School of Mechanical Engineering

Engineering Thermodynamics-II, ME- 401

Assignment-I

4th Semester **Date of Submission: 11/02/11**

Section 1: Thermodynamic Relations (T-ds relations)

Q1. Show that the internal energy of (a) an ideal gas and (b) an incompressible substance is a function of temperature only, u = u(T).

Q2. Show that the Joule-Thomson coefficient of an ideal gas is zero.

Q3. Prove for an ideal gas that (a) the P = constant lines on a T-v diagram are straight lines and (b) the high-pressure lines are steeper than the low-pressure lines.

Q4. Derive a relation for the slope of the v = constant lines on a T-P diagram for a gas that obeys the van der Waals equation of state. Answer: (v - b)/R

Q5. Using the Maxwell relations, determine a relation for $(\partial s/\partial P)_T$ for a gas whose equation of state is P(v - b) = RT. Answer: R/P

Q6. Using the Maxwell relations, determine a relation for $(\partial s/\partial v)_T$ for a gas whose equation of state is

$$(P - a/v^2)(v - b) = RT.$$

Q7. What is the value of the Clapeyron equation in thermodynamics?

Q8. Does the Clapeyron equation involve any approximations, or is it exact?

Q9. What approximations are involved in the Clapeyron- Clausius equation?

Q10. Derive expressions for (a) Δu, (b) Δh, and (c) Δs for a gas whose equation of state is P*(v - a) = RT for an isothermal process. Answers: (a) 0, (b) $a*(P_2 - P_1)$, (c) $- R \ln (P_2/P_1)$

Q11. What does the Joule-Thomson coefficient represent?

Q12. Describe the inversion line and the maximum inversion temperature.

Q13. Derive a relation for the Joule-Thomson coefficient and the inversion temperature for a gas whose equation of state is $(P - a/v^2)*v = RT$.

Q14. Estimate the Joule-Thomson coefficient of steam at (a) 3 MPa and 300°C and (b) 6 MPa and 500°C.

Q15. For a homogeneous (single-phase) simple pure substance, the pressure and temperature are independent properties, and any property can be expressed as a function of these two properties. Taking v = v(P, T), show that the change in

specific volume can be expressed in terms of the volume expansivity β and isothermal compressibility α as

$$\frac{dv}{v} = \beta dT - \alpha dP$$

Q16. Consider an infinitesimal reversible adiabatic compression or expansion process. By taking s = s(P, v) and using the Maxwell relations, show that for this process Pv^k = constant, where k is the isentropic expansion exponent defined as

$$k = \frac{v}{p}\left(\frac{\partial P}{\partial v}\right)_s$$

Also, show that the isentropic expansion exponent k reduces to the specific heat ratio c_p / c_v for an ideal gas.

Section 2: Vapor Power Cycles

Q1. Consider a steady-flow Carnot cycle with water as the working fluid. The maximum and minimum temperatures in the cycle are 350 and 60°C. The quality of water is 0.891 at the beginning of the heat-rejection process and 0.1 at the end. Show the cycle on a T-s diagram relative to the saturation lines, and determine (a) the thermal efficiency, (b) the pressure at the turbine inlet, and (c) the net work output. Answers: (a) 0.465, (b) 1.40 MPa, (c) 1623 kJ/kg

Q2. Consider a simple ideal Rankine cycle with fixed boiler and condenser pressures. What is the effect of superheating the steam to a higher temperature on

i. Pump work input: (a) increases, (b) decreases,(c) remains the same
ii. Turbine work output: (a) increases, (b) decreases, (c) remains the same
iii. Heat supplied: (a) increases, (b) decreases, (c) remains the same
iv. Heat rejected: (a) increases, (b) decreases, (c) remains the same
v. Cycle efficiency: (a) increases, (b) decreases, (c) remains the same
vi. Moisture content at turbine exit: (a) increases, (b) decreases, (c) remains the same

Q3. A steam power plant operates on a simple ideal Rankine cycle between the pressure limits of 3 MPa and 50 kPa. The temperature of the steam at the turbine inlet is 300°C, and the mass flow rate of steam through the cycle is 35 kg/s. Show the cycle on a T-s diagram with respect to saturation lines, and determine (a) the thermal efficiency of the cycle and (b) the net power output of the power plant.

Q4. Consider a 210-MW steam power plant that operates on a simple ideal Rankine cycle. Steam enters the turbine at 10 MPa and 500°C and is cooled in the condenser at a pressure of 10 kPa. Show the cycle on a T-s diagram with respect to saturation lines, and determine (a) the quality of the steam at the turbine exit, (b) the thermal efficiency of the cycle, and (c) the mass flow rate of the steam. Answers: (a) 0.793, (b) 40.2 percent, (c) 165 kg/s

Q5. Repeat the above question assuming an isentropic efficiency of 85 percent for both the turbine and the pump. Answers: (a) 0.874, (b) 34.1 percent, (c) 194 kg/s

Q6. Consider a coal-fired steam power plant that produces 300 MW of electric power. The power plant operates on a simple ideal Rankine cycle with turbine inlet conditions of 5 MPa and 450°C and a condenser pressure of 25 kPa. The coal has a heating value (energy released when the fuel is burned) of 29,300 kJ/kg. Assuming that 75 percent of this energy is transferred to the steam in the boiler and that the electric generator has an efficiency of 96 percent, determine (a) the overall plant efficiency (the ratio of net electric power output to the energy input as fuel) and (b) the required rate of coal supply. Answers: (a) 24.5 percent, (b) 150 t/h

Q7. How do the following quantities change when a simple ideal Rankine cycle is modified with reheating? Assume the mass flow rate is maintained the same.

i. Pump work input: (a) increases, (b) decreases, (c) remains the same
ii. Turbine work output: (a) increases, (b) decreases, (c) remains the same
iii. Heat supplied: (a) increases, (b) decreases, (c) remains the same
iv. Heat rejected: (a) increases, (b) decreases, (c) remains the same
v. Moisture content at turbine exit: (a) increases, (b) decreases, (c) remains the same

Q8. A steam power plant operates on an ideal reheat Rankine cycle between the pressure limits of 15 MPa and 10 kPa. The mass flow rate of steam through the cycle is 12 kg/s. Steam enters both stages of the turbine at 500°C. If the moisture content of the steam at the exit of the low-pressure turbine is not to exceed 10 percent, determine (a) the pressure at which reheating takes place, (b) the total rate of heat input in the boiler, and (c) the thermal efficiency of the cycle. Also, show the cycle on a T-s diagram with respect to saturation lines.

Q9. Consider a steam power plant that operates on a reheat Rankine cycle and has a net power output of 80 MW. Steam enters the high-pressure turbine at 10 MPa and 500°C and the low-pressure turbine at 1 MPa and 500°C. Steam leaves the condenser as a saturated liquid at a pressure of 10 kPa. The isentropic efficiency of the turbine is 80 percent, and that of the pump is 95 percent. Show the cycle on a T-s diagram with respect to saturation lines, and determine (a) the quality (or temperature, if superheated) of the steam at the turbine exit, (b) the thermal efficiency of the cycle, and (c) the mass flow rate of the steam. Answers: (a) 88.1°C, (b) 34.1 percent, (c) 62.7 kg/s

Q10. Consider an ideal steam regenerative Rankine cycle with two feedwater heaters, one closed and one open. Steam enters the turbine at 12.5 MPa and 550°C and exhausts to the condenser at 10 kPa. Steam is extracted from the turbine at 0.8 MPa for the closed feedwater heater and at 0.3 MPa for the open one. The feedwater is heated to the condensation temperature of the extracted steam in the closed feedwater heater. The extracted steam leaves the closed feedwater heater as a saturated liquid, which is subsequently throttled to the open feedwater heater. Show the cycle on a T-s diagram with respect to saturation lines, and determine (a)

the mass flow rate of steam through the boiler for a net power output of 250 MW and (b) the thermal efficiency of the cycle.

Q11. A steam power plant operates on the reheat regenerative Rankine cycle with a closed feedwater heater. Steam enters the turbine at 12.5 MPa and 550°C at a rate of 24 kg/s and is condensed in the condenser at a pressure of 20 kPa. Steam is reheated at 5 MPa to 550°C. Some steam is extracted from the low-pressure turbine at 1.0 MPa, is completely condensed in the closed feedwater heater, and pumped to 12.5 MPa before it mixes with the feedwater at the same pressure. Assuming an isentropic efficiency of 88 percent for both the turbine and the pump, determine (a) the temperature of the steam at the inlet of the closed feedwater heater, (b) the mass flow rate of the steam extracted from the turbine for the closed feedwater heater, (c) the net power output, and (d) the thermal efficiency. Answers: (a) 328°C, (b) 4.29 kg/s, (c) 28.6 MW, (d) 39.3 percent

Q12. Steam enters the turbine of a cogeneration plant at 7 MPa and 500°C. One-fourth of the steam is extracted from the turbine at 600-kPa pressure for process heating. The remaining steam continues to expand to 10 kPa. The extracted steam is then condensed and mixed with feedwater at constant pressure and the mixture is pumped to the boiler pressure of 7 MPa. The mass flow rate of steam through the boiler is 30 kg/s. Disregarding any pressure drops and heat losses in the piping, and assuming the turbine and the pump to be isentropic, determine the net power produced and the utilization factor of the plant.

Q13. A textile plant requires 4 kg/s of saturated steam at 2 MPa, which is extracted from the turbine of a cogeneration plant. Steam enters the turbine at 8 MPa and 500°C at a rate of 11 kg/s and leaves at 20 kPa. The extracted steam leaves the process heater as a saturated liquid and mixes with the feedwater at constant pressure. The mixture is pumped to the boiler pressure. Assuming an isentropic efficiency of 88 percent for both the turbine and the pumps, determine (a) the rate of process heat supply, (b) the net power output, and (c) the utilization factor of the plant. Answers: (a) 8.56 MW, (b) 8.60 MW, (c) 53.8 percent

Q14. A binary vapor cycle operates on mercury and steam. Saturated mercury vapor at 4.5 bar is supplied to the mercury turbine, from which it exhausts at 0.04 bar. The mercury condenser generates saturated steam at 15 bar which is expanded in a steam turbine to 0.04 bar. (a) Find the overall efficiency of the cycle. (b) If 50,000 kg/h of steam flows through the steam turbine, what is the flow through the mercury turbine? (c) Assuming that all processes are reversible, what is the useful work done in the binary vapor cycle for the specified steam flow ? (d) If the steam leaving the mercury condenser is superheated to a temperature of 300 °C in a superheater located in the mercury boiler, and if the internal efficiencies of mercury and steam turbines are 0.85 and 0.87 respectively, calculates the overall efficiency of the cycle.