The University of Nottingham

DEPARTMENT OF MECHANICAL, MATERIALS AND MANUFACTURING ENGINEERING

A LEVEL 2 MODULE, AUTUMN SEMESTER 2021-2022

THERMODYNAMICS AND FLUID MECHANICS 2

Time allowed TWO HOURS

Candidates may complete the front cover of their answer book and sign their desk card but must NOT write anything else until the start of the examination period is announced

Answer ALL questions

Only a calculator from approved list B may be used in this examination.

Basic Models	***Scientific Calculators***	***Graphical Calculators***
Aurora HC133	Aurora AX-582	Casio FX9750 family
Casio HS-5D	Casio FX83 family	
Deli – DL1654	Casio FX85 family	
Sharp EL-233	Casio FX570 family	
	Casio FX 991 family	
	Sharp EL-531 family	

Dictionaries are not allowed with one exception. Those whose first language is not English may use a standard translation dictionary to translate between that language and English provided that neither language is the subject of this examination. Subject specific translation dictionaries are not permitted.

No electronic devices capable of storing and retrieving text, including electronic dictionaries, may be used.

DO NOT turn examination paper over until instructed to do so

ADDITIONAL MATERIAL: Five printed sheets of formulae
Thermodynamic Properties of Fluids & other data (in S.I. units, 5th edition)
Enthalpy-Entropy chart – A3 sized photocopy

INFORMATION FOR INVIGILATORS:

Question papers should be collected in at the end of the exam – do not allow candidates to take copies from the exam room.

Answer all questions

1. Consider the following vector field representing a steady-state velocity field in two dimensions:

$$V(x,y)=u(x,y)i+v(x,y)\hat{j}=(x^2y-2e^y)\hat{i}+(xe^x-xy^2)\hat{j}.$$

Demonstrate whether this velocity field represents an incompressible flow or not.

2. Water falls steadily through the gap formed between two vertical, parallel, stationary, infinitely extended walls, as sketched in Fig. Q2. The steady-state momentum equation along the y-coordinate, for an incompressible and fully-developed flow, a Newtonian fluid, and in the absence of a pressure gradient driving the flow, can be written as follows:

$$\mu\frac{d^2v}{dx^2}+\rho g=0,$$

where μ is the dynamic viscosity of the fluid, $v(x)$ is the vertical component of the velocity which is a function of the horizontal coordinate x only, ρ is the density of the fluid and g is the gravitational acceleration.

Based on the equation above and the boundary conditions indicated in Fig. Q2:

(a) Produce the theoretical velocity profile in the duct $v(x)$.

(b) Taking $\mu=0.001$ kg· m^{-1}·s^{-1}, $\rho=1000$kg·m^{-3}, $g=-9.81$ m·s^{-2} and $H=0.001m$, calculate the maximum speed of water in the duct.

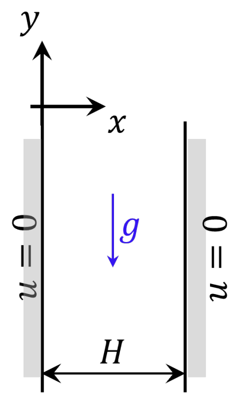

Figure Q2

3. Consider the following linear expression for the velocity profile in a laminar boundary layer developing over a flat plate:

$$u(y)=\frac{y}{\delta}U_0, 0\le y\le \delta(x),$$

where *u* is the streamwise velocity, *δ* is the boundary layer thickness which depends on the streamwise coordinate *x*, and *y* is the orthogonal distance from the plate. Derive an expression for the boundary layer thickness *δ(x)* based on this velocity profile.

4. A boundary layer is developing on a flat plate. The free stream velocity *U* is equal to 80 m·s^{-1}. The density of the fluid is 1.2 kg·m^{-3} and its kinematic viscosity is 1.8·10^{-5} m^2·s^{-1}. The length of the plate in the streamwise direction is 3 m, whereas its width is 0.6 m. Calculate the drag force acting on the plate assuming:

(a) Smooth plate.

(b) Fully-rough plate with a surface roughness of 1 mm.

5. A pipeline that forms part of a propotype is used to transport engine oil SAE 15W-40 (density: 879 kg·m^{-3}, dynamic viscosity: 0.287 kg·m^{-1}·s^{-1}); the prototype pipe ha... ...e mass flow rate of oil in the pipe is of 2... ...uired to build a model using water (dens... ....001 kg·m^{-1}·s^{-1}) and a pipe of diameter of 5 cm. Find the mass flow rate of water in the model pipe that will ensure physical similarity between model and prototype.

There is no dimensionless analysis in January 2023 exam, it will be lift and drag instead

6. Within a capillary channel of diameter D, a liquid of density ρ_l and dynamic viscosity μ_l flows ... ...ty ρ_g and dynamic viscosity μ_g, is inje... ...ong bubble that is transported down... ...ketch in Fig. Q6. The surface tension of the gas-liquid mixture is denoted with γ. Using Buckingham's Pi theorem:

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(a) How many dimensionless groups are sufficient to describe the flow?

There will only be 5 thermodynamics questions and 5 fluid mechanics questions in the January 2023 exam

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(b) Using ρ_l, U, D as repeating variables, find the dimensionless group related to the surface tension γ and state its relevance.

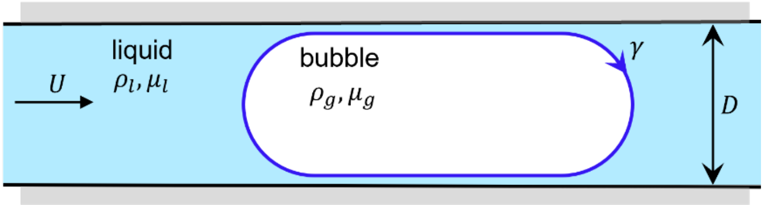

Figure Q6

7. Use the tables on page 10 to state the specific heat capacity at constant pressure, dynamic viscosity and thermal conductivity of saturated steam at 100°C, including the units. Use these values to calculate the Prandtl number for saturated steam at 100°C, which is determined by the following formula:

$$Pr = \frac{c_p \mu}{k}$$

Verify your value against the value indicated on the column on the right on the table of data.

8. Calculate the thermal power required to heat 20 kg·s^{-1} of water from 30°C up to 160 bar and 550°C.

9. The steam turbine shown in Figure Q9 receives steam at 180 bar and 550°C with ingoing specific enthalpy and entropy, h_{in} = 3411.5 kJ·kg^{-1}, s_{in} = 6.394 kJ·kg^{-1}K^{-1} respectively. The isentropic efficiency of the turbine is 96%. Calculate the specific work out of the turbine if the steam outlet condition is at 0.05 bar.

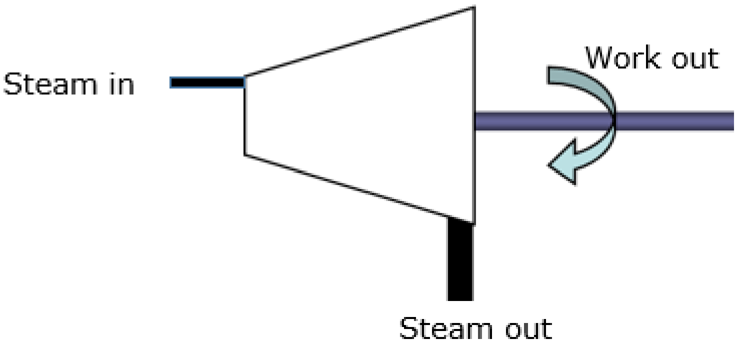

Figure Q9

10. The atmospheric air in Kolkata in July on some days can be measured as 40℃ and 80% relative humidity. An air conditioning unit for a room offers only cooling, and the air reaches 21℃, with no further conditioning. Calculate the specific humidity at 21℃. State, with brief reasons, whether you think this is a good air condition.

11. The chart in Figure Q11 shows the p-h (i.e. pressure versus enthalpy) characteristics of the saturation pressure of refrigerant R134a. Draw a similar sketch of a p-h diagram and indicate on it the processes of a typical refrigeration cycle, using arrows to show the direction of the cycle and labelling the main components of the refrigeration unit that the cycle represents.

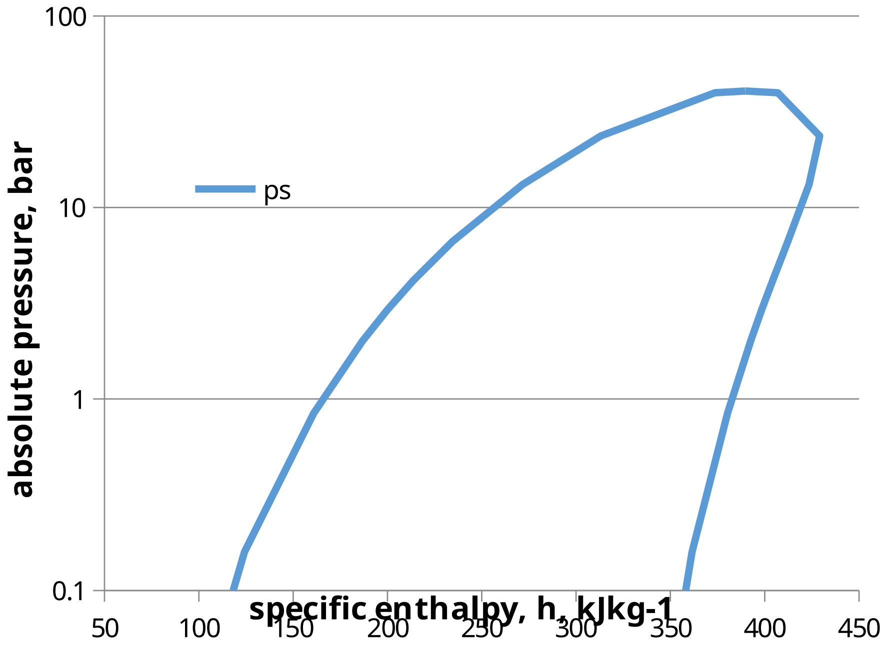

Figure Q11

12. A vapour power cycle has a specific steam consumption of 3 $kg \cdot kWh^{-1}$, and a work ratio of 97%. Calculate the net specific power output and hence the gross (i.e. turbine) specific work output. Given that the power consumed by the pump is 1 MW, calculate the water flow rate, and hence the net power output.

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