3.8 Viscosity of a fluid

Viscosity describes a fluid's internal resistance to flow and may be thought of as a measure of fluid friction.

Various liquids show considerable differences with respect to their viscosity. Oil, honey or liquid tar are, for example, considerably more viscous than water and therefore show also a different flow behavior. The viscosity of a fluid arises from inner friction of the liquid particles which must be overcome in order to flow. **The viscosity strength F** becomes measurable, when a flat disk with an area A is pulled at a constant speed v along the surface of the liquid with a layer thickness y (Figure 3.8.-1). In this experiment the liquid is exposed to a shear stress or shear strain τ.

The speed reaches a maximum in the immediate proximity of the disk, i. e. the medium has the same speed as the disk. On the other hand the speed of the medium becomes zero in the immediate proximity of the firm counterpart or plate. A proportional distribution of the speed is found between the extremes as shown in the illustration. The required force for moving the disk along the firm plate can be calculated, if the area A, **the viscosity** η and the quotient of dv/dy are known. In this case dy is the layer thickness of the liquid.

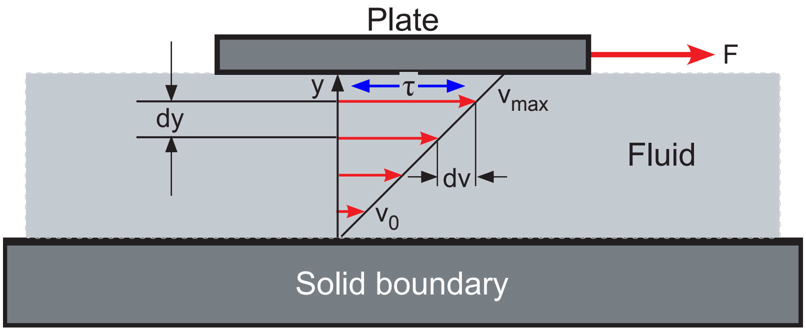

Figure 3.8.-1: Definition of shear stress τ and dynamic viscosity η

$$F = A \cdot \tau \tag{3-13}$$

The shear stress τ is defined as the friction force related to the area A.

$$\tau = \eta \cdot \frac{dv}{dy} \tag{3-14}$$

Dynamic viscosity η

The expression dv/dy is the quotient of velocity v and distance y and is described as the dynamic viscosity η. The recommended **SI-unit is Ns/m^2**.

The SI physical unit of dynamic viscosity is the pascal-second (Pa·s), which is identical to kg·m−1·s−1.

If a fluid with a viscosity of one Pa·s is placed between two plates, and one plate is pushed sideways with a shear stress of one pascal, it moves a distance equal to the thickness of the layer between the plates in one second.

The **cgs physical unit** for dynamic viscosity is the poise (P), named after **Jean Louis Marie Poiseuille**. It is more commonly expressed, particularly in ASTM standards, as centipoise (cP). Water at 20 °C has a viscosity of 1.0020 cP.

More common, however, are the units Poise (P) or Centipoise (cP).

$1\,P = 1\,g \cdot cm^{-1} \cdot s^{-1}$	$1\,cP = 0.001\,Ns/m^2$

$1\,Poise\,(P) = 0.1\,Pa \cdot s = 0.1\,\frac{N \cdot s}{m^2}$	$1\,cP = 1\,mPa \cdot s = 1\,\frac{mN \cdot s}{m^2}$

The kinematic viscosity ν

The kinematic viscosity ν of a fluid is frequently obtained through a relation of its density. The expression

$$\nu = \frac{\eta}{\rho} \tag{3-15}$$

is described as **kinematic viscosity *ν***. The **SI unit of kinematic viscosity is m^2/s**. But the old units Stokes (St) and Centistokes (cSt) are still frequently used:

$$1\,St = 1\,\frac{cm^2}{s} = 10^{-4}\,\frac{m^2}{s}$$

$$1\,cSt = 1\,\frac{mm^2}{s} = 10^{-6}\,\frac{m^2}{s}$$

The viscosity of a liquid is determined by means of special measuring equipment where the outflow time from a standardized receptacle is measured.

Non-standard units

Englergrad E (named after the inventor Carl Oswald Viktor Engler) is a unit of kinematic viscosity and defines the ratio of outflow times of the test fluid compared to that of distilled water. The volume of the receptacle is in this case 200 cm^3, the temperature shall be 20 °C. A conversion into the recommended SI-unit is carried out as follows:

$$\nu = \left(7.37 \cdot E\right) - \frac{6.31}{E} \cdot 10^{-6}\,m^2/s \tag{3-16}$$

Other common viscosity units are e. g. **Saybolt-Universal and Redwood-Viscosity. Saybolt-Universal** is a unit which is common in the USA. Here also the outflow time t of a certain quantity of the test liquid is determined by means of a special viscosity meter. A conversion into the recommended SI-unit is carried out as follows:

$$\nu = \left(0.266 \cdot t - \frac{185}{t}\right) \cdot 10^{-6}\, m^2/s \tag{3-17}$$

The equation above is limited, however, to the following slowing times: Minimum 32 seconds, maximum 100 seconds. For slowing times above 100 seconds the following conversion equation applies:

$$\nu = \left(0.22 \cdot t - \frac{135}{t}\right) \cdot 10^{-6}\, m^2/s \tag{3-18}$$

In Anglo-American countries the **Redwood-Viscosity** is also common. The outflow time is measured by a special viscosity meter at standard conditions. Similar to **Saybolt-Universal Viscosity (SUV)** two different equations apply to convert this unit into the recommended SI-unit.

$$\nu = \left(0.26 \cdot t - \frac{179}{t}\right) \cdot 10^{-6}\, m^2/s \tag{3-19}$$

On condition that: 34 s < t < 100 s

For outflow times more than 100 s applies:

$$\nu = \left(0.247 \cdot t - \frac{50}{t}\right) \cdot 10^{-6}\, m^2/s \tag{3-20}$$

The following explanations will help to illustrate the properties of a liquid or a gas with regard to their viscosity:

- The viscosity is usually not a constant value. It depends rather on the temperature and sometimes also on the pressure of the fluid.
- The temperature effect has a larger influence on the viscosity than the static pressure and is different for liquids and gases. The viscosity of liquids decreases at rising temperatures (e.g. oil). For gases and vapors however, the viscosity increases at higher temperatures.
- The normally foreseeable effects on viscosity loses validity for certain media. Liquids which behave according to equation (3-14) are described as Newtonian liquids. For these media the shear stress remains constant, provided temperature and pressure do not change. Most fluids used in the process automation industries (water, air, natural gas etc.) belong to this group. Non-Newtonian fluids are liquids with solid particles (slurries), slime, suspensions and highly viscous substances such as tar, special oils or varnishes.
- Distinctive characteristics of a non-Newtonian fluid are either a variable viscosity or a behavior which does not conform with equation 3-13. A typical example for a variable viscosity is a so-called "thixotropic" varnish whose viscosity depends on the painting

speed with a brush. This effect is intended to avoid "tears" or "noses" when painting a vertical body like a frame of a window. For such fluids a sufficiently low viscosity arises in the context of a normal painting speed.

The high basic viscosity of such a varnish avoids, the slow vertical flow and the ugly „tears“. Also special motor oils as used in motor vehicles today, fall into this category. By adding certain components (additives) the oil has almost a constant viscosity independent of its temperature. A mixture of liquids and solid substances is another example for a non-Newtonian liquid which behaves differently compared with a pure liquid.

Dynamic viscosity of various liquids at 25 °C:

	Dynamic Viscosity η Pa·s	Dynamic Viscosity η cP
Acetone	$3.06 \cdot 10^{-4}$	0.306
Benzene	$6.04 \cdot 10^{-4}$	0.604
Castor oil	0.985	985
Corn syrup	1.3806	1380.6
Ethanol	$1.074 \cdot 10^{-3}$	1.074
Ethylene glycol	$1.61 \cdot 10^{-2}$	16.1
Glycerol	1.5	1500
HFO-380	2.022	2022
Mercury	$1.526 \cdot 10^{-3}$	1.526
Methanol	$5.44 \cdot 10^{-4}$	0.544
Nitrobenzene	$1.863 \cdot 10^{-3}$	1.863
Liquid nitrogen	$1.58 \cdot 10^{-4}$	0.158
Propanol	$1.945 \cdot 10^{-3}$	1.945
Olive oil	0.081	81
* Pitch	$2.3 \cdot 10^{8}$	$2.3 \cdot 10^{11}$
Sulfuric acid	$2.42 \cdot 10^{-2}$	24.2
Water	$8.94 \cdot 10^{-4}$	0.894

Table 3.8.-2: Dynamic Viscosity η of various liquids

* Pitch is the name for any of a number of highly viscous liquids which appear solid. Pitch can be made from petroleum products or plants. Petroleum-derived pitch is also called bitumen. Pitch produced from plants is also known as resin. Products made from plant resin are also known as rosin.

Dynamic Viscosity Unit Convertor:

See the Homepage: http://www.uniteasy.com/en/unitsCon/Dynamic_viscosity.htm