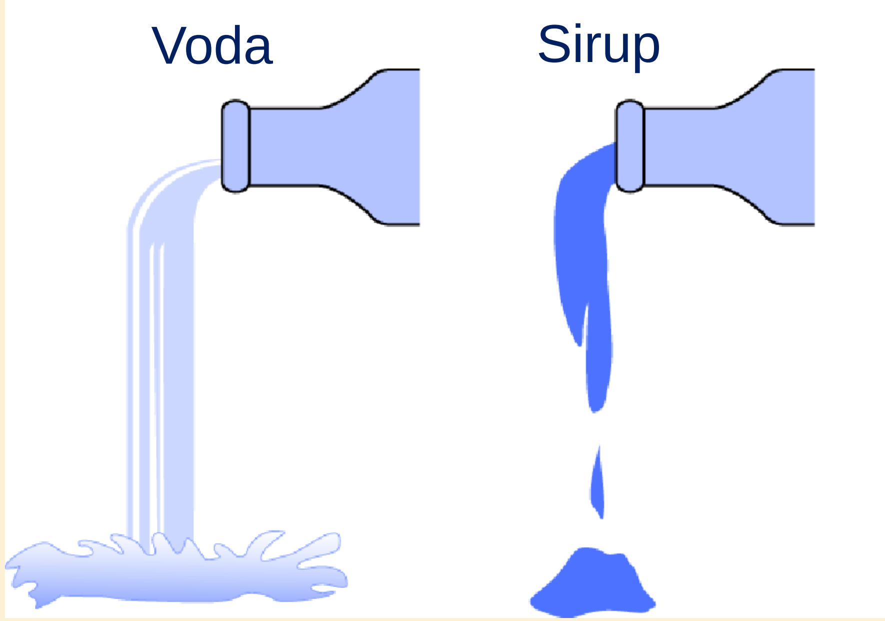
VISKOZNOST TEČNOSTI

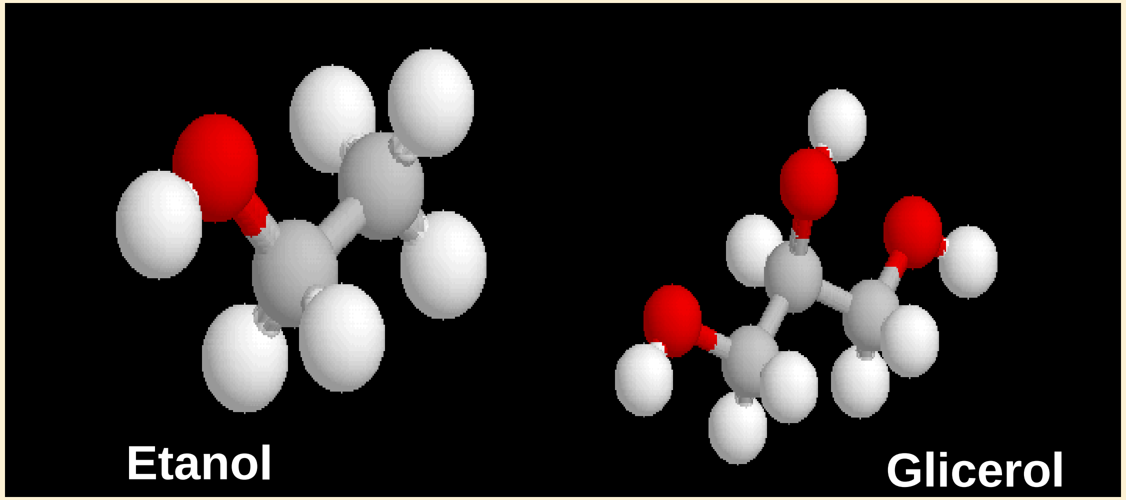
Viskoznost tečnosti

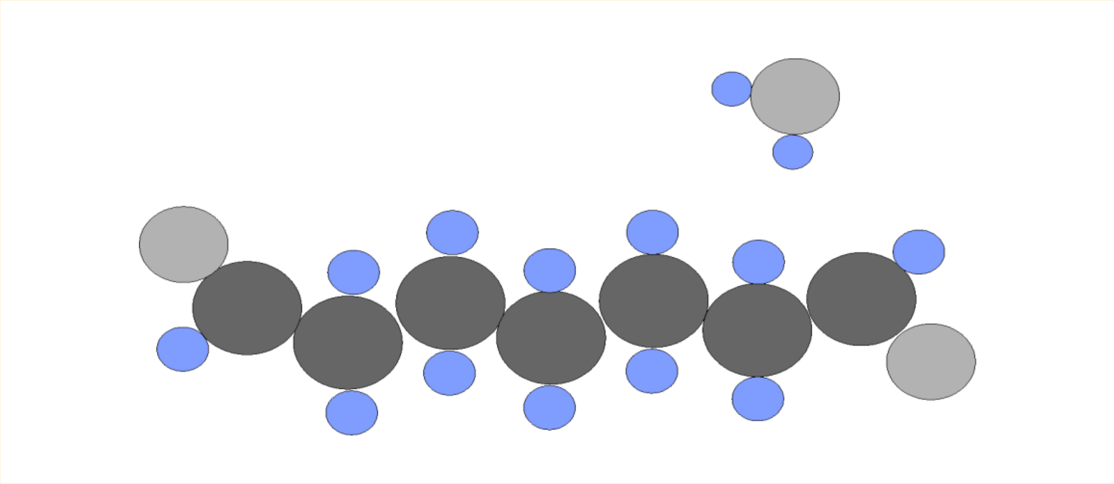
Viskoznost: otpor kojim se pojedini slojevi tečnosti suprotstavljaju kretanju jednih u odnosu na druge (vrsta unutrašnjeg trenja koja dovodi do protoka fluida konstantnom brzinom).



Uzroci otpora proticanju tečnosti

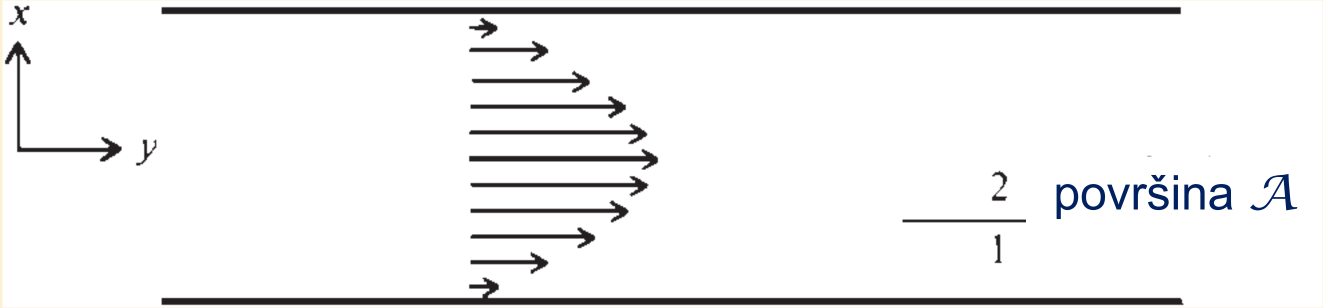
- međumolekulske interakcije
- oblik i veličina molekula





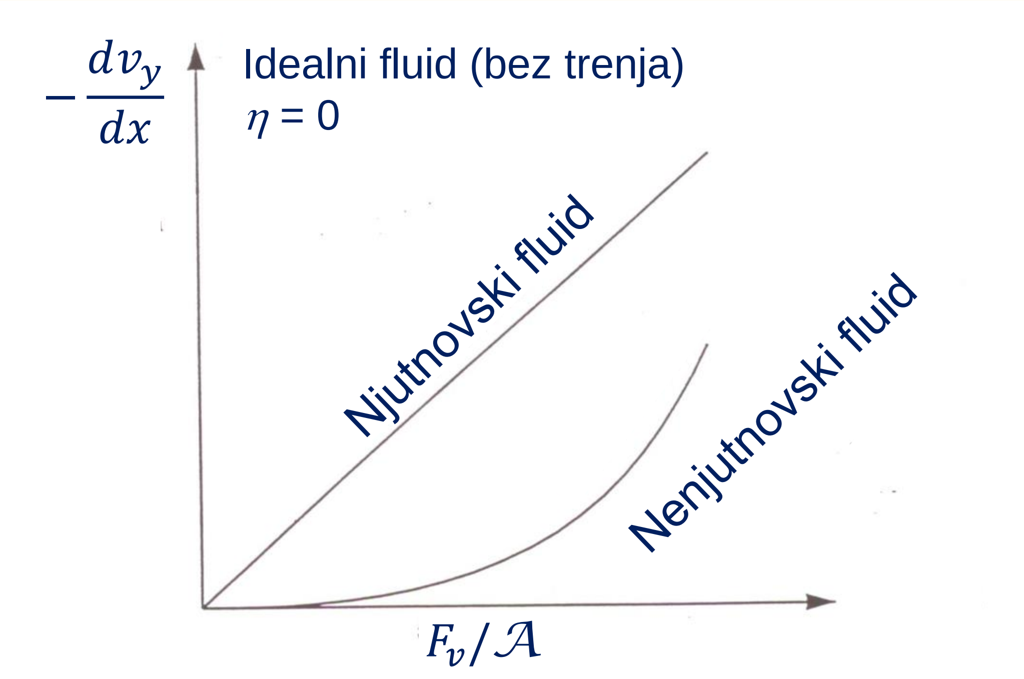
Model

fluid protiče između dve paralelne ploče



Njutnov zakon viskoznosti:

$$F_v = -\eta \mathcal{A} \frac{dv_y}{dx}$$



$$\eta = -\frac{F_v/\mathcal{A}}{dv_y/dx}$$

η : dinamički koeficijent viskoznosti

jedinica je poaz: 1 P = 0,1 Pa s

Dinamički i kinematički koeficijent viskoznost

koeficijent viskoznosti	definicija	jedinica
dinamički	$\eta = -\frac{F_v/\mathcal{A}}{dv_y/dx}$	Poaz: 1 P = 0,1 Pa s
kinematički	$\nu = \frac{\eta}{\rho}$	Stoks: 1 St = 10^{-4} m^2 s^{-1}

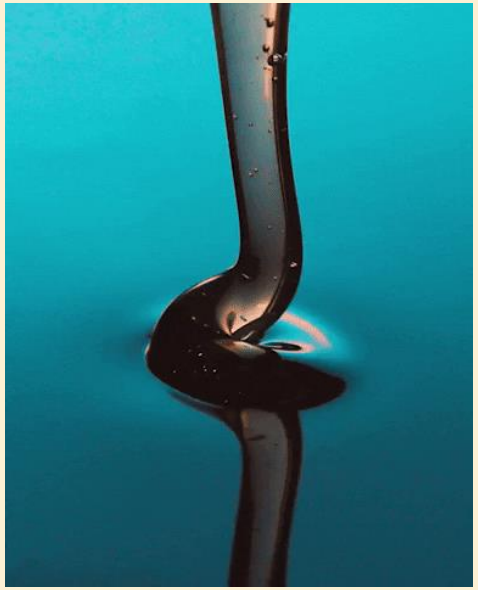
Dinamički i kinematički koeficijent viskoznost

	temperatura / °C	dinam. koef. viskoznost / Pa s	gustina / kg/m^3	kinem. koef. viskoznosti / m^2/s
vazduh	0	$17{,}09 \cdot 10^{-6}$	1,293	$13{,}22 \cdot 10^{-6}$
	20	$18{,}08 \cdot 10^{-6}$	1,205	$15{,}00 \cdot 10^{-6}$
	40	$19{,}04 \cdot 10^{-6}$	1,128	$16{,}88 \cdot 10^{-6}$
sveža voda	0	$1{,}787 \cdot 10^{-3}$	$1{,}000 \cdot 10^{3}$	$1{,}787 \cdot 10^{-6}$
	20	$1{,}002 \cdot 10^{-3}$	$0{,}998 \cdot 10^{3}$	$1{,}004 \cdot 10^{-6}$
	40	$0{,}653 \cdot 10^{-3}$	$0{,}992 \cdot 10^{3}$	$0{,}658 \cdot 10^{-6}$
morska voda	20	$1{,}072 \cdot 10^{-3}$	$1{,}024 \cdot 10^{3}$	$1{,}047 \cdot 10^{-6}$
aceton	20	$0{,}326 \cdot 10^{-3}$	$0{,}792 \cdot 10^{3}$	$0{,}412 \cdot 10^{-6}$
glicerin	20	$1{,}490 \cdot 10^{-3}$	$1{,}261 \cdot 10^{3}$	$1{,}182 \cdot 10^{-3}$
živa	20	$1{,}554 \cdot 10^{-3}$	$13{,}546 \cdot 10^{3}$	$0{,}115 \cdot 10^{-6}$

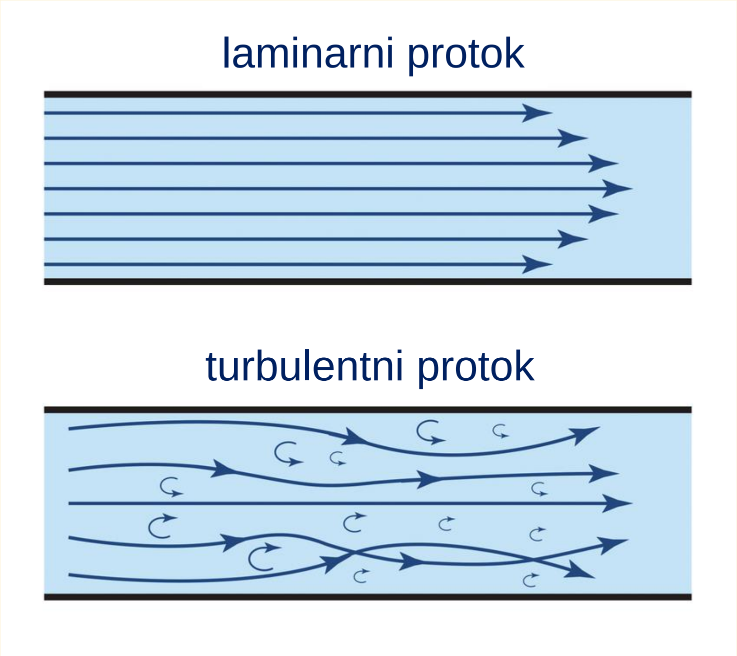
Fluidnost

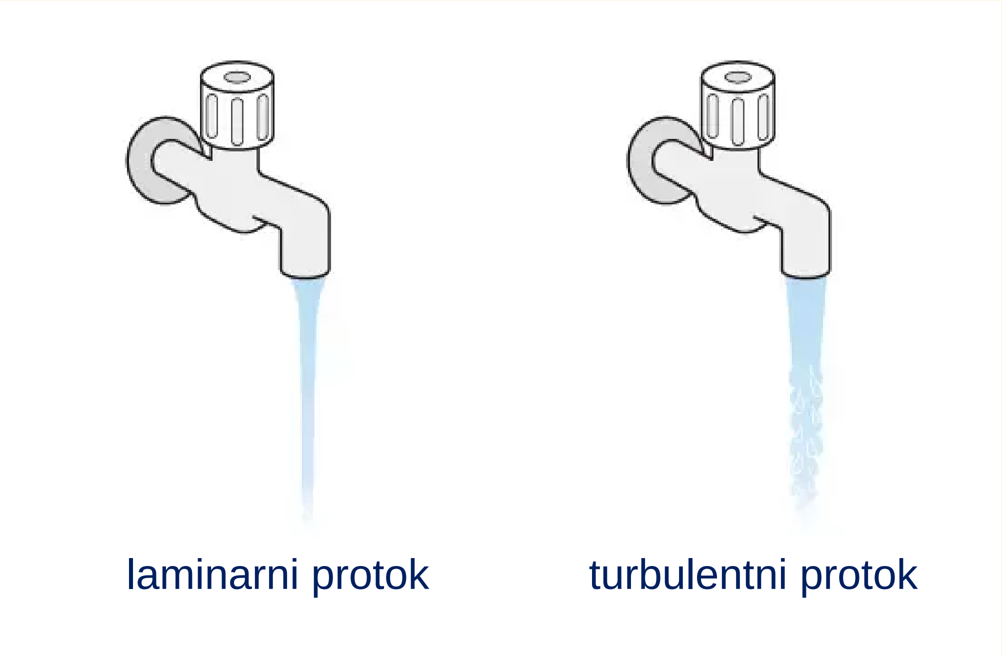
koeficijent fluidnosti: $\phi = \frac{1}{\eta}$

(pokazuje lakoću kojom tečnost teče)

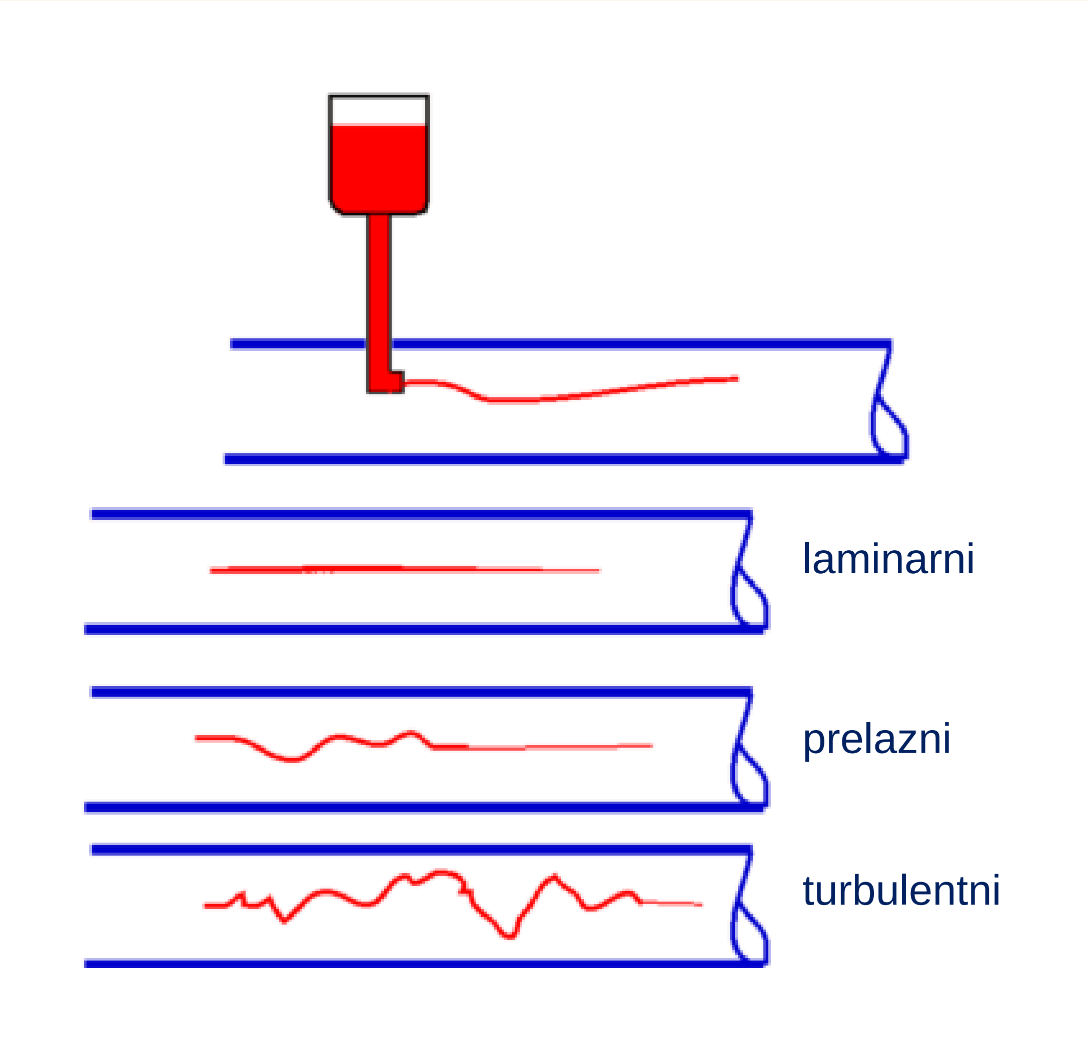


Vrste protoka





Rejnoldsov eksperiment



$$R_e = \frac{\rho v d}{\eta}$$

ρ – gustina fluida

v – srednja brzina kretanja fluida kroz cev

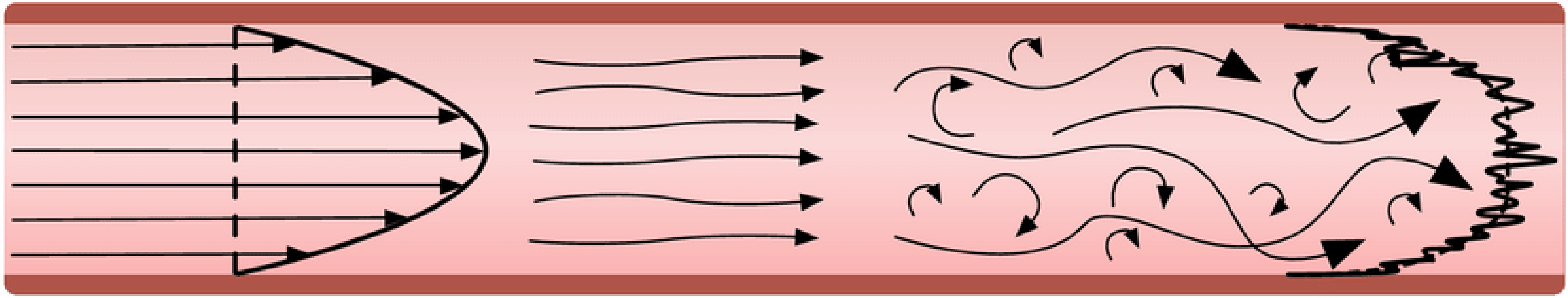
d – prečnik cevi

η – koeficijent viskoznosti fluida

Tipovi protoka fluida

$$R_e = \frac{\rho v d}{\eta}$$

Laminarni protok ($R_e < 2000$) Prelazni protok Turbulentni protok ($R_e > 4000$)

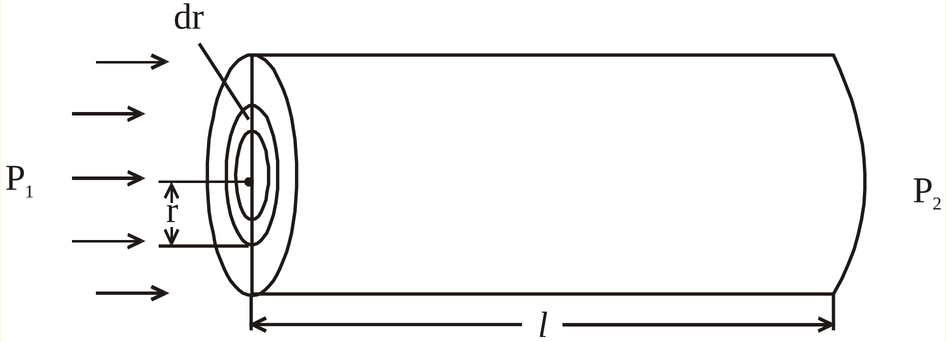


Uobičajeni tip protoka pri sporom proticanju.

Česti tip protoka pri brzom proticanju.

Poazejev zakon

Posmatra se stacionarno proticanje nestišljivog fluida kroz cev pod dejstvom konstantne razlike pritiska.



$$F^r = \Delta P \cdot \pi r^2$$

$$F_v^r = -\eta \frac{dv}{dr} 2\pi r l$$

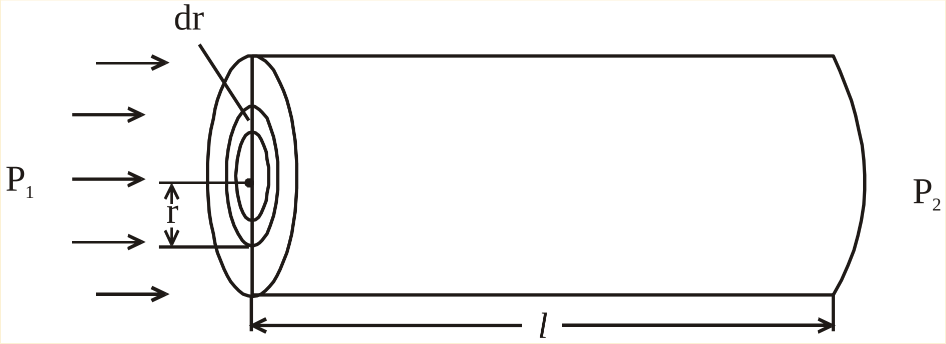
$$-\eta \frac{dv}{dr} \cdot 2\pi r l = \pi r^2 \Delta P$$

$$\int_v^0 dv = -\frac{\Delta P}{2\eta l} \int_r^R r dr$$

$$dv = -\frac{\Delta P}{2\eta l} r dr$$

$$v = \frac{\Delta P}{4\eta l} (R^2 - r^2)$$

Poazejev zakon

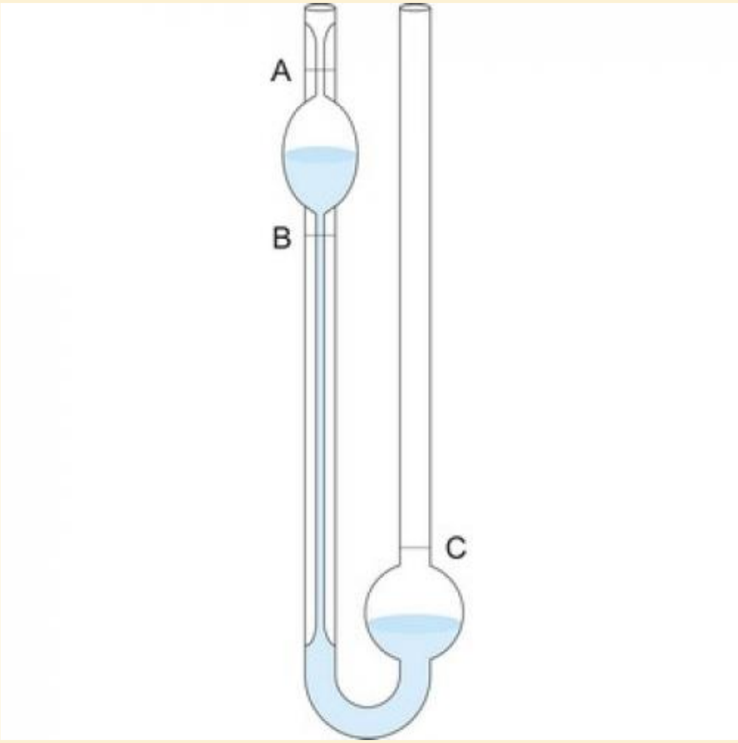


$$dV = vt2\pi r dr = \frac{\Delta P}{2\eta l}\pi(R^2 r - r^3)dr$$

$$V = \frac{\Delta P \pi t}{2\eta l}\int_0^R (R^2 r - r^3)dr$$

$$\boxed{V = \frac{\Delta P \pi R^4 t}{8\eta l}}$$

Merenje koeficijenta viskoznosti: Ostvaldov viskozimetar



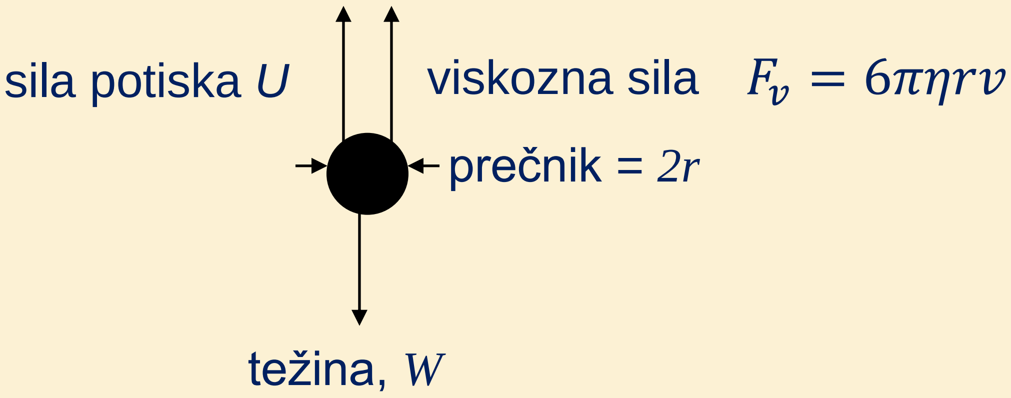
$$\eta = \frac{\Delta P \cdot \pi R^4 t}{8Vl} = \frac{\rho g h \cdot \pi R^4 t}{8Vl}$$

$$\frac{\eta}{\eta_0} = \frac{t}{t_0}\frac{\rho}{\rho_0}$$

Stoksov zakon

$$U = m_l g = \frac{4}{3}\pi r^3 \rho_l g$$

$$W = m_s g = \frac{4}{3}\pi r^3 \rho_s g$$

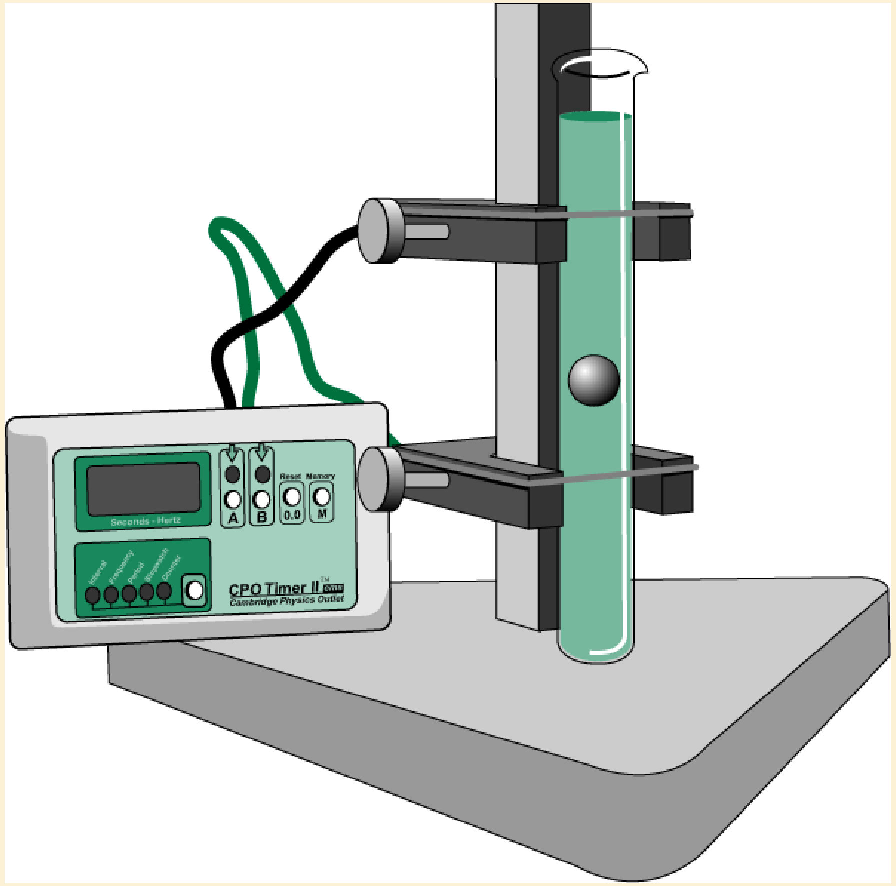


U stanju ravnoteže nema ubrzanja: $U - W + F = 0$

$$\frac{4}{3}\pi r^3(\rho_l - \rho_s)g + 6\pi\eta r\frac{l}{t} = 0$$

$$\boxed{\eta = \frac{2}{9l}r^2 g(\rho_s - \rho_l)t}$$

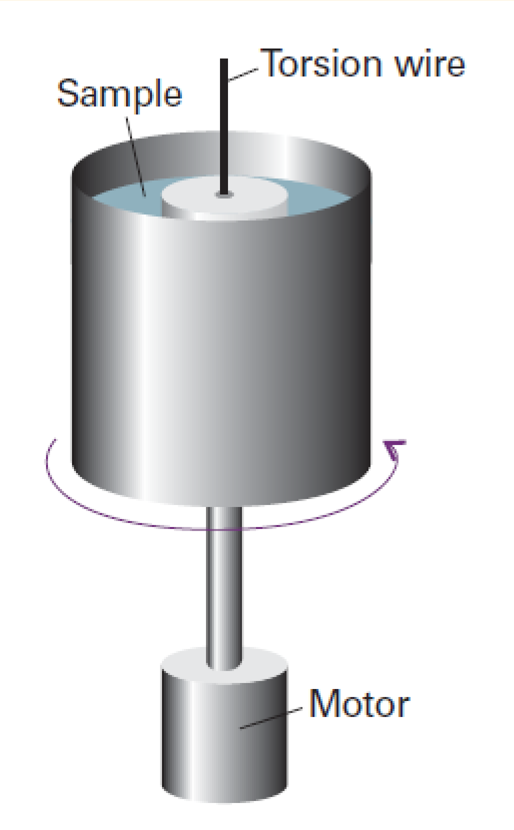
Merenje koeficijenta viskoznosti: Stoksov zakon



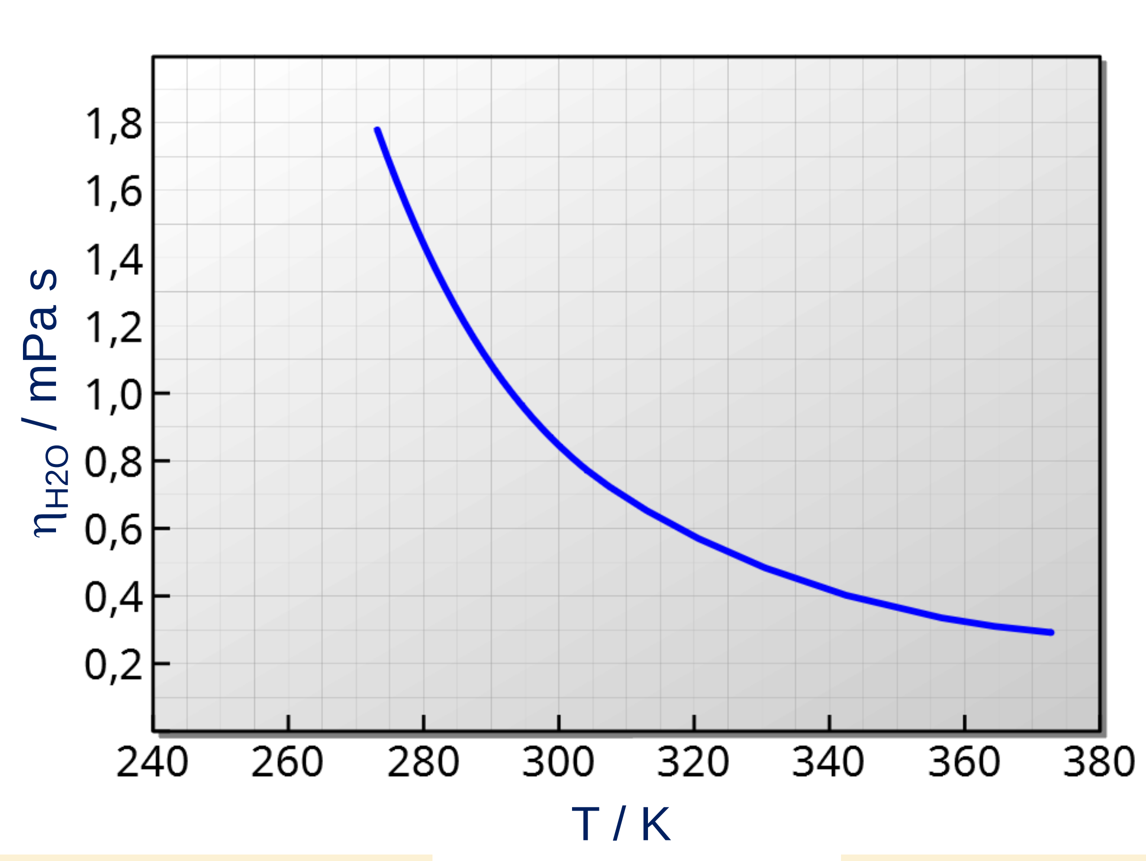
$$\eta = \frac{2t}{9l} r^2 g(\rho - \rho')$$

$$\frac{\eta_1}{\eta_2} = \frac{(\rho - \rho_1')t_1}{(\rho - \rho_2')t_2}$$

Merenje koeficijenta viskoznosti: rotacioni viskozimetar



Viskoznost i temperatura



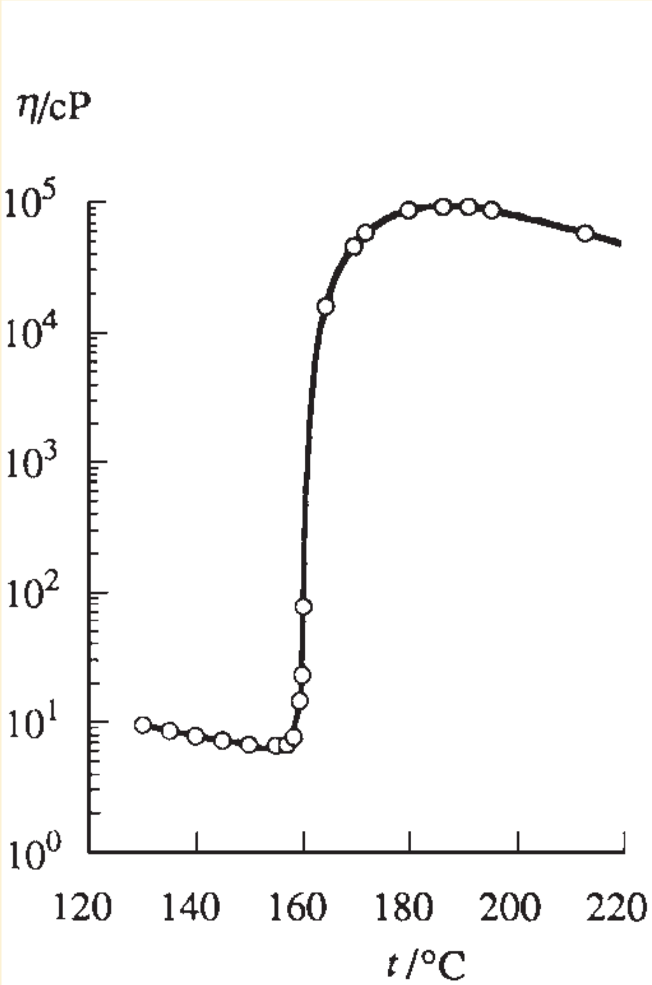
Arenijus i Gucman: $\eta = Aexp\left(\frac{B}{RT}\right)$

Andrade: $\eta v_{sp}^{1/2} = Aexp\left(\frac{B}{RTv_{sp}}\right)$

Bačinski: $\eta = \frac{c}{v_{sp} - b}$

$v_{sp} - b \approx$ zapremina šupljina

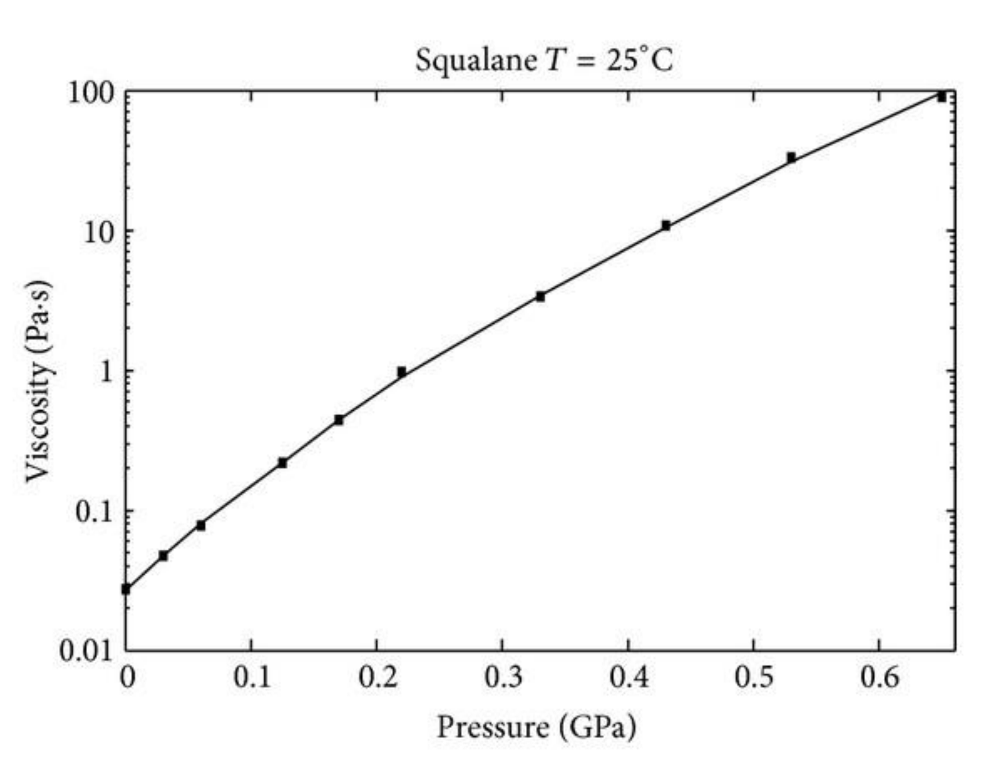
Anomalno ponašanje tečnog sumpora



Viskoznost i pritisak

$$\eta = \eta_0 exp\left(\frac{P\Delta V_h}{RT}\right)$$

ΔV_h - zapremina šupljina po molu tečnosti



Viskoznost binarnih sistema

Relativna viskoznost: $$\eta_r = \frac{\eta}{\eta_0}$$

Specifična viskoznost: $$\eta_{sp} = \frac{\eta - \eta_0}{\eta_0} = \frac{\eta}{\eta_0} - 1 = \eta_r - 1$$

Redukovana viskoznost: $$\eta_{red} = \frac{\eta_{sp}}{c}$$

Unutrašnja viskoznost: $$[\eta] = \lim_{c \to 0} \frac{\eta_{sp}}{c}$$

Primer: polimeri

Mark-Houvinkova relacija:

$$[\eta] = K\bar{M}^a$$

$[\eta]$ - unutrašnja viskoznost

K, a - konstante za posmatrani sistem polimer – tečnost

$\bar{M}$ - srednja molarna masa polimera