Carleton University

MAAE 2400 Final Exam

Professor Beausoleil-Morrison, Professor Rocha, and Dr Tang

Fall 2015

Course : MAAE 2400 Sections A, D, and E
Number of students : 309
Duration : 3 hours
Authorized memoranda : Open book, standard calculator
Students **MUST** count the number of pages in this examination question paper before beginning to write, and report any discrepancies immediately to a proctor. This question paper has 15 pages.
This examination question paper **MAY** be taken from the examination room.
In addition to this question paper, students require an examination booklet.
Students require a Scantron sheet.

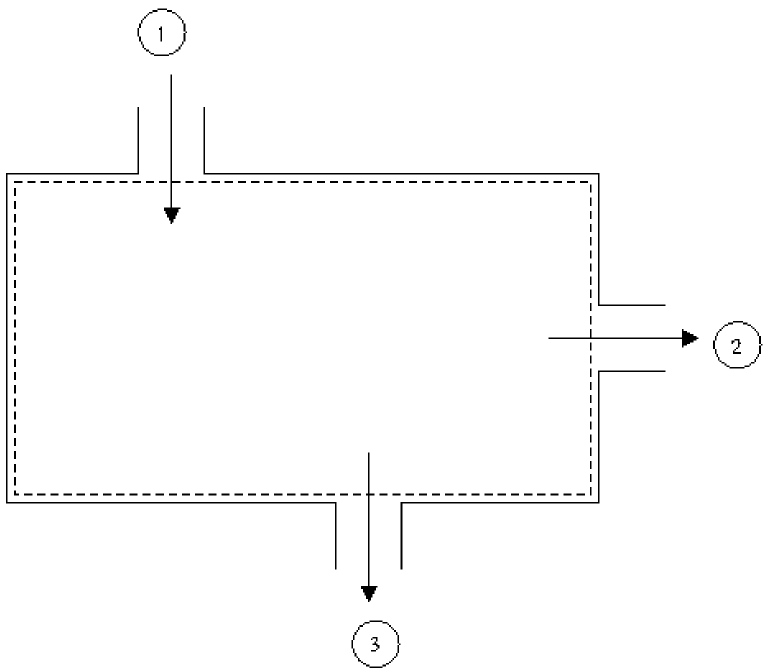
General instructions

1. Read all questions thoroughly before attempting to answer them.
2. You are to submit handwritten solutions in an examination booklet for Questions 1 through 3. These handwritten questions are worth 65% of the total grade. Do the following in answering these questions:
   (a) Clearly identify the question number at the top right of each page in your examination booklet, e.g. *Q3*.
   (b) Clearly indicate which tables from the textbook are used as the source of the data used in your analysis, e.g. *Table A-7*.
   (c) Your analysis of each process should be accompanied by an appropriate schematic that clearly indicates the system boundary and the directions of energy transfers between the system and the surroundings. A complete 1^{st} law energy balance that is consistent with the schematic should be written for each process. Clearly list all assumptions to justify the cancellation of unnecessary terms from the 1^{st} law energy balances.
3. Questions 4 through 17 are multiple choice. These questions are worth 35% of the total grade. You must provide your answers to these questions on a Scantron form.

Handwritten questions (examination booklet)

Question 1 (25 marks)

Steam flows through the system illustrated below and undergoes a steady-state process. The velocity of the steam entering the system at state point 1 is 90 m/s, its pressure is 12 MPa, and its temperature is 440^{o}C. The cross-sectional area of the inlet at state point 1 is 0.225 m^2.



Eighty-four percent of the mass of the working fluid exits the system as saturated vapour at state point 2 at a pressure of 10 kPa and at a velocity of 30 m/s. The remainder of the working fluid exits the system at state point 3 at a pressure 1.5 MPa and at a velocity of 450 m/s.

The system produces work at the rate of 460 MW and loses heat to the surroundings at the rate of 20 MW. Potential energy effects can be neglected. The temperature of the boundary of the system at which the heat losses to the surroundings occurs is 300^{o}C.

Do the following:

(a) Draw a schematic of the system, clearly indicating the system boundary and the direction of energy transfer by work and the direction of heat transfer between the system and its surroundings. **(3 marks)**

(b) Write a 1^{st} law energy balance for the system that is consistent with the schematic drawn in Part (a). List all assumptions and cancel the unnecessary terms. **(5 marks)**

(c) Determine the enthalpy at state 1 in kJ/kg. **(1 mark)**

(d) Determine the enthalpy at state 2 in kJ/kg. **(1 mark)**

(e) Determine the enthalpy at state 3 in kJ/kg. **(5 marks)**

(f) Determine the temperature at state 2. **(1 mark)**

(g) Determine the temperature at state 3. **(1 mark)**

(h) Determine the quality at state 3. **(1 mark)**

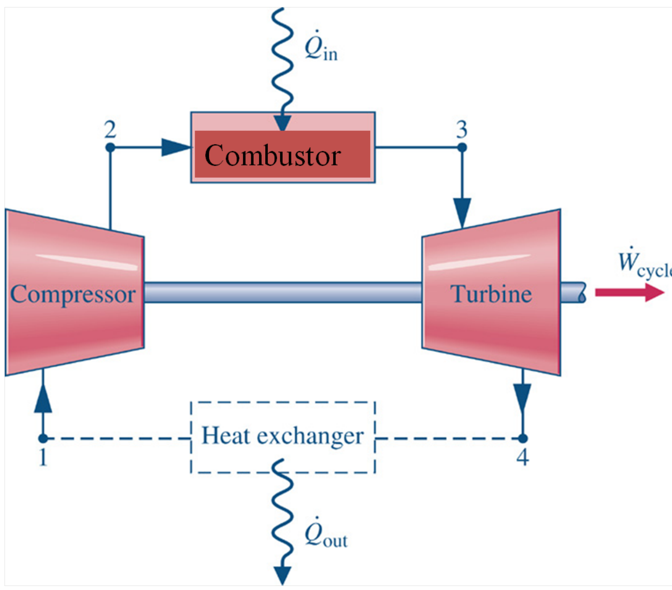
(i) Sketch the process on a T-s diagram. Clearly indicate states 1, 2, and 3 on the diagram. Illustrate the isobars corresponding to these states on the diagram as well. **(4 marks)**

(j) Prove that the process is possible by using the 2^{nd} law. **(3 marks)**

Question 2 (25 marks)

A simple Brayton cycle operating under steady conditions is used to produce electricity. Air enters the compressor at 300 K and 100 kPa and is compressed to 1 MPa by a compressor with an isentropic efficiency of 86%. The mass flow rate of air through the cycle is 120 kg/s. 70 MW of heat is added to the air stream at the combustor. The air is then expanded to 100 kPa by a turbine before being rejected to the ambient. The turbine's isentropic efficiency is 91%.

Analyze the cycle using the air standard analysis. Do not assume constant specific heats. Use the state point numbering scheme indicated in the following schematic:



Do the following:

(a) Determine the power input to the compressor, in MW. **(5 marks)**

(b) Determine the temperature at state 2. **(1 mark)**

(c) Determine the temperature at state 3. **(3 marks)**

(d) Determine the power produced by the turbine, in MW. **(5 marks)**

(e) Determine the temperature at state 4. **(1 mark)**

(f) Calculate the net power output of the cycle, in MW. **(2 marks)**

(g) Calculate the cycle's back work ratio. **(2 marks)**

(h) Calculate the cycle's thermal efficiency. **(2 marks)**

(i) Indicate the state points of the cycle on a T-s diagram. **(4 marks)**

Question 3 (15 marks)

A house is heated by a vapour-compression heat pump employing Refrigerant 134a as its working fluid. On a cold day the house requires 25 kW of heating from the heat pump in order to maintain its indoor temperature at 21^{o}C.

On this day the heat pump operates under steady conditions. The working fluid enters the condenser at 1.4 MPa and 80^{o}C and exits the condenser at 48^{o}C. The working fluid enters the compressor at 160 kPa and -12^{o}C. The mass flow rate of the refrigerant is 0.1 kg/s. The compressor draws 6.423 kW of power.

Do the following:

(a) Draw a schematic of the cycle clearly indicating state points and energy transfer between components and their surroundings. **(3 marks)**

(b) Indicate the state points of the cycle on a T-s diagram clearly indicating the phase at each state point. **(5 marks)**

(c) Determine the cycle's heating capacity, in kW. **(3 marks)**

(d) Determine the heat pump's coefficient of performance. **(2 marks)**

(e) What will happen to the house's air temperature on this day? Why? Provide this answer in 1-2 sentences: no equations or calculations required. **(2 marks)**

Multiple choice questions (Scantron sheet)

Question 4 (2 marks)

An open system:

(a) Can exchange heat, work, and mass with the surroundings.

(b) Can exchange only heat and work with the surroundings.

(c) Can exchange only heat with the surroundings.

(d) Can not exchange heat, work, or mass with the surroundings.

Question 5 (2 marks)

When energy stored within a system is at a steady state then:

(a) Energy is not crossing the system boundary via work or heat transfer.

(b) The energy contained within the system is not changing.

(c) The properties of the system are uniform throughout the system.

(d) The system is isolated from the surroundings.

Question 6 (2 marks)

The enthalpy of water in the two-phase region is given by:

(a) $h = h_f + x(h_g - h_f)$

(b) $h = h_g - x(h_g - h_f)$

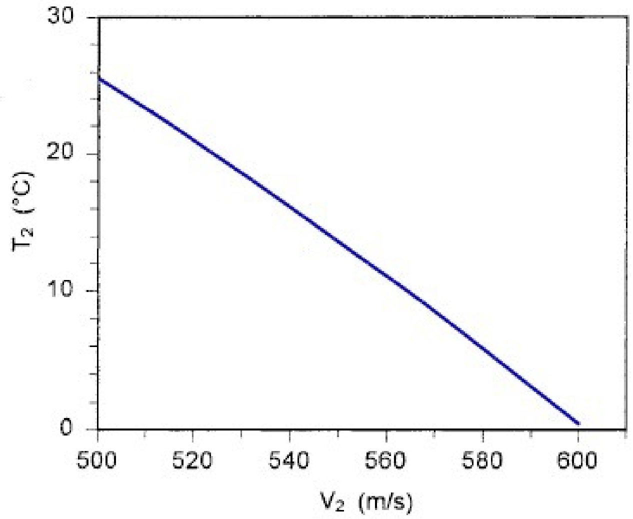
(c) $h = h_f + xh_{fg}$

(d) $h = xh_{fg}$

(e) a and c

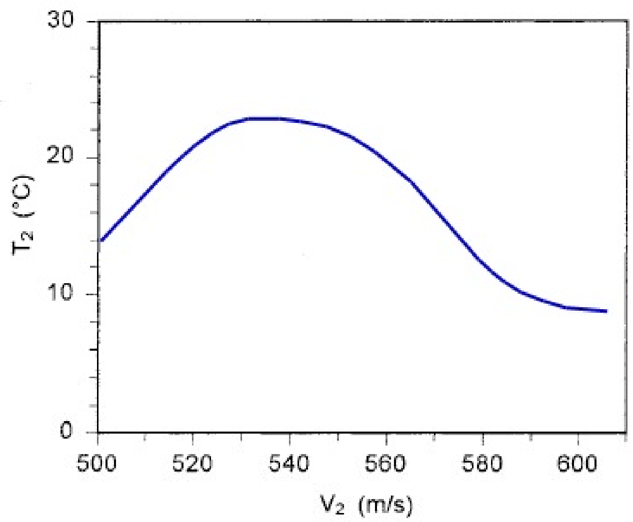
Question 7 (4 marks)

Methane (CH_4) gas enters a horizontal, well-insulated nozzle operating at steady state at 80^{o}C and a velocity of 10 m/s. Assuming ideal gas behavior for the methane, select the sketch of the temperature of the gas exiting the nozzle (in ^{o}C) versus the exit velocity ranging from 500 to 600 m/s.



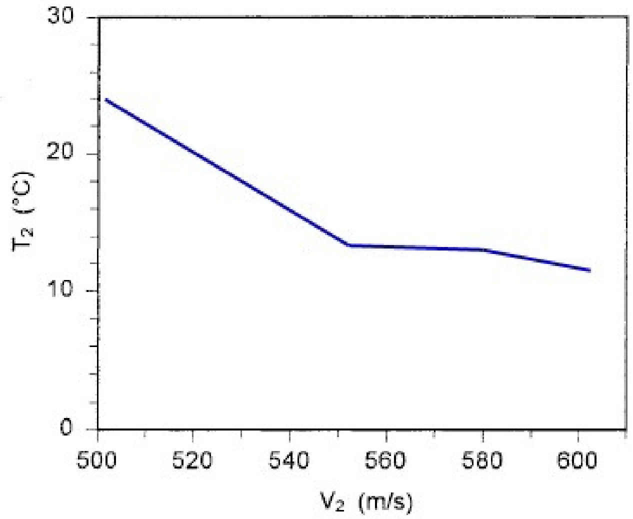
30
20
10
0
T2 (°C)
500
520
540
560
580
600
V2 (m/s)

(a)

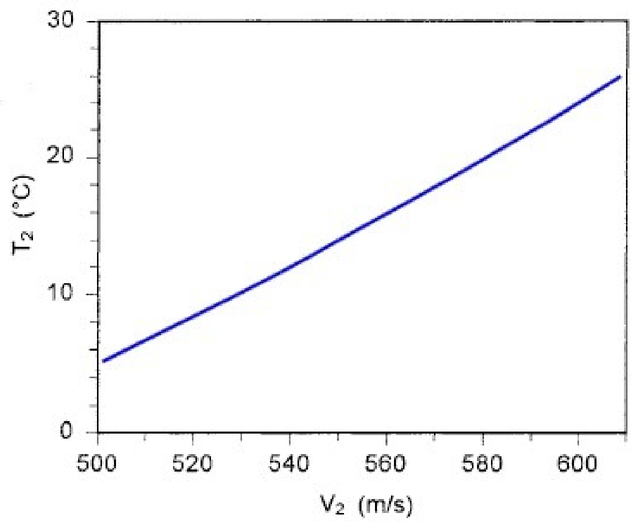


30
20
10
0
T2 (°C)
500
520
540
560
580
600
V2 (m/s)

(b)


30
20
10
0
500
520
540
560
580
600
T2 (°C)
V2 (m/s)

(c)


30
20
10
0
500
520
540
560
580
600
T2 (°C)
V2 (m/s)

(d)

Question 8 (2 marks) A power cycle operates under steady conditions between a hot reservoir at 1000 K and a cold reservoir at 300 K. The net power production from the cycle is 350 kW and heat is rejected to the cold reservoir at the rate of 150 kW.

(a) The power cycle operates reversibly.

(b) The power cycle operates irreversibly.

(c) It is impossible for such a power cycle to operate.

Question 9 (2 marks)

For a system undergoing a cyclic process and producing work, the thermal efficiency:

(a) Cannot be greater than zero unless the process is ideal.

(b) Is greater than zero if the process is ideal.

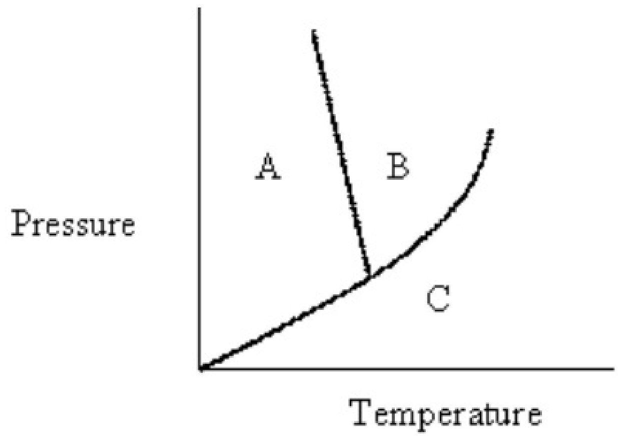
(c) Can be greater than 100 % if the process is ideal.

(d) Can not be greater than zero if there are irreversibilities.

(e) Can not be greater than 100% even if the process is ideal.

Question 10 (2 marks)

A phase diagram for water is shown below on p-T (pressure-temperature) diagram. The phases of water in regions A, B, and C are:



(a) A is solid, B is liquid, and C is vapour.

(b) A is solid, B is vapor, and C is liquid.

(c) A is vapor, B is liquid, and C is solid.

(d) A is liquid, B is vapor, and C is solid.

Question 11 (2 marks)

Enthalpy is defined as $h = u + pv$. To determine the enthalpy of saturated vapor:

(a) Only the one property u needs to be known because pressure, p, and specific volume, v, are not independent.

(b) Two independent properties such as u and p, or u and v, or p and v need to be known.

(c) p and v are independent but not enough to define the state and u still needs to be known.

(d) Although temperature is an independent property it can't be used because it doesn't appear in the definition of enthalpy.

Question 12 (4 marks)

Water is the working fluid in a Carnot vapor power cycle. Saturated liquid enters the boiler at 16 MPa, and saturated vapor enters the turbine. The condenser pressure is 8 kPa. The mass flow rate of steam entering the turbine is 120 kg/s. The thermal efficiency of the cycle is (in %):

(a) 95.

(b) 75.

(c) 25.

(d) 50.

Question 13 (2 marks)

Find the specific entropy of water at v = $0.25 m^3/kg$ and h = 3100 kJ/kg. (Hint: this is an interpolation problem.)

(a) 8.012 kJ/kg K

(b) 4.301 kJ/kg K

(c) 7.173 kJ/kg K

(d) 1.567 kJ/kg K

Question 14 (2 marks)

Find pressure for water at T = 323^oC, v = $0.2 m^3/kg$ (Hint: this is an interpolation problem).

(a) 1342 kPa

(b) 1400 kPa

(c) 1223 kPa

(d) 1300 kPa

Question 15 (2 marks)

Space suits worn by astronauts include insulation to prevent heat loss, and heating systems to maintain comfortable conditions for the astronaut. By what mode(s) is heat transferred from the outside surface of the space suit to the surroundings when the astronaut is in outer space?

(a) Conduction.

(b) Natural convection.

(c) Forced convection.

(d) Radiation.

(e) All of the above.

Question 16 (2 marks)

The conduction mode of heat transfer occurs when:

(a) There is a temperature gradient within a body, resulting in energy transfer from higher temperature regions to lower temperature regions.

(b) There is a temperature gradient within a body, resulting in energy transfer from lower temperature regions to higher temperature regions.

(c) No temperature gradient exists, resulting in energy transfer from lower temperature regions to higher temperature regions.

(d) None of the above.

<u>Question 17</u> (5 marks)

A 75 m length of pipe is used to transport steam from the boiler to the turbine in a Rankine cycle power plant. The pipe is 1.8 m in diameter and its surface temperature is 400^{o}C. Energy is lost from the pipe to the surroundings due to heat transfer by convection and by radiation. The convection coefficient between the pipe and the surrounding air is 6.5 W/m^{2}K and the air temperature is 25^{o}C. The radiation portion of the heat transfer can be treated as emission from a grey body to an enclosure. The enclosure temperature (i.e. the surfaces formed by the power plant containing the pipe and turbine) can be taken as 12^{o}C. The emissivity of the surface of the pipe is 0.15. The system can be considered to be at steady-state. Calculate the total rate of energy transfer from the pipe to the surroundings due to convective heat transfer and due to radiation heat transfer, in MW.

(a) 1.03 MW

(b) 1.75 MW

(c) 0.72 MW

(d) 5.81 MW

(e) 1.13 MW