UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 3 Examination in Engineering: February 2023

Module Number: ME3302 **Module Name: Fluid Mechanics**

[Three Hours]

[Answer **all questions**, each question carries **12** marks]

Useful equations with usual notations are given in page number 06

Q1 a) Briefly explain the following terms which are applicable for boundary layer thickness.

i) Displacement thickness.

ii) Momentum thickness.

iii) Energy thickness.

[1.5 Marks]

b) The velocity profile for a laminar boundary layer is given by $\frac{u}{U} = 2\left(\frac{y}{\delta}\right) - \left(\frac{y}{\delta}\right)^2$

, where u is the velocity at any point in the boundary layer, U is the free stream velocity and δ is the boundary layer thickness. Use the **Von Karman momentum integral equation** to prove that the shear stress on a flat plate (τ_0) is given by the expression: $\frac{2}{15}\rho U^2 \frac{\partial\delta}{\partial x}$.

[4.5 Marks]

c) Figure Q1(c) shows a loop of a municipal water distribution pipe circuit. The incoming volumetric flow rate at the node B and the outgoing volumetric flow rates at the nodes A and C are given in the diagram itself. Apply the "**Hardy Cross Method**" to determine the water flow rate through each pipe.

Q1 is continuing to page 2…

Q1 is continuing from page 1…

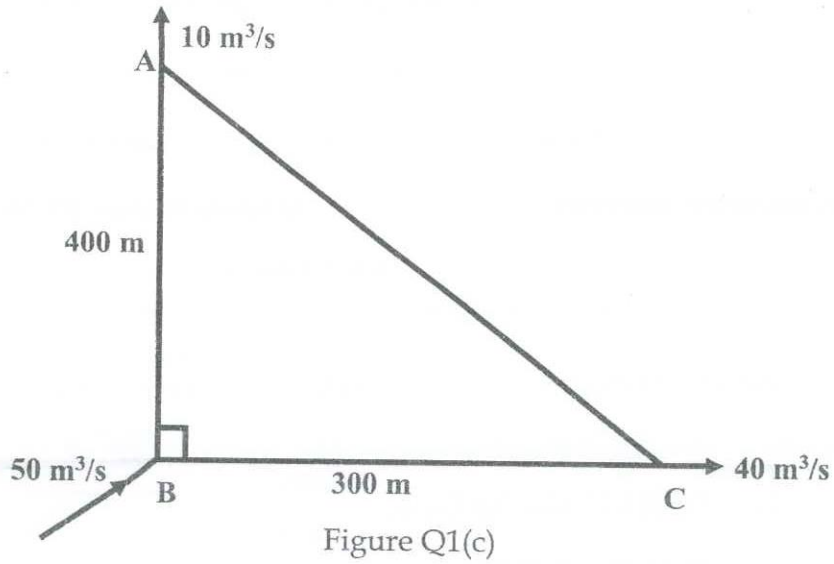


Figure Q1(c)

[6.0 Marks]

Q2 a) Briefly explain the following terms as applicable for steady, incompressible fluid flow in pipe networks.

i) Hèad loss

ii) Pressure loss

iii) Major energy losses

iv) Minor energy losses

v) Vena contracta

[2.5 Marks]

b) Starting from the first principles, prove that the head loss due to contraction of a pipe (h_c) is given by $\frac{V_2^{\,2}}{2g}\left[\frac{1}{C_c}-1\right]^2$, where V_2 is the velocity of the fluid stream after contraction.

[3.5 Marks]

c) Table Q2(c) includes the Darcy-Weisbach friction factor values obtained in an experiment of flow inside water pipes at different Reynolds number values observed at 20°C. Using the data given, answer the following questions.

Q2 is continuing to page 3…

Q2 is continuing from page 2…

Table Q2(c)

Reynolds number	**Friction factor ($\times 10^{-2}$)**
2.4×10^{3}	5.2
4.0×10^{3}	4.5
1.0×10^{4}	3.9
2.0×10^{4}	3.6
5.0×10^{4}	3.4
1.0×10^{5}	3.3
2.0×10^{5}	3.25
1.0×10^{6}	3.2
1.0×10^{7}	3.2
1.0×10^{8}	3.2

Data:

Pipe radius = 25 mm

Pipe length = 50 m

Dynamic viscosity of water at 20 °C = 1×10^{-3} Pa s

i) What are the factors affecting on the change of Reynolds number of the flow?

ii) Mark the experimental results on an approximate curve of the given Moody diagram in page 7 and attach with the answer script.

iii) Predict the pipe material.

iv) Calculate the head loss of the pipe due to friction when the flow is at the margin of transition to turbulent flow.

[6.0 Marks]

Q3 a) State key functions of the following components of a centrifugal pump.

i) Foot valve.

ii) Volute casing.

iii) Delivery valve.

[3.0 Marks]

b) Briefly describe reasons for the cavitation occurring in a centrifugal pump and state **three** common corrective precautions.

[2.0 Marks]

c) A centrifugal pump is delivering 0.25 m^3/s of water against a head of 21 m; the speed of rotation of the impeller being 600 r.p.m. The diameters at the outer and inner periphery of the impeller are 600 mm and 300 mm, respectively. The area of flow is constant at 0.085 m^2 from inlet to outlet of the impeller. If the vanes of the impeller are bent at an angle of 35° to the tangent at exit, determine the following.

i) The manometric efficiency.

[3.0 Marks]

ii) Inlet vane angle.

[2.0 Marks]

iii) Loss of head at the inlet of the impeller when the discharge is reduced by 35%.

[2.0 Marks]

Q4 a) What is the difference between Impulse and Reaction turbines in terms of type of energy available at the inlet of the turbine?

[2.0 Marks]

b) Briefly describe the process of selection of a suitable turbine for a varying load application using the operating characteristic curve of hydraulic turbines.

[2.0 Marks]

c) A Francis turbine works at 450 r.p.m. under a head of 140 m. Its diameter at the inlet is 1.2 m and the flow area is 0.4 m^2. The angles made with the tangential velocity by absolute and relative velocities at inlet are 20° and 60°, respectively. Determine the following.

Q4 is continuing to page 5…

Q4 is continuing from page 4…

i) The volume flow rate.

[4.0 Marks]

ii) The power developed by the turbine.

[2.0 Marks]

iii) The hydraulic efficiency of the turbine.

[2.0 Marks]

Q5 a) State **four** applications of dimensional and model analysis in solving engineering problems.

[2.0 Marks]

b) A model of Francis turbine that is one-fourth of the full size develops 2.5 kW at 300 rpm, working under a head of 1.6 m. If the prototype turbine operates under a head of 5.5 m, and the efficiency of the model and the prototype turbine are same, calculate the following parameters associated with the prototype.

i) Working speed.

[2.0 Marks]

ii) Power developed.

[2.0 Marks]

c) The pressure difference Δp in a pipe of diameter D and length l under a turbulent flow condition depends on the velocity V, viscosity μ, density ρ and roughness k. Use the Buckingham's π-theorem to show that the Δp is given by the following equation.

Note: Pipe roughness is given in mm

$$\Delta P = \rho V^2 \phi \left[\frac{l}{D}, \frac{\mu}{DV\rho}, \frac{k}{D}\right]$$

[6.0 Marks]

Useful equations with usual notations

The relevant equations and the meaning of the notations of the given equations are listed below. For any notation is not mentioned here, assume their standard meaning.

1) Von Karmann momentum integral equation $\frac{\tau_0}{\rho U^2} = \frac{\partial\theta}{\partial x}$

   where $\theta = \int_0^\delta \frac{u}{U}\left[1 - \frac{u}{U}\right] dy$

2) $h_f = r\,Q^2$, where $r = \frac{L}{100}$, L = pipe length

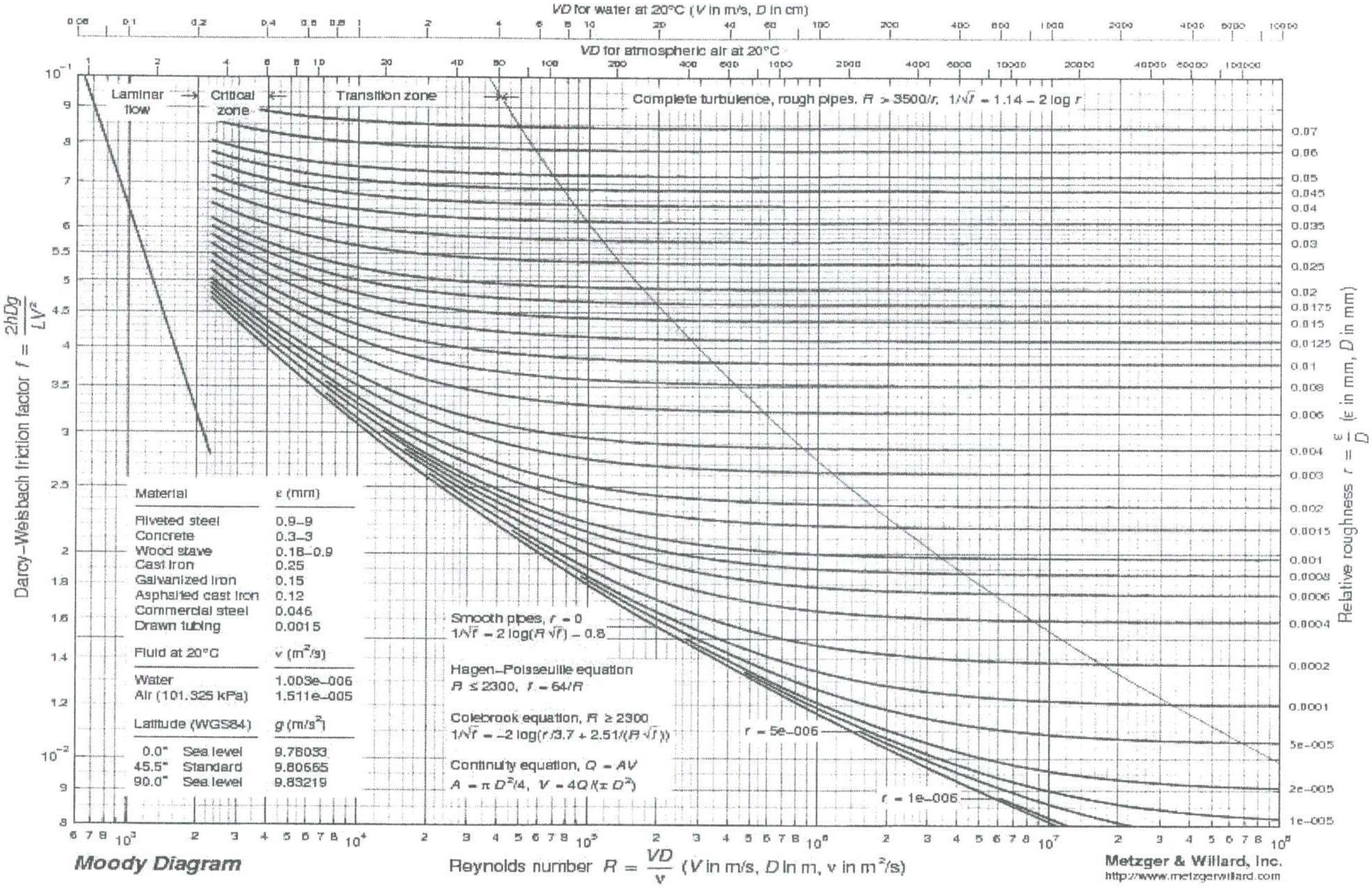
3) $\Delta Q = \frac{-\sum rQ^2}{\sum 2rQ}$

4) $C_c = \frac{A_c}{A_2}$, where A_c = Fluid flow area at Vena-contracta, A_2 = Fluid flow area at the exit of the pipe after contraction

5) Darcy-Weisbach equation $h_f = \frac{fLV^2}{2dg}$

Notations

- ρ = Fluid density
- θ = Momentum thickness
- h_f = Head loss due to friction
- Q = Volumetric flow rate
- f = Darcy-Weisbach friction factor
- V = Fluid flow velocity at a particular measurement
- d = pipe diameter/characteristic length for a circular pipe flow
- g = acceleration due to gravity


VD for water at 20°C (V in m/s, D in cm)
VD for atmospheric air at 20°C
Laminar flow
Critical zone
Transition zone
Complete turbulence, rough pipes. R > 3500/r, 1/√f = 1.14 − 2 log r
Darcy–Weisbach friction factor f = 2hDg / LV²
Relative roughness r = ε / D (ε in mm, D in mm)
Material | ε (mm)
Riveted steel | 0.9–9
Concrete | 0.3–3
Wood stave | 0.18–0.9
Cast iron | 0.25
Galvanized iron | 0.15
Asphalted cast iron | 0.12
Commercial steel | 0.046
Drawn tubing | 0.0015
Fluid at 20°C | ν (m²/s)
Water | 1.003e–006
Air (101.325 kPa) | 1.511e–005
Latitude (WGS84) | g (m/s²)
0.0° Sea level | 9.78033
45.5° Standard | 9.80665
90.0° Sea level | 9.83219
Smooth pipes, r = 0
1/√f = 2 log(R √f) − 0.8
Hagen–Poiseuille equation
R ≤ 2300, f = 64/R
Colebrook equation, R ≥ 2300
1/√f = −2 log(r/3.7 + 2.51/(R √f))
Continuity equation, Q = AV
A = π D²/4, V = 4Q/(π D²)
r = 5e–006
r = 1e–006
Moody Diagram
Reynolds number R = VD/ν (V in m/s, D in m, ν in m²/s)
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