NAME WAITZ SOLUTIONS

Unified Quiz 1: Thermodynamics

October 3, 2002

One 81/2" x 11" sheet (two sides) of notes
Calculators allowed.
No books allowed.

- **Put your name on each page of the exam.**
- **Read all questions carefully.**
- **Do all work for each problem on the pages provided.**
- **Show intermediate results.**
- **Explain your work --- don't just write equations.**
- **Partial credit will be given (unless otherwise noted), but only when the intermediate results and explanations are clear.**
- **Please be neat. It will be easier to identify correct or partially correct responses when the response is neat.**
- **Show appropriate units with your final answers.**
- **Box your final answers.**

Exam Scoring

#1 (10%)	
#2 (10%)	
#3 (36%)	
#4 (44%)	
Total	

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1) (10%, partial credit given) In a few sentences describe the meaning of the First Law of Thermodynamics. For what situations is it valid? Make sure to include definitions of heat and work in your answer. (MO#1)

THE FIRST LAW OF THERMODYNAMICS RELATES THE CHANGE IN ENERGY OF A SYSTEM TO ENERGY TRANSFERS TO AND FROM THE SYSTEM BY WAY OF HEAT (ENERGY TRANSFER DUE TO A TEMPERATURE DIFFERENCE ONLY) AND WORK (ALL OTHER ENERGY TRANSFERS). THE CHANGE IN ENERGY IS EQUAL TO THE DIFFERENCE BETWEEN THE HEAT ADDED TO THE SYSTEM AND THE WORK DONE BY THE SYSTEM. THE FIRST LAW IS VALID FOR ALL SITUATIONS IN WHICH IT IS POSSIBLE TO DEFINE THE STATE OF THE SYSTEM.

2) (10%, partial credit given) What relationship between different time-scales is required to model the flow in a gas turbine compressor as quasi-static and adiabatic? (MO#4, #5, #6)

$$t_{\text{SMALL CHUNK OF GAS TO COME TO THERMODYNAMIC EQUILIBRIUM}} \ll t_{\text{FLOW TO PASS THROUGH THE DEVICE}} \ll t_{\text{HEAT TO BE TRANSFERRED TO THE FLOW}}$$

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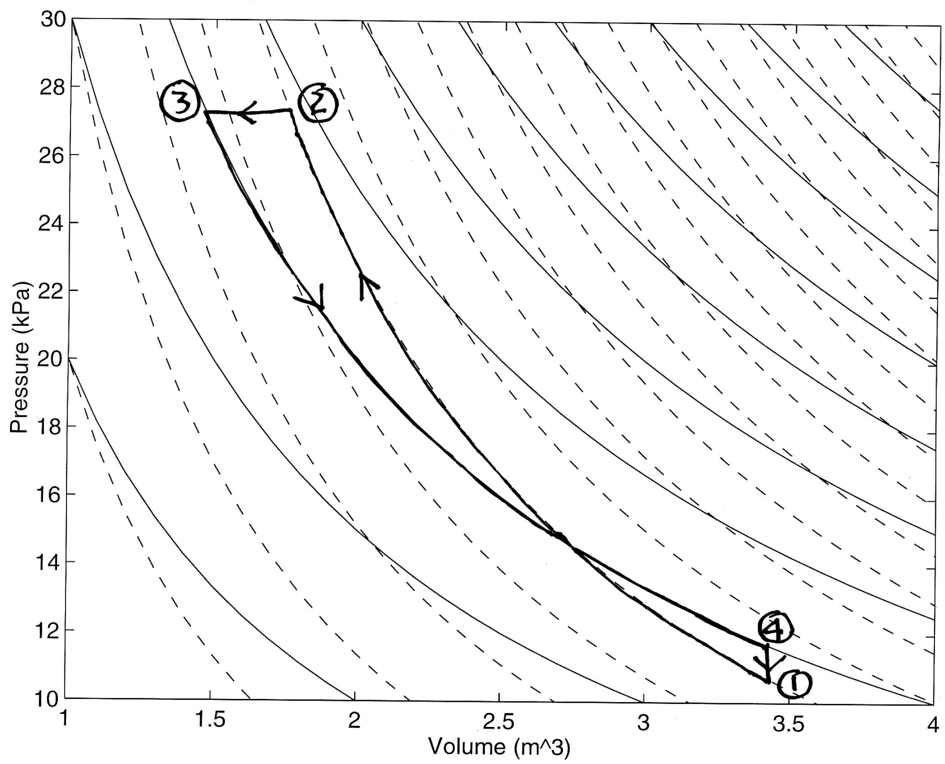
3) An unusual thermodynamic cycle is shown below. It consists of four processes involving an ideal gas:

Leg 1-2: quasi-static adiabatic process
Leg 2-3: isobaric process
Leg 3-4: quasi-static isothermal process
Leg 4-1: isochoric process



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a) **(24%, partial credit given)** Label the heat and work transfers and change in internal energy for each leg as (+), (-), or zero. (MO#4, #6)

USING $\Delta U = Q - W$, $PV = RT$, $\Delta U = C_v \Delta T$

	Q (+, - or zero)	W (+, - or zero)	Δu (+, - or zero)
Leg 1-2	0	−	+
Leg 2-3	−	−	−
Leg 3-4	+	+	0
Leg 4-1	−	0	−

b) **(12%, partial credit given)** For the cycle as a whole (the sum of legs 1-2-3-4) label the net work, net heat flow and change in internal energy as (+), (-), or zero. (MO#4, #6)

Cycle work: −

Heat flow to cycle: −

Net change in internal energy: 0

Describe your reasoning:

- FOR A CYCLE, $\Delta U = 0$ ∴ $Q = W$
- THE WORK $= \int p\,dV$ (THE AREA ON A P-V DIAGRAM).
- THE AREA UNDER LEGS 1-2-3 IS LARGER (AND WORK IS NEGATIVE SINCE VOLUME IS DECREASING) THAN THE AREA UNDER LEGS 3-4-1 (WHICH IS POSITIVE WORK)
- THEREFORE $W < 0$ & $Q < 0$

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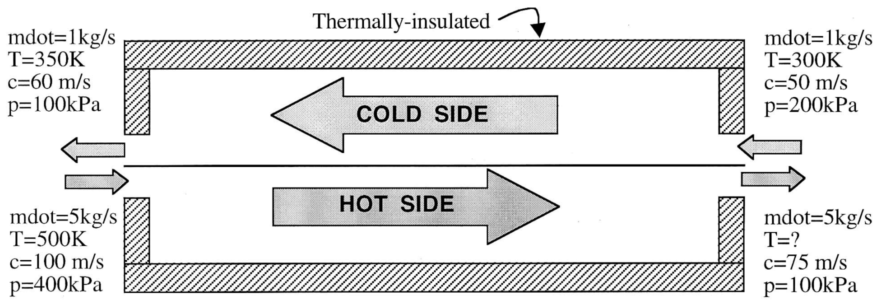
4) A device called a heat exchanger is shown below. Energy in the form of heat can pass through the wall between the cold side and the hot side. The rest of the device is thermally-insulated. Assume that both the hot side flow and the cold side flow behave as ideal gases with R=287 J/kg-K, c_p=1003.5 J/kg-K, and c_v = 716.5 J/kg-K.



a) **(19%, partial credit given)** What is the temperature at the exit of the hot side flow? (MO# 4)

b) **(10%, partial credit given)** This is a quote from Thermodynamics for Engineers by Wong,©2000 by CRC Press. "No work is done in a heat exchanger." Do you agree or disagree and why? Please substantiate your argument with a calculation. (MO# 4)

c) **(5%, partial credit given)** Is the process in this device reversible or irreversible and why? (Do not do a calculation) (MO# 5)

d) **(10%, partial credit given)** Describe the energy exchange processes in the device in terms of various forms of internal energy, kinetic energy, heat and work. (MO# 2)

a) APPLY SFEE TO COLD SIDE TO FIND J/s TRANSFERRED AS HEAT ($\dot{Q}$). THEN USE THIS IN SFEE FOR HOT SIDE TO SOLVE FOR T_{OUT}, HOT

SFEE: $q - w_s = h_2 - h_1 + \frac{c_2^2}{2} - \frac{c_1^2}{2}$

$q = \dot{Q}/\dot{m}$ $\quad h_2 - h_1 = c_p (T_2 - T_1)$ (IDEAL GAS)

- BLANK PAGE FOR ADDITIONAL WORK -

COLD SIDE

$$\dot{Q} = 1\,\frac{kg}{s}\left[1003.5\,\frac{J}{kg\text{-}K}(350K - 300K) + \frac{(60\,m/s)^2}{2} - \frac{(50\,m/s)^2}{2}\right]$$

$\dot{Q} = 50725$ J/s (+) SINCE ADDED TO SYSTEM

HOT SIDE

$\dot{Q}_{HOT} = -\dot{Q}_{COLD}$ (*) SINCE REMOVE FROM HOT SIDE

$$\frac{-50725\,J/s}{5\,kg/s} = \left[1003.5\,\frac{J}{kg\text{-}K}(T_{OUT,HOT} - 500K) + \frac{(75\,m/s)^2}{2} - \frac{(100\,m/s)^2}{2}\right]$$

$\Rightarrow T_{OUT,HOT} = 492K$

b) NO SHAFT WORK, EVALUATE FLOW WORK

$$W_f = P_{OUT}V_{OUT} - P_{IN}V_{IN} = R(T_{OUT} - T_{IN})$$

$$W_{f\,COLD} = 287\,\frac{J}{kg\text{-}K}[350 - 300] = 14.4\ kJ/kg$$

$\dot{W}_{f\,COLD} = 14.4\ kJ/kg \cdot 1\ kg/s = 14.4\ kW$ (WORK DONE BY FLOW EXPANDING)

$\dot{W}_{f\,HOT} = 5\,\frac{kg}{s} \cdot 287\,\frac{J}{kg\text{-}K}[492 - 500] = -11.5\ kW$ (WORK DONE ON FLOW TO COMPRESS IT)

SO THERE IS NET WORK DONE BY HEAT EXCHANGER (2.87 kW)

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- BLANK PAGE FOR ADDITIONAL WORK -

c) PROCESS IS IRREVERSIBLE – LIKE PUTTING A HOT BRICK AND A COLD BRICK TOGETHER. COULD NOT PUT SYSTEM BACK TO INITIAL STATE W/O CHANGING THE SURROUNDINGS (HEAT X-FER ACROSS FINITE TEMP. DIFFERENCE)

D) THE HOT FLOW ENTERS THE DEVICE WITH HIGH INTERNAL ENERGY AND KINETIC ENERGY. THE COLD FLOW ENTERS THE DEVICE WITH LOWER INTERNAL ENERGY AND KINETIC ENERGY. BECAUSE OF THE TEMPERATURE DIFFERENCE, ENERGY FLOWS FROM THE HOT SIDE TO THE COLD SIDE (HEAT TRANSFER), THEREBY RAISING THE KINETIC AND INTERNAL ENERGY OF COLD STREAM AND LOWERING THE KINETIC AND INTERNAL ENERGY OF THE HOT STREAM. THERE IS ALSO ENERGY FLOW OUT OF THE SYSTEM ASSOCIATED WITHE THE NET WORK DONE ON THE SURROUNDINGS BY THE FLOW ENTERING AND LEAVING THE DEVICE.