UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 4 Examination in Engineering: December 2015

Module Number: ME 4310 **Module Name: Applied Thermodynamics (O.C)**

[Three Hours]

[Answer **all questions**; each question carries **ten marks**]

Note: provide neat sketches where necessary; state any assumptions made.

Q1 a) Draw the neat line diagrams and corresponding T-S diagrams for the following- vapour power cycles.

i) Ideal regenerative Rankine cycle with a closed feed water heater.

[2.0 Marks]

ii) Ideal regenerative Rankine cycle with an open feed water heater.

[2.0 Marks]

b) In a steam turbine cycle, the turbine is supplied with steam at a pressure of 32 bar and a temperature of 410 °C. Through the turbine, steam expands isentropically to a saturated state at a pressure of 0.08 bar, and thereafter condensed into a saturated liquid state though a condenser. Additional data related with the cycle are given below.

Enthalpy of steam at the turbine inlet = 3250 kJ/kg
Enthalpy of steam at the turbine outlet = 2170 kJ/kg
Specific volume of steam at the condenser outlet = 0.0010084 m^3/kg
Enthalpy of steam at the condenser outlet = 173.9 kJ/kg

Answer the following questions.

i) Find the thermal efficiency of the cycle.

[3.0 Marks]

ii) The above steam turbine cycle is to be modified by adding a new low-pressure turbine such that the outlet flow of the original turbine is reheated at 5.5 bar upto 400 °C, and fed in to the low pressure turbine. At this low-pressure turbine, steam expands isentropically to the same previous outlet pressure of 0.08 bar. Calculate the thermal efficiency of the cycle using the additional data given below.

Enthalpy of steam at the outlet of the first turbine = 2830 kJ/kg
Enthalpy of steam at the inlet of the second turbine = 3270 kJ/kg
Enthalpy of steam at the outlet of the second turbine = 2430 kJ/kg

[3.0 Marks]

Q2 a) What are the assumptions made when evaluating the thermal efficiency of a gas turbine in an ideal Brayton cycle? Also, state the reasons for making those assumptions.

[3.0 Marks]

b) In a gas turbine plant which is working on Brayton cycle with a regenerator of 75% effectiveness, the air at the inlet of the compressor is at 0.1 MPa and 30 °C. The pressure ratio of the cycle is 6.0 and the maximum cycle temperature is 900 °C. The efficiencies of both the turbine and the compressor are 80%. Additional data and key formulae related with the cycle are given below.

Isentropic relations for ideal gases:

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$$

Constant C_p of air throughout the cycle = 1.005 kJ/kg K

Specific heat ratio of air (γ) = 1.4

Answer the following questions.

i) Thermal efficiency of the cycle without the regenerator.

[3.0 Marks]

ii) Thermal efficiency of the cycle with the regenerator.

[3.0 Marks]

iii) Percentage increase of the cycle efficiency due to regeneration.

[1.0 Mark]

Q3 a) Explain whether would there be any possibility to observe a shock wave development in the converging section of a converging-diverging nozzle.

[2.0 Marks]

b) What is meant by the "Choked Flow" of a fluid?

[2.0 Marks]

c) Nitrogen gas (N_2) enters a steady-flow heat exchanger at 150 kPa, 10 °C, and 100 m/s, and receives heat at 120 kJ/kg as it flows through it. The gas leaves the heat exchanger at 100 kPa with a velocity of 200 m/s. Additional data related with the process are given below.

Constant C_p of N_2 throughout the process = 1.040 kJ/kg K

Gas constant (R) = 0.2968 kJ/kg K

Specific heat ratio of N_2 (γ or k) = 1.4

Answer the following questions.

i) Determine the Mach number of the flow at the inlet.

[3.0 Marks]

ii) Determine the Mach number of the flow at the outlet.

[3.0 Marks]

Q4 a) In axial flow turbines, the actual work done by the rotor is given by $P = \dot{m}\, U\, \Delta V_W$. Using this relationship, construct the velocity diagram of an axial turbine and hence derive the below relationship.

$$P = \frac{\dot{m}}{2}\left[\left(C_1{}^2 - C_2{}^2\right) + \left(V_1{}^2 - V_2{}^2\right)\right]$$

Here,

P = power output of the turbine
$\dot{m}$ = mass flow rate through the turbine
C_1= absolute velocity of the fluid at the turbine inlet
C_2= absolute velocity of the fluid at the turbine outlet
V_1= velocity of the fluid at the turbine inlet, relative to the respective turbine blade
V_2= velocity of the fluid at the turbine outlet, relative the respective turbine rotor blade
U = turbine rotor blade velocity
ΔV_W = whirl velocity difference (i.e. the difference between the tangential velocities at the turbine inlet and outlet)

[2.0 Marks]

b) Steam flows through an impulse stage turbine in a power plant. The turbine is running at a speed of 20,000 rpm and has a mean blade diameter of 25 cm. The nozzle angle (α_1) of the turbine is ~~20°~~ 70°. Steam velocity at the nozzle outlet was found to be 900 m/s at a mass flow rate of 0.18 kg/s.

i) Calculate the blade velocity (U).

[1.0 Mark]

ii) Construct the velocity diagram for the impulse turbine and calculate the axial velocity at the inlet (C_{a1}), relative velocity V_1 at the inlet and the blade angle (β_1).

[2.0 Marks]

iii) Explain what happens to the relative velocities and the blade angles at the inlet and outlet of the above impulse stage turbine.

[1.0 Mark]

iv) Derive an expression for ΔV_W of the impulse turbine, and hence calculate the total power generated by the above turbine.

[2.0 Marks]

v) Power at the rotor blades (input power) of the above impulse turbine is given by: $\frac{\dot{m}}{2}[(C_1^2) + (V_1^2 - V_2^2)]$. Calculate the maximum power that could be generated by the turbine.

[2.0 Marks]

Q5 a) The combustion process is a chemical reaction whereby fuel is oxidised and energy is released.

i) Name **three** different types of internal energies stored in a matter or a system, which influence the enthalpy.

[1.0 Mark]

ii) Define the term "air-fuel ratio" and briefly explain the importance of providing excess air to a combustion process.

[1.0 Mark]

b) The Otto cycle is the ideal cycle used in spark-ignition-based reciprocating engines. Describe the cycle using a P-V diagram.

[2 Marks]

c) In an Otto cycle with a compression ratio of 9.5, the total volume available in the cylinder just before the start of the compression stroke is found to be 600 cm^3. The pressure and the temperature of the air volume are 100 kPa and 290 K, respectively. Then, the air volume is compressed isentropically. The temperature of air at the end of the compression stroke is found to be 800 K. Additional properties of air are given below.

Constant C_p of air throughout the cycle = 1.005 kJ/kg K
Constant C_v of air throughout the cycle = 0.718 kJ/kg K
Gas constant (R) of air = 0.287 kJ/kg K
Specific heat ratio of air = 1.4
Ideal gas law: $m = PV/RT$

Answer the following questions.

i) The highest temperature and the pressure in the cycle.

[1.0 Mark]

ii) The amount of heat transferred into the cycle.

[1.0 Mark]

iii) Thermal efficiency of the cycle.

[1.0 Mark]

iv) Mean effective pressure.

[1.0 Mark]

d) Explain the difference between the Diesel Cycle and the Otto Cycle. Also, explain why the Diesel Cycle can reach higher compression ratios than the Otto cycle.

[2 Marks]