University of Waterloo

ECE309

THERMODYNAMICS & HEAT TRANSFER
MIDTERM EXAMINATION

June 13, 2016 2:30 pm - 4:30 pm

Instructor: R. Culham

Name: _____

Student ID Number: _____

Instructions

1. This is a 2 hour, closed-book examination.
2. Permitted aids include:
   - one 8.5 in.× 11 in. crib sheet (one side only),
   - Property Tables Booklet for Introduction to Thermodynamics and Heat Transfer, Yunus Cengel, 2nd ed
   - calculator
3. Answer all questions in the space provided. If additional space is required, use the back of the pages or the blank pages included.
4. It is your responsibility to write clearly and legibly. Clearly state all assumptions. Part marks will be given for part answers, provided that your methodology is clear.

Question	**Marks**	**Grade**
1	15	
2	19	
3	16	
TOTAL	50	

Question 1 (15 marks)

A rigid container holds water at the critical point. The container is cooled until the pressure reaches a) **10** $\boldsymbol{MPa}$, b) **1.0** $\boldsymbol{MPa}$ and c) **0.1** $\boldsymbol{MPa}$. Determine the temperature, $\boldsymbol{T_{crit}}$ and pressure, $\boldsymbol{P_{crit}}$ at the critical point. Determine the quality of the water at each value of pressure, the temperature and the heat loss necessary to move between each value of pressure. Enter your calculated values in the table below. Show all calculations.

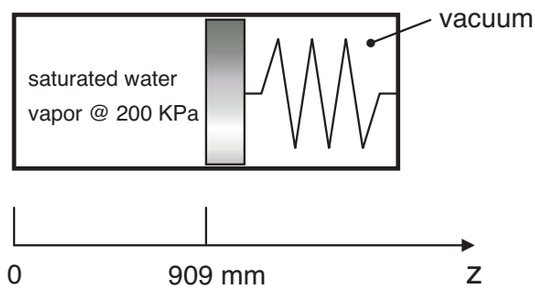
State Point	Pressure ($\boldsymbol{MPa}$)	Temperature ($\boldsymbol{°C}$)	Quality ($-$)	$\boldsymbol{\Delta q}$ ($\boldsymbol{kJ/kg}$)
critical point $\Rightarrow$ 1				
2	**10.0**			
3	**1.0**			
4	**0.1**			

Question 2 (19 marks)

A cylinder fitted with a frictionless piston and a linear spring initially contains saturated water vapor at $\mathbf{200\ kPa}$. The spring side of the piston is completely evacuated. Under these conditions the piston is $\mathbf{909\ mm}$ from the left end of the cylinder. The cross-sectional area of the cylinder is $\mathbf{0.05\ m^2}$. The spring force is given by

$$F_s = k \times z$$

where the spring constant is given as $k = 11\ kN/mm$ and z is the distance in mm between the piston face and the left end of the cylinder. The contents of the cylinder are then cooled until the pressure reaches $\mathbf{100\ kPa}$. Assume that pressure changes in a linear manner between state 1 and state 2 and that the surrounding air temperature is $\mathbf{20\ °C}$.



a) determine the amount of heat transfer $[kJ]$
b) draw and label a $T - s$ diagram, including all relevant state points, and property values at those state points
c) determine the entropy generated during the process $[kJ/K]$

Question 3 (16 marks)

A vortex tube is a steady-state device that splits a high pressure gas stream into two streams, one warm and one cool. During a controlled test, it was determined that **85%** of the compressed air entering the vortex tube went to the warm air stream and **15%** went to the cool air stream. Compressed air enters the vortex tube at $\mathbf{19.3\ °C}$, $\mathbf{0.52\ MPa}$ and a mass flow rate of $\mathbf{1.5\ kg/s}$. Warm air leaves the vortex tube at $\mathbf{26.3\ °C}$ while the cool air leaves at $\mathbf{-21.8\ °C}$. Both exit streams are at atmospheric pressure of $\mathbf{101.35\ kPa}$. The temperature of the surroundings can be assumed to be $\mathbf{20\ °C}$. Determine:

a) the rate of heat loss from the vortex tube to the surroundings, [$\boldsymbol{kW}$]
b) the rate of entropy generation in the vortex tube, [$\boldsymbol{kW/K}$]