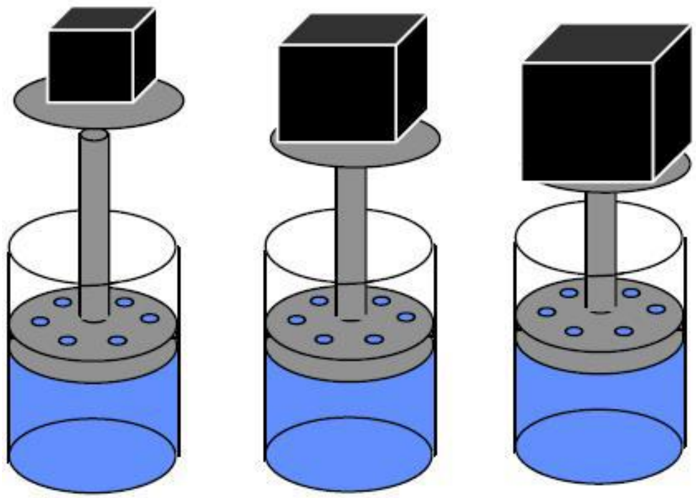
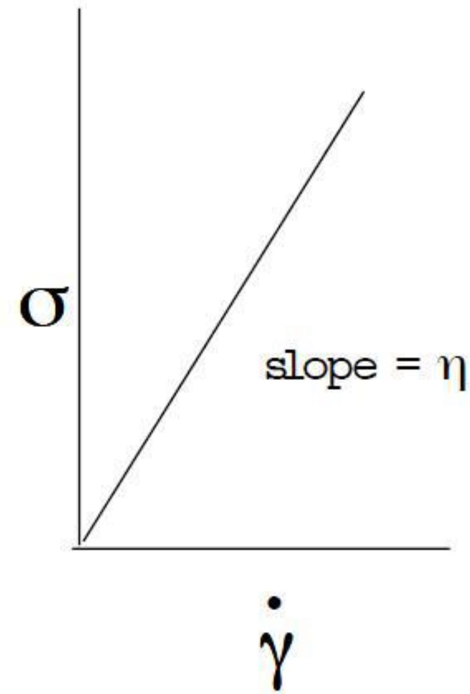
Fluids properties-Viscosity

Viscosity

- Measure of resistance to deformation
- by shear stress or tensile strength
- – ‘thickness’ of liquids
- – resistance to flow
- SI unit for viscosity is Pa.s
- Polymer viscosity is usually between
- 10^{1}-10^{10} Pa·s

The viscous limit: Newtonian behavior





The speed at which the fluid flows through the holes (the strain rate) increases with stress!!!

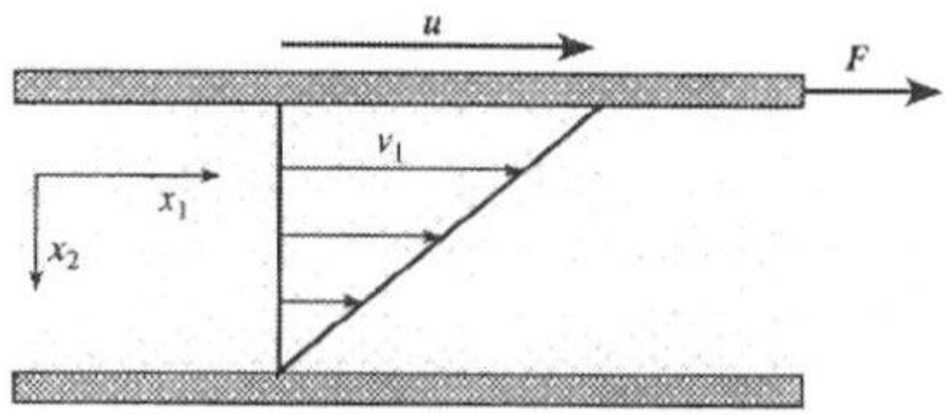
– Newtonian fluid

Viscosity does not depend on shear rate

Fluids are almost always Newtonian

Viscosity: Steady, simple shear flow

- Fluid confined between two parallel plates
- Upper plate moves at a constant velocity while the lower plate is at rest
- The force needed to move the upper plate is F and the contact area of the upper plate to the liquid is A
- The shear stress is
- $\delta = F/A$



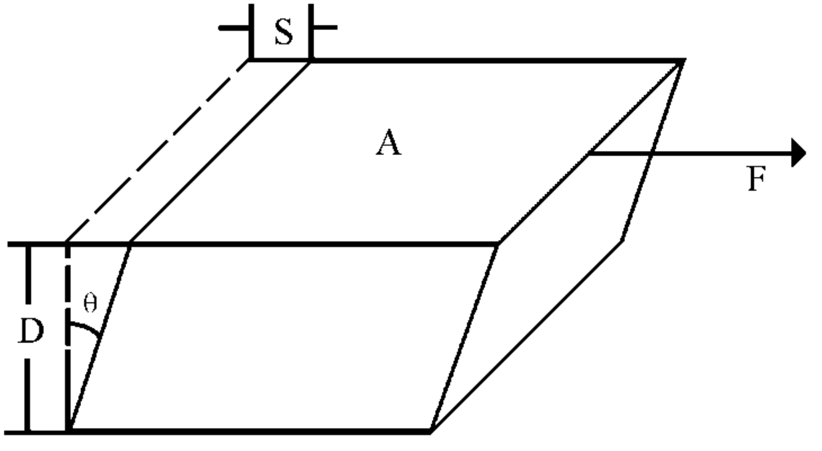
Shear viscosity

Dynamic (or Absolute) Viscosity:

- Shear stress δ = *F* /*A* (Pa)

- Shear deformation $\gamma = S/D = \tan\Theta$

- Viscosity $\eta = \frac{\delta}{\frac{d\gamma}{dt}} = \frac{\delta}{\dot{\gamma}}$ (Pa×s)



Shear viscosity

Kinematic Viscosity :

- It is defined as the ratio of absolute viscosity to the density of fluid.

$\nu = \eta/\rho$ m^2/s ; ρ= density of fluid

Kinematic Viscosity, $\nu = \mu/\rho$

Where,.

ν = Kinematic viscosity

μ = Dynamic viscosity

ρ = Density of the fluid

Measurement of viscosity

- Rheological properties are measured as a function of temperature and shear rate
- Methods are divided:

1. Static shear strain methods

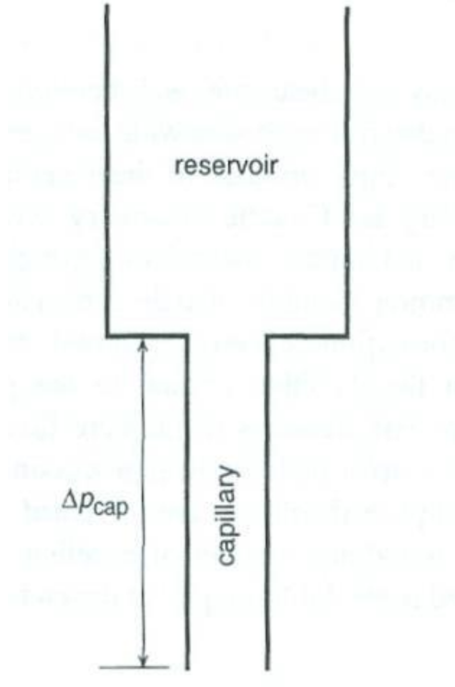
- Capillary Rheometer
- Couette Rheometer (Concentric cylinder)
- Parallel plate
- Cone and plate

2. Dynamic shear strain methods

Dynamic Rheometer

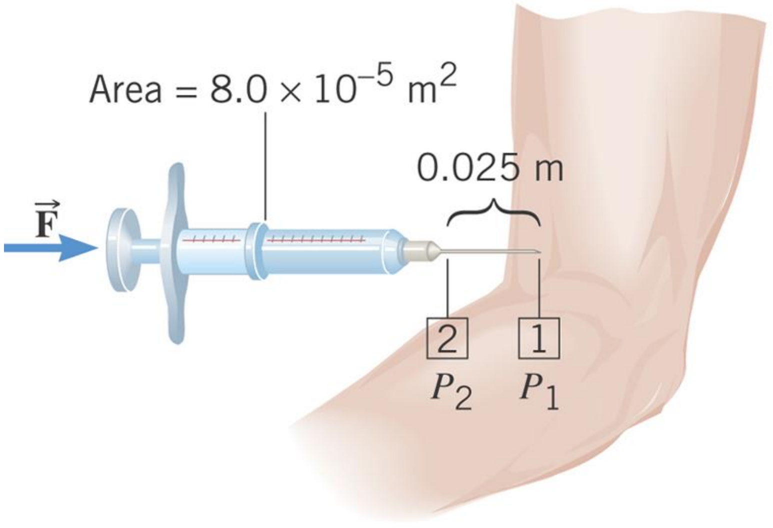
Capillary rheometer

- The measurement of **volumetric flow rate**, **Q**, as a function of D**P** through a capillary of known dimensions. The capillary is attached to a reservoir containing the polymer solution or melt. Pressuration of the reservoir forces the fluid through the capillary:



- $\eta = \dfrac{\pi R^4 P}{8LQ}$
- *R* = radius of capillary (m)
- *L* = length of capillary (m)
- *P* = pressure drop across the capillary (Pa)
- *Q* = volumetric flow rate (m3/s)

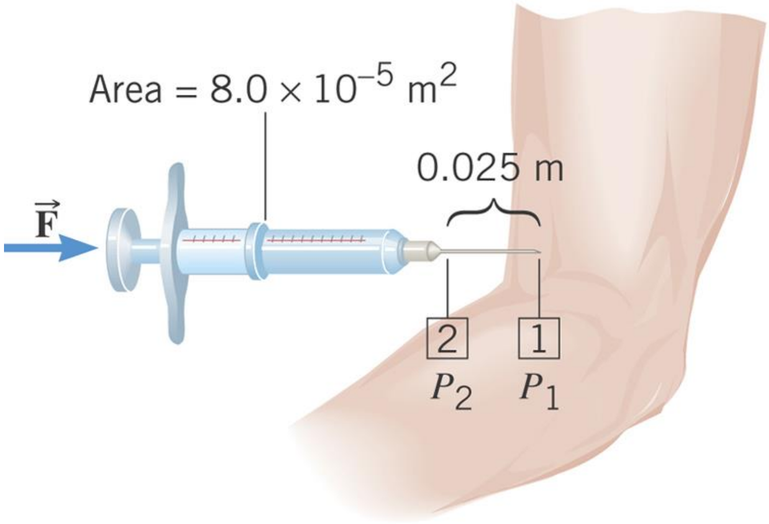
Example-1



***Example 17* Giving and Injection**

A syringe is filled with a solution whose viscosity is 1.5×10^{-3} Pa·s. The internal radius of the needle is 4.0×10^{-4}m.

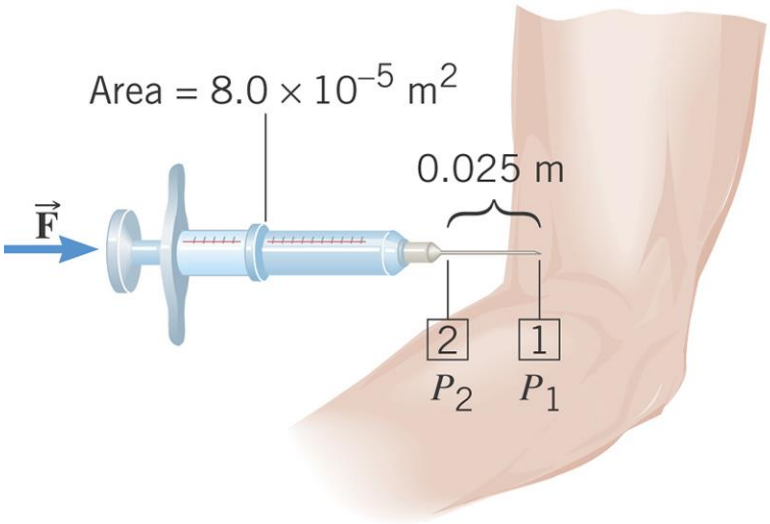
The gauge pressure in the vein is 1900 Pa. What force must be applied to the plunger, so that 1.0×10^{-6}m^3 of fluid can be injected in 3.0 s?



$$P_2 - P = \frac{8\eta LQ}{\pi R^4}$$

$$= \frac{8\left(1.5\times10^{-3}\,\mathrm{Pa\cdot s}\right)\left(0.025\,\mathrm{m}\right)\left(1.0\times10^{-6}\,\mathrm{m^3}/3.0\,\mathrm{s}\right)}{\pi\left(4.0\times10^{-4}\,\mathrm{m}\right)^4}$$

$$= 1200\,\mathrm{Pa}$$



$$P_1 = 1900\,\mathrm{Pa}$$

$$P_2 - P_1 = 1200\,\mathrm{Pa}$$

$$\Downarrow$$

$$P_2 = 3100\,\mathrm{Pa}$$

$$F = P_2 A = (3100\,\mathrm{Pa})(8.0\times10^{-5}\,\mathrm{m}^2) = 0.25\mathrm{N}$$

Effects of Temperature

Liquids

- Temperature increase= viscosity decrease
- Temperature decrease= viscosity increase

Gases

- Temperature increase= viscosity increase
- Temperature decrease=viscosity decrease

Circulation

- The main function of the systemic circulation is to deliver adequate oxygen, nutrients to the systemic tissues and remove carbon dioxide & other waste products from the systemic tissues
- The systemic circulation is also serves as a conduit for transport of hormones, and other substances and allows these substances to potentially act at a distant site from their production

Functional Parts

- systemic arteries
  - designed to carry blood under high pressure out to the tissue beds
- capillaries- one cell layer thick
  - exchange between tissue (cells) & blood
- systemic veins
  - return blood to heart/dynamic storage

Basic theory of circulatory function

- Blood flow is proportional to metabolic demand
- Cardiac output controlled by local tissue flow
- Arterial pressure control is independent of local flow or cardiac output

Hemodynamics

- Flow
- Pressure gradient
- Resistance
- Ohm's Law
  - $V = IR$ (Analogous to $\Delta P = QR$)

Flow (Q)

- The volume of blood that passes a certain point per unit time (eg. ml/min)
- Q = velocity, X cross sectional area
  - At a given flow, the velocity is inversely proportional to the total cross sectional area
- $Q = \Delta P / R$
  - Flow is directly proportional to ΔP and inversely proportional to resistance (R)

Viscosity

- Internal friction of a fluid associated with the intermolecular attraction
- Blood is a suspension with a viscosity of 3
  - most of viscosity due to RBC's
- Plasma has a viscosity of 1.5
- Water is the standard with a viscosity of 1
- viscosity $\propto$ 1/ velocity

Example-2

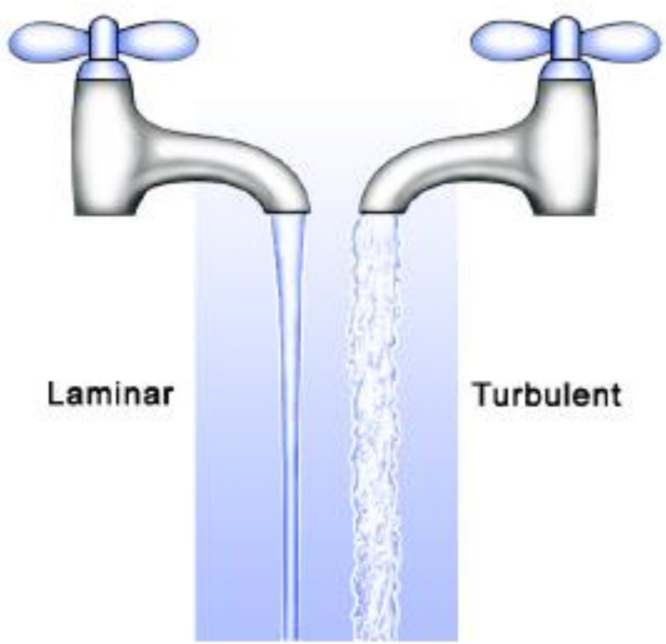
- The main artery which takes oxygenated blood from the left ventricle of the heart to the body is the aorta. It has a mean radius of around 1 cm, before branching into smaller arteries which supply blood to the various organs. The viscosity of normal blood is around 2.1×10^{-3} Pa.s at body temperature.
- a. If the flow rate along the aorta is 25 l.min-1, what is the pressure drop per centimeter along the aorta?
- b. What would be the pressure drop if the flow rate was maintained, but the mean radius of the artery was reduced to 0.9 cm?
- c. Smoking, a poor diet and lack of exercise contribute to hardening of the arteries, making them less able to flex to allow greater blood flow. A diet high in fat and cholesterol can also lead to the formation of fatty deposits in the arteries. Why are these contributing factors to heart disease?

Viscosity considerations at microcirculation

- velocity decreases which increases viscosity
  - due to elements in blood sticking together

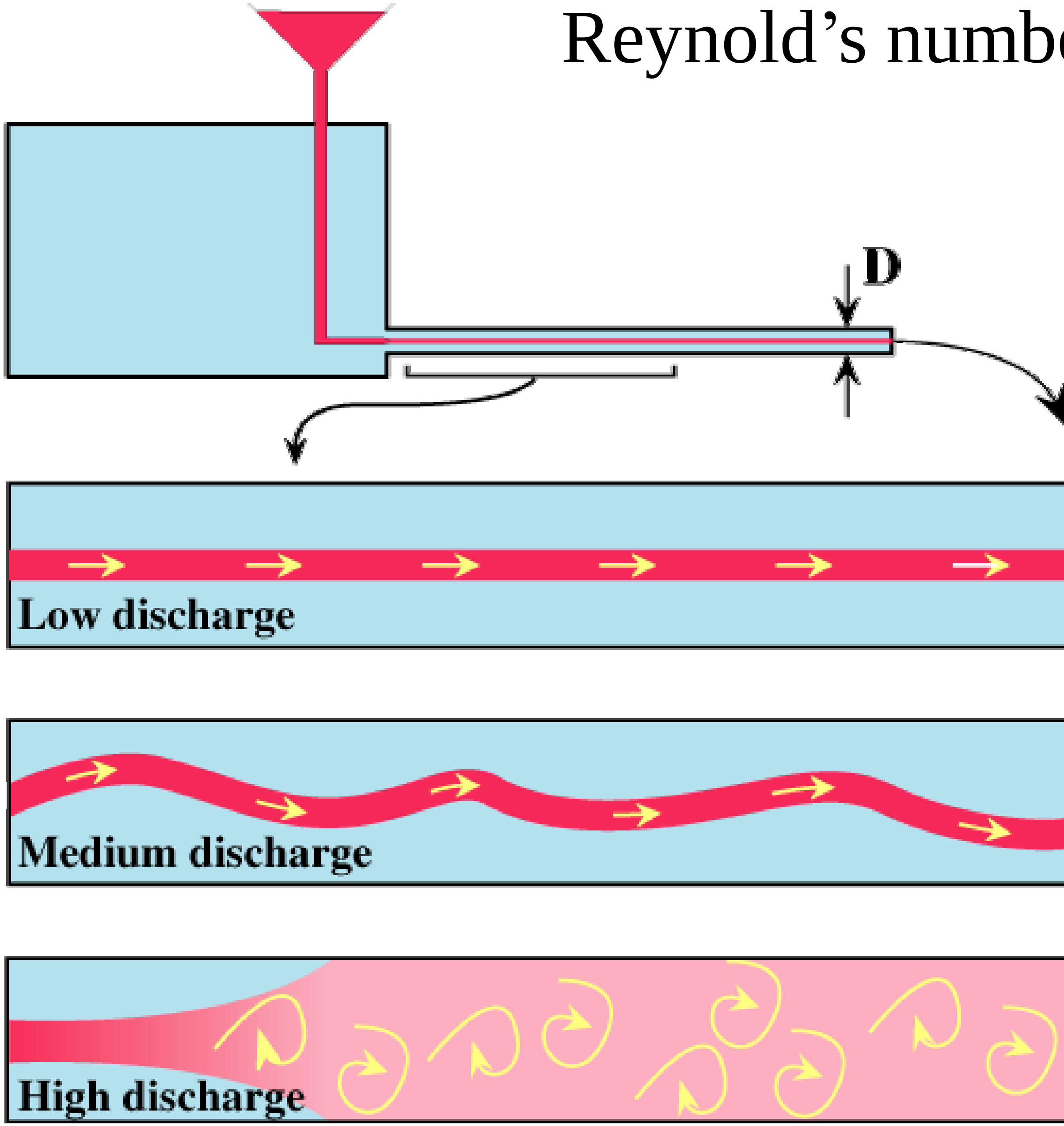
Laminar vs. Turbulent Flow

- Streamline
- silent
- most efficient
- normal



- Cross mixing
- vibrational noise
- least efficient
- frequently associated with vessel disease

Reynold’s number



- Probability statement for turbulent flow
- The greater the N_R, the greater the probability for turbulence

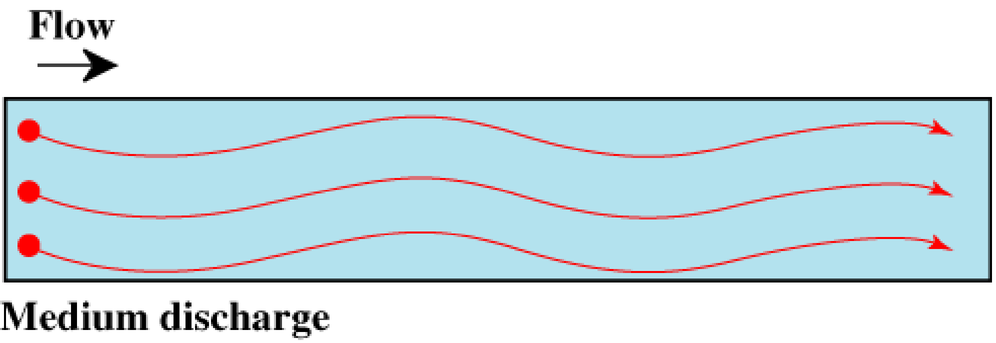
Dye followed a straight path.

Dye followed a wavy path with streak intact.

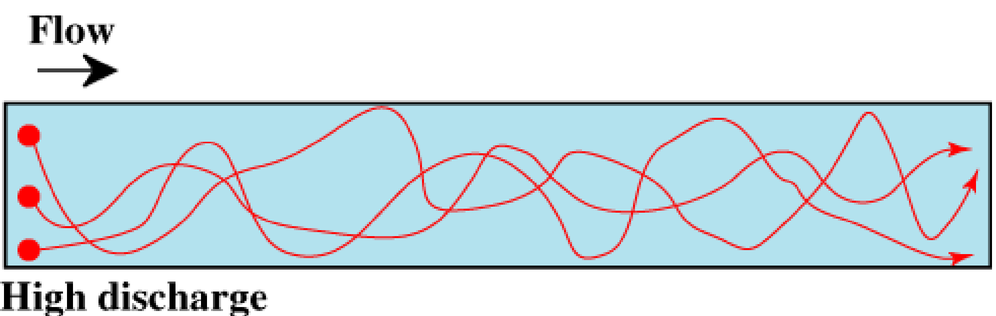
Dye rapidly mixed through the fluid in the tube

Reynolds classified the flow type according to the motion of the fluid.

Laminar Flow: every fluid molecule followed a straight path that was parallel to the boundaries of the tube.



Transitional Flow: every fluid molecule followed wavy but parallel path that was not parallel to the boundaries of the tube.



Turbulent Flow: every fluid molecule followed very complex path that led to a mixing of the dye.

Reynolds' Number

Reynolds found that conditions for each of the flow types depended on:

1. The velocity of the flow (υ)
2. The diameter of the tube (d)
3. The density of the fluid (ρ).
4. The fluid's dynamic viscosity (η).

He combined these variables into a dimensionless combination now known as the Flow Reynolds' Number (N_R) where:

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

Example-3

Given two pipes, one with a diameter of 10 cm and the other with a diameter of 1 m, at what velocities will the flows in each pipe become turbulent? The density of water is 998 kg/m^3 and viscosity is 1.005X 10^{-3} Pa·s

What is the critical velocity for N_R = 2000?

$$N_R = \frac{\rho v d}{\eta} = 2000 \qquad \frac{N_R \eta}{\rho d} = v$$

Solve for υ:

Solve for D = 0.1 m and D = 1.0 m.

$$\frac{N_R \eta}{\rho d} = v \qquad \frac{N_R \eta}{\rho d} = v$$

Example-4

Calculate Reynolds number, if a fluid having viscosity of 0.4 Ns/m^2 and relative density of 900 Kg/m^3 through a pipe of 20mm with a velocity of 2.5 m/s.

Given that,

Viscosity of fluid η

- η=0.4Nsm2
- Density of fluid ρ

- ρ=900Kg/m2
- Diameter of the fluid
- $d=20\times10^{-3}$m
- $N_R = \frac{\rho v d}{\eta}$

$=(900\times2.5\times20\times10^{-3})/0.4$

$=112.5$

Blood Flow

- Rest CO = 5.9 L/min
  - Coronary-250 ml/min
  - Brain-750 ml/min
  - Organs-3100 ml/min
  - Inactive muscle-650 ml/min
  - Active muscle-650 ml/min
  - Skin- 500 ml/min
- Exercise = 24 L/min
  - Coronary-1000 ml/min
  - Brain-750 ml/min
  - Organs-600 ml/min
  - Inactive muscle-300 ml/min
  - Active muscle-20,850 ml/min
  - Skin- initially↓, then ↑as body temp ↑