

## Final Exam

**Date:** Sunday, December 13, 2015  
**Exam start time:** 1:00 PM  
**Exam normal duration:** 180 min. (3 hours)  
**Exam Location:** Fieldhouse (GYM Rows: B D F)

Last name                      ,                      First

Student's Name: \_\_\_\_\_ , \_\_\_\_\_

St. ID # : \_\_\_\_\_

Student Seat # (as in class attendance sheet):

Signature: \_\_\_\_\_

**\*Important Exam Instructions (student should read them before starting the exam):**

1. This is a closed-book & closed-note exam. An external formula sheet is NOT allowed. Only a standard-type calculator only allowed.
2. Some information/Equations are provided in the **Appendix** (last page of this exam booklet). Whenever you do a calculation based on a certain Equation obtained from the Appendix, you need first to write the Equation (as in Appendix), and then show the substitution of values in the Equation to find the answers. In general, always show the applicable equations before substituting the corresponding values.
3. Put away any electronic devices other than a standard calculator (e.g. cell phones, iPads, etc). Turn them off before you put them away.
4. Do not separate the exam papers from the booklet (if separated, will deduct 1 mark)
5. Show your solution and answers in the specified space for each problem. You can use back of the pages in case extra space is needed. However, indicate the continuation whenever the reverse of page is used. Writing or showing answers in the space within the question part of any problem will not be marked.
6. No questions are allowed during the test as the exam is well-written and specific (**use your time efficiently!**).
7. This exam contains **18 pages** including the cover page (make sure you have them all). Otherwise, report any discrepancy to the exam invigilator right away before the exam starts.
8. This exam booklet **MAY NOT** leave the exam room. After completion, exam booklets should be submitted to the course professor/designated exam invigilator.

Problem #	Assigned Marks	Score
<b>1</b>	<b>20</b>	
<b>2</b>	<b>20</b>	
<b>3</b>	<b>20</b>	
Total Marks	<b>60</b>	

**Problem # 1:**  
**Part A – 10 marks**

(Total marks = 20)

Consider the composite wall system shown in Figure P-1A below used in a furnace facility. The wall has the following characteristics:

$T_\infty$	$10^\circ\text{C}$
$T_3$	$200^\circ\text{C}$
$k_B$	$1.8 \text{ W/m}\cdot^\circ\text{C}$
$k_A$	$0.5 \text{ W/m}\cdot^\circ\text{C}$
$k_C$	$2.5 \text{ W/m}\cdot^\circ\text{C}$
$w_1$	10 cm
$w_2$	20 cm
$L_A$	30 cm
$L_C$	15 cm
$h$	$150 \text{ W/m}^2\cdot^\circ\text{C}$

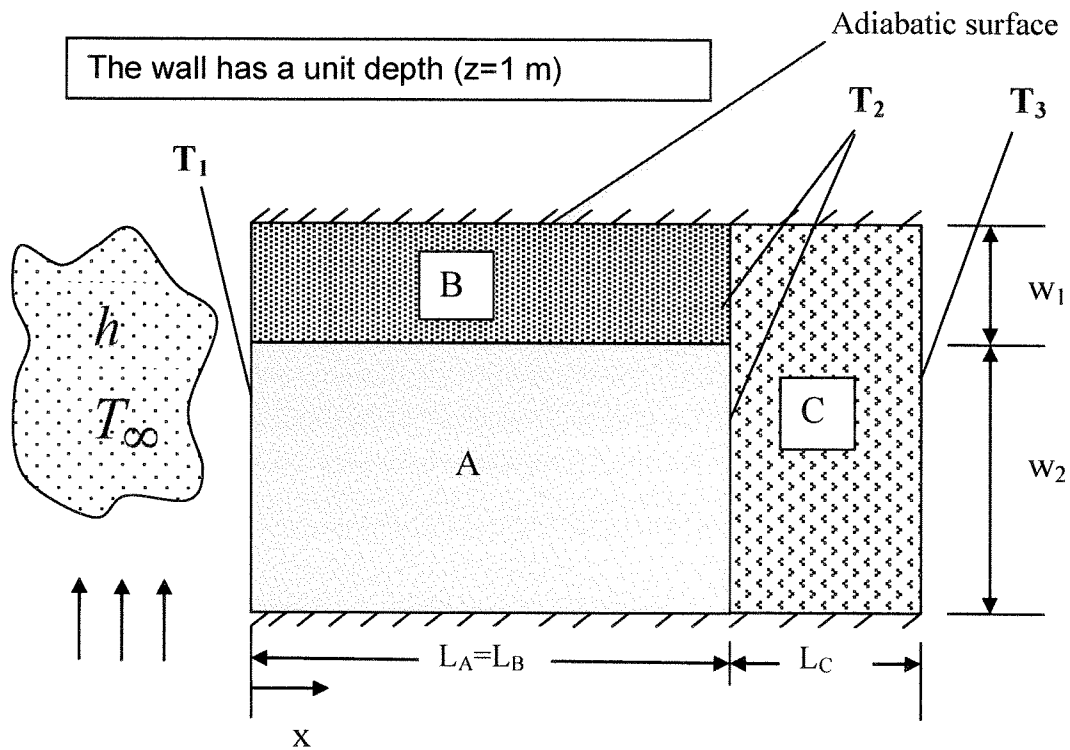


Figure P-1A: The composite wall system

**Required:**

Determine the following - show systematic and consistent approach with numerical analysis and justify the use of your equations and assumptions wherever applicable (**Circle your final answers**):

- a) Show the steady-state 1-D (in x-direction shown) thermal circuit for the above composite wall system and label the associated circuit resistances, temperatures, and heat transfer rates on the schematic;
- b) Calculate the individual thermal resistances associated with the thermal circuit;
- c) Calculate the total thermal resistance for the system;
- d) Calculate the heat transfer rate across the composite wall system,  $\dot{Q}_{wall}$  ;
- e) Determine the temperatures  $T_1$  and  $T_2$ ;
- f) Calculate the heat transfer rates across wall materials A and B using resistance analogy; check your results using energy balance at the interface surface between C and A&B (i.e. at  $x = L_A = L_B$ );
- g) Is this a safe furnace composite wall system (hint: consider the surface temperature at  $x=0$ )? Briefly justify why?

**Solution starts below this line here:**

Extra Worksheet for Problem # 1-A:

**Problem#1- Part B – 10 marks**

Consider a stainless steel pipe ( $k_p = 14.2 \text{ W/m.K}$ ) transporting an industrial fluid which is maintained at an average temperature of  $6 \text{ }^\circ\text{C}$  and convection heat transfer coefficient of  $400 \text{ W/m}^2\text{.K}$ . The pipe has a length of  $1 \text{ m}$ , an inner diameter of  $3.6 \text{ cm}$ , and a wall thickness of  $2 \text{ mm}$ . The pipe runs inside a room with a surrounding air temperature of  $23 \text{ }^\circ\text{C}$  and convection heat transfer coefficient of  $6.0 \text{ W/m}^2\text{.K}$ .

**Required:**

1. Draw a standard schematic for the problem;
2. Draw the standard thermal-circuit representing the heat transfer in the pipe system and properly label the associated circuit resistances, temperatures, and heat transfer rates on the schematic;
3. Assuming 1-D heat transfer (in  $r$ -direction) through the pipe wall, analyze the problem systematically, state your assumptions, and determine (calculate) the following using the standard thermal-circuit analogy method **(Circle your final answers)**:
  - (a) The individual thermal resistances values associated with the thermal circuit;
  - (b) The total thermal resistance value for the pipe system;
  - (c) The rate of heat transfer (in  $\text{W}$ ) across the pipe. Is this a heat gain or loss? Briefly justify;
  - (d) The inner surface temperature  $T_1$  (in  $^\circ\text{C}$ ) of the pipe;
  - (e) Re-do the above (1, 2, 3(a,b,c)), considering there is a  $10 \text{ mm}$  thick thermal insulation material ( $k_{\text{insu}} = 0.05 \text{ W/m.K}$ ) wrapped around the pipe. All other conditions remain the same. Also for this part, determine the temperature  $T_2$  (in  $^\circ\text{C}$ ) at the interface between the pipe surface and insulation.

**Solution starts below this line here:**

Extra Worksheet for Problem # 1-B:

Extra Worksheet for Problem # 1-B:

**Problem # 2:***(Total marks = 20)***Part A – 10 marks**

Consider a compressor using air as the working fluid. Air enters the compressor steadily at 25 °C and 100 kP with negligible velocity and leaves at 620 K with 90 m/s. The compressor loses heat to the surroundings at 24.88 kW and requires power input at 249.85 kW. The air leaves the compressor through a circular pipe with a diameter of 50 mm. Potential energy change across the compressor is negligible and air can be treated as an ideal gas.

**Air Data:**  $C_v = 0.717$  kJ/kg.K;  $C_p = 1.004$  kJ/kg.K;  $R = 0.287$  kJ/kg.K

Temperature (K)	u (kJ/kg)	h (kJ/kg)
200	142.77	200.17
298	213.04	298.20
400	286.49	401.30
500	359.84	503.36
600	435.10	607.32
620	450.42	628.07
640	465.83	649.53

**Required:**

Draw standard and clear schematic of the problem and label the performance data on the schematic. Perform step-by-step CV energy and mass analyses, state your assumptions and determine the following (**Circle your final answers**):

- The specific enthalpy values at inlet and exit of the compressor;
- The specific kinetic energy at exit of the compressor;
- The mass flow rate of air using accurate approach of specific enthalpies of air. What would be the mass flow rate using constant specific heat method? Find the % error.
- The specific heat transfer;
- The density of air at the inlet and exit of the compressor;
- The air pressure at the exit of the compressor.
- The specific work input.

**Start your solution on the next page →**

Worksheet for Problem # 2(A):

**Solution:**

Extra Worksheet for Problem # 2(A)

**Problem#2- Part B – 10 marks**

Consider a steam turbine operating SSSF with conditions as given in the Table below. The turbine loses heat to the surrounding at a rate of 9.98 kW.

**Table 2B:**

	Inlet conditions	Exit conditions
Mass flow rate (kg/s)	29.87	
Pressure (MPa)	3.0	0.80
Temperature (K)	773	
Phase		Saturated vapor
Velocity (m/s)	59.8	109.8
Elevation above reference surface (m)	8.0	3.0

Thermodynamic Tables:

**A) Saturated water Data**

P (kPa)	T <sub>sat</sub> (°C)	v <sub>f</sub> (m <sup>3</sup> /kg)	v <sub>g</sub> (m <sup>3</sup> /kg)	h <sub>f</sub> (kJ/kg)	h <sub>g</sub> (kJ/kg)
10	45.81	0.001010	14.670	191.80	2584.6
20	60.06	0.001017	7.6481	251.42	2608.9
175	116.04	0.001057	1.0037	487.01	2700.2
200	120.23	0.001061	0.88578	504.71	2706.3
600	158.83	0.001101	0.31560	670.38	2756.2
800	170.41	0.001115	0.24035	720.87	2768.3
2000	212.38	0.001177	0.099587	908.47	2798.3
3000	233.90	0.001216	0.06668	1008.41	2804.1
7000	285.83	0.001352	0.027378	1267.5	2772.6
8000	295.01	0.001384	0.023525	1317.1	2758.7

**B) Superheated vapor water Data**

P=200 kPa (T <sub>sat</sub> = 120.23°C)				P=800 kPa (T <sub>sat</sub> =170.41°C)			
T (°C)	v (m <sup>3</sup> /kg)	u (kJ/kg)	h (kJ/kg)	T (°C)	v (m <sup>3</sup> /kg)	u (kJ/kg)	h (kJ/kg)
Sat.	0.88578	2529.1	2706.3	Sat.	0.24035	2576.0	2768.3
150	0.95986	2577.1	2769.1	200	0.26088	2631.1	2839.8
200	1.08049	2654.6	2870.7	300	0.32416	2797.5	3056.9
300	1.31623	2808.8	3072.1	400	0.38429	2960.2	3267.7
500	1.78142	3131.4	3487.7	500	0.44332	3126.6	3481.3

Continued next page (superheated vapor data) =>

P=3000 kPa ( $T_{\text{sat}}= 233.90^{\circ}\text{C}$ )			
T ( $^{\circ}\text{C}$ )	v ( $\text{m}^3/\text{kg}$ )	u (kJ/kg)	h (kJ/kg)
Sat.	0.06668	2604.10	2804.14
250	0.07058	2644.00	2855.75
400	0.09936	2932.75	3230.82
500	0.11619	3107.92	3456.48
600	0.13243	3285.03	3682.34
700	0.14838	3466.59	3911.70

**Required:**

Draw standard and clear schematic of the problem and label the performance data on the schematic. Perform step-by-step CV energy and mass analyses, state your assumptions and determine the following:

**Circle your final answers**

- The specific enthalpy values at inlet and exit of the turbine;
- The rate of kinetic energy at inlet and exit of the turbine (in kW);
- The rate of kinetic energy difference between inlet and exit (in kW);
- The rate of potential energy at inlet and exit (in kW);
- The rate of potential energy difference between inlet and exit (in kW);
- The specific heat transfer loss from the turbine;
- The rate of work (power) delivered by the turbine (in kW); Is the energy balance across the device satisfied?
- Draw a T-v diagram showing the inlet and exit states and indicate the process with respect to the dome and appropriately label the diagram.

**Solution starts below this line here:**

Extra Worksheet for Problem # 2(B):

**Problem # 3:**

(Total marks = 20)

**Part (A) – 7 marks**

Consider an electric power transistor that is mounted on a circuit board (base) and with dimensions as shown in Figure 3-B. below. At steady-state operation, the transistor receives an input of electrical power of 0.0469 W. The transistor is cooled by a fluid (air) flowing over it with a temperature of 55°C. The heat transfer from the transistor base is negligible. For safe operation, the transistor case temperature is not to exceed 343 K.

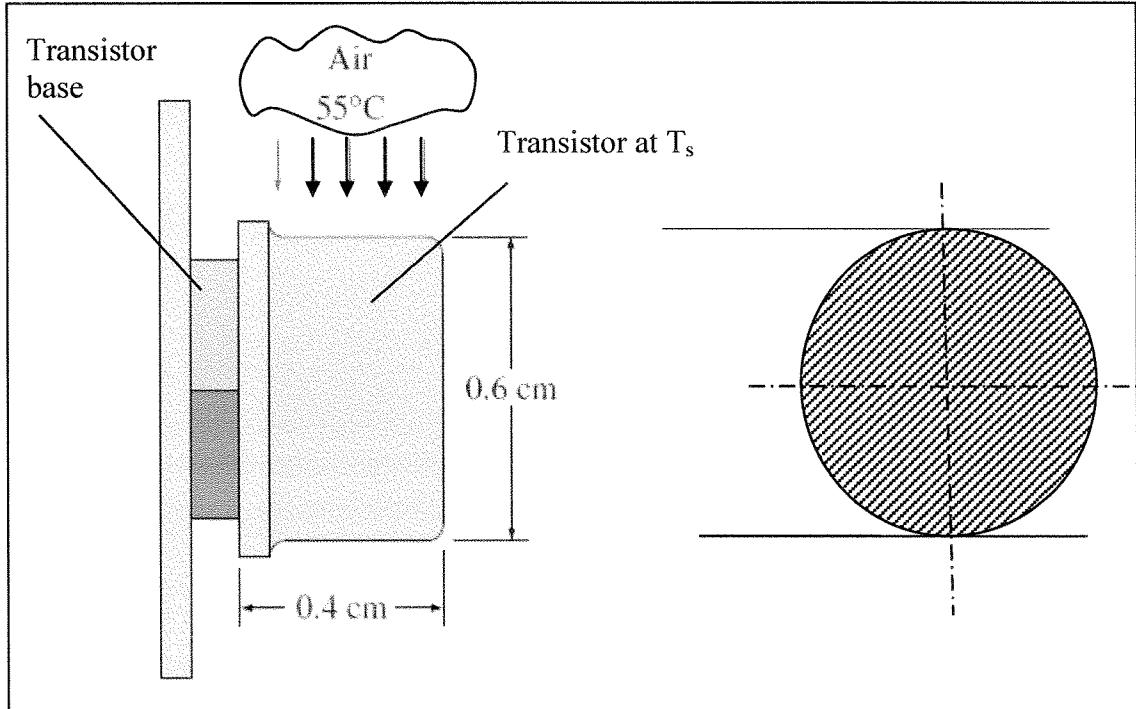


Figure 3-B: Heat Transfer from an electrical power device (transistor).

**Required:**

Using the first-law of thermodynamics (in a rate form) and the appropriate heat transfer law (mechanism) determine the minimum convection heat transfer coefficient,  $h$  required for the safe operation of the transistor under the rating conditions above. State your assumptions and show the system boundary in your analysis and the forms of energy crossing the boundary.

**Solution starts below this line here:**

Extra Worksheet for Problem # 3(A):

**Problem # 3 - Part (B) – 13 marks**

Consider a piston-cylinder device containing 1.998 kg of air as an ideal gas. The system undergoes an isothermal process from an initial state at 0.60 MPa and 473 K to the final state at 80 kPa.

**Data if needed:**

Air:  $R = 0.287 \text{ kJ/kg.K}$ ,  $C_v = 0.718 \text{ kJ/kg.K}$ ,  $C_p = 1.005 \text{ kJ/kg.K}$

**Required:**

Draw standard and clear schematic for this problem (with data labeled) and determine the following using a systematic approach of energy analysis and justifying the use of equations and assumptions (**Circle your final answers**):

- a) The initial volume (in  $\text{m}^3$ ) of the system;
- b) Show the process on a  $P - V$  diagram and label the data on the diagram;
- c) Calculate the work done (in kJ) during this process. Indicate the work done on the  $P - V$  diagram;
- d) Can this process be called polytropic (Yes/No)? If yes, what is the polytropic constant in this case? Show a simple analysis to justify.
- e) The internal energy change (in kJ) in this process (constant-specific heat approximation can be used);
- f) The amount of heat transfer (in kJ) during this process.

**Solution starts below this line here:**

Extra Worksheet for Problem # 3(B):

## Appendix

### Data (general):

The universal gas constant =  $\bar{R} = 8.314 \text{ kJ} / \text{kmol.K}$

Gravity acceleration =  $g = 9.81 \text{ m/s}^2$

$$\sigma = 5.67 \times 10^{-8} \text{ W/m}^2 \cdot \text{K}^4$$

### Conversions:

1bar = 100 kPa

(K) = (°C) + 273

1 Pa = 1 N/m<sup>2</sup>

### Equations:

$$R = \frac{\bar{R}}{M} ; M = \frac{m}{n} ; P_r = \frac{P}{P_{cr}} ; T_r = \frac{T}{T_{cr}} ; x \equiv \frac{mg}{m} ; h = h_f + xh_{fg}$$

$$du = \int C_v dT ; \Delta U = mC_v \Delta T ; \dot{W} = \dot{m} w ; dh = \int C_p dT ; \Delta H = mC_p \Delta T ; \dot{Q} = \dot{m} q$$

$${}_1W_2 = \int P dV ; \dot{Q} - \dot{W} = \frac{dE}{dt} ; \delta Q - \delta W = dE = dU + d(KE) + d(PE) ; h \equiv u + pv$$

$$\kappa = \frac{C_p}{C_v} ; C_p = C_v + R$$

$$\dot{m} = \rho VA = \rho \dot{V}$$

$$\dot{E} = \dot{m} \hat{e} = \dot{m} \left( h + \frac{V^2}{2} + gZ \right) ; \hat{e} = \left( h + \frac{V^2}{2} + gZ \right)$$

$$\dot{m} = \rho VA = \rho \dot{V}$$

$$\sum_{in} E \dot{N} = \sum_{out} E \dot{N}$$

### Heat transfer thermal resistances

$$R_1 = \frac{L}{kA} ; R_2 = \frac{\ln(r_2/r_1)}{2\pi kL} ; R_3 = \frac{1}{hA} ; R_4 = \frac{1}{\sigma \epsilon A (T_s + T_{sur})(T_s^2 + T_{sur}^2)}$$