INSTRUCTIONS TO CANDIDATES

You should have the following for this examination:
- Answer booklet;
- Drawing instruments;
- Mathematical tables/Non-programmable scientific calculator;
- Thermodynamic and Transport properties of fluid tables by Rogers and Mayhew.

This paper consists of EIGHT questions in TWO sections; A and B.
Answer THREE questions from section A and TWO questions from section B.
All questions carry equal marks.
Maximum marks for each part of a question are as shown.
Candidates should answer the questions in English.

This paper consists of 6 printed pages.
Candidates should check the question paper to ascertain that all the pages are printed as indicated and that no questions are missing.
SECTION A: THERMODYNAMICS

Answer THREE questions from this section.

1. (a) Define the following terms as applied to thermodynamics:

(i) system;
(ii) boundary.  

(2 marks)

(b) (i) Distinguish between isothermal and adiabatic processes.

(ii) State the first law of thermodynamics.  

(4 marks)

(c) (i) Show that for a perfect gas:

\[ C_p = \frac{\gamma R}{(\gamma - 1)} \]

where \( C_p \) = specific heat capacity at constant pressure;
\( \gamma \) = ratio of specific heat capacity at constant pressure to the specific heat capacity at constant volume;
\( R \) = gas constant.

(ii) A quantity of carbon dioxide is compressed from an initial state of 0.092 m\(^3\), 1.2 bar to a final state of 0.043 m\(^3\) and 4.2 bar. The observed temperature rise is 154 K. Determine the:

(I) gas constant;
(II) mass of gas present;
(III) increase in internal energy of the gas.

Assume carbon dioxide to be a perfect gas.

Take: \( C_p = 0.82 \text{ kJ/kg K} \) and \( C_v = 0.63 \text{ kJ/kg K} \)  

(14 marks)
2. (a) With the aid of a P-V diagram, describe the processes of the ideal dual combustion cycle. (8 marks)

(b) Show that for an air standard Otto cycle:
\[ \frac{T_2}{T_1} = r_v^{\gamma-1} \]

Where:
- \( T_2 \) = temperature at the end of compression;
- \( T_1 \) = temperature at the beginning of compression;
- \( r_v \) = compression ratio;
- \( \gamma \) = adiabatic index. (6 marks)

(c) In an air standard Otto cycle, the maximum and minimum temperatures are 1,500 °C and 14 °C. The heat supplied per kg of air is 700 kJ. Determine the:

(i) compression ratio;
(ii) thermal efficiency.

Take \( \gamma = 1.4 \);
\( C_v = 0.718 \) kJ/kg K. (6 marks)

3. (a) Define each of the following as used in combustion of fuels:

(i) stoichiometric mixture;
(ii) ultimate analysis;
(iii) mixture strength;
(iv) calorific value. (4 marks)

(b) A petrol engine uses ethyl alcohol \( (C_2H_6O) \) for combustion. Determine the:

(i) stoichiometric air fuel ratio by mass;
(ii) wet and dry analysis by volume of the exhaust gas in b(i);
(iii) air fuel ratio for a mixture strength of 80%. (16 marks)

4. (a) With the aid of a T-S diagram, explain the function of an intercooler in a gas turbine plant. (4 marks)
(b) In an aircraft gas turbine unit, a high pressure stage turbine drives the compressor and a low pressure stage turbine drives the propeller through suitable gearings. The overall pressure ratio is 5/1 and the maximum temperature is 700° C. The isentropic efficiencies of the compressor, high pressure turbine and low pressure turbine are 0.8, 0.82 and 0.86 respectively. The air intake conditions are 1.013 bar and 30° C.

(i) Draw the plant and T-S diagrams:

(ii) Calculate the:

(I) pressure between turbine stages;
(II) thermal efficiency.

Take: \( C_p = 1.005 \text{ kJ/kg K}, \quad C_p = 1.15 \text{ kJ/kg K}; \quad \gamma = 1.4 \) for both compression and expansion.

(16 marks)

5. (a) Distinguish between the following types of heat exchangers:

(i) regenerative and evaporative;
(ii) parallel flow and counter flow.

(4 marks)

(b) (i) State the Fourier’s law of conduction.

(ii) Show that for a single cylindrical wall of unit length, the logarithmic mean area \( A_m \) is given by:

\[
A_m = \frac{2\pi (r_2 - r_1)}{\ln\left(\frac{r_2}{r_1}\right)}
\]

where: \( r_1 = \) internal radius;
\( r_2 = \) external radius.

(9 marks)

(c) In a parallel flow tubular heat exchanger, hot gases are cooled from 600° C to 200° C by water initially at 18 °C. The mass flow rate of the gas is 0.4 kg/s and that of water 0.5 kg/s. The specific heat capacities of the gas and water are 1.2 kJ/kg K and 4.2 kJ/kg K respectively. The overall heat transfer coefficient from gases to water is 150 W/m²K.

(i) Sketch the temperature variation along the length of the heat exchanger.

(ii) Calculate the surface area required.

(7 marks)
SECTION B: FLUID MECHANICS

Answer TWO questions from this section.

6/ (a) Assuming that the frictional resistance per unit area of pipe wall $q$ is proportional to the square of the mean velocity of flow, show that the loss of head due to friction $h_r$ in a pipeline is given by the formula:

$$h_r = \frac{4fLV^2}{2dg}.$$  

Where: $f =$ resistance coefficient;
$L =$ length of pipe;
$V =$ velocity;
$d =$ diameter of pipe;
$g =$ gravitational acceleration.  

(9 marks)

(b) The discharge through a horizontal pipe of varying cross-section is 0.96 m$^3$/s. The first part of the pipe is 3 m long and 0.2 m diameter. The second part is 4 m long and 0.5 m diameter. The third part is 5 m long and 0.3 m diameter. The coefficient of contraction $C_c = 0.6$ and frictional coefficient $f = 0.01$.

If the change of sections are sharp, determine the total loss of head due to:

(i) sudden enlargement;
(ii) sudden contraction;
(iii) friction.  

(11 marks)

7/ (a) Define the following terms as used in fluid mechanics:

(i) coefficient of dynamic viscosity;
(ii) kinematic viscosity.  

(3 marks)

(b) Show that the total discharge $Q$ of a viscous incompressible fluid flowing between parallel flat plates is given by:

$$Q = \frac{Pbh^3}{12\mu L}.$$  

where: $P =$ pressure difference between the ends of the plates;
$\mu =$ coefficient of dynamic viscosity;
$L =$ length of plates;
$h =$ distance between the plates;
$b =$ width of the plates.  

(13 marks)
(c) A dashpot consists of a cylinder 60 mm diameter in which slides a piston 90 mm long. The radial clearance between the piston and the cylinder is 1.5 mm. The cylinder is filled with an oil of dynamic viscosity 0.1 kg/ms. If the piston is pushed by a force of 200 N, determine the volume of oil leaving the cylinder per second. (4 marks)

8. (a) Define the following terms as applied to pumps:

(i) specific speed;
(ii) coefficient of discharge. (2 marks)

(b) (i) State two assumptions made while deriving the equation for work done by a centrifugal pump.

(ii) With the aid of a diagram, show that for a centrifugal pump, the work done per unit weight is given by the equation:

\[ \text{Work done per unit weight} = \frac{W_2 u_2}{g} \]

Where: \( w_2 \) = tangential component of absolute velocity at exit (whirl velocity at exit);
\( u_2 \) = tangential velocity of impellor at outlet;
\( g \) = gravitational acceleration. (10 marks)

(c) A centrifugal pump running at 900 rev/min works against a total head of 24 m. The external diameter of the impeller and outlet width are 520 mm and 80 mm respectively. The vanes angle at outlet is 36° and the manometric efficiency is 80%. Determine the:

(i) flow velocity at outlet;
(ii) absolute velocity of the fluid leaving the vane;
(iii) angle of absolute velocity at exit;
(iv) impeller power. (8 marks)

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