APPLIED HEAT

Attempt SIX questions only

All questions carry equal marks

Marks for each part question are shown in brackets

All formulae used must be stated and the method of working and all intermediate steps must be made clear in the answer

1. A mass of 0.5 kg of gas is at a pressure and temperature of 4 bar and 60°C respectively.

   It is heated a constant volume until the pressure is 12 bar and then cooled at constant pressure to the initial temperature. It then undergoes isothermal expansion to the initial pressure.

   The change in specific entropy for the isothermal process is 2.282 kJ/kgK.

   (a) Sketch the processes on EACH of the following:

   (i) a Pressure-volume diagram; (1)

   (ii) a Temperature-specific entropy diagram. (2)

   (b) Calculate EACH of the following:

   (i) the maximum and minimum volumes of the gas; (5)

   (ii) the net work transfer; (3)

   (iii) the change in entropy for the constant pressure process. (5)

   Note: for the gas c_v *= 3.116 kJ/kgK*

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2. The gas turbine plant shown in Fig Q2 uses two stage compression with Inter-Cooling.

Each compressor has the same pressure ratio and intercooling may be considered perfect.

Air enters the Low Pressure Compressor at a temperature of 20°C and a mass flow rate of 120 kg/s.

The air fuel ratio is 75:1 and 74.1 MW of heat energy is supplied in the Combustion Chamber.

The isentropic efficiency of each compressor is 80% and that of the turbine is 88%.

The overall pressure ratio of the plant is 12:1.

(a) Calculate EACH of the following:

(i) the compressor power; (4)

(ii) the turbine inlet temperature; (3)

(iii) the net power output of the plant. (5)

(b) Sketch the cycle on a Temperature-specific entropy diagram showing the temperatures. (4)

Note: for the air $\gamma = 1.4$, $c_p = 1.005$ *kJkgK*
for the gas $\gamma = 1.33$, $c_p = 1.11$ *kJkgK*

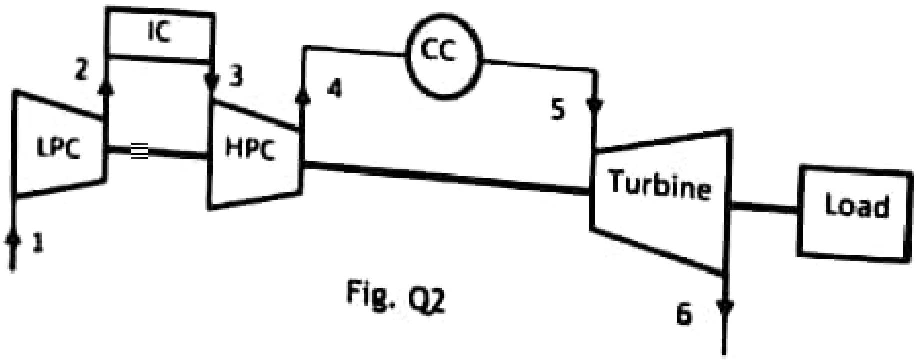

Fig. Q2

3. A fuel containing 80% carbon, 17% hydrogen and 3% oxygen by mass is completely burned with 10% excess air.

Use the equations of combustion by mass to calculate EACH of the following:

(a) the air to fuel ratio by mass; (5)

(b) the volumetric analysis of the flue gas; (5)

(c) the characteristic gas constant for the dry flue gas; (2)

(d) the adiabatic index for the dry flue gas. (4)

Note: *atomic mass relationships C = 12, N = 14, O = 16, H = 1.*
Air contains 23.3 % oxygen by mass
the universal gas constant R_o = 8.3145 kJ/kmolK
for: CO_2 c_p = 1.148 kJ/kgK
N_2 c_p = 1.111 kJ/kgK
O_2 c_p = 1.043 kJ/kgK

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4. In the steam plant shown in Fig Q4, steam enters the turbine at a pressure and temperature of 60 bar 580°C respectively. It leaves at a pressure of 0.1 bar and dryness fraction of 0.98.

In the Surface Feed Heater. The bled steam enters at a pressure of 7 bar and leaves as a saturated liquid. It then cascades via a throttle to the direct contact heater.

The boiler feed leaves at the saturation temperature of the bled steam.

In the Direct Contact Feed Heater. The bled steam enters at a pressure of 2 bar and the boiler feed leaves as a saturated liquid.

The boiler feed water leaves the condenser as a saturated liquid.

The feed pump work may be ignored.

(a) Draw the steam expansion process as a straight line on worksheet Q4. (2)

(b) Determine the specific enthalpy at the cardinal points of the cycle. (2)

(c) Calculate EACH of the following for 1kg of steam leaving the boiler:

  (i) the mass flow of bled steam flowing through the surface heater; (4)

  (ii) the mass flow of bled steam flowing through the contact heater; (4)

  (iii) the turbine work output. (4)

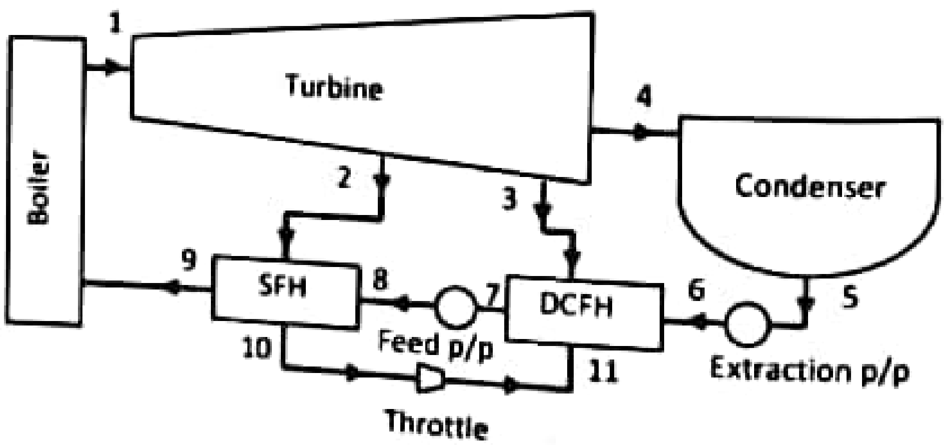

Fig. Q4

5. The speed of rotation of a 50% reaction turbine is 4244 rev/min.

In a particular stage the mean blade speed is 200 m/s and the blade height is 10% of the blade ring mean diameter.

The blade speed ratio is 0.6 and the blade exit angle is 25°.

The pressure and temperature of the steam in the stage is 0.5 bar and 100°C respectively.

(a) Sketch the velocity vector diagram indicating ALL the velocities and blade angles. (4)

(b) State the velocity and angle relationships for a 50% reaction turbine (2)

(c) Calculate EACH of the following:

(i) the absolute velocity of the steam leaving the stage; (3)

(ii) the diagram efficiency; (3)

(iii) the mass of steam flowing through the stage; (4)

6. A vapour compression refrigeration plant uses R134a as the working fluid.

The refrigerant enters the compressor as a dry saturated vapour at a temperature of -20°C and leaves at a pressure of 11.595 bar.

The isentropic efficiency of the compressor is 86.4% and the refrigerant enters the expansion valve at 40°C.

Sea water flows through the condenser at the rate of 5 m^3/hour and increases in temperature by 10 K.

Calculate EACH of the following:

(a) the temperature of the refrigerant at the end of compression; (5)

(b) the cooling load; (5)

(c) the compressor power; (2)

(d) the coefficient of performance for the cycle; (2)

(e) the COP for the reversed Carnot cycle operating between the same pressures. (2)

Note: *for sea water specific heat capacity c = 4.0 kJ/kgK*
Density ρ = 1025 kg/m^3

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7. A deck steam line is 120 m long and carries 720 kg/hour of saturated steam.

The steam enters the line in a dry saturated state at a pressure of 20 bar.

The pipe has an outer diameter of 140 mm and is covered in two layers of insulation each 50 mm thick.

A change in the vessels operating conditions requires an additional layer of insulation to be added to the pipeline. The additional layer limits the steam condensation to 31.42 kg/hour and maintains the outer surface temperature of the pipe at 9°C.

Calculate EACH of the following:

(a) the dryness fraction of the steam leaving the pipe; (2)

(b) the heat loss from the pipe per meter length; (3)

(c) the thickness of the additional layer of insulation; (6)

(d) the interface temperature between the second and outer layers of insulation. (5)

Note: *thermal conductivity of inner layer of insulation = 0.075 W/mK*
thermal conductivity of second layer of insulation = 0.4 W/mK
thermal conductivity of additional outer layer of insulation = 0.04 W/mK

8. A two stage single acting reciprocating gas compressor has a clearance ratio of 0.045 and runs at 200 rev/min.

The low pressure cylinder swept volume is 0.0848 m³ and the pressure and temperature at inlet are 0.9 bar and 20°C respectively.

The maximum temperature of the gas is limited to 180°C.

The polytropic index of expansion and compression is 1.28 in both stages and intercooling is perfect.

(a) Sketch the cycle on a Pressure-volume diagram indicating ALL the volumes. (2)

(b) Calculate EACH of the following;

(i) the inter-stage and delivery pressures; (2)

(ii) the volumetric efficiency; (2)

(iii) the indicated power; (5)

(iv) the rate of heat removal in the intercooler. (5)

Note: *for the gas molecular mass M = 4.003 kg/kmol, c_p = 5.193 kJ/kgK*
Universal gas constant R_o = 8.3145 kJ/kmolK

9. A jet of fresh water from an orifice plate strikes a series of flat vanes mounted on a rotor as shown in Fig Q9.

The orifice plate has a diameter of 15 mm and operates under a head of 2 m. It has a coefficient of velocity of 0.97 and a coefficient of contraction of 0.64.

The point of impact is at a horizontal distance of 200 mm from the orifice and gives an effective radius of 180 mm from the point of rotation.

The vanes rotate at a speed of 200 rev/min.

Calculate EACH of the following:

(a) the actual velocity of the jet; (2)

(b) the angle between the jet and the vane at the point of contact; (6)

(c) the force acting on the vane; (6)

(d) the power developed by the rotor at the instant shown in Fig.Q9. (2)

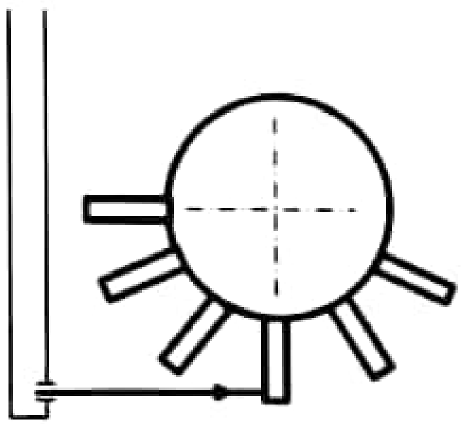

Fig Q9