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THE OPEN UNIVERSITY OF SRI LANKA
FACULTY OF ENGINEERING TECHNOLOGY
BACHELOR OF TECHNOLOGY (ENGINEERING)– LEVEL 05
FINAL EXAMINATION– 2009/2010

MEX5231 – APPLIED THERMODYNAMICS

DATE : 18th MARCH 2010
TIME : 0930 HRS. – 1030 HRS.
DURATION : THREE HOURS

ANSWER FIVE QUESTIONS ONLY. ALL QUESTIONS CARRY EQUAL MARKS.

(1) A design for a steam power plant includes:

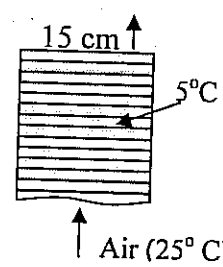
- A boiler delivering saturated steam at 55 bar
- A superheater, bringing steam temperature up to 500°C
- A high pressure (HP) turbine with isentropic efficiency 80% and exhausting at 12 bar
- A reheater, bringing steam temperature up to 500°C
- A low pressure (LP) turbine with isentropic efficiency 85% and exhausting at 0.06 bar
- A condenser, bringing steam to saturated liquid state at the LP turbine outlet pressure
- A feed pump, with isentropic efficiency 90% bringing the pressure of the feed water up to 55 bar before entry to the boiler

(i) Sketch the T-S diagram for the cycle.
(ii) Calculate the net work ourtput, the external heat supplied and hence the thermal efficiency of the cycle.
(iii) Calculate the work ratio.

(2) The gravimetric analysis of a coal used as boiler fuel is 80% C, 6% H, 2% O and 12% ash. The dry flue gas volumetric analysis is 15% CO_2, 2% CO, 4% O_2 and 79% N_2. Determine,

(i) the proportion of carbon burned to CO
(ii) the mass of air supplied per kg of coal
(iii) the percentage of excess air supplied

(3) (i) Define Nusselt Number (Nu), Reynolds number (Re) and Prandtle number (Pr).
(ii) As shown in the figure below a domestic air cooler has a cooling coil with 32 parallel tubes of 0.7 cm outside diameter and length 15 cm, fitted into a space of 15 cm high by 25 cm wide. The coils are kept at a constant surface temperature of 5°C by a refrigeration circuit. The air enters at 0.2 ms^{-1} and 25°C to perpendicular to the tube array.



You may use

$$N_u = \frac{hd}{k} = 0.26 Re^{0.6} Pr^{0.3}$$

Properties of air at 15 °C (average of tube surface and air temperature)

P = 1.228 kg/m^3
k = 2.530 x 10^{-2} W/mK
μ = 1.788 x 10^{-5} kg/ms
Pr = 0.710

Calculate:

(a) heat transfer rate for a single tube in the array considered in isolation and hence for the whole array.
(b) temperature of the air leaving the array

(4) A supersonic wind tunnel nozzle is to be designed for exit Mach no $M_2 = 2$ with a throat section 0.12m^2 in area. The supply pressure and temperature at the nozzle inlet, where the velocity is negligible are 80 kPa and 35 °C respectively.

Determine,
(i) mass flow rate
(ii) exit area
(iii) pressure, temperature and velocity at the throat and exit.

Take $\gamma = 1.4$

You may use following equations.

$$\frac{A_2}{A_1} = \left[\left(\frac{2}{\gamma+1}\right)\left(1+\frac{\gamma-1}{2}M_2^2\right)\right]^{\frac{\gamma+1}{2(\gamma-1)}} \times \frac{1}{M_2}$$

$$\frac{T_1}{T_o} = \frac{2}{\gamma+1}$$

$$\frac{P_o}{P_2} = \left[1+\frac{\gamma-1}{2}M_2^2\right]^{\frac{\gamma}{\gamma-1}}$$

$$\frac{P_1}{P_o} = \left(\frac{2}{\gamma+1}\right)^{\frac{\gamma}{\gamma-1}}$$

$$\frac{T_o}{T_2} = \left[1+\frac{\gamma-1}{2}M_2^2\right]$$

(5) A refrigeration machine using R-12 as refrigerant operates between the pressure 2.2 bar and 9.2 bar. The compression is isentropic and there is no undercooling in the condenser. The vapour is in dry saturated condition at the beginning of the compression. Actual coefficient of performance is 0.6 of theoretical value and the refrigerant flow is 6 kg per minute.

(i) Sketch the process on T-S and p-h diagrams
(ii) Estimate the theoretical coefficient of performance
(iii) Calculate the net cooling produced and refrigerator capacity.

Properties of refrigerant are

Pressure , bar	Saturation temperature, °C	Enthalpy kJ/kg		Entropy of saturated vapour, kJ/kgK
		liquid	Enthalpy	
9.2	38	72.56	202.51	0.6830
2.2	-10	26.87	183.2	0.7019

Take Cp for superheated vapour at 9.2 bar as 0.64 kJ/kgK

(6) One stage of an impulse turbine consists of a converging nozzle and one ring of moving blades. The nozzles are inclined at 22° to the blades which are having inlet and outlet angles 35°.

(i) If the velocity of steam at exit from the nozzle is 660 m/s, find the blade speed so that the steam shall pass on without shock (no end thrust).
(ii) Find the diagram efficiency neglecting losses, if the blades run at this speed.
(iii) If the relative velocity of steam is reduced by 15% in passing through the blade ring, find the efficiency and the end thrust on the shaft when the blade ring develops 1.7 kW.

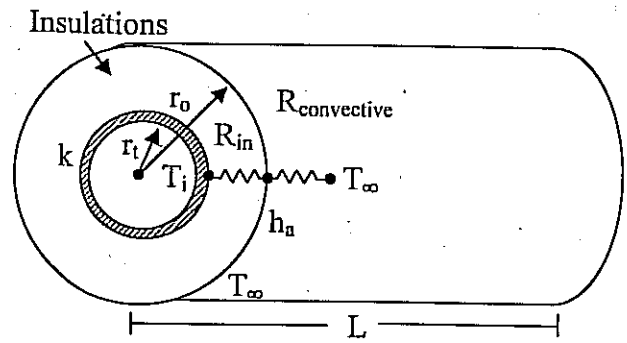
(7) The air supplied to a gas turbine plant is 10 kg/s. The pressure ratio is 6 and pressure at the inlet of the compressors is 1 bar. The compressor is two stage and provided with perfect intercooler. The inlet temperature is 300 K and maximum temperature is limited to 1073 K

Isentropic efficiency of compressor each stage – 80%
Isentropic efficiency of turbine = 85%
A regenerator is included in plant whose effectiveness is 0.7.

Neglecting the mass of fuel determine the thermal efficiency of the plant.
Take Cp for air = 1.005 kJ/kgK

(8) (i) Consider a tube as shown in the figure below having radius r_i and at temperature T_i is covered with an insulating material of thermal conductivity k with outside radius of r_0. Convection heat transfer coefficient is h_a, atmospheric air temperature is T_∞. Write down an expression for the total heat transfer from the tube. Heat transfer through a hollow tube is given by the

$$Q = \frac{2\pi kL}{\ln \frac{r_0}{r_i}} \Delta T$$



(ii) Hence show that the ratio of heat loss from the tube with insulation, to that without having insulation is given by

$$\frac{Q_{with}}{Q_{without}} = \frac{r_0}{r_i}\left[\frac{1+\frac{r_0 h_a}{k}\ln r_0}{r_i}\right]^{-1}$$

(iii) A tube having outside diameter 2 cm is maintained at uniform temperature T_i and is covered with an insulation (k = 0.20 W/mK) to reduce the heat loss. Heat is dissipated from the outer surface of insulation by natural convection with ha = 15W/m^{2}K into the ambient air at T∞ .

(a) Write down the formula for critical thickness of insulation interms of k and h. Determine the critical thickness of insulation .
(b) Calculate the ratio of the heat loss from the tube with insulation to that without insulation for

- the thickness of insulation equal to the critical thickness and
- the thickness of insulation 2cm thicker than the critical thickness.

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