Fluid Mechanics Primer

Part II

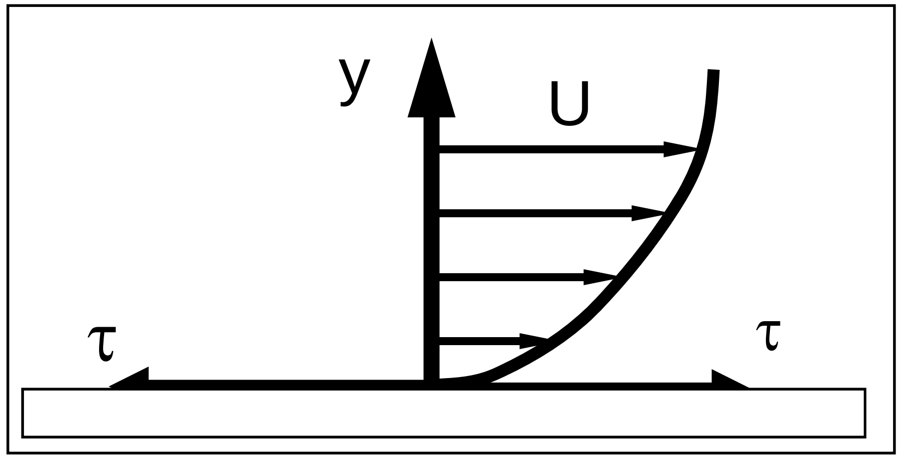
Shearing of a fluid

- Fluids are broadly classified in terms of the relation between the shear stress and the rate of deformation of the fluid.
- Fluids for which the shear stress is directly proportional to the rate of deformation are know as *Newtonian* fluids.
- Engineering fluids are mostly Newtonian. Examples are water, refrigerants and hydrocarbon fluids (e.g., propane).
- Examples of non-Newtonian fluids include toothpaste, ketchup, and some paints.

Shear stress in moving fluids

Newtonian fluid

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

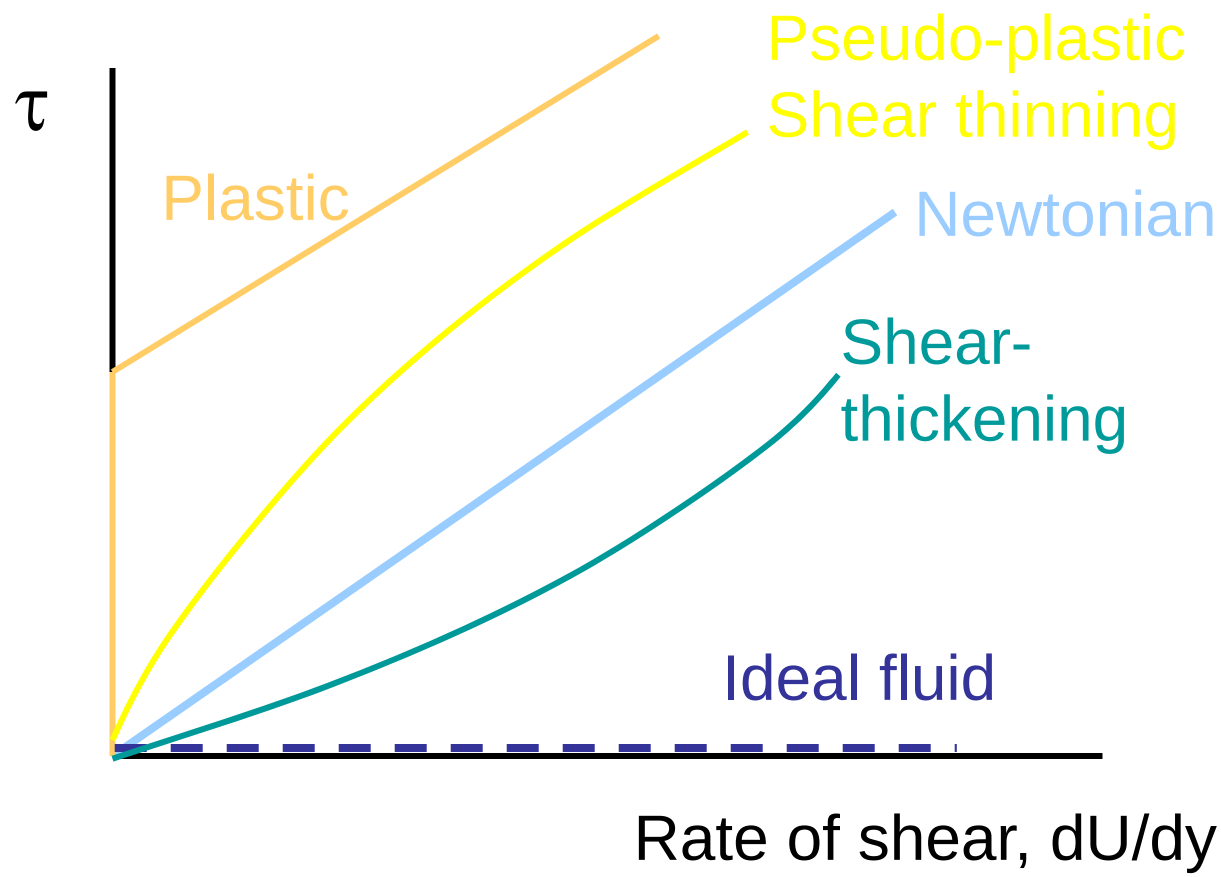


μ = (mu)= viscosity (or dynamic viscosity) kg/m s

ν = (nu)= kinematic viscosity m^2/s

$$\nu = \mu / \rho$$

Non-Newtonian Fluids



Viscous forces: F_u

$$\tau = \frac{F_u}{Unit\ Area} = \mu \frac{V}{h}$$

$$\tau \approx \frac{F_u}{h^2} = \mu \frac{V}{h}$$

$$F_u = \mu V h$$

Reynolds number (1)

Inertial force = F_I

$$F_I = \rho V^2 h^2$$

Viscous force = F_u

$$F_u = \mu V h$$

$$\mathrm{Re} = \frac{F_I}{F_u} = \frac{\rho V^2 h^2}{\mu V h} = \frac{\rho V h}{\mu}$$

$$\boxed{\mathrm{Re} = \frac{\rho V h}{\mu}}$$

Re indicates when inertial forces for the fluid flow are large compared to the viscous forces. It is one of the most important non-dimensional numbers in fluid mechanics. Geometrically similar flows with similar Re will have similar boundary layers and other flow structures.

Reynolds number (2)

- Kinematic viscosity = dynamic viscosity/density

$$\nu \equiv \frac{\mu}{\rho}$$

- So Reynolds number becomes:

$$\mathrm{Re} = \frac{Vh}{\nu} = \frac{Velocity \bullet Length}{Kinematic\ Vis\cos ity}$$

- Re described by a velocity, length, and viscosity

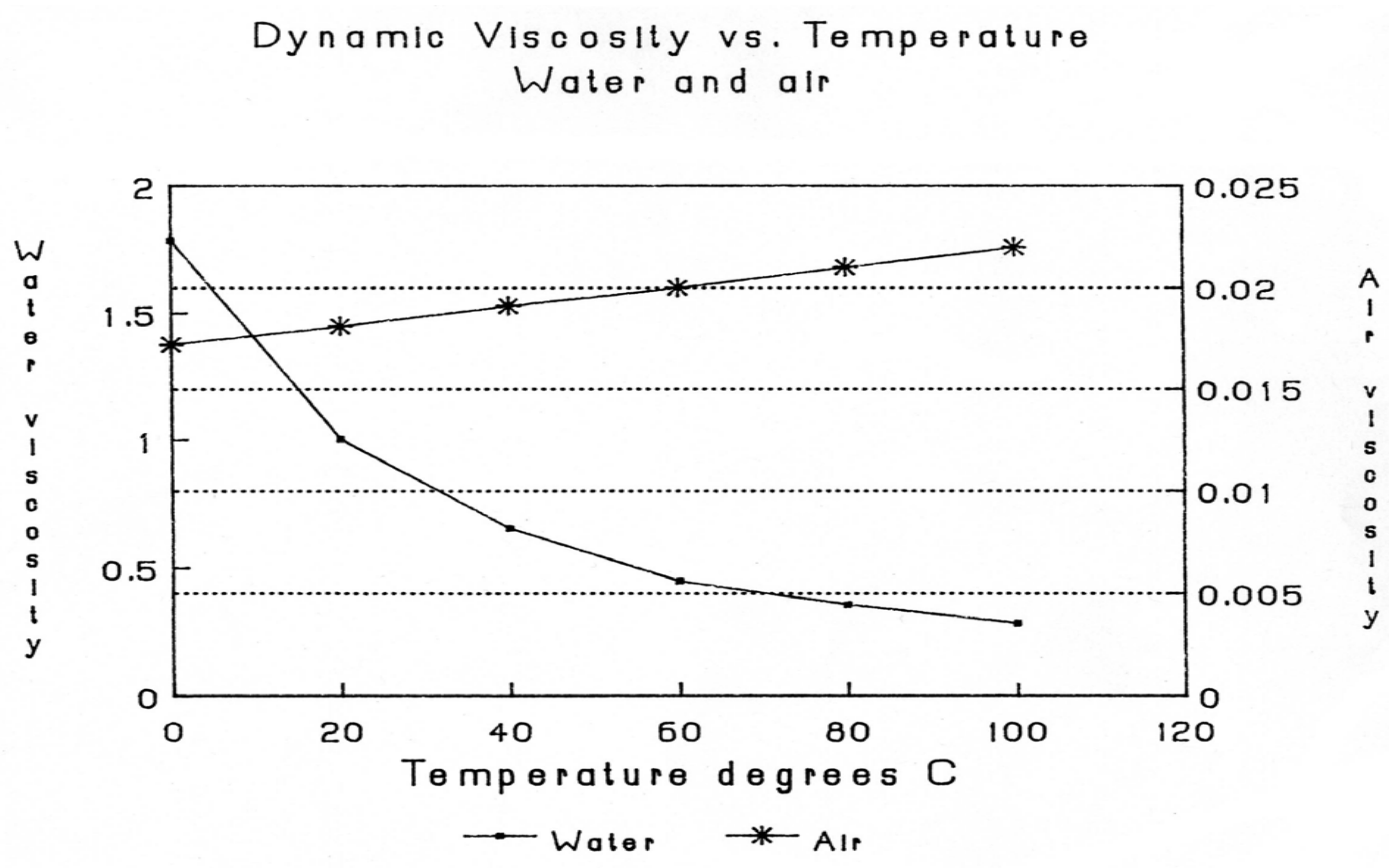
Application of Reynolds number

- The Re is useful to describe when the inertial of the fluid is important relative to the viscosity
  - Inertial forces → keeps things moving
  - Viscous forces → makes things stop
- Re also tells when the flow is smooth (laminar) or chaotic (turbulent)
  - High Inertial forces → large Re → turbulent flow
  - High viscous forces → small Re → laminar flow
- Laminar flow generally for Re < 1000
- Turbulent flow generally for Re > 10,000

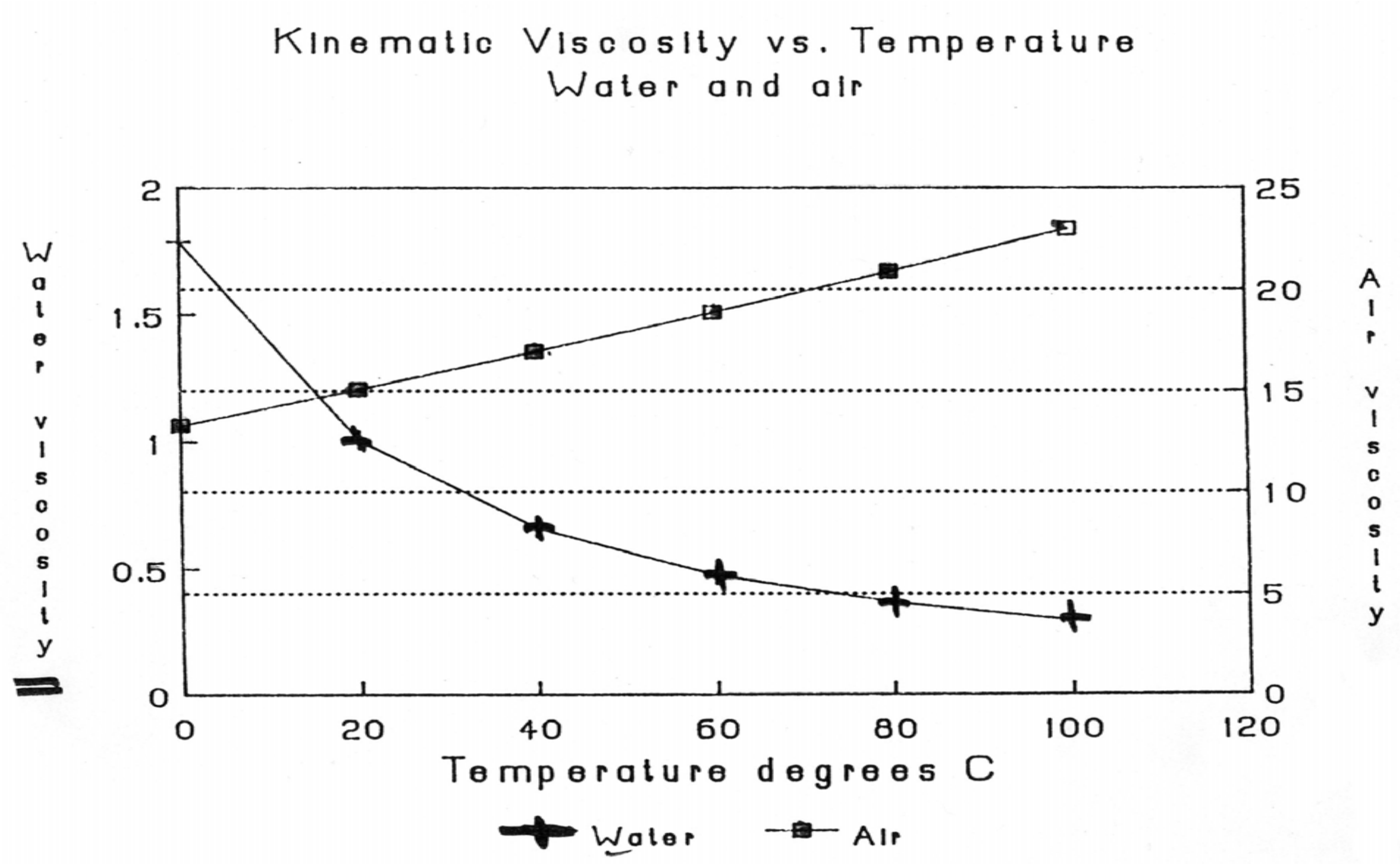
Viscosity changes with Temp

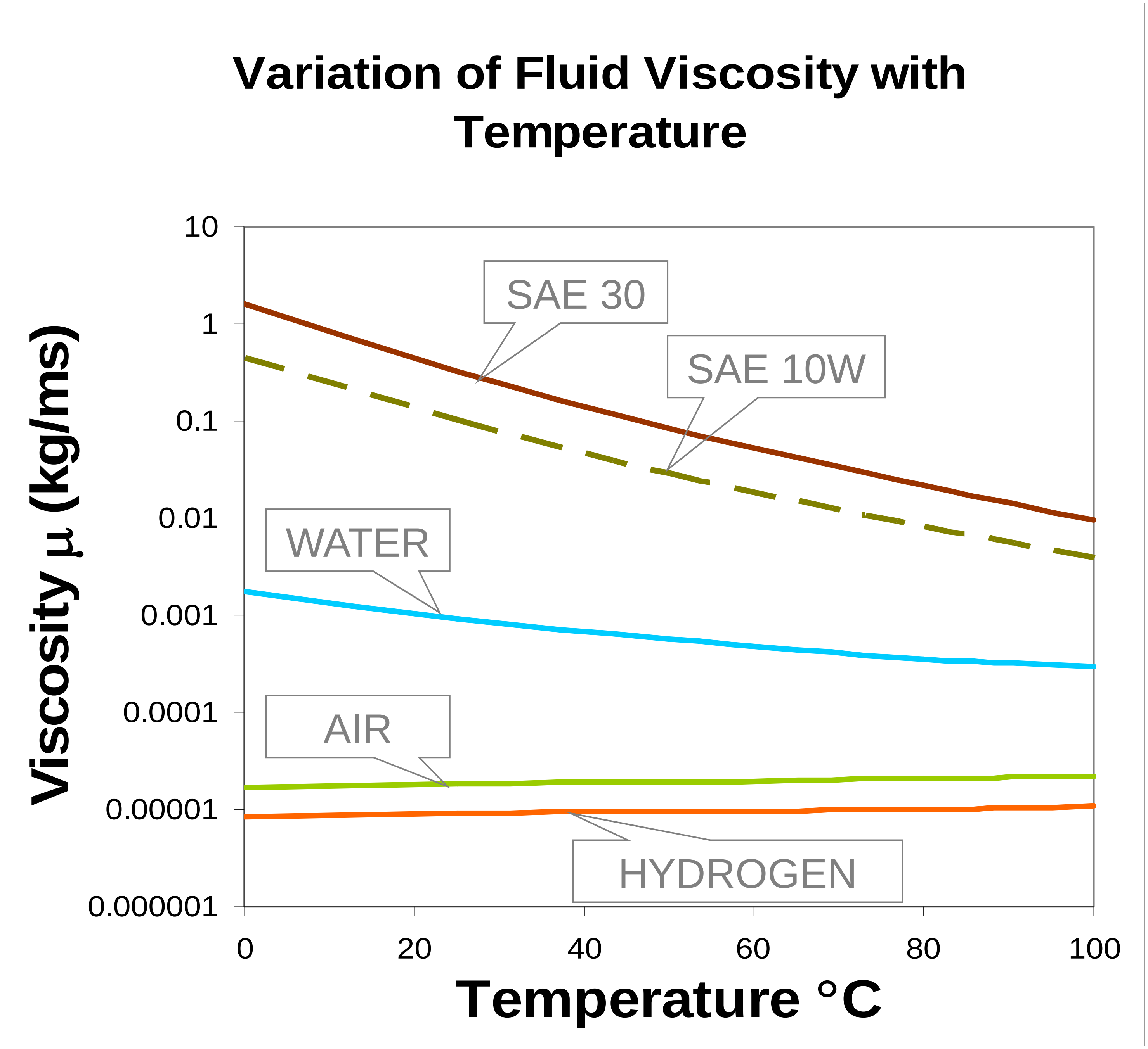
- Fluid properties depend on T (and P somewhat) because of molecular interactions
  - For a liquid, as T increases viscosity decreases
  - For a gas, as T increases viscosity increases
- Gases also change density significantly with T, so the kinematic viscosity increases more rapidly than the dynamic viscosity

Dynamic viscosity



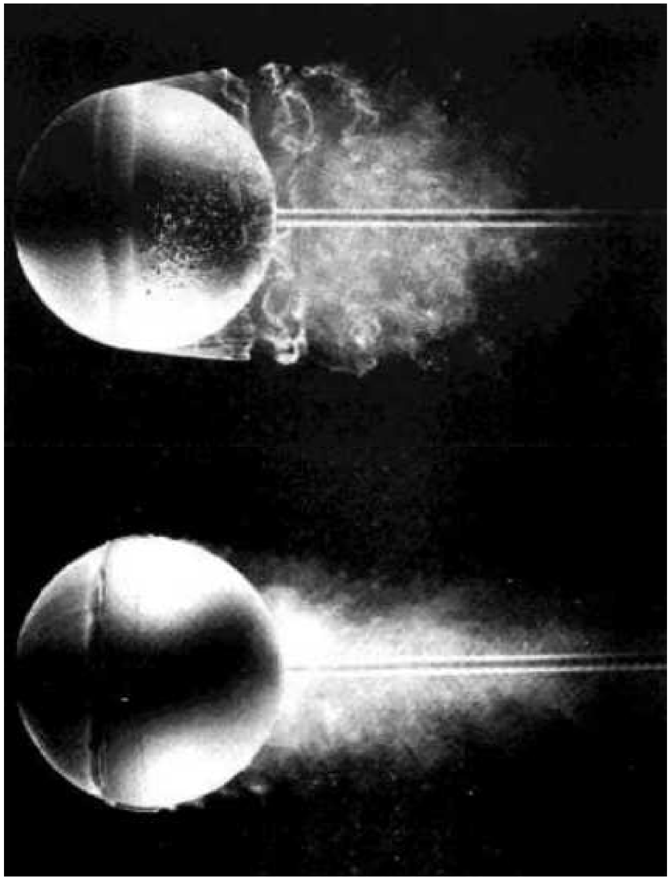
Kinematic Viscosity

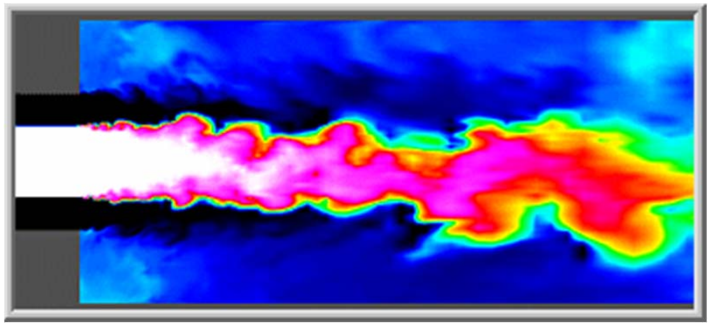



Variation of Fluid Viscosity with Temperature
10
1
0.1
0.01
0.001
0.0001
0.00001
0.000001
Viscosity μ (kg/ms)
SAE 30
SAE 10W
WATER
AIR
HYDROGEN
0
20
40
60
80
100
Temperature °C

Laminar and Turbulent flow

- UPPER IMAGE: Flow past a sphere at Re =15,000. Boundary layer separating ahead of the equator and remaining laminar ~ one radius, then becomes unstable and turbulent.
- BOTTOM IMAGE: Flow past a sphere at Re =30,000 with a trip wire. Wire hoop ahead of the equator trips the boundary layer, so it separates farther back than if it were laminar. The overall drag is dramatically reduced. This occurs naturally on a smooth sphere only at a Re numbers 10 times as great.
- Flow from a turbulent jet [car exhaust]





Jet: Werle, 1980 (ONERA) Photos from Album of Fluid Motion," by Van Dyke

Flow in a pipe for different Re

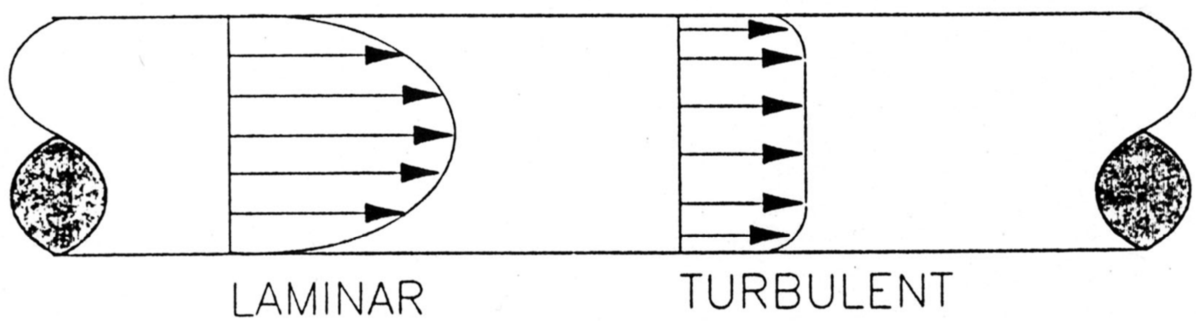
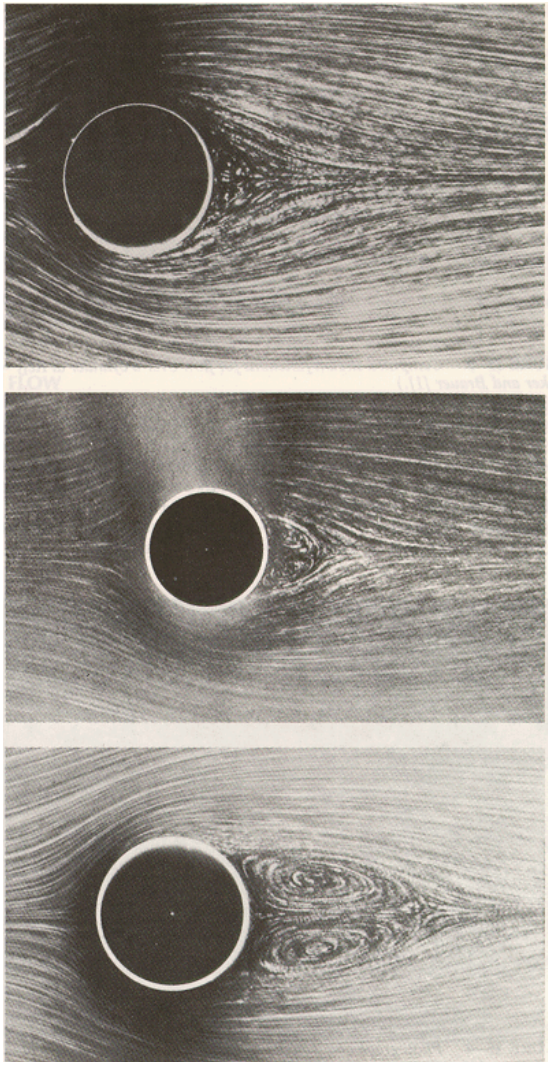


Figure 2.6 Flow-velocity profiles of laminar ($Re < 2000$) and turbulent ($Re > 4000$) flow regimes. The turbulent flow profile is nearly uniform across the radius, whereas the laminar profile is more parabolic.

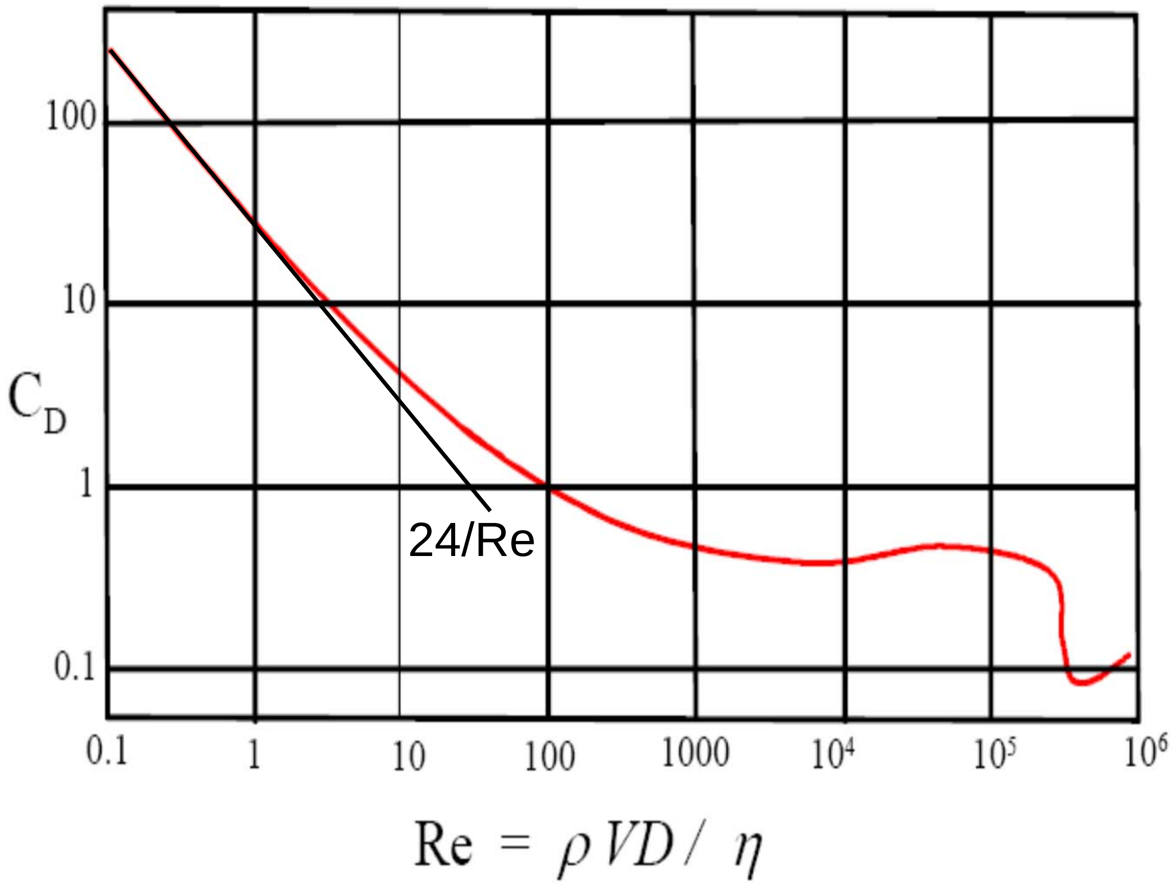
Flow around a sphere



- Re ~ 1
- Re ~ 10
- Re ~ 100

http://www.youtube.com/watch?v=vQHXIHpvcvU

Coefficient of Drag for a Sphere



$$F_D = \left(\frac{1}{2}\rho V^2\right) C_D A_D$$

$$A_D = \pi D^2 / 4$$

Variation of Log (Cd) vs Log(Re) for a smooth sphere

Line shows Cd for stokes region (Re<1)

Eqn's: Drag Coefficient (Spheres)

- For smooth spheres Newton's drag law:

$$F_D = C_D \frac{\pi}{8} \rho_G d^2 V^2$$

- Re < 1, Cd = 24/Re

- 1< Re<1000

$$C_D = \frac{24}{Re}\left(1 + \frac{Re^{\frac{2}{3}}}{6}\right)$$

- 1000 < Re < 10^5
  Cd ≈ 0.44 Re

Typical values

Property	Water	Air
Density ρ (kg/m^3)	1000	1.23
Bulk modulus K (N/m^2)	2×10^9	--------
Viscosity μ (kg/ms)	1.14×10^{-3}	1.78×10^{-5}

END HERE Part II