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PipeLine Viscometer

Aim: To prepare the shear diagram for the fluid under study and to calculate its viscosity

Theory:

The shear stress(τ) for fluids is a function of the rate of strain dγ/dt. The property of a fluid to resist the growth of shear deformation is called viscosity. The form of the relation between shear stress and rate of strain depends on fluid, and most common fluids obey Newton's law of viscosity, which states that the shear stress is proportional to the strain rate:

$$\tau = \mu \frac{du}{dy}$$

When a fluid flows through a pipe, it experiences drag because of the stationary boundary wall of the pipe. The fluid being viscous there sets in a velocity gradient. If ΔP is the pressure drop due to drag over a length of pipe L, of diameter D, at the volumetric flow rate of fluid Q, then the shear stress at the wall and average rate of shear are given by:

$$\tau_{avg} = \frac{(\Delta P)\, D}{4L} \qquad \left(\frac{du}{dr}\right)_{avg} = \frac{32Q}{\pi D^3}$$

Where,
τ = shear stress(kgf/m^2)
ΔP = Pressure drop
L = Length of pipe
Q = Volumetric flow rate

Let us consider the parallel motion of fluid where all particles are moving in the same direction, but different layers have different velocities. After a small-time Δt the fluid volume abcd moves to a ′ b ′ c ′d ′ (figure 1), where |aa′ | = |bb′ | = u(y + δy)Δt and |cc′ | = |dd′ | = u(y)Δt. The corresponding shear strain is

$$\gamma = \frac{\Delta x}{\delta y} = \frac{(\,u(y+\delta y) - u(y)\,)\,\Delta t}{\delta y}\,.$$

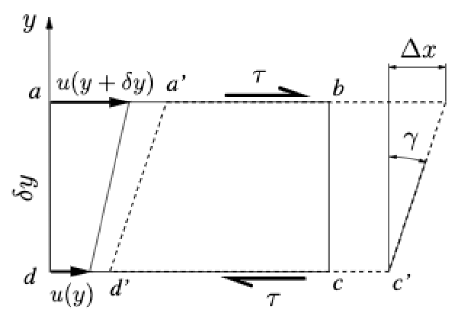


Fig. 1

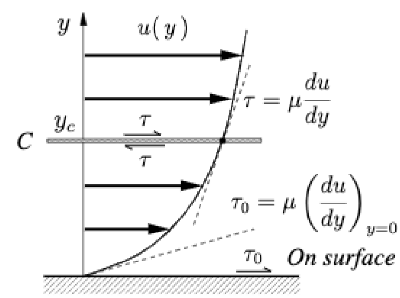


Fig. 2

For small Δt the strain can be expressed via its rate of change as

$$\gamma = \frac{d\gamma}{dt}\Delta t\,.$$

Then we can write

$$\frac{d\gamma}{dt} = \frac{u(y+\delta y) - u(y)}{\delta y}$$

and for small δy this gives

$$\frac{d\gamma}{dt} = \frac{du}{dy}\,.$$

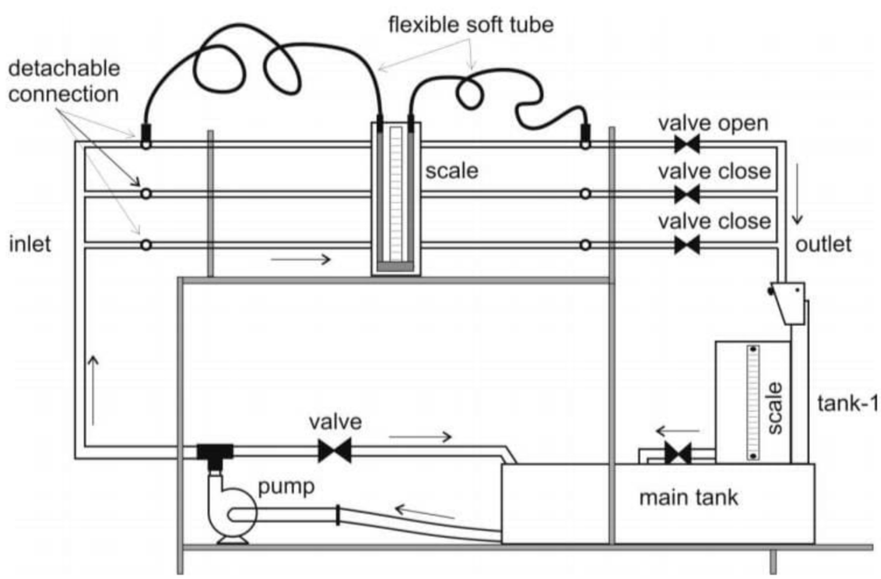
Therefore, for a parallel flow of a Newtonian fluid shear stress is proportional to the gradient of velocity in the direction perpendicular to the flow, that is

$$\tau = \mu \frac{du}{dy}\,.$$

Let a surface C : y = yc is parallel to the flow and the velocity gradient is positive (figure 2). The flow above y = yc will apply the positive shear force on the upper surface of C, and the equal negative shear force will act on the lower surface of C from the fluid behind y = yc. Both of these forces are due to the same shear stress τ , which is considered positive in this case. On a rigid surface (y = 0, figure 2) the fluid velocity is equal to the surface velocity (no-slip condition), and the shear force on a solid wall can be found from the value of the velocity gradient on the wall (figure 2). For a uniform flow, τ is constant along the wall, an

$$F_\tau = A\,\mu \left(\frac{du}{dy}\right)_{y=0} .$$

Schematic -



Observation Table

Pipe:1 **D:1.37 cm ρ=1.67 g/cc L= 186 cm**

Sl. No.	Mass of fluid collected g)	Time (s)	Volumetric flow rate (m^3/s)	Pressure drop (manometer)		Difference Δh(cm)	$P = (\Delta h/100)g\,(\rho_m - \rho)$ (kgf/m^2)
				Left limb (cm)	Right limb (cm)		
1.	200	3.42	0.000035	17.1	9.4	7.7	506.098
2.	275	3.22	0.0000511	5.3	15.9	10.6	696.706
3.	195	2.24	0.0000521	7.4	11.5	4.1	269.481
4.	200	3.82	0.0000314	9.9	6.7	3.2	210.326
5.	180	4.81	0.0000224	11.3	3.9	7.4	486.38

Pipe:2 **D:0.5 cm ρ= 1.67 g/cc L= 186 cm**

Sl. No.	Mass of fluid collected g)	Time (s)	Volumetric flow rate (m^3/s)	Pressure drop (manometer)		Difference Δh(cm)	$P = (\Delta h/100)\,g\,(\rho_m - \rho)$ (kgf/m^2)
				Left limb (cm)	Right limb (cm)		
1.	10	9	0.000001	11.6	9.7	1.9	486.378
2.	10	5.53	0.000002	12.3	8.7	3.6	124.881
3.	50	13.5	0.000004	7.4	6.6	0.8	236.617
4.	45	11.75	0.000004	6.4	8.6	2.2	52.582
5.	50	9.69	0.000005	4.6	12.6	8	144.599

<u>Pipe:3</u> **D:0.3 cm ρ=1.67 g/cc L= 186 cm**

Sl. No.	Mass of fluid collected g)	Time (s)	Volumetric flow rate (m^3/s)	Pressure drop (manometer)		Difference Δh(cm)	$P = (\Delta h/100)\, g\, (\rho_m - \rho)$ (kgf/m^2)
				Left limb (cm)	Right limb (cm)		
1.	10	1.37	0.000007	9.4	6.5	2.9	190.6083
2.	20	8.95	0.000002	10.1	6.0	4.1	269.4807
3.	30	4.79	0.000006	13.2	2.6	10.6	696.7062
4.	30	4.03	0.000007	12	4.1	7.9	519.2433
5.	53	5.72	0.000009	15.6	0.6	15	985.905

<u>Pipe:4</u> **D:0.6 cm ρ= 13.6 g/cc L= 186 cm**

Sl. No.	Mass of fluid collected g)	Time (s)	Volumetric flow rate (m^3/s)	Pressure drop (manometer)		Difference Δh(cm)	$P = (\Delta h/100)\, g\, (\rho_m - \rho)$ (kgf/m^2)
				Left limb (cm)	Right limb (cm)		
1.	29	8.52	0.000003	11.9	5.5	6.4	7910.784
2.	52	10.63	0.000005	13.2	4.3	8.9	11000.934
3.	30	5.36	0.000006	14.1	3.4	10.7	13225.842
4.	30	4.41	0.000007	15.5	1.8	13.7	16934.022
5.	31	4.6	0.000007	16	0.9	15.1	18664.506

Calculations Table

S. No.	Pipe No.	Volumetric flow rate (m^3/s)	Difference Δh(cm)	$P = (\Delta h/100)g(\rho_m - \rho)$ (kgf/m^2)	Shear Stress	du/dr	Viscosity	Mean Viscosity
1	Pipe-1	0.000058	7.7	506.098	0.932	231.854	0.004019	0.0034306
		0.000085	10.6	696.706	1.283	338.467	0.00379	
		0.000087	4.1	269.481	0.496	345.205	0.001437	
		0.000052	3.2	210.326	0.387	207.678	0.001865	
		0.000037	7.4	486.38	0.896	148.228	0.006042	
2	Pipe-2	0.000001	1.9	124.881	0.084	89.682	0.000936	0.000657
		0.000002	3.6	236.617	0.159	146.752	0.001084	
		0.000004	0.8	52.582	0.035	301.656	0.000117	
		0.000004	2.2	144.599	0.097	309.809	0.000314	
		0.000005	8	525.816	0.353	423.949	0.000834	
3	Pipe-3	0.000007	2.9	190.608	0.077	2755.367	0.000028	0.000093
		0.000002	4.1	269.481	0.109	830.385	0.000131	
		0.000006	10.6	696.706	0.281	2377.919	0.000118	
		0.000007	7.9	519.243	0.209	2793.112	0.000075	
		0.000009	15	985.905	0.398	3510.262	0.000113	
4.	Pipe-4	0.000003	6.4	7910.784	6.38	160.415	0.03977	0.0417392
		0.000005	8.9	11000.934	8.872	231.187	0.038375	
		0.000006	10.7	13225.842	10.666	264.213	0.040369	
		0.000007	13.7	16934.022	13.656	320.83	0.042566	
		0.000007	15.1	18664.506	15.052	316.112	0.047616	

The final value of the viscosity of water is the average of all the individual viscosity.
Hence viscosity of water from the observations is 0.01143 (Pa.s)

Calculations

Consider the following case,
For Pipe-2,
Mass of fluid collected (m) = 10g D = 1.37 cm
Time (t) = 4.81s L = 186 cm
Δh = Left limb - right limb
= 3.6 cm

$$\text{Volumetric flow rate } (V) = \text{Mass rate} \times \frac{1}{\rho}$$

$$= \frac{m}{\rho t}$$

$$V = \frac{10}{1000} \times \frac{1}{5.53} \times \frac{1}{1000}$$

$$= 2 \times 10^{-6} \, m^3/s$$

$$\Delta P = \frac{\Delta h}{100} \times (\rho m - \rho) * g$$

$$= \frac{3.6}{100} \times (1000 - 1670) * 9.8$$

$$= 236.617 \text{ kg-f}/m^2$$

$$\tau_{avg} = \frac{(\Delta P) D}{4L} = \frac{236.617 \times 1.37 \times 10^{-2}}{4 \times 186 \times 10^{-2}}$$

$$= 0.159 \, N/m^2$$

$$\left(\frac{du}{dr}\right)_{avg} = \frac{32 Q}{\pi D^3} = \frac{32 \times 2 \times 10^{-6}}{3.14 \times 1.37^3 \times 10^{-6}}$$

$$= 146.752 \, s^{-1}$$

From Newton's law of Viscosity,

$$\tau = \mu \frac{du}{dr}$$

$$\Rightarrow \mu = 0.001028 \text{ poise}$$

Shear Diagram

For Pipe 1,

$$Re = \frac{\rho v L}{\mu}$$

$$\Rightarrow Re = \frac{1000 \times 0.237 \times 1.37 \times 10^{-2}}{0.0006547}$$

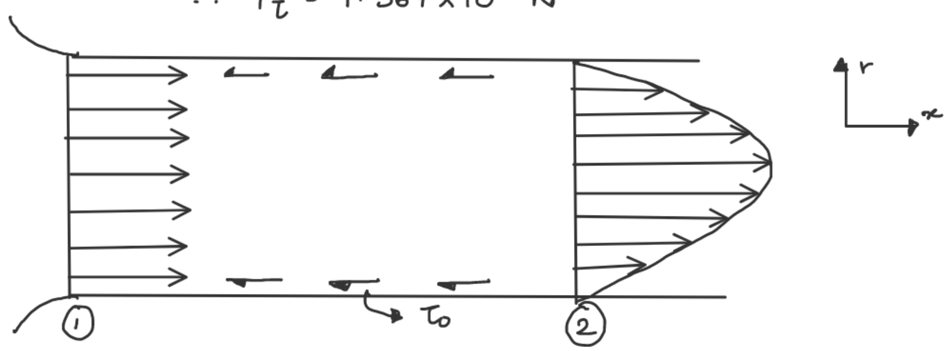
$$= 495.937$$

$\therefore$ The flow is laminar

$$F_\tau = A \mu \left(\frac{du}{dy}\right)_{y=0}$$

$$= \pi \times 1.37^2 \times 10^{-4} \times 2.32$$

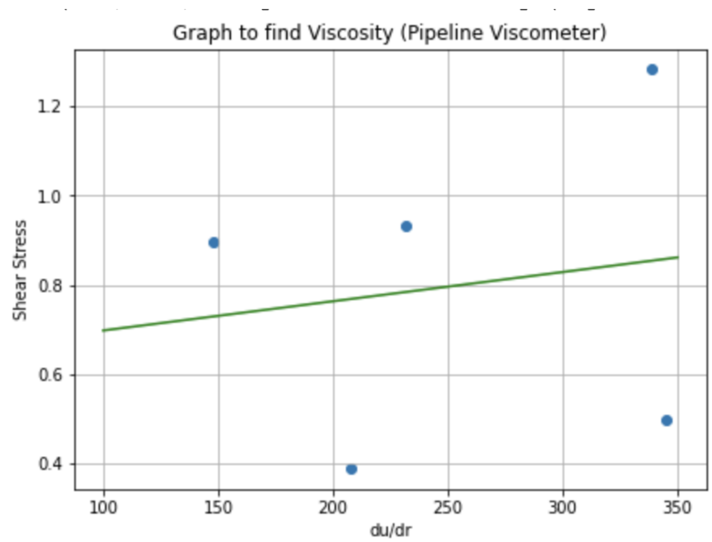
$$\therefore F_\tau = 1.367 \times 10^{-3} \text{ N}$$



There are two regions being shown ① is at the entrance region and ② is at fully developed region with $F_\tau = 1.367 \times 10^{-3}$ N

Plot

For Pipe-1,



Thus, the viscosity from the curve is 0.65472 cp

Conclusion

The difference between the values is because we didn't take the losses into account. The losses that we should account for to get accurate results are frictional losses, possible errors from the rotameter etc. The value of the viscosity of water at 25°C is 0.00089 Pa.s, and the value of viscosity from the plot is 0.000659 which is the closest value we got from the plot of pipe-1. But the value of viscosity we got from averaging all the values is 0.01143 Pa.s, which is far away from the actual value of viscosity of water at 25°C. The reason for this inconsistency can be the improper data set collection, improper working of the instruments, capillary rise in the manometer. From the experiment, we got to know that shear stress is directly proportional to shear rate for Newtonian fluids and the value of the viscosity is the slope of the graph between shear stress and shear rate. Hence we calculated the viscosity of water and concluded that water is a Newtonian fluid.