NATIONAL EXAMINATIONS MAY 2011

07-Mec-A1 Applied Thermodynamics and Heat Transfer

3 Hours Duration

Notes :

1. If doubt exists concerning the interpretation of any question, the candidate is urged to make assumptions and clearly explain what has been assumed along with the answer to the question.

2. The examination is open book. As a consequence, candidates are permitted to make use of any textbooks, references or notes.

3. Any non-communicating calculator is permitted. However, candidates must indicate the type of calculator(s) that they have used by writing the name and model designation of the calculator(s) on the inside of the cover of the first examination book.

4. It is expected that each candidate will have copies of both a thermodynamics text and a heat transfer text in order to make use of the information presented in the tables and graphs contained.

5. The answers to five questions, either three questions from Part A and two questions from Part B or two questions from Part A and three questions from Part B, comprise a complete examination.

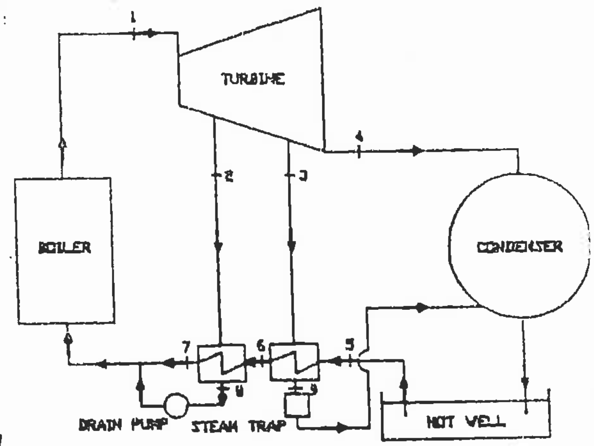
6. Candidates must indicate the answers that they wish to have graded on the cover of the first examination book. Otherwise the answers will be graded in the order in which they appear in the examination book(s) up to a maximum of three answers per section .

7. The answer to any question carries the same value in the grading .

PART A - THERMODYNAMICS

1. For a certain gas, the equation of state is $pv = 310\ (\ T + 273\ )$ and the internal energy is predicted by the relationship $u = u_0 + 837\ T$ where p is the pressure in N/m^2, v is the specific volume in m^3/kg, T is the temperature in K and u is the internal energy in J/kg. A cylinder fitted with a piston contains 0.025 m^3 of the gas at a pressure of 345 kPa and a temperature of 82°C. During expansion to a lower pressure, work equivalent to 2845 J was done by the gas and heat equivalent to 1900 J was transferred from it. Determine the temperature of the gas after the expansion. If the gas undergoes a process between the same end states in which the heat transfer is zero, how much work is done by the gas ?

2. A turbine supplied with steam at 1.80 MN/m^2 and 300°C and exhausting at 0.005 MN/m^2 is fitted with a two-stage feedwater heating system using steam bled from the turbine. The high pressure heater takes steam at 0.400 MN/m^2 to heat the feed water to 140°C and the condensate from this heater is pumped by a drain pump into the boiler feed line. The low pressure heater takes steam at 0.075 MN/m^2 to heat the feed water from 35°C to 90°C and the condensate from this heater is released through a steam trap to the condenser. The steam flow rate to the turbine is 15,900 kg/hr. Calculate the flow rate of the steam entering each of the two heaters and determine the total power produced by the turbine rotor, given the enthalpy of the exhaust steam is 2,350 kJ/kg at 0.005 MN/m^2 and that the state points through which the steam in the turbine passes can be represented by a straight line drawn on the entropy-entropy diagram distributed with the examination. Neglect external heat losses and assume that there is no undercooling of the condensate in the heaters.

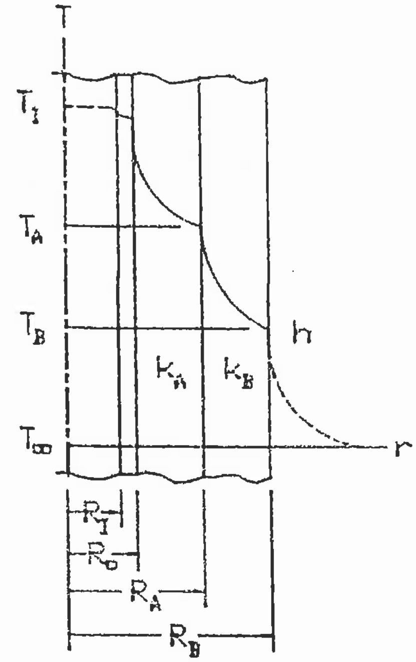


3. A gas turbine power plant which will be powered by a heat source having a temperature of at least 840°C is to be designed with a pressure ratio of 4. Regeneration is to be incorporated into the power plant design and it is expected that the regenerator effectiveness will be at least 90%. It is intended that the working fluid will enter the compressor at 100 kPa and 15°C. Using air-standard cycle analysis, calculate the minimum thermal efficiency of the power plant.

4. a 20 ton capacity ice-making refrigeration plant (1 ton = 3.516 kW) uses ammonia as the refrigerant. The evaporator operates at -14°C and the ammonia condenses at 28°C. Assuming 90% compressor efficiency and neglecting all piping losses, determine the coefficient of performance and the power required to drive the compressor per ton of refrigerant. If the water that cools the condenser enters at 20°C and leaves at 27°C, what cooling water flowrate is required ? Sketch the refrigeration process on a temperature entropy diagram.

PART B - HEAT TRANSFER

5. Saturated steam at temperature T_I = 270°C flows through a steel pipe R_I = 30 mm inside radius by R_0 = 35 mm outside diameter. The temperature of the ambient air T_∞ = 20°C and the heat transfer coefficient between the outer surface of the insulation and the ambient air is predicted by the relationship $h = 0.56(T_B-T_\infty)^{1/4}$ W/m²°C. When a 40 mm thick layer of insulation A was placed around the pipe and a 55 mm thick layer of insulation B was placed around the insulation, the temperature of the outer surface of the insulation T_B = 95°C. When a 15 mm thick layer of insulation A was placed around the pipe and a 100 mm thick layer of insulation B was placed around the insulation, the temperature of the outer surface of the insulation T_B = 65°C. Determine the thermal conductivities k_A and k_B. Assumptions may be made to simplify the analysis but they must be justified.



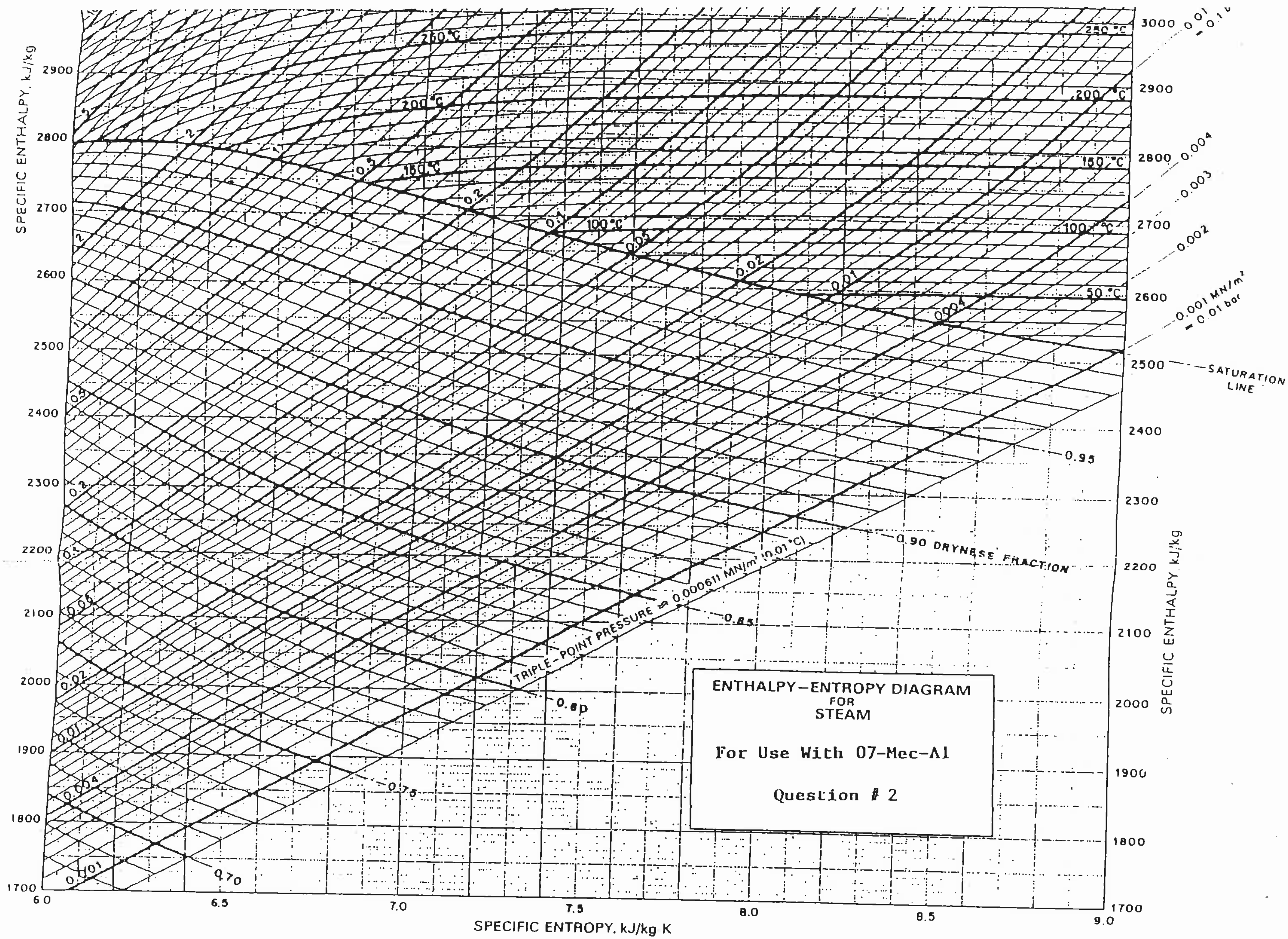
6. Lead shot is manufactured by solidifying the 1.5 mm diameter droplets of molten lead that form upon passing through a screen and become spherical as they fall through the air into a water bath maintained at 100°C. The molten droplets are deemed to have solidified sufficiently that they will not deform when they come to rest at the bottom of the water bath if the temperature at the center is equal or less than 120°C. Assuming that the temperature of the molten droplets is uniform at 300°C when they enter the water and that the heat transfer coefficient at the interface between the lead and the water is 5000 W/m²°C, calculate the minimum depth of the water bath required for the lead shot to solidify sufficiently if the lead shot falls at 1.5 m/s when it is in the water. For the purposes of the analysis, the thermophysical properties of solid lead may be assumed to be applicable throughout the solidification process.

7. An inexpensive construction site heater is created by passing condensing steam at 120°C through four 30 m lengths of 7.5 cm outside diameter horizontal steel pipe manifolded together in parallel. The natural convection heat transfer coefficient at the interface between the steel and the air is 10 W/m²°C. Considering that even at the relatively low temperature levels involved, the radiation heat transfer effect is likely to be just as significant as the natural convection heat transfer effect and therefore must be included in the analysis, how much heat will the heater produce if the emissivity of the surface of the steel pipe is 0.8 and the temperature of the surrounding air is 15°C ? Determine the relative magnitudes of the convection and radiation heat transfer effects.

8. Hot water flowing at $\mathring{m}_h$ = 1 kg/s through a crossflow heat exchanger in which both fluids are unmixed is cooled from T_{hi} = 90°C to T_{ho} = 60°C by cold water flowing at $\mathring{m}_c$ = 2 kg/s which enters the heat exchanger at T_{ci} = 40°C. The overall heat transfer coefficient between the hot and cold streams U = 1000 W/m²°C.

(a) Determine the surface area A required to promote the heat transfer process.

(b) Compute the outlet temperatures T_{co} and T_{ci} corresponding to U′ = 800 W/m²°C.


ENTHALPY–ENTROPY DIAGRAM
FOR
STEAM
For Use With 07-Mec-A1
Question # 2
SPECIFIC ENTROPY, kJ/kg K
SPECIFIC ENTHALPY, kJ/kg
SATURATION LINE
0.90 DRYNESS FRACTION
TRIPLE-POINT PRESSURE = 0.000611 MN/m² (0.01 °C)
0.001 MN/m² = 0.01 bar
0.002
0.003
0.004
0.01
250 °C
200 °C
150 °C
100 °C
50 °C
0.95
0.85
0.80
0.75
0.70
6.0
6.5
7.0
7.5
8.0
8.5
9.0
1700
1800
1900
2000
2100
2200
2300
2400
2500
2600
2700
2800
2900
3000