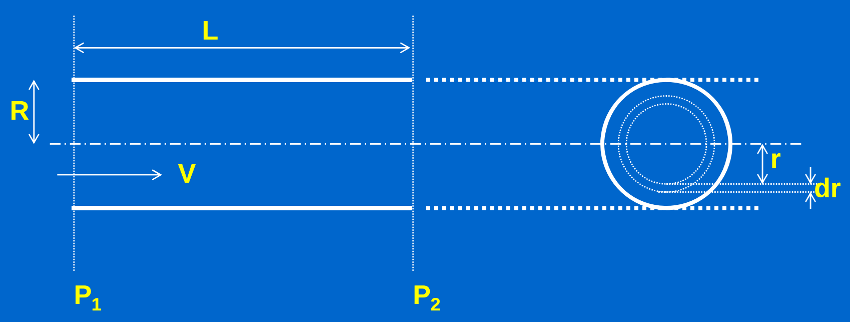
ALIRAN FLUIDA NEWTONIAN DALAM PIPA



Gaya bekerja pada permukaan silinder (r) ············> $F = (P_1 - P_2)(\pi r^2)$
Luas permukaan silinder ············> $A = 2\pi rL$
Jadi, gaya geser (τ_r) :

$$\tau = \frac{(P_1 - P_2)(\pi r2)}{2\pi rL} = \frac{(P_1 - P_2)r}{2L} = \frac{\Delta P.r}{2L}$$

Ingat : $\tau = \mu\left(-\frac{dv}{dy}\right)$

Jadi $$\frac{(P_1 - P_2)r}{2L} = \mu\left(-\frac{dv}{dr}\right)$$

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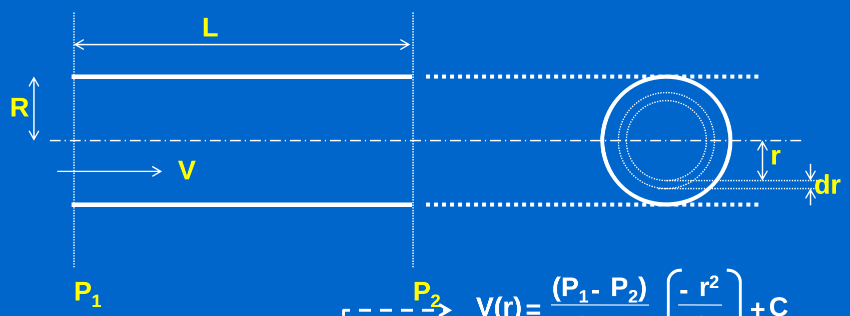
ALIRAN FLUIDA NEWTONIAN DALAM PIPA



$$\frac{(P_1 - P_2)r}{2L} = \mu\left(-\frac{dV}{dr}\right)$$

$$dV = \frac{(P_1 - P_2)}{2L\mu}(-rdr)$$

$$\int dV = \frac{(P_1 - P_2)}{2L\mu}\int - r.dr$$

$$V(r) = \frac{(P_1 - P_2)}{2L\mu}\left(\frac{-r^2}{2}\right) + C$$

Diketahui bahwa pada r=R ·····> V=0

maka, $C = \frac{(P_1 - P_2)(R^2)}{4L}$

Jadi :

$$V = \frac{(P_1 - P_2)}{4L\mu}(R^2 - r^2) = \frac{\Delta P}{4L\mu}(R^2 - r^2)$$

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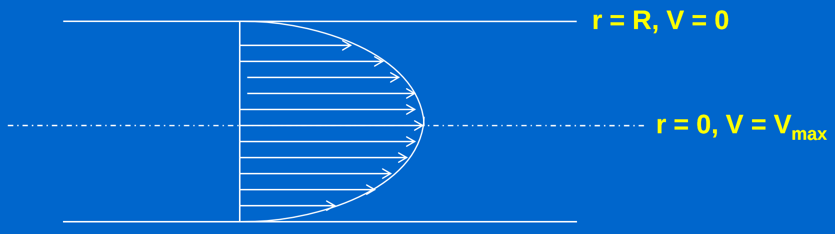
DISTRIBUSI KECEPATAN

$$V = \frac{(P_1 - P_2)}{4L\mu}(R^2 - r^2) = \frac{\Delta P}{4l\mu}(R^2 - r^2)$$

Terlihat bahwa :

pada r = R ··········> V = 0

pada r = 0 ··········> $V = V_{max} = \frac{(P_1 - P_2)}{4l\mu}(R^2) = \frac{\Delta PR^2}{4L\mu}$



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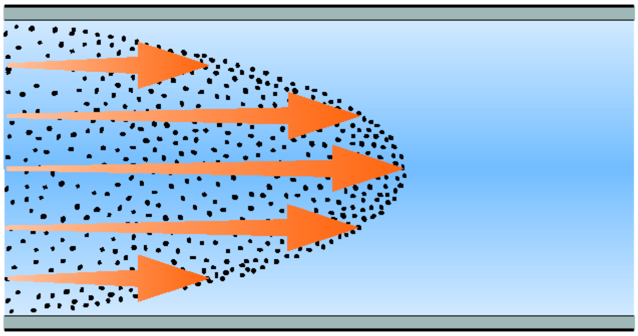
DISTRIBUSI KECEPATAN

$$V = \frac{(P_1 - P_2)}{4L\mu}(R^2 - r^2) = \frac{\Delta P}{4l\mu}(R^2 - r^2)$$

Terlihat bahwa :

pada r = R ....> $V = 0$

pada r = 0 ....> $V = V_{max} = \frac{(P_1 - P_2)}{4l\mu}(R^2) = \frac{\Delta PR^2}{4L\mu}$



The length of an arrow corresponds to the velocity of a particle.

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KECEPATAN RATA-RATA

$dA = \pi \{(r+dr)^2-r^2\}$

$dA = \pi \{(r^2+2rdr+(dr)^2-r^2\}$

dr kecil mendekati nol , maka : $(dr)^2$ .....> 0

$dA = 2 \pi rdr$

Laju aliran volumetrik melalui dA ....> $VdA = V(2\pi rdr)$

Debit total (melalui A)

..........> $\overline{V}dA = \frac{(P_1 - P_2)}{4L\mu}(R^2 - r^2)(2\pi rdr)$

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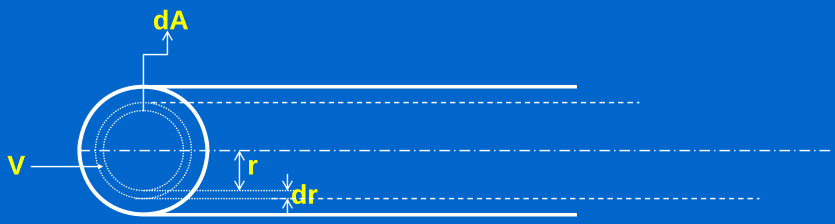
KECEPATAN RATA-RATA



$$\bar{V}dA = \frac{(P_1 - P_2)}{4L\mu}(R^2 - r^2)(2\pi\, rdr)$$

$$\bar{V}(\pi R^2) = \frac{(P_1 - P_2)}{4L\mu}(2\pi)\int_0^R (R^2 - r^2)\, rdr$$

$$\bar{V} = \frac{(P_1 - P_2)R^2}{8L\mu} = \frac{\Delta PR^2}{8L\mu} \Rightarrow \bar{V} = 1/2\, V_{max}$$

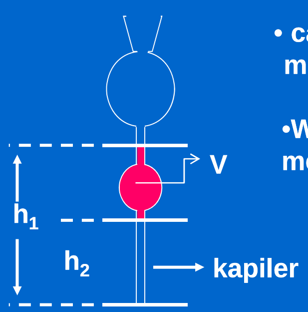
$$\text{Debit} = Q = \frac{\Delta PR^2}{8L\mu}(\pi R^2) \Rightarrow Q = \frac{\Delta P\pi R^4}{8L\mu}$$

KECEPATAN RATA-RATA dan VISKOSITAS

Pada /pipa tabung dengan jari-jari R

$$\bar{V} = \frac{(P_1 - P_2)R^2}{8L\mu} = \frac{\Delta P\, R^2}{8L\mu} \quad \text{atau} \quad \mu = \frac{\Delta P\, R^2}{8L\bar{V}}$$

APLIKASI .....1 : VISKOMETER KAPILER



- catat waktu yang diperlukan untuk mengalirkan fluida dengan volume tertentu
- Waktu yang diperlukan untuk mengosongkan sejumlah volume = t

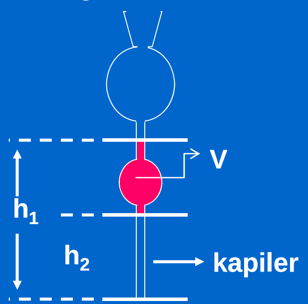
$$Q = \frac{V}{t}$$

APLIKASI ...1: VISKOMETER KAPILER

$$\Delta P = \rho g h$$
$$h = (h_1 - h_2)$$
$$Q = \frac{\Delta P \pi R^4}{8 L \mu}$$
$$Q = \frac{V}{t}$$

$$\frac{\mu}{\rho} = K = \frac{\pi R^4 g h}{8LQ} = \left(\frac{\pi R^4 g h}{8LV}\right) t$$

$$K = b\,t$$



K : viskositas kinematik
b : konstanta viskometer
L: panjang kapiler
R: jari-jari kapiler
V: volume
h: tinggi kolom penampung (h_1-h_2)

Nilai b, konstanta viskometer: dicari dengan menggunakan larutan standar (diketahui μ dan ρ)

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ALIRAN FLUIDA NON-NEWTONIAN DALAM PIPA

$$\tau_w = \frac{\Delta PR}{2L}$$

$$v(r) = \frac{2L}{\Delta P}\,\frac{1}{1/n + 1}\,\frac{1}{K^{1/n}}\left[\left(\frac{\Delta PR}{2L} - \tau_o\right)^{1/n+1} - \left(\frac{\Delta Pr}{2L} - \tau_o\right)^{1/n+1}\right]$$

$$v\max = \frac{2L}{\Delta P}\,\frac{1}{1/n + 1}\,\frac{1}{K^{1/n}}\left(\frac{\Delta PR}{2L} - \tau_o\right)^{1/n+1}$$

$$\gamma_w = \frac{4\overline{V}}{R}\left(\frac{3}{4} + \frac{1}{4n}\right)$$

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NON-NEWTONIAN Vs NEWTONIAN :

$$\tau_w = \frac{\Delta PR}{2L} \qquad \tau = K(\gamma)^n$$

$$\gamma_w = \frac{4V}{R} \qquad \tau_w = K(\gamma_w)^n$$

$$\frac{\Delta P R}{2L} = K\left(\frac{4\bar{V}}{R}\right)^n$$

$$\log \Delta P + \log\frac{R}{2L} = \log K + n\log\left(\frac{4\bar{V}}{R}\right)$$

$$\log \Delta P = n\log \bar{V} + \left(n\log\frac{4}{R} + \log K - \log\frac{R}{2L}\right)$$

$$y = nx + b$$

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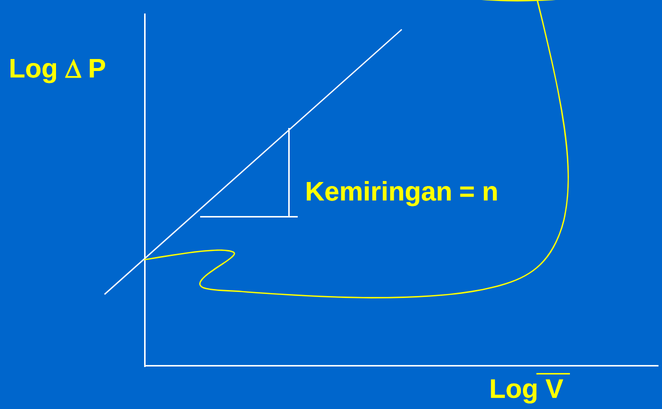
NON-NEWTONIAN Vs NEWTONIAN :

$$\log \Delta P = n\log \bar{V} + \left(n\log\frac{4}{R} + \log K - \log\frac{R}{2L}\right)$$



Jika n = 1
····> newtonian

Maka : $\mu = \frac{\Delta P R^2}{8L\bar{V}}$

jika n <1 atau n >1
····> non-newtonian

harus dicari nilai K

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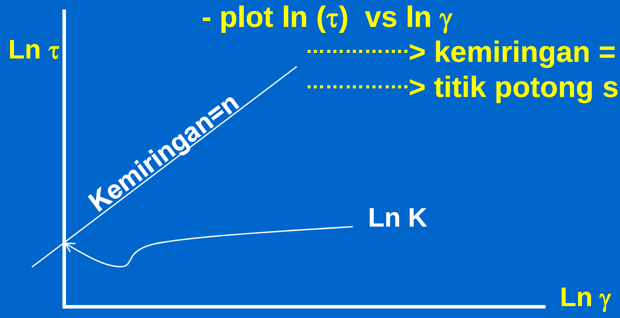
NON-NEWTONIAN Vs NEWTONIAN :

Mencari K ??

- ingat model umum : $\tau = \tau o + K(\gamma)^n$
- linierkan :
  ·················> $\ln (\tau - \tau o) = \ln K + n \ln \gamma$
- asumsikan to ·····> 0
  ·················> $\ln (\tau) = \ln K + n \ln \gamma$
- plot $\ln (\tau)$ vs $\ln \gamma$
  ·················> kemiringan = n (Cek and recek!)
  ·················> titik potong sb y = ln K



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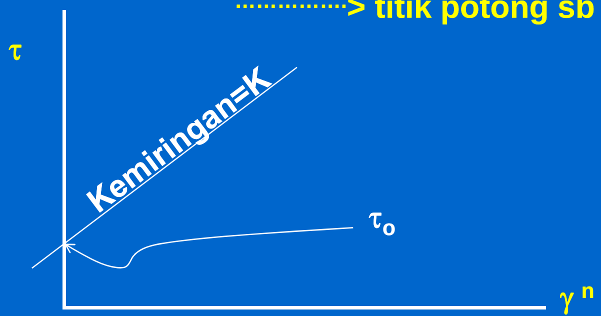
NON-NEWTONIAN Vs NEWTONIAN :

Mencari τ_o ??

- ingat model umum : $\tau = \tau o + K(\gamma)^n$
- setelah diketahui nilai n, maka :
- plot τ vs $(\gamma)^n$
  ·················> kemiringan = K (Cek and recek!)
  ·················> titik potong sb y = τ_o



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Contoh : Force Flow Tube or Capilary Viscometer

Viskometer tabung mempunyai diameter dalam (ID) 1.27 cm, panjang 1.219 m. Digunakan untuk mengukur viskositas fluida (ρ=1.09 g/cm^3).

Data yang diperoleh adalah sbb:

(P1-P2)[=]kPa	Debit (g/s)
19.187	17.53
23.497	26.29
27.144	35.05
30.350	43.81
42.925	87.65

Ditanyakan nilai K dan n!

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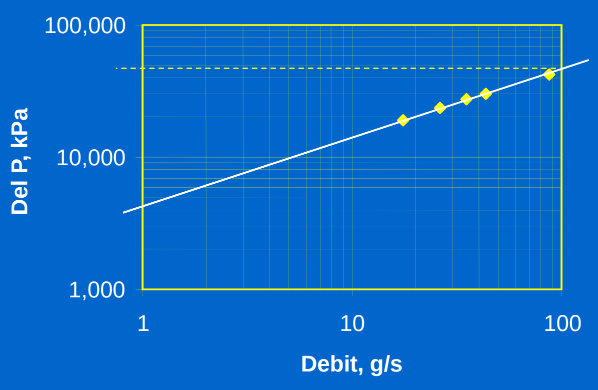
Contoh : Force Flow Tube or Capilary Viscometer



Kemiringan :

$$\frac{\log 48 - \log 4.3}{\log 100 - \log 1}$$

$$= \frac{1,6812-0,6335}{2}$$

$$= 0.523$$

n = 0.523

Berikutnya : K???

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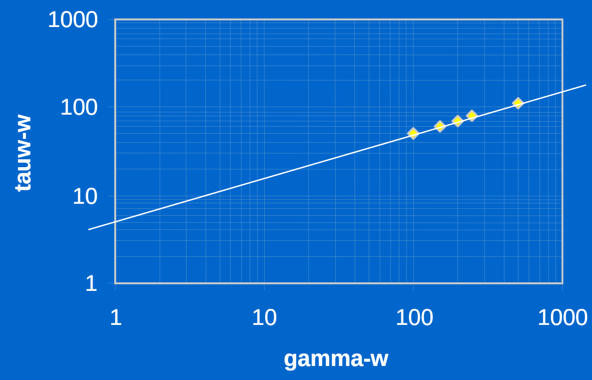
Contoh : Force Flow Tube or Capilary Viscometer

$$\tau_w = \frac{\Delta PR}{2L} \qquad \tau_w = [0.00635(0.5)/1.219]\Delta P = 0.002605\ \Delta P\ \text{Pa}$$

$$\gamma_w = \frac{4\bar{V}}{R}\left(\frac{3}{4} + \frac{1}{4n}\right) \qquad \gamma_w = 5.7047\ Q$$



Log-log plot :

$\log\tau_w = \log K + n\log\gamma_w$

cek/recek n

$K = 5\ \text{pa.s}^{0.5}$

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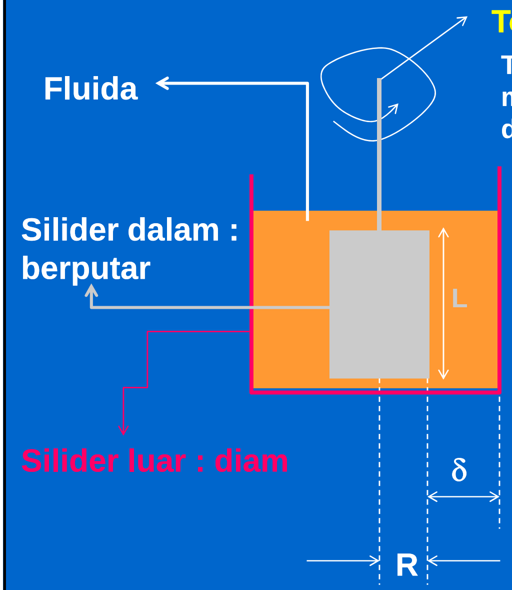
Contoh : VISKOMETER ROTASIONAL



Torsi, T

Torsi yang diperlukan untuk memutar silider dalam diukur dan dicatat

Gaya bekerja pada permukaan silinder dalam :

$F = T/R$

Gaya geser di dinding :

$$\tau_w = \frac{T}{R}\,\frac{1}{2\pi RL} = \frac{T}{R^2(2\pi L)}$$

Laju geser di dinding :

$$\dot{\gamma}_w = \frac{2\pi RN}{\delta}$$

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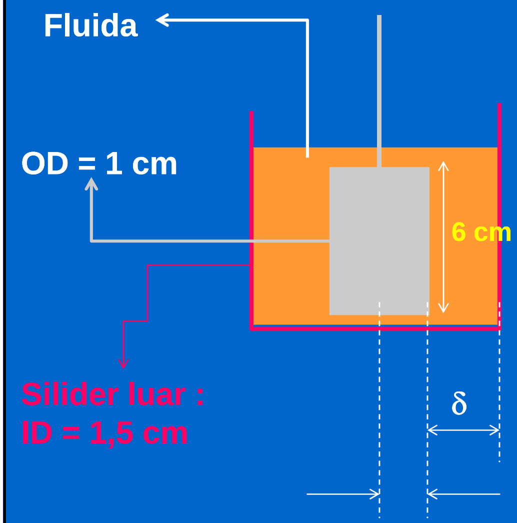
Contoh soal....(1)



Viskometer rotasional mempunyai, pada skala pembacaan penuh mempunyai konstanta pegas = 7187 dyne-cm.

Hasil percobaan menunjukkan hasil sbb :

N (RPM)	Torsi (% skala penuh)
2	15
4	26
10	53
20	93

Tentukan parameter reologinya!

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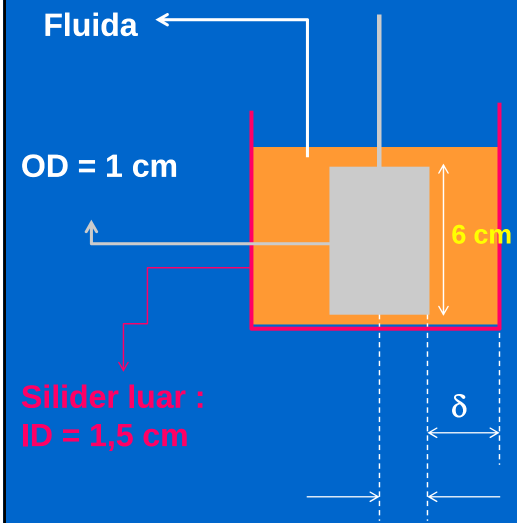
Contoh soal.... (2)



$$\tau_w = \frac{T}{R^2(2\pi L)} = \frac{7187(\%FS)}{(0.5)(2\pi)(6)}$$

$$=(762.56)(\%FS)$$

$$\dot{\gamma}_w = \frac{2\pi RN}{\delta}$$

$$= \frac{2(\pi)(0.5)N}{(0.75-0.5)(60)} = 0.2094\ N$$

Buat plot ln τ_w vs ln γ_w

....

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Contoh soal …. (3) ……………… analisis data

N. rpm	Torsi terbaca (%FS)	γw (1/s)	τw (dyne/cm^2)	Ln γw	Ln τw
2	0,15	0,4188	114,38	-0,87	4,7396
4	0,26	0,8376	198,27	-0,177	5,2896
10	0,53	2,094	404,16	0,7391	6,0018
20	0,93	4,188	709,18	1,4322	6,5641

Ingat : $\tau_w = K(\gamma_w)^n$

$\ln \tau_w = \ln K + n \ln(\gamma_w)$

- cari persamaan garis lurus $\ln\tau_w$ vs $\ln\gamma_w$
- kemiringan = n
- intersep = ln K

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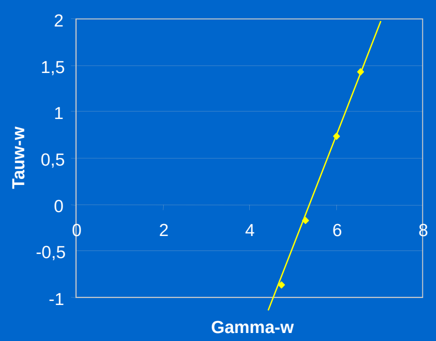
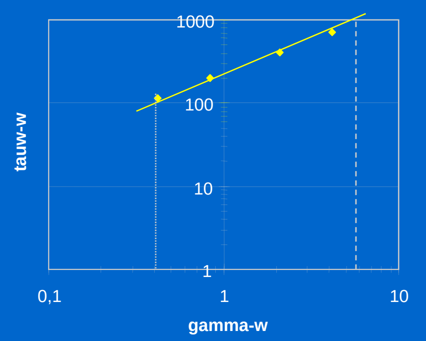
Hub antara $\ln \tau_w$ dan $\ln \gamma_w$ dalam kertas grafik linier-linier



Hub antara τ_w dan γ_w dalam kertas grafik log-log



Kemiringan :
= (log 1000-log100)/(log 5,3-log 0,43)
= 0.79

Intersep :
K = 225 Pa.s

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