Pearson BTEC Level 5 Higher Nationals in Engineering (RQF)

Unit 64: Thermofluids

Unit Workbook 3

in a series of 4 for this unit

Learning Outcome 3

Viscosity

Contents

INTRODUCTION

Illustrate the effects of viscosity in fluids

- *Viscosity in fluids:*
  - Viscosity: shear stress, shear rate, dynamic viscosity, kinematic viscosity.
  - Viscosity measurement: operating principles of viscosity measuring devices e.g. falling sphere, U-tube, rotational and orifice viscometers (such as Redwood).
  - Newtonian fluids and non-Newtonian fluids: pseudoplastic, Bingham plastic, Casson plastic and dilatant fluids.

GUIDANCE

This document is prepared to break the unit material down into bite size chunks. You will see the learning outcomes above treated in their own sections. Therein you will encounter the following structures;

Purpose

Explains *why* you need to study the current section of material. Quite often learners are put off by material which does not initially seem to be relevant to a topic or profession. Once you understand the importance of new learning or theory you will embrace the concepts more readily.

Theory

Conveys new material to you in a straightforward fashion. To support the treatments in this section you are strongly advised to follow the given hyperlinks, which may be useful documents or applications on the web.

Example

The examples/worked examples are presented in a knowledge-building order. Make sure you follow them all through. If you are feeling confident then you might like to treat an example as a question, in which case cover it up and have a go yourself. Many of the examples given resemble assignment questions which will come your way, so follow them through diligently.

Question

Questions should not be avoided if you are determined to learn. Please do take the time to tackle each of the given questions, in the order in which they are presented. The order is important, as further knowledge and confidence is built upon previous knowledge and confidence. As an Online Learner it is important that the answers to questions are immediately available to you. Contact your Unit Tutor if you need help.

Challenge

You can really cement your new knowledge by undertaking the challenges. A challenge could be to download software and perform an exercise. An alternative challenge might involve a practical activity or other form of research.

Video

Videos on the web can be very useful supplements to your distance learning efforts. Wherever an online video(s) will help you then it will be hyperlinked at the appropriate point.

3.1 Viscosity

Viscosity is a fluid's resistance to deformation under shear stresses.

Viscosity is an important property of any fluid, as it also helps determine their behaviour and motion against solid boundaries (such as pipes, gears, sliding contacts etc.). The viscosity is determined by the inter-molecular friction that is seen when one layer slides over the other. Or to put it simply, ***viscosity is how runny the fluid is***. The higher the viscosity, the thicker, and less runny, the fluid is.

It is very important to note that viscosity is temperature dependent, when considering a shortlist of fluids to a given application, it is vital that the temperature of the system is also considered.

3.1.1 Dynamic Viscosity

The dynamic viscosity the fluid's resistance to flow when an external force is applied. Dynamic viscosity can be though of as the tangential force per unit area required to move one plane of fluid with respect to another. The velocity between layers of a laminar fluid moving in straight parallel lines for a Newtonian fluid can be seen in Fig.3.1.

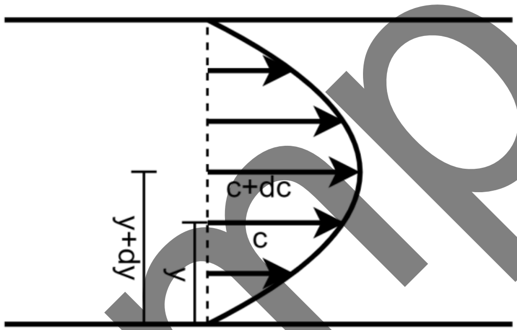

Figure 3.1: Velocity between layers of a laminar fluid

The shear stress τ can be defined by Eq.3.1, where μ is the dynamic viscosity, c is the velocity of the fluid, y is the height from the surface. dc/dy is also known as the "shear rate".

$$\tau = \mu \frac{dc}{dy} \qquad \text{(Eq.3.1)}$$

The SI units for dynamic viscosity is $\mathrm{Pa \cdot s}$, the values used are typically very low (e.g., the dynamic viscosity of water at $20^{\circ}\mathrm{C}$ is $0.0010005\ \mathrm{Pa \cdot s}$. More commonly the units that are used are the Poise, or centipoise, where $10\mathrm{P} = 1\mathrm{Pa \cdot s}$, therefore the dynamic viscosity of water at $20^{\circ}\mathrm{C}$ is $0.010005\mathrm{P}$ or $1.0005\mathrm{cP}$.

3.1.2 Kinematic Viscosity

Kinematic viscosity is the fluid's resistive flow under its own weight (no external forces are applied, just gravity). The substance with the highest kinematic viscosity is tar pitch which, despite appearing to be a solid and even shatters when it is hit with a hammer, is actually an incredibly viscous liquid, and will drip roughly once every ten years. The experiment widely recognised as the longest running in the University of Queensland in Australia is analysing the drip of tar pitch which began in 1927. Since the drip occurs around once every ten years, it has never actually been seen; the last time it did drip, the webcam failed and missed it.

Kinematic viscosity ν can be calculated using Eq.3.2, where ρ is the density of the fluid

$$\nu = \frac{\mu}{\rho} \qquad \text{(Eq.3.2)}$$

It is not just the University of Queensland conducting this experiment, Trinity College in Dublin also have their own experiment, which has been running since 1944. In July 2013 Trinity College managed to record the drop on video. The URL below shows the only drop that has been recorded.

https://www.youtube.com/watch?v=k7jXjn7mIao

The SI units for kinematic viscosity are given as $\mathrm{m^2/s}$; however, due to the low numbers that are generally used (e.g., the kinematic viscosity of water at $20°C$ is $0.0000010023\mathrm{m^2/s}$), more commonly the units are Stokes or centistokes, where $1\mathrm{cSt} = 1 \cdot 10^{-6}\mathrm{m^2/s}$. Therefore, the kinematic viscosity of water at $20°\mathrm{C}$ is $1.0023\mathrm{cSt}$.

3.1.3 The Importance of Viscosity

3.1.3.1 Lubrication

The application of viscosity is most commonly seen in lubrication. It has recently been discovered that lubrication dates back to ancient Egypt. Fig.3.2 shows a wall painting from the tomb of Djehutihotep, a Nomarch (official) of the twelfth dynasty of Egypt (~ 1900 B.C). Notice the person on top of the sled pouring a liquid in front of it. Most Egyptologists believed that this was nothing more than a ritual, however, recent studies have shown that by adding water to the sand reduces the force required to pull an object by 50%. The mixture of water and sand increased the viscosity of the water and also eliminated the possibility that sand would simply form a heap in front of the sled. However, this still had to be delicately controlled, adding too much water to the to the sand results in a loss of stability in the ground, which would cause the statue to sink; too little water would mean that there is no real difference to the situation than if the sand was just dry.

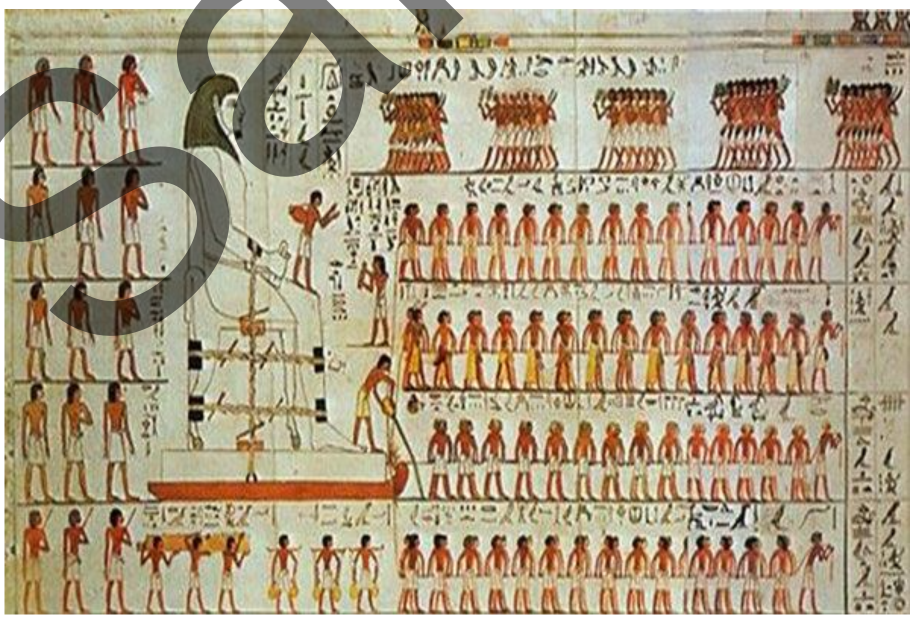

Figure 3.2: The wall painting in the tomb of Djehutihotep showing the earliest known use of lubrication

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This use of lubrication is considered to be the first recorded case, and helps solve a lot of questions as to how the monuments of ancient Egypt (such as the keystones atop the pyramids) are in place. Lubrication is seen in almost all mechanical parts, where two parts will be in contact with each other, they will produce a lot of shear stresses, and the similar hardness between the components will cause a lot of wear. Lubrication is used to take the shear stresses that would normally damage the solid contacts, gearboxes will use grease to cover the gears teeth, prolonging the life of the gears. Grease can also be found in the ball bearings that help the wheels and pedals rotate. Grease is a very viscous fluid, comparing it to engine oil, which is a low viscosity. Viscosity is therefore one of the key components in tribology (the study of wear), knowing the viscosity of a fluid can help create a variety of lubricants across a range of applications.

Machine wear is an expensive problem in industry, with estimates suggesting that around 10% of the UK's GDP is lost due to wear, whether this is replacing the parts themselves, or the downtime as a result. Improving machinery tribology could boost the economy by millions of pounds.

3.1.3.2 Food and Drinks Industry

The food and drinks industry also relies on viscosity measurements, it is a good way to ensure that a mixture has the correct ingredients, and in the correct proportions, examples of this can include syrups, yoghurts, drinks, etc. If a syrup was too runny then there is too much water in the batch, if it is too thick then there is not enough water in the batch; in the case of yoghurts, if the mixture is not correct, then it could be the same problems as the syrup, or the milk may have expired and congealed, meaning it is not safe for consumption.