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Thermodynamics
MET 300

Instructor: Nathan Luetke

Test 3

Summer 2024

Take home – Due August 4 at 11:59 pm.

- ***Late tests will be penalized 20% and not accepted after 6:00 am August 5***
- **Upload your completed test to Canvas as a single word document or pdf file and include your name on the first page – you will lose 5 points if either of these requirements are not met. It is your responsibility to verify that it is not corrupted and can be open. Be sure that when you scan it in it is dark enough to be read when printed out. Be sure to hit SUBMIT once you have uploaded it.**

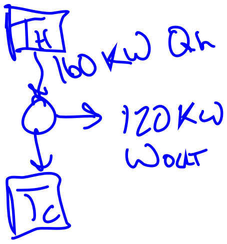
90 points – Solutions to the six equally weighted test problems
10 points – Homework 3.1 and 3.2

1. What you turn in should be only your own work. You cannot discuss the exam with anyone, except me. Email me if you have any questions.
2. This is intended to be open book/open notes.
3. You should be explicit and organized in your answers, I can only grade what I see on the paper. Use drawings and figures when needed and clearly identify your final answers
4. Cheating is completely wrong. The ODU Student Honor Pledge reads: "I pledge to support the honor system of Old Dominion University. I will refrain from any form of academic dishonesty or deception, such as cheating or plagiarism." By attending Old Dominion University you have accepted the responsibility to abide by this code. This is an institutional policy approved by the Board of Visitors. It is important to remind you the following part of the Honor Code:

IX. PROHIBITED CONDUCT
A. Academic Integrity violations, including:
1. *Cheating*: Using unauthorized assistance, materials, study aids, or other information in any academic exercise (Examples of cheating include, but are not limited to, the following: using unapproved resources or assistance to complete an assignment, paper, project, quiz or exam; collaborating in violation of a faculty member's instructions; and submitting the same, or substantially the same, paper to more than one course for academic credit without first obtaining the approval of faculty).

Problem 1

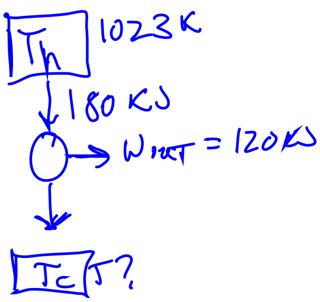
A heat engine working between two reservoirs produces 120 kW of power. The energy input to the engine is 160 kW. Calculate the thermal efficiency of the engine.



$$\eta_{Th} = \frac{W_{OUT}}{Q_{in}} = \frac{120\ kW}{160\ kW} = \boxed{.75 \text{ or } 75\%}$$

Problem 2

The temperature of the hot reservoir from which a reversible heat engine engine absorbs 180 kJ of heat is 1023 K. If the work done by the engine is 120 kJ. Calculate the temperature of the cold reservoir to which the engine rejects heat.



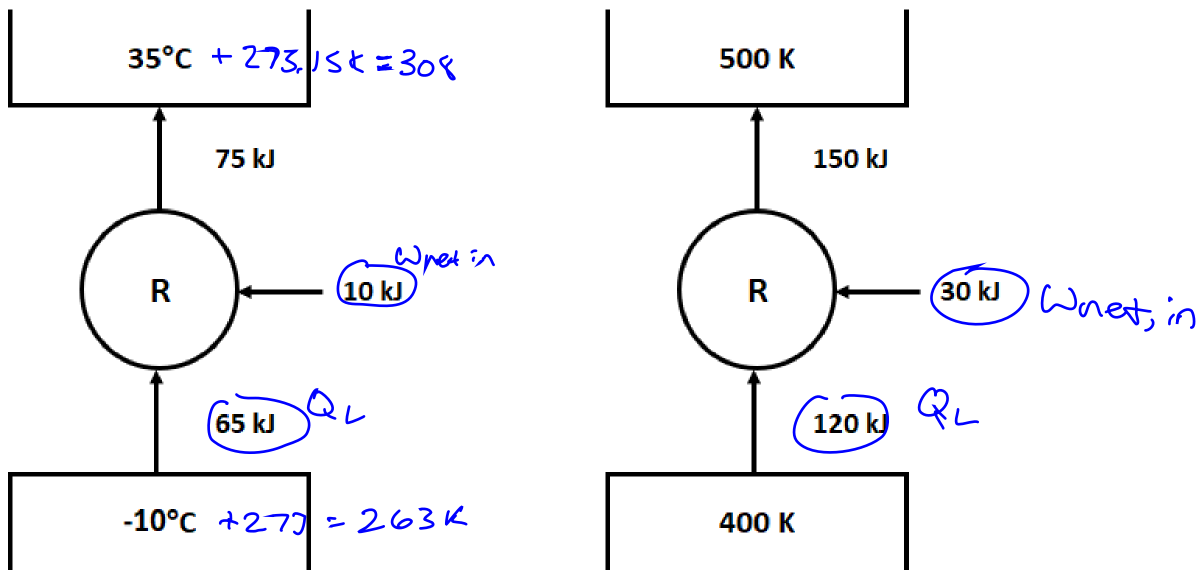
$$\frac{W_{net,rev}}{Q_{h,rev}} = 1 - \frac{T_L}{T_h}$$

$$T_L = \left(\frac{W_{net,rev}}{Q_{h,rev}} - 1\right)(-T_h)$$

$$T_L = \left(\frac{120\ kJ}{180\ kJ} - 1\right)(-1023\ K) = \boxed{341\ K}$$

Problem 3

Consider the following two refrigeration cycles and determine which is the correct answer:



Refrigerator (a) **Refrigerator (b)**

i. Refrigerator (a) is a Carnot refrigerator
ii. Refrigerator (b) is a Carnot refrigerator
iii. Neither (a) or (b) is a Carnot refrigerator

$$CoP_{R,carnot} = \frac{1}{\frac{T_H}{T_C} - 1}$$

$$CoP_r = \frac{Q_C}{W_{net,in}}$$

a) $CoP_{r,carnot} = \frac{1}{\frac{308K}{263K} - 1} = 5.844$

$CoP_r = \frac{65 kJ}{10 kJ} = 6.5$

$CoP_{r,R} > CoP_{r,carnot}$ - impossible

b) $CoP_{r,carnot} = \frac{1}{\frac{500K}{400K} - 1} = 4$

$CoP_r = \frac{120 kJ}{30 kJ} = 4$

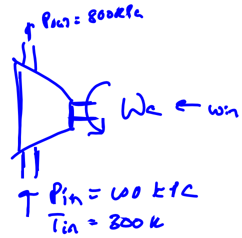
$CoP_r = CoP_{r,carnot}$ Carnot refrigerator

ii. b is a carnot refridgerator

Problem 4

Complete the following table of operating parameters for an adiabatic air compressor *using variable specific heats* and the units indicated.

w_a (kJ/kg)	P_{in} (kPa)	P_{out} (kPa)	T_{in} (K)	η_C (%)
265.39	100	800	300	92



$$\eta_c = \frac{\text{Isentropic work}}{\text{Actual work}} = \frac{h_{2s} - h_1}{h_{2a} - h_1}$$

$$s_1 = s_2$$

s_1: Air @ 300°K

$s_1^\circ = 1.70203$ kJ/kg·K

$R = .2870 \frac{kJ}{kg \cdot K}$

$h_1 = 300.19 \frac{kJ}{kg}$

$$\Delta s^{0} = (s_2^\circ - s_1^\circ) = R \ln\left(\frac{P_2}{P_1}\right)$$

$$s_2^\circ = R \ln\left(\frac{P_2}{P_1}\right) + s_1^\circ$$

$$s_2^\circ = .2870 \frac{kJ}{kg \cdot K} \ln\left(\frac{800 \text{ kPa}}{100 \text{ kPa}}\right) + 1.70203 \frac{kJ}{kg \cdot K}$$

$$s_2^\circ = 2.29882 \frac{kJ}{kg \cdot K}$$

$s_2^\circ = 2.29882 \frac{kJ}{kg \cdot K}$

Air

$T = 540°K$

$h_2 = 544.35 \frac{kJ}{kg}$

$$W_a = \frac{h_2 - h_1}{\eta_c} = \frac{544.35 \text{ kJ/kg} - 300.19 \frac{kJ}{kg}}{.92}$$

$$\boxed{W_a = 265.39 \frac{kJ}{kg}}$$

Problem 5

Complete the following table of operating parameters for an adiabatic air compressor *using constant specific heats at room temperature* and the units indicated.

w_a (kJ/kg)	P_{in} (kPa)	P_{out} (kPa)	T_{in} (K)	η_C (%)
265.39	100	800	300	92

$$\left(\frac{T_2}{T_1}\right)_{s=c} = \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}}$$

$k = 1.4$

h_1: Air @ 300 K

$h_1 = 300.19 \frac{kJ}{kg}$

T_2: $T_2 = \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} \cdot T_1 = \left(\frac{800\ kPa}{100\ kPa}\right)^{\frac{1.4-1}{1.4}} \cdot 300\ K = 543.43\ K$

h_2: Air @ 543.43 K

$h_2 = 544.35 \frac{kJ}{kg}$

$$\eta_c = \frac{\text{Isentropic work}}{\text{actual work}} = \frac{h_{2s} - h_1}{h_{2a} - h_1}$$

$$W_a = \frac{h_{2s} - h_1}{\eta_c} = \frac{544.35 \frac{kJ}{kg} - 300.19 \frac{kJ}{kg}}{.92} = \boxed{265.39 \frac{kJ}{kg}}$$

Problem 6

Complete the following table of operating parameters for an adiabatic steam turbine using the units indicated.

w_a (kJ/kg)	P_{in} (kPa)	P_{out} (kPa)	T_{in} (°C)	η_T (%)
950	6000	15	500	27.75

$$\eta_T = \frac{W_a}{W_s} = \frac{h_1 - h_{2a}}{h_1 - h_{2s}}$$

$k = 1.327$

h_1: Steam @ 500°C, 6000 kPa } Super heated

$T_{in} = 500°C + 273 = 773°K$

$h_1 = 3423.1 \frac{KJ}{Kg}$

$S = 6.8826 \frac{KJ}{Kg \cdot K}$

$$\left(\frac{T_2}{T_1}\right)_{S=c} = \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}}$$

$$T_2 = \left(\frac{15\,kPa}{6000\,kPa}\right)^{\frac{1.327-1}{1.327}} \cdot 773°K = 176.595°K - 273 = -96.4°c$$

$$\eta_T = \frac{W_a}{W_s} = \frac{950 \frac{KJ}{Kg}}{3423.1 \frac{KJ}{Kg} - .001 \frac{KJ}{Kg}} = .2775 \text{ or } 27.75\%$$