1 REOLOGI BAHAN PANGAN

ITP530

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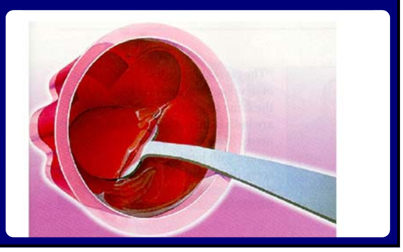
MENGAPA BELAJAR REOLOGI?

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



Fluid Foods

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

FLUIDA : → GAS
→ CAIRAN
→ PADATAN

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

Karakteristik Fluida

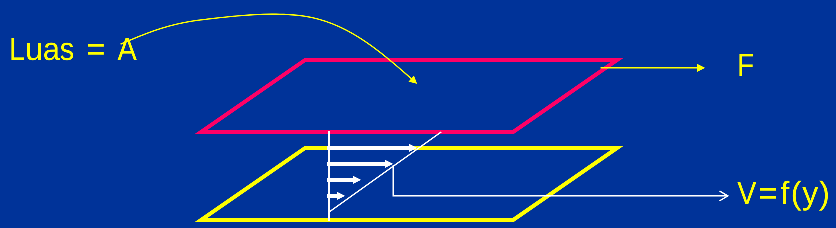
Densitas :
massa per satuan volume

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

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

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

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

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

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

Diketahui Hk Newton ttg viskositas

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

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

Viskositas

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

1 poise = 100 cp

Contoh:

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

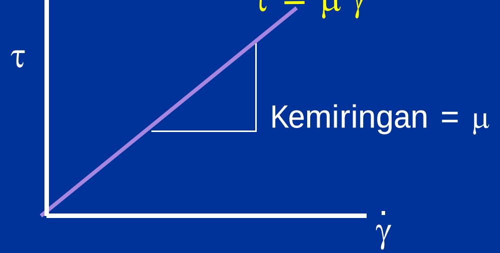
FLUIDA : NEWTONIAN & NON-NEWTONIAN

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

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

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

τ = gaya geser



Fluida-fluida yang menganut hukum Newton:
FLUIDA NEWTONIAN

NON-NEWTONIAN

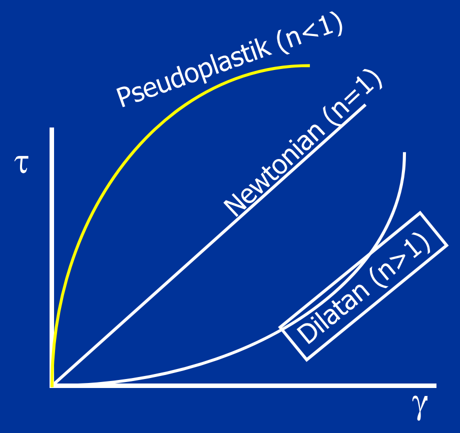
1 $\tau = K(\gamma)^n$ ……………> model "Power law"

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

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



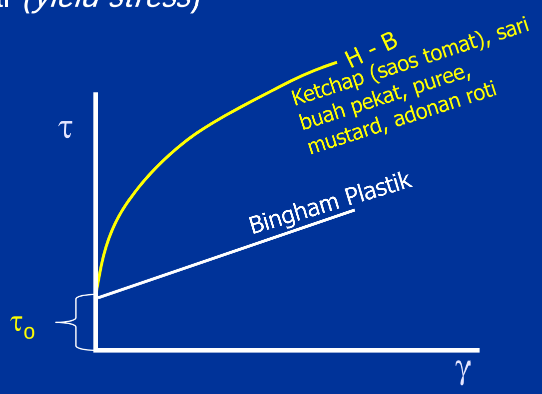
NON-NEWTONIAN

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

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

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

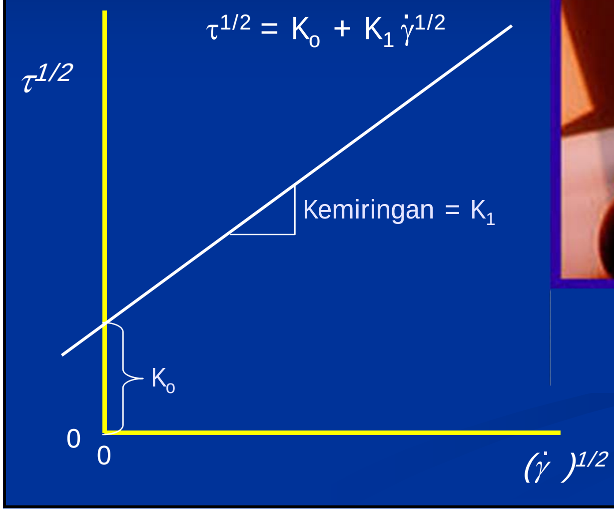
B. Fluida H - B
$\tau = \tau_o + K(\gamma)^n$; $n<1$



NON-NEWTONIAN

3 Rheologi “Melted Chocolate”:

Model Casson :



Apa pengaruh Ko thd bentuk coklat?

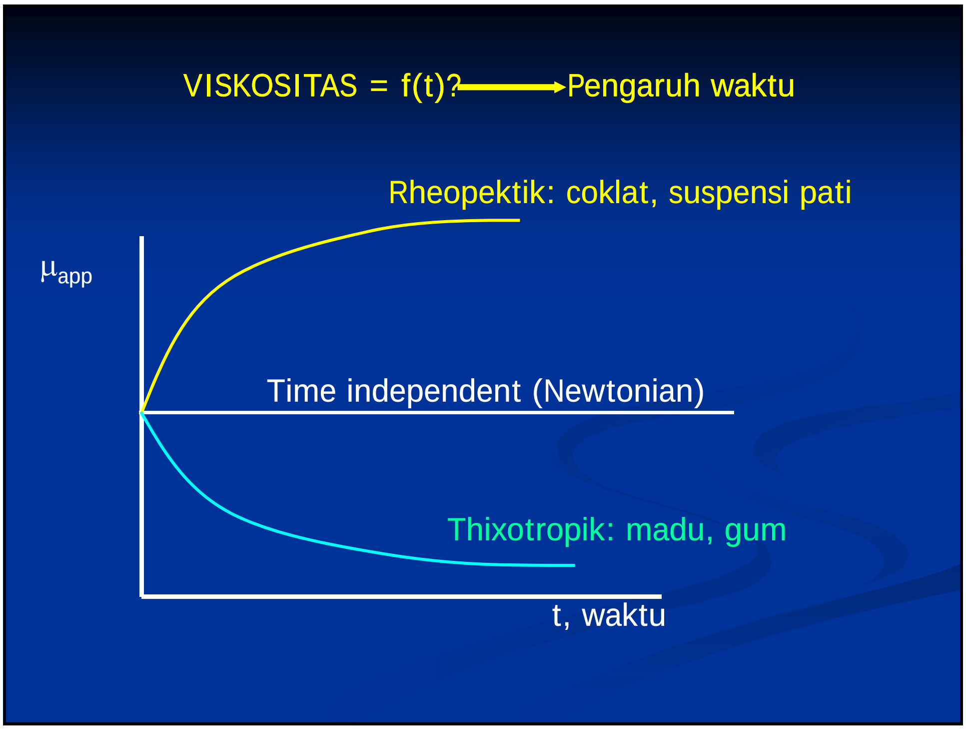
VISKOSITAS = f(γ)? ⟶ Pengaruh shear rate

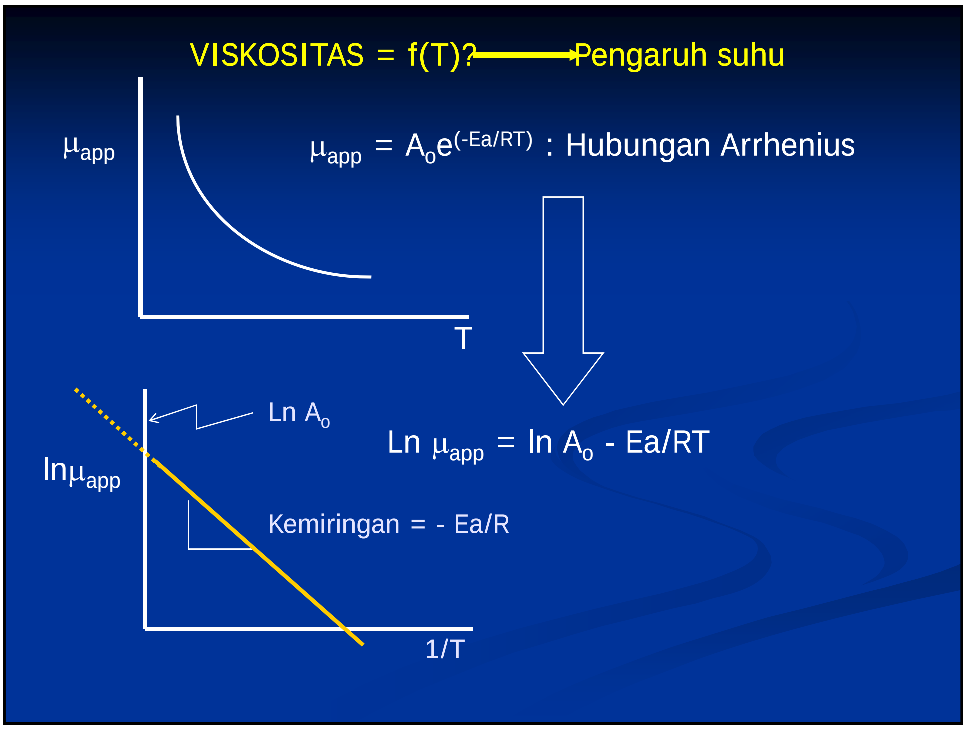
Dapat pula digunakan viskositas apparent (μ_{app})

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

Newtonian ⟶ $\mu_{app} = \mu$

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

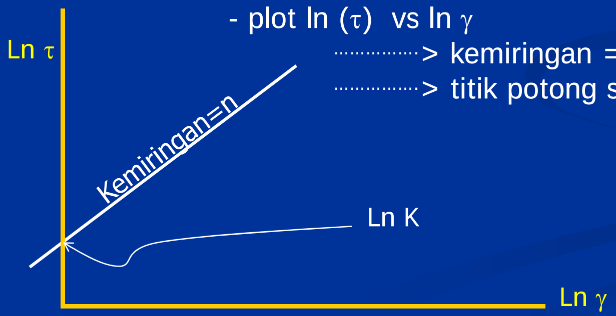

VISKOSITAS = f(t)? Pengaruh waktu
Rheopektik: coklat, suspensi pati
μapp
Time independent (Newtonian)
Thixotropik: madu, gum
t, waktu


VISKOSITAS = f(T)? Pengaruh suhu
μapp
$\mu_{app} = A_o e^{(-Ea/RT)}$: Hubungan Arrhenius
T
Ln A_o
$\ln \mu_{app}$
Ln μ_{app} = ln A_o - Ea/RT
Kemiringan = - Ea/R
1/T

NON-NEWTONIAN Vs NEWTONIAN :

Mencari K ??

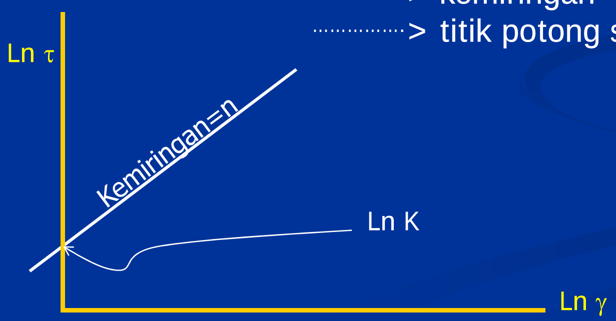
- ingat model umum : $\tau = \tau_o + K(\gamma)^n$
- linierkan :
  ···············> $\ln(\tau-\tau_o) = \ln K + n \ln \gamma$
- asumsikan τ_o ·····> 0
  ···············> $\ln(\tau) = \ln K + n \ln \gamma$
- plot $\ln(\tau)$ vs $\ln \gamma$
  ···············> kemiringan = n (Cek and recek!)
  ···············>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



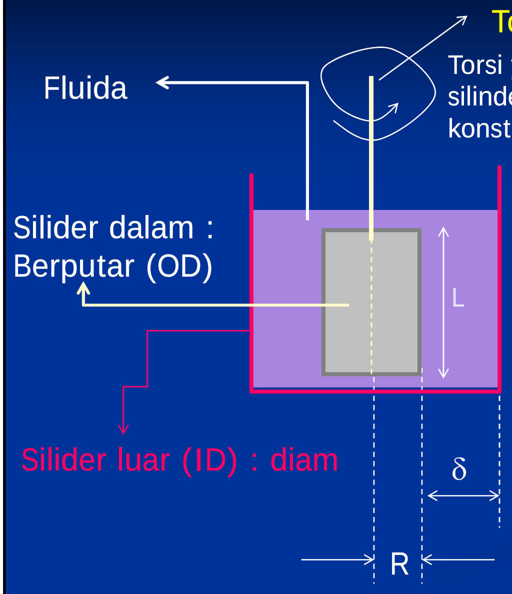
NON-NEWTONIAN Vs NEWTONIAN :

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



VISKOMETER ROTASIONAL



Torsi, T

Torsi yang diperlukan untuk memutar silinder dalam diukur dan dicatat → konstanta pegas → 0-100%

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 :

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

N= rpm (radius/minute)

Faktor untuk Brookfield model LV (spindle #3) (untuk menentukan nilai viskositas apparent)

Kecepatan rotasi (rpm)	**Faktor**
0,3	4000
0,6	2000
1,5	800
3	400
6	200
12	100
30	40
60	20

Contoh soal

Untuk menghitung sifat fluida dari sauce, dilakukan pengukuran dengan menggunakan viscometer rotational dan diperoleh data hubungan antara shear stress (τ) dan shear rate (γ) (lihat Tabel).

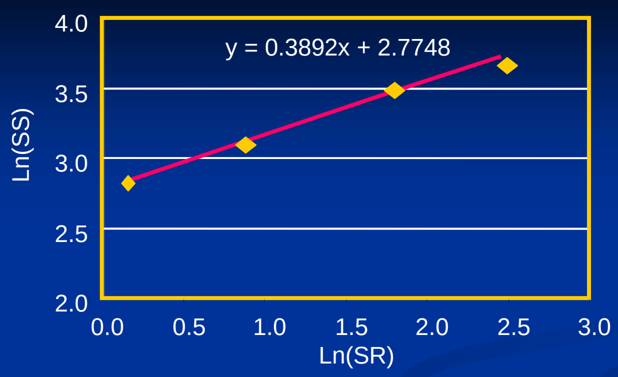
1. Buat grafik hubungan τ vs γ
2. Tentukanlah: nilai n, K dan yield stress (τ_o)

Data hasil pengukuran dengan Rotational viskometer

Shear stress (τ, N/m^2)	Shear rate (γ, 1/det)
16.5	1.16
22.7	2.33
33.6	5.82
39.9	11.64

Rumus: $\tau = K\gamma^n \rightarrow Ln\tau = LnK + nLn\gamma$

Rubah data dalam bentuk Ln → Plot grafik Ln SR (x) vs Ln SS (y)



$Y = 0.3892x + 2.7748$

Dimana: $Y = \ln(\tau)$

$x = \ln(\gamma)$

$n = 0.3892$ (pseudoplastic)

$\ln K = 2.7748 \rightarrow K = 16.04$ Pa.s^n

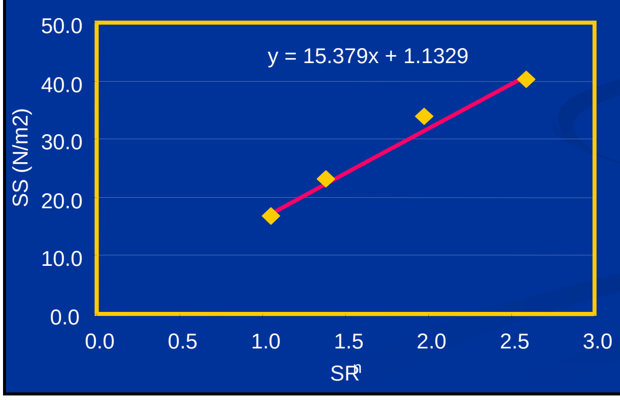
Menghitung Yield stress τ_o)

$\tau = \tau_o + K\gamma^n$

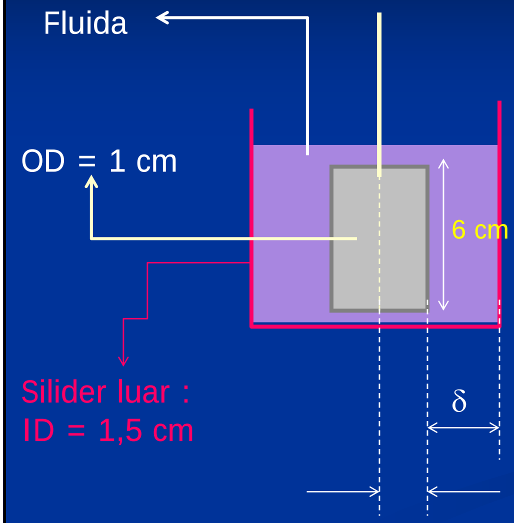
Plot hubungan: τ vs $\gamma^n \rightarrow \tau = \tau_o + K\gamma^{0.3892}$

$Y = \tau$

$\tau_o = 1.13$ N/m^2



Contoh soal lain



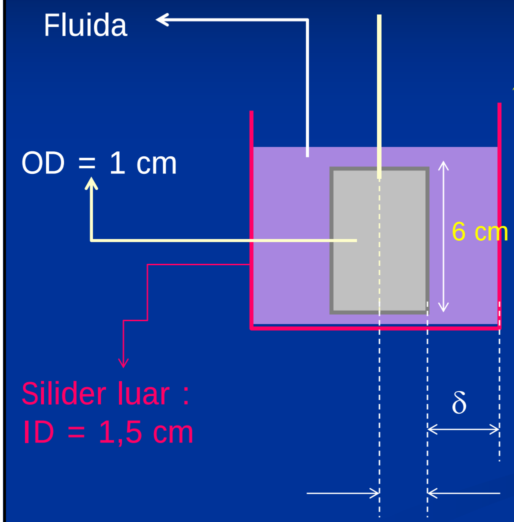
Viskometer rotasional pada skala pembacaan penuh mempunyai konstanta pegas = 7187 dyne-cm.

Percobaan menunjukkan hasil sbb :

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

Tentukan parameter reologinya! (n,K)

Contoh soal .... (2)



Konversi data N dan Torsi ke shear rate dan shear stress

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

$$=(762.56)(\%T)$$

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

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

Buat plot ln τ_w vs ln γ_w ……………………..

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

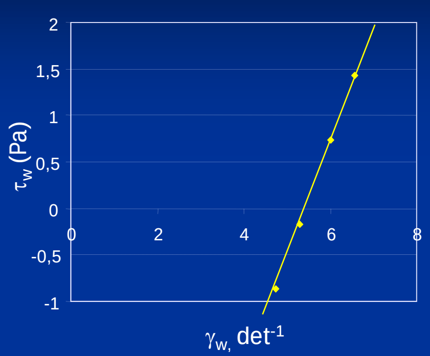
N. rpm	Torsi terbaca (%FS)	γ_w (1/s)	τ_w (dyne/cm^2)	Ln γ_w	Ln τ_w
2	0,15	0,4188	114,38	-0,87	4,7396
4	0,26	0,8376	198,27	-0,177	5,2896
10	0,53	2,094	404,16	0,7391	6,0018
20	0,93	4,188	709,18	1,4322	6,5641

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

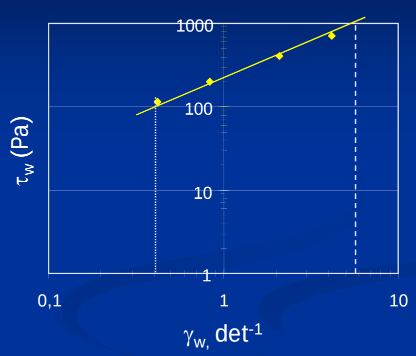
$\ln \tau_w = \ln K + n \ln(\gamma_w)$

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

Hub antara ln τ_w dan ln γ_w dalam kertas grafik linier-linier



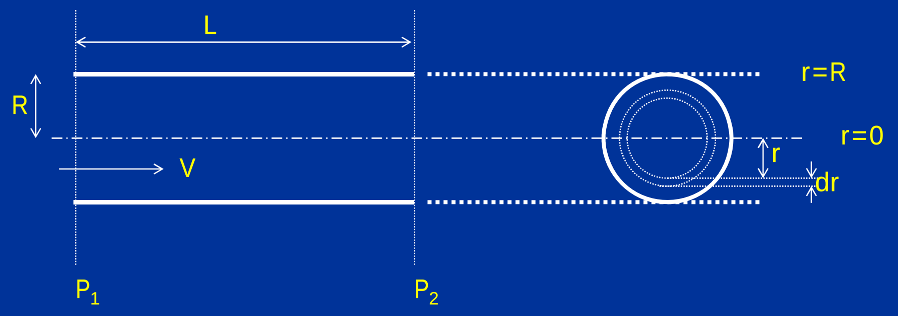
Hub antara τ_w dan γ_w dalam kertas grafik log-log



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

Intersep :
K = 225 Pa.s

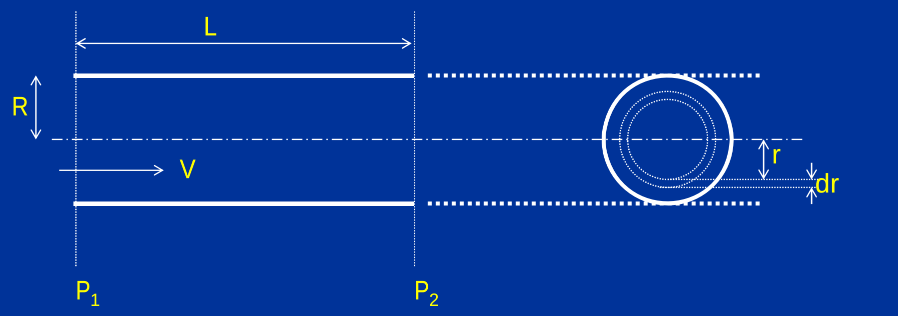
KECEPATAN ALIRAN FLUIDA NEWTONIAN DALAM PIPA



Perhatikan : tabung silinder panjang L,
Radius 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

KECEPATAN ALIRAN FLUIDA NEWTONIAN DALAM PIPA



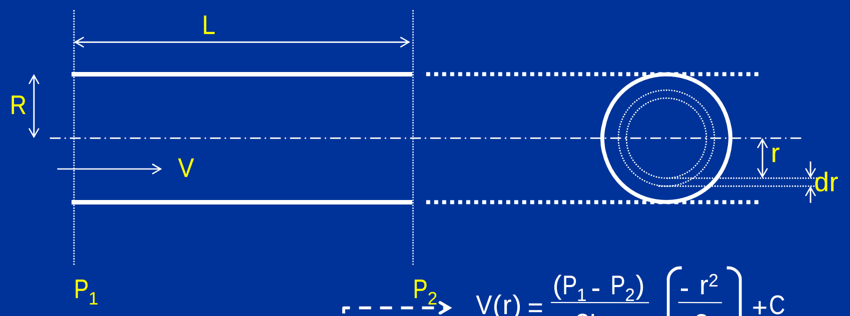
Gaya bekerja pada permukaan silinder (r) ....> $F = (P_1 - P_2)(\pi r^2)$
Luas permukaan silinder ....> $A = 2\pi rL$
Jadi, gaya geser (τ_r) :

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

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

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

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

Jadi :

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

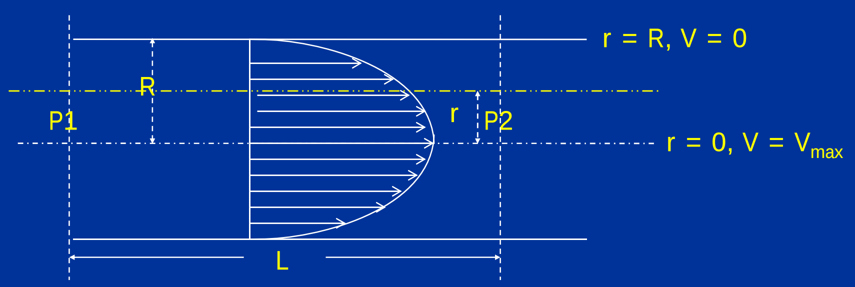
DISTRIBUSI KECEPATAN

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

Terlihat bahwa :

pada r = R ··········> V = 0

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



DISTRIBUSI KECEPATAN

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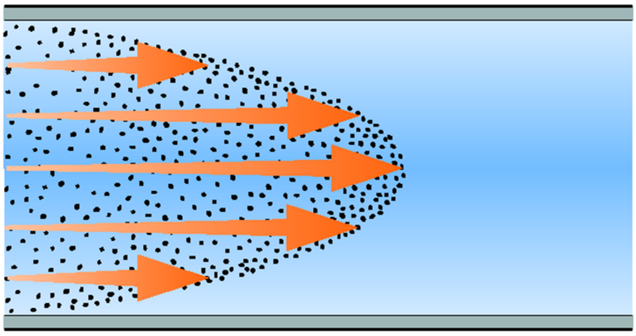


The length of an arrow corresponds to the velocity of a particle.

KECEPATAN RATA-RATA

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

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

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

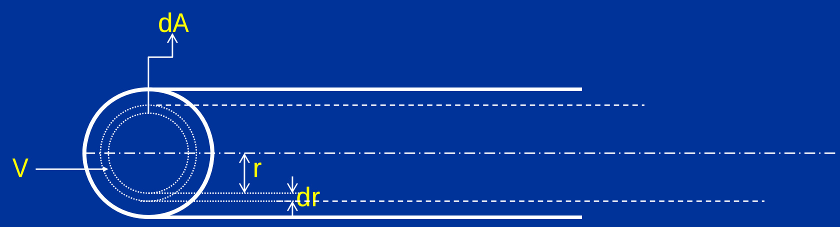
$dA = 2\,\pi\,rdr$

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

Debit total (melalui A)

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

KECEPATAN RATA-RATA



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

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

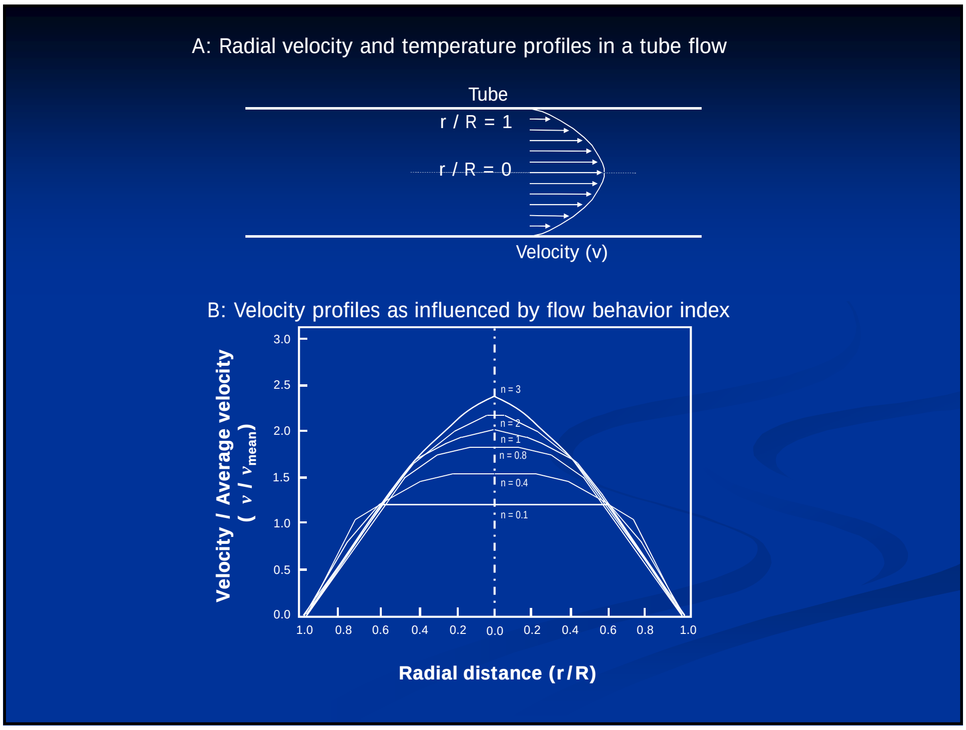
$$\bar{V} = \frac{(P_1 - P_2)R^2}{8L\mu} = \frac{\Delta PR^2}{8L\mu} \Rightarrow \bar{V} = 1/2\, V_{max}$$

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

Kecepatan rata-rata ($\bar{v}$) fluida dalam pipa

Untuk Newtonian fluida: $\bar{v} = \frac{v_{max}}{2}$

Untuk Non-Newtonian fluida: $\bar{v} = \frac{(n+1)}{(3n+1)} v_{max}$

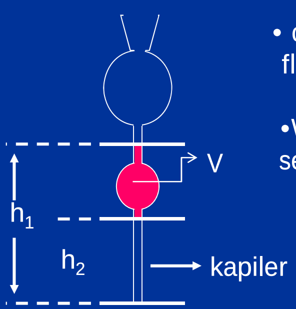


KECEPATAN RATA-RATA dan VISKOSITAS

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

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

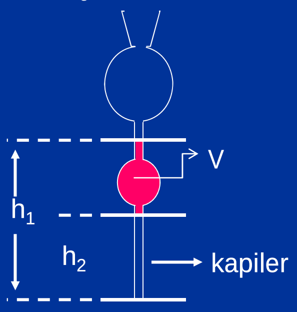
APLIKASI ...1: VISKOMETER KAPILER

$$\left.\begin{aligned} \Delta P &= \rho g h \\ h &= (h_1 - h_2) \\ Q &= \frac{\Delta P \pi R^4}{8 L \mu} \\ Q &= \frac{V}{t} \end{aligned}\right\}$$

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

$$K = b\, t$$

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)

KECEPATAN ALIRAN FLUIDA NON-NEWTONIAN DALAM PIPA

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

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

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

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

NON-NEWTONIAN Vs NEWTONIAN :

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

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

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

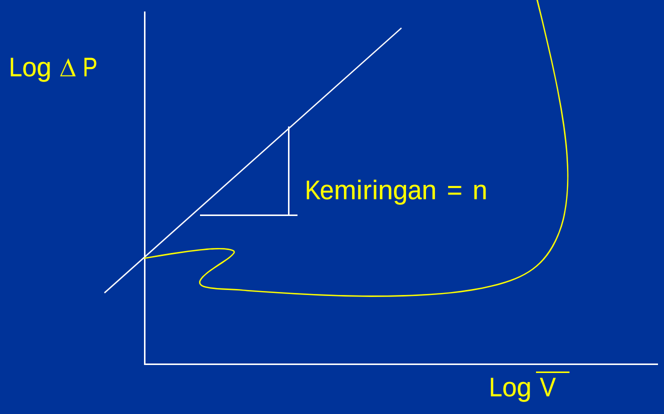
$$\log \Delta P + \log\frac{R}{2L} = \log K + n\log\left(\frac{4\bar{V}}{R}\right)$$

$$\underbrace{\log \Delta P}_{y} = \underbrace{n}_{n}\,\underbrace{\log \bar{V}}_{x} + \underbrace{\left(n\log\frac{4}{R} + \log K - \log\frac{R}{2L}\right)}_{b}$$

$$y = nx + b$$

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

jika n <1 atau n >1

····> non-newtonian

harus dicari nilai K

Contoh soal: Force Flow Tube or Capilary Viscometer

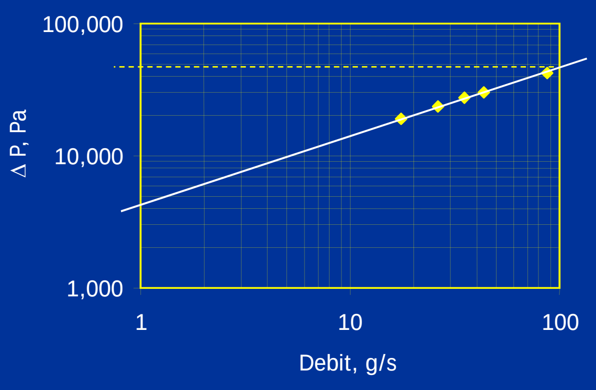
Viskometer tabung mempunyai diameter dalam (ID) 1.27 cm, panjang 1.219 m. Digunakan untuk mengukur viskositas fluida (ρ=1.09 g/cm^3).

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!

Contoh soal: Force Flow Tube or Capilary Viscometer



Kemiringan :

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

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

$$= 0.523$$

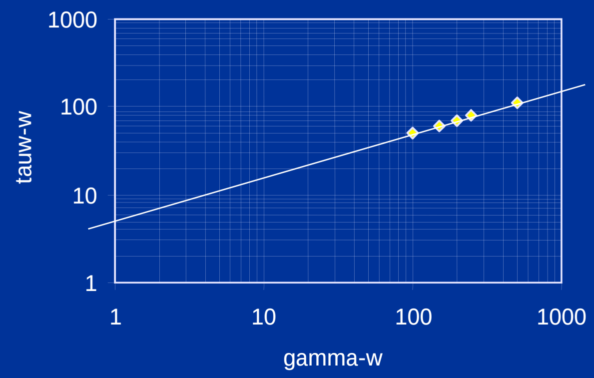
n = 0.523

Berikutnya : K???

Contoh soal: Force Flow Tube or Capilary Viscometer

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

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



Log-log plot :

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

cek/recek n

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

Contoh soal: Analisis Data

N. rpm	Torsi terbaca (%FS)	γ_w (1/s)	τ_w (dyne/cm^2)	Ln γ_w	Ln τ_w
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 ???

Contoh soal:

- Viskometer tabung digunakan untuk menentukan nilai kekentalan cairan pada laju aliran tertentu.
- Cairan mengalami *pressure drop* sebesar 700 Pa setelah diberi gaya alir ke dalam tabung viskometer berdiameter 0,75 cm dan panjang 30 cm dengan laju aliran 50 cm3/detik.
- Tentukanlah viskositas dari cairan tersebut! Hitunglah pula *shear rate* pada pada laju aliran tersebut!

Contoh soal:

Diketahui:

- ΔP = 700 Pa,
- D = 0,75 cm atau R = 0,375 cm = 0,00375 m,
- L = 30 cm = 0.3 m, Q = 50 cm^3/detik atau $\bar{V}$= 50/(π0.375^2)=113.18 cm/s = 1,1318 m/s

Viskositas apparent (μ_{app}) $\mu = \dfrac{\Delta P\, R^2}{8L\bar{V}} = \dfrac{700*(0.00375^2)}{8*0.3*1,1318}$

Shear rate (γ) = $\dfrac{4\bar{V}}{R} = \dfrac{4*1,1318}{0,00375}$ = 1294 s^{-1}

Check juga ke
http://www.egr.msu.edu/bae/profiles/james-steffe

(bisa unduh buku (i) Rheology dan (ii) pipeline design

http://phariyadi.staff.ipb.ac.id/teaching/

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Selesai.................
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