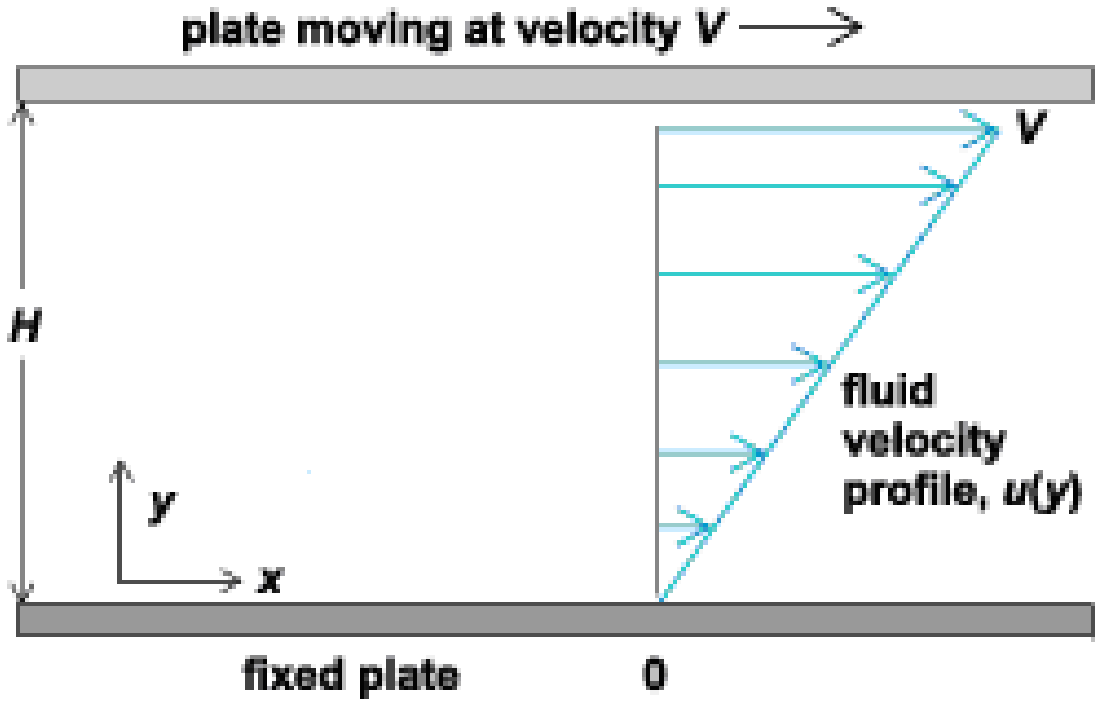
Shear stress in a moving fluid

- Although there can be no shear stress in a fluid at rest, shear stresses are developed when the fluid is in motion, if the particles of the fluid move relative to each other so that they have different velocities, causing the original shape of the fluid to become distorted.
- If, on the other hand, the velocity of the fluid is same at every point, no shear stresses will be produced, since the fluid particles are at rest relative to each other.

Fluid shear between two parallel plates



Newtonian & Non-Newtonian fluids

- It has been found that the Shear stress for flow of fluid is directly proportional to the velocity gradient (velocity/distance). $\tau \alpha \frac{du}{dy}$

- Introduce the proportionality constant "viscosity"… μ we get "Newton's law of viscosity"

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

- This is an equation originally proposed by Newton and which is obeyed by fluids such as water.

- However, for many of the actual fluids encountered in the fermentation industry (in fact during process also…), measurements show deviations from this simple relationship, and lead towards a more general equation:

- $\tau = k\,(du/dy)^n$

- which can be called the **power-law equation**, and where *k* is a constant of proportionality.

- Where *n* = 1 the fluids are called *Newtonian fluids* because they conform to Newton's equation and $k = \mu$;

- and all other fluids which don't obey this relationship are known as *non-Newtonian fluids*.

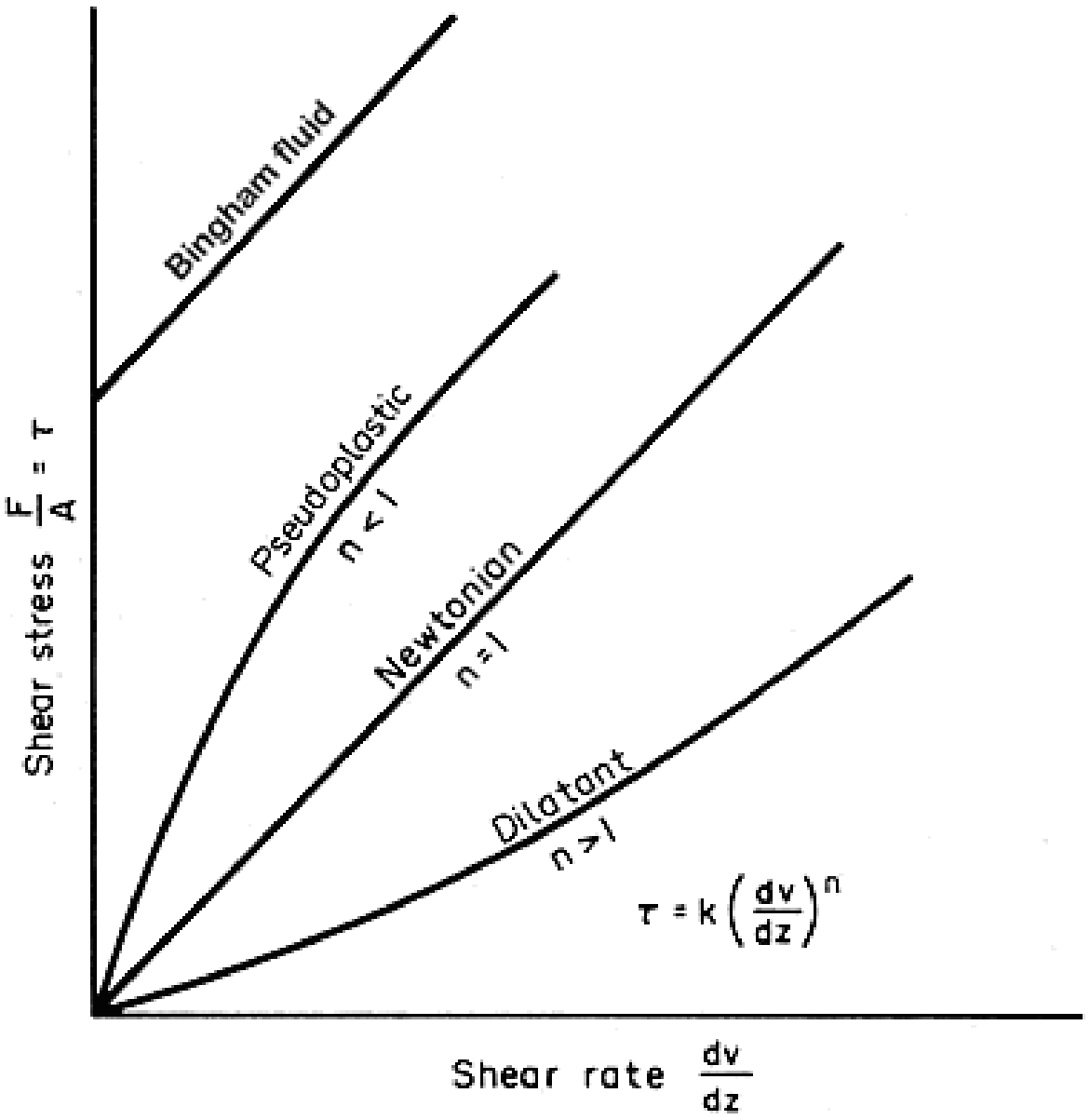
- All gases and most liquids which have simpler molecular formula and low molecular weight such as water, benzene, ethyl alcohol, CCl_4, hexane and most solutions of simple molecules are Newtonian fluids.

- Generally non-Newtonian fluids are complex mixtures: slurries, pastes, gels, polymer solutions etc.,

- In many instances in practice non-Newtonian characteristics are important, and they become obvious when materials that it is thought ought to pump quite easily just do not.

- They get stuck in the pipes, or overload the pumps, or need specially designed fittings before they can be moved.

- It is necessary to determine experimentally the rheological properties of the material so that equipment and processes can be adequately designed.


Bingham fluid
Pseudoplastic
n < 1
Newtonian
n = 1
Dilatant
n > 1
$\tau = k\left(\frac{dv}{dz}\right)^n$
Shear stress $\frac{F}{A} = \tau$
Shear rate $\frac{dv}{dz}$

Various non-Newtonian Behaviors

- *Bingham-plastic*: Resist a small shear stress but flow easily under larger shear stresses. e.g. tooth-paste, jellies, and some slurries.

- *Pseudo-plastic*: ($n<1$) Most non-Newtonian fluids fall into this group. Viscosity decreases with increasing velocity gradient. e.g. polymer solutions, blood.
  - Pseudo-plastic fluids are also called as Shear thinning fluids. At low shear rates (du/dy) the shear thinning fluid is more viscous than the Newtonian fluid, and at high shear rates it is less viscous.

- *Dilatant fluids*: ($n>1$) Viscosity increases with increasing velocity gradient. They are uncommon, but suspensions of starch and sand behave in this way.
  - Dilatant fluids are also called as shear thickening fluids.