Pearson BTEC Level 4 Higher Nationals in Engineering (RQF)

Unit 11: Fluid Mechanics

Unit Workbook 3

in a series of 4 for this unit

Learning Outcome 3

Dynamic Fluid Flow

Contents

INTRODUCTION

Investigate dynamic fluid parameters of real fluid flow

- *Fluid flow theory:*
  - Energy present within a flowing fluid and the formulation of Bernoulli's equation.
  - Classification of fluid flow using Reynolds numbers.
  - Calculations of flow within pipelines.
  - Head losses that occur within a fluid flowing in a pipeline.
  - Viscous drag resulting from fluid flow and the formulation of the drag equation.
- *Aerodynamics:*
  - Application of prior theory of fluid flow to aerodynamics.
  - Principles of aerofoils and how drag induces lift.
  - Flow measuring devices and their operating principles.

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.

4.1.3 The Reynold's Number

They Reynold's number (Re) is a dimensionless constant that is used to describe fluid flow. The Reynold's number is calculated using Eq.3.1, and is a ratio of inertia forces to viscous forces.

$$\mathrm{Re} = \frac{\rho \mathrm{uL}}{\mu} = \frac{uL}{v} \quad (3.1)$$

Where:

- ρ is the density of the fluid $(\mathrm{kg/m^3})$
- u is the velocity of the fluid $(\mathrm{m/s})$
- L is the length that you are measuring over (m)
- μ is the dynamic viscosity $(\mathrm{Pa \cdot s})$
- v is the kinematic viscosity $(\mathrm{m^2/s})$

The corresponding value for the Reynold's number defines the flow as:

- $\mathrm{Re} < 2000$: Flow is laminar
- $\mathrm{Re} = 2000$: Known as the critical Reynold's number, flow is no longer laminar and will start to transition towards turbulent flow
- $2000 < \mathrm{Re} < 4000$: Flow is considered transitional, or unstable, it is not laminar, but it is not fully turbulent yet either.
- $4000 < \mathrm{Re}$: Flow is turbulent

Example 1

Give the flow characteristic of:

a) Honey $(1450\ \mathrm{kg/m^3}, 14.095\ \mathrm{Pa \cdot s})$ flowing through a $3\ \mathrm{m}$ length of pipe at $0.3\ \mathrm{m/s}$.
b) Castor oil $(961\ \mathrm{kg/m^3}, 950\ \mathrm{cP})$ flowing through $1\ \mathrm{m}$ length of pipe at $20\ \mathrm{m/s}$
c) Water $(1000\ kg/m^3, 1\ cP)$ flowing through a $1\ m$ length of pipe at $0.3\ m/s$.

Answers:

a) Re is given as:

$$\mathrm{Re} = \frac{\rho \mathrm{uL}}{\mu} = \frac{1450(0.3)(3)}{14.095} = \mathbf{92.6}$$

The flow is laminar

b) $950\ \mathrm{cP} = 9.5\ \mathrm{Pa \cdot s}$, so Re is:

$$\mathrm{Re} = \frac{961(20)(1)}{9.5} = \mathbf{2023}$$

The flow is transitional

$$\text{Relative Roughness} = \frac{\text{k}}{\text{d}} \quad (3.2)$$

Fig.3.5 gives a graphical demonstration of the dimensions.

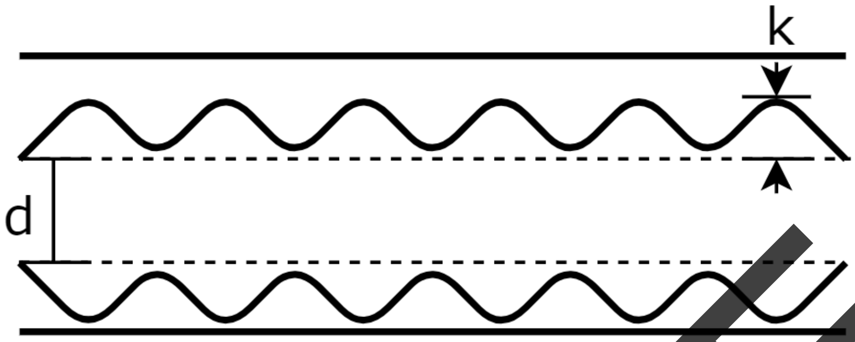

Figure 3.5: The measurement of the diameter and height of irregularities in a pipe.

4.2.2 Moody Diagrams

A Moody diagram is a diagram to measure the coefficient of friction in pipes (noted in this workbook as f, although some sources will use λ). Calculating the coefficient of friction (sometimes referred to as the friction factor) depends on both the flow in the pipe and its relative roughness.

The equations used for calculating f are:

Laminar: $$\text{f} = \frac{16}{\text{Re}} \quad (3.3)$$

Turbulent Smooth pipes: $$\text{f} = 0.079Re^{-0.25} \quad (3.4)$$

Turbulent Rough pipes: $$\frac{1}{\sqrt{f}} = -3.6\, log_{10}\left[\frac{6.9}{Re} + \left(\frac{k}{3.71d}\right)^{1.11}\right] \quad (3.5)$$

These equations are quite long to calculate, with the exception of the laminar equation (Eq.3.3). So, alternatively, the Moody chart is available for reference. The Moody chart is a graph that has already plotted the values for the friction factor across a range of Reynold's numbers, and relative roughness, to give a quick (and fairly accurate) estimate. Fig.3.6 shows a Moody chart, and the lines show the variation of friction factor at a given relative roughness, but a varying Reynold's number. Most Moody diagrams will also include an absolute roughness value for some materials. The absolute roughness value is a typical estimate for ϵ for certain materials.

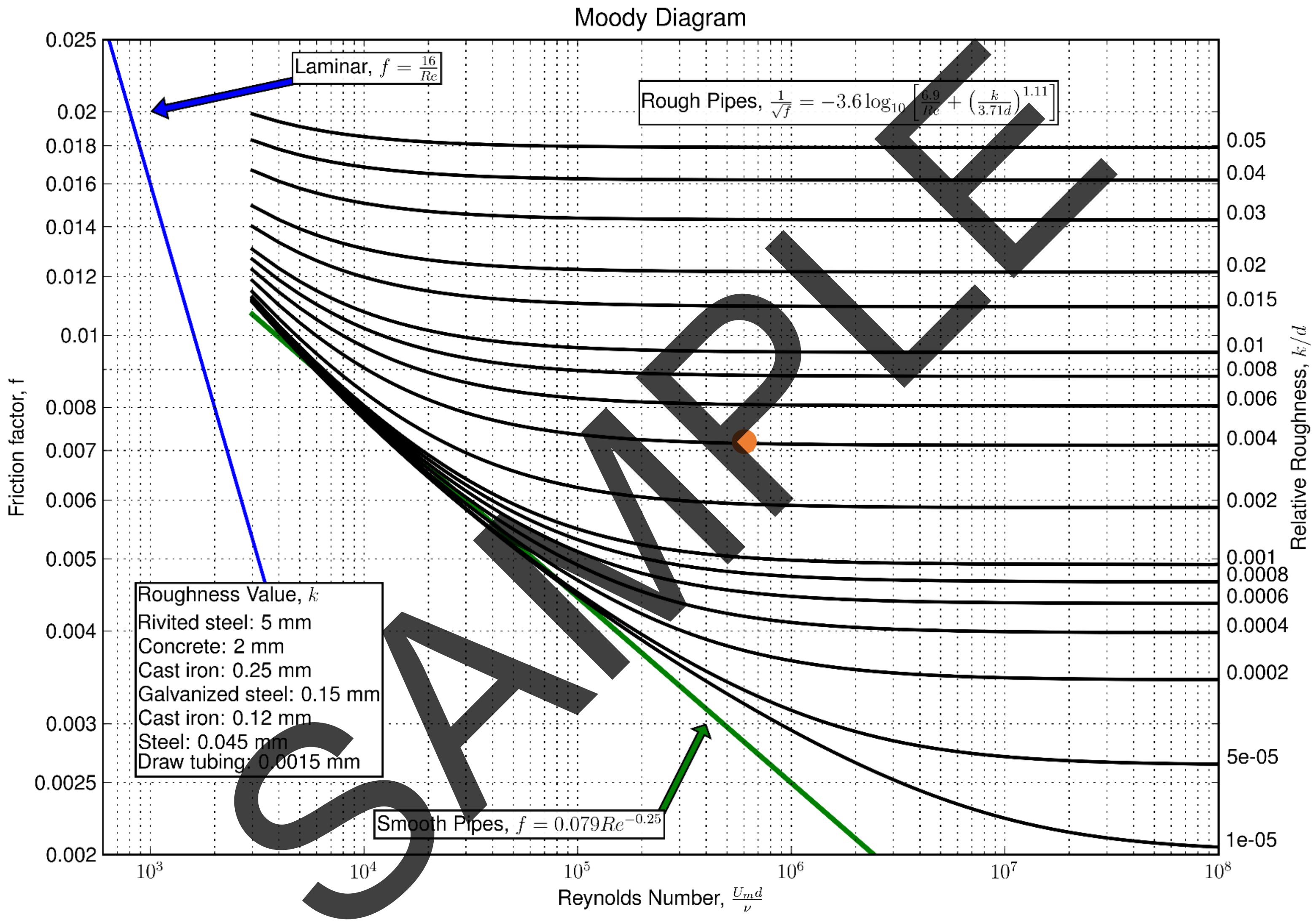

Figure 3.6: Moody Diagram

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3.2.3 Bernoulli's Equation

Bernoulli's equation is a conservation of energy equation used in fluid mechanics. This can draw similarities to the thermodynamic Steady Flow Energy Equation (SFEE).

$$Q - W = \left(U_2 + \frac{1}{2}mc_2^2 + mgz_2\right) - \left(U_1 + \frac{1}{2}mc_1^2 + mgz_1\right)$$

Where:

- Q is the heat transferred through the system
- W is the work done in the system
- U_i is the internal energy of the system at point i
- $\frac{1}{2}mc_i^2$ is the kinetic energy at point i
- mgz_i is the potential energy at point i

The same principle can be applied to flow through a pipe, since no heat is transferred in the flow of the pipe. Bernoulli's equation is given as Eq.3.7:

$$\mathrm{P_1} + \frac{1}{2}\mathrm{\rho u_1^2} + \mathrm{\rho g h_1} = \mathrm{P_2} + \frac{1}{2}\mathrm{\rho u_2^2} + \mathrm{\rho g h_2} \quad (3.7)$$

Where:

- P is the pressure at a given point (Pa)
- ρ is the density (kg/m^3)
- u is the velocity at a given point (m/s)
- g is acceleration due to gravity (m/s^2)
- h is the height at a given point (m)

When using Bernoulli's equation, it's always important to know the equation for volumetric flow rate $\dot{\mathrm{Q}}$, which is Eq.3.8, where A is the area of the pipe.

$$\dot{\mathrm{Q}} = \mathrm{u} \cdot \mathrm{A} \quad (3.8)$$

Where:

- u is the velocity of the fluid (m/s)
- A is the cross-sectional area (m^2)

Example 4

Fig.3.7 shows water $\rho = 1000\ \mathrm{kg/m^3}$ travelling through a converging-diverging pipe. The figure also gives the known values for each point in the pipe. Calculate

a) The volumetric flow rate
b) The velocity at point 2
c) The pressure at point 2