The University of Nottingham

DEPARTMENT OF MECHANICAL, MATERIALS AND MANUFACTURING ENGINEERING

A LEVEL 2 MODULE, SPRING 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 Casio HS-5D Deli – DL1654 Sharp EL-233	Aurora AX-582 Casio FX82 family Casio FX83 family Casio FX85 family Casio FX350 family Casio FX570 family Casio FX 991 family Sharp EL-531 family Texas Instruments TI-30 family Texas BA II+ family	Casio FX9750 family Texas Instruments TI82 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.

Part A: Thermodynamics

1. A solid biomass has an ultimate gravimetric composition of 48% carbon, 6% hydrogen and 44% oxygen. It is burned completely in air in a power generation plant, and produces an exhaust stream with 5% oxygen in the wet products by volume.

   (a) Determine the mass and number of moles of carbon dioxide and water vapour produced by the stoichiometric combustion of 1 kg of the biomass. [4]

   (b) Calculate the mass of air required for stoichiometric combustion of 1 kg of biomass. [5]

   (c) Use a table of the wet products of combustion to help determine the specific heat capacity at constant pressure for the product gas mixture at 300 K. [4]

2. (a) A single pass, counterflow shell and tube heat exchanger uses tubes of diameter 20 mm with water flowing at the rate of 0.1 kg/s in each tube at 20 °C. Calculate the heat transfer coefficient at the inner wall of the tube given the Nusselt number correlations:

$$Nu = 0.023Re^{0.8}Pr^{0.4} \text{ for Re} > 2000, \text{ and}$$

$$Nu = 3.66 \text{ for Re} < 2000.$$

[5]

   (b) The heat exchanger has a shell and tube arrangement, containing 10 tubes, with a flow of air entering the shell at 1000 K. The air enters at a flow rate of 0.5 kg/s and the heat transfer coefficient on the outer surface of the tubes is 100 W/m^{2}K, and the conduction resistance of the pipe wall is negligible. Calculate the overall heat transfer coefficient and the length of the tubes in order to produce a gas exit temperature of 400 K. The correction factor may be assumed to be 1.0. [8]

Part B: Fluid Mechanics

3. A small airship, shown in Figure Q.3a, is cruising at a steady speed and constant altitude at a velocity of 20 $km \cdot h^{-1}$. It is filled entirely with 4000 m^3 of helium. The temperature of the surrounding air is 286 K.

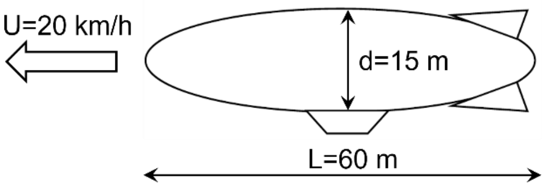
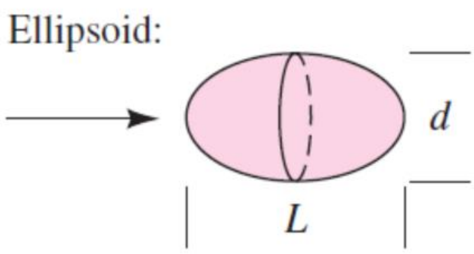


Figure Q.3a: Airship dimensions. The airship cross-section is circular.

(a) Calculate the Reynolds number of the airship based on diameter. Given the transition to turbulent flow occurs at $Re = 2 \times 10^5$, state whether the flow past the airship is turbulent or laminar. (Take the density of air to be 1.2 $kg \cdot m^{-3}$ and the kinematic viscosity to be 1.4×10^{-5} $m^2 \cdot s^{-1}$). [2]

(b) The airship can be approximated by a three-dimensional ellipsoid. Using the information in Table Q.3b that shows C_D values as a function of L/d, estimate the drag coefficient of the airship, and calculate the drag force. [5]



	Laminar	Turbulent
L/d	C_D	C_D
0.75	0.5	0.2
1	0.47	0.2
2	0.27	0.13
4	0.25	0.1
8	0.2	0.08

Figure Q.3b: Drag coefficients of an ellipsoid, based on frontal area.

(c) A problem develops with the airship and helium leaks through a nozzle to atmospheric pressure of 0.99 bar. By treating the flow through the system as one-dimensional isentropic, and neglecting all friction losses, calculate the Mach number of the helium at the nozzle if the stagnation pressure of helium in the airship is 1.2 bar. Take the ratio of specific heats for Helium (g) to be 1.66 and the gas constant for helium, R_{helium} to be 2077 $J \cdot kg^{-1} \cdot K^{-1}$ [3]

(d) Assuming the helium inside the airship has the same temperature as the surrounding air, what is the temperature of helium at the point of exit through the nozzle? [3]

4. A centrifugal pump is used to mobilise Q=10 $m^3 \cdot h^{-1}$ of viscous oil, density r=900 $kg \cdot m^{-3}$. The pump being used is the 4.75″ pump from the HTO-80 series from MP Pumps Inc, the performance curves for the pump are shown in Figure Q.4.

(a) Using the graph and appropriate calculations, determine the head delivered by the pump, the differential pressure generated, the efficiency of the pump, the power delivered to the fluid and the brake horsepower in Watts, with the pump operating at 3450 rpm. Note that 1 hp=746 W. [5]

(b) If the eye of the pump has a diameter of D=5 cm, what should be the lowest oil pressure at the inlet to prevent cavitation? Consider that the vapour pressure of oil at the inlet is p_v=15 kPa. [5]

(c) The company wish to operate at a higher flowrate of Q=19 $m^3 \cdot h^{-1}$. The engineer considers buying a larger pump from the same series and operate at the same speed. Using pump similarity laws, work out what size pump should be bought and what power it will require. [3]

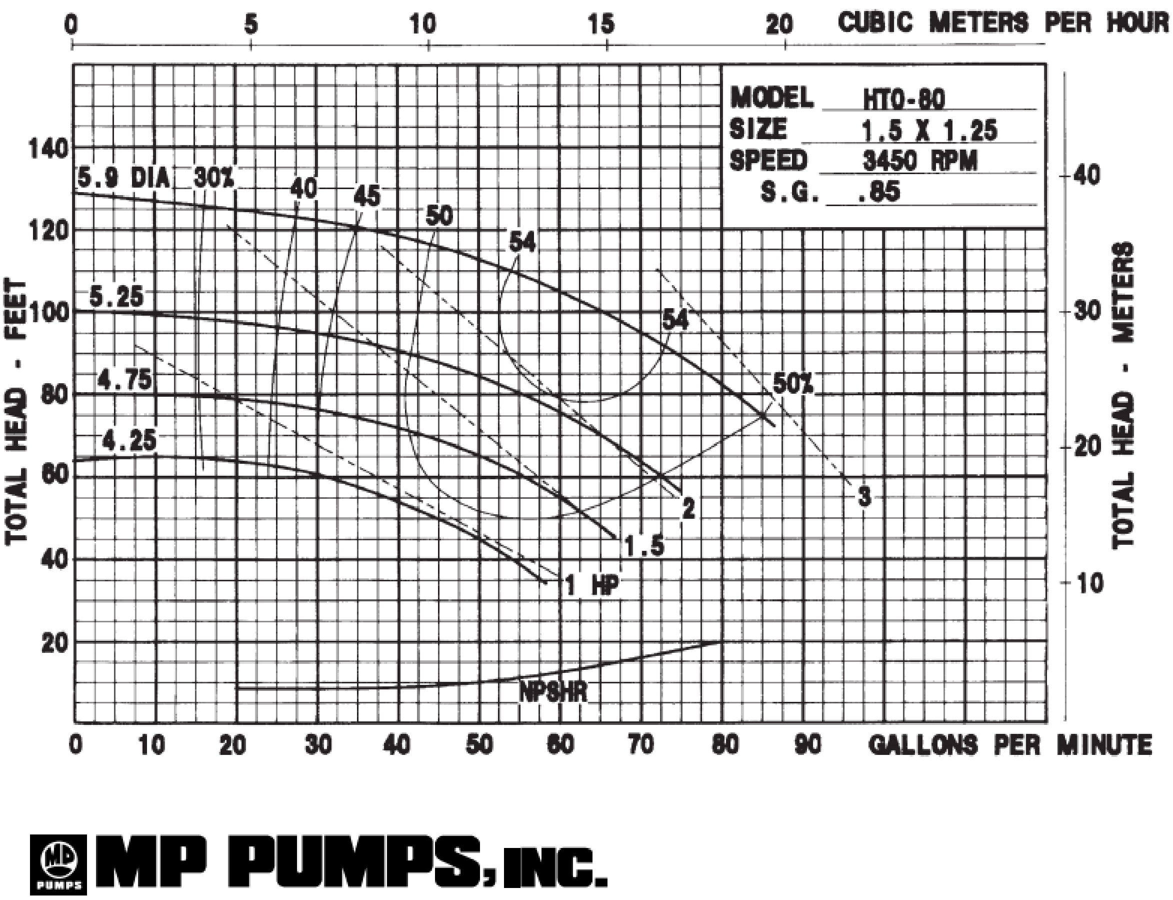


Figure Q.4: Performance curves for pump HTO-80.

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