School of Engineering, University of Edinburgh
Engineering Thermodynamics 2

THE UNIVERSITY of EDINBURGH
School of Engineering

Tutorial 7: More 2nd Law Analysis and Refrigeration Cycles

Note: numerical solution are based on one approach to solving the tutorial questions. Other approaches can also be correct and could lead to slightly different numerical answers.

1. A piston/cylinder device contains 2 kg of water at 5 MPa and 100°C. Heat is added from a reservoir at 600°C to the water until it reaches 600°C. The piston/cylinder device expands during this process with a constant force acting on the piston.

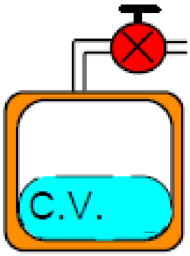
(a) Determine the work done.

(b) Determine the heat transfer to the water.

(c) Determine the total entropy production (in kJ/K) for the system and the surroundings

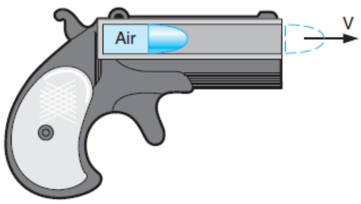
[ans: a)776.6 kJ, b) 6488 kJ, c) 4.48 kJ/K]

2. A rigid, insulated vessel contains superheated vapour steam at 3 MPa, 600°C. A valve on the vessel is opened, allowing steam to escape. The overall process is irreversible, but the steam remaining inside the vessel goes through a *reversible, adiabatic* expansion. Determine the fraction of steam that has escaped when the final state inside is a saturated vapor.



[ans: 0.949]

3. Consider a small air pistol with a cylinder volume of 1 cm^3 at 250 kPa and 27°C. The bullet acts as a piston initially held by a trigger. The bullet is released so that the air expands in an *adiabatic, reversible* process. If the pressure should be 100 kPa as the bullet leaves the cylinder, find the final volume and the work done by the air. Assume ideal gas with constant specific heats (Cv = 0.717 kJ/kgK, Cp = 1.004 kJ/kgK, R = 0.287 kJ/kgK)



[ans: V_2 = 1.92 cm^3, Work = 0.145 J]

4. A spring-loaded piston/cylinder setup contains 1.5 kg of air at 27°C and 160 kPa. It is now heated in a process where pressure is linear in volume (i.e. P = *A* + *B**V) to twice the initial volume where it reaches 900K. Assuming an ideal gas with constant specific heats (Cv = 0.717 kJ/kgK, Cp = 1.004 kJ/kgK, R = 0.287 kJ/kgK).

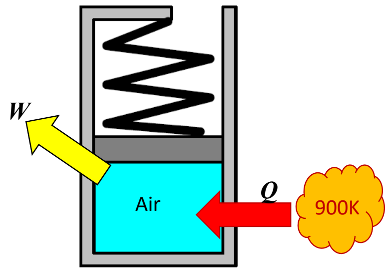


Fig. 4

a) Determine the work performed.

b) Determine the heat transfer.

c) Determine the total entropy generated assuming the heat transfer comes from a constant temperature surroundings of 900K.

[*ans: a) 161.4 kJ, b) 806.7 kJ, c) 0.584 kJ/K*]

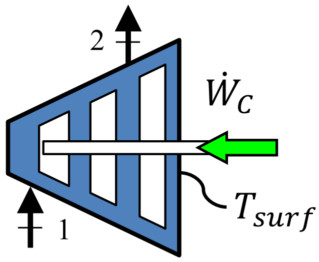
5) Steam enters a turbine at 300°C, 600 kPa and exhausts as a saturated vapor at 20 kPa. Assume the turbine to be adiabatic.

a) Determine isentropic efficiency of the turbine.

b) Determine the amount of entropy generated during this process.

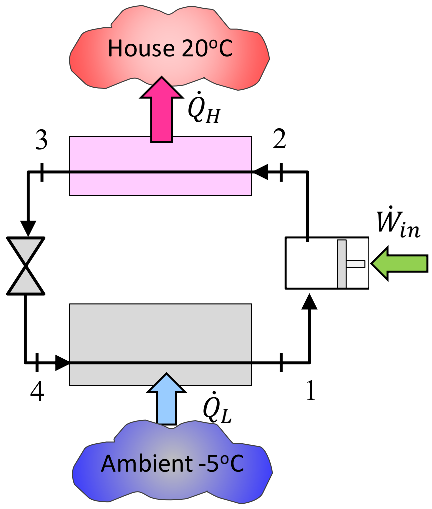
[ans: (a) $\boldsymbol{\eta_{turbine} = 0.716}$*, (b)* $\boldsymbol{s_{gen} = 0.5362\,\frac{kJ}{kgK}}$*]*

6) Air is compressed in an axial flow compressor operating at steady state from 300K, 100 kPa to a pressure of 400 kPa. Heat loss from the compressed air occurs at the rate of 34.5 kJ/kg on the compressor's surface where the temperatures is constant at 50°C. Assuming variable specific heats for air, determine the minimum compressor work (in kJ/kg air) in order to accomplish this pressure increase. Take R_{air} = 0.287 kJ/kgK.



[w_c = 135.63 kJ/kg]

7) A refrigeration system is used as a heating device (i.e. heat pump). The refrigeration system uses R-410A. The cycle is used to warm a house and maintain a constant house temperature of 20°C. The electric power required to operate the heat pump is 2 kW and it exchanges heat with the ambient at -5°C. The high and low operating pressures of the refrigeration cycle are 2000 kPa and 400 kPa, respectively. Assume the cycle to operate on the ideal refrigeration cycle



a) Determine the COP of the heat pump.

b) Determine the heating rate in kW.

c) Determine the change of entropy for the surroundings in kW/K.

[ans: (a) $\boldsymbol{COP = 4.55}$*, (b)* $\boldsymbol{\dot{Q}_{32} = 9.1 kW}$*, (c)* $\boldsymbol{\Delta S_{surr} = 0.00456\ kW/K}$*]*

8) Consider the heat pump in problem (7), however, the compressor is now irreversible (but still adiabatic) and the R-410a refrigerant exits the compressor at 2000 kPa, 65°C.

a. Determine the increase in compressor work.

b. Determine the heating rate (Q_{32})

c. Determine the COP given the new conditions of the compressor.

d. Determine the entropy generated during the compression process.

[ans: (a) $\boldsymbol{\dot{W}_{21} = 2.39\ kW}$*, increase = 0.39 kW, (b)* $\boldsymbol{\dot{Q}_{32} = 9.49 kW}$*, (c) COP = 3.97, (d)* $\boldsymbol{S_{gen} = 0.001146 \frac{kW}{K}}$*]*

9) A refrigerator uses R-134a as the working fluid and operates on an IDEAL vapor-compression refrigeration cycle between 100 kPa and 800 kPa. The mass flow rate of the refrigerant is 0.05 kg/s.

a) Determine the quality of the refrigerant entering the evaporator.

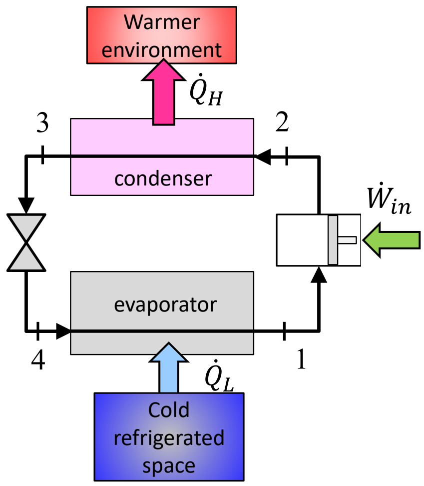
b) Determine the rate of heat removal from the refrigerated space.

c) Determine the power input to the compressor.

d) Determine the COP.

e) Determine the heat rejected to the warmer environment.

f) Show the processes on the T-s diagram.



[ans: (a) $x_4 = \mathbf{0.36}$, (b) $\dot{Q}_{14} = \mathbf{6.92kW}$, (c) $\dot{W}_{21} = \mathbf{2.16kW}$ (d) COP = 3.2, (e) $\dot{Q}_{32} = \mathbf{9.08kW}$]

10) Take the same refrigeration system as in problem 9, but now the throttle is replaced by an isentropic turbine.

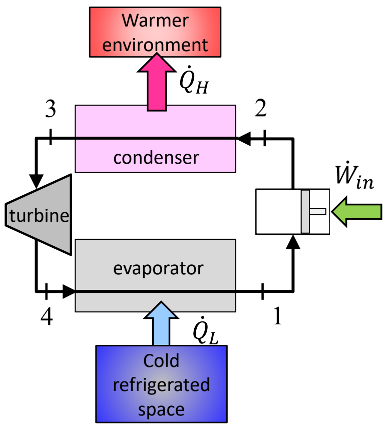
a) Determine the quality of the refrigerant entering the evaporator.

b) Draw the processes on the T-s diagram

c) Determine the new cooling capacity.

d) Determine the percentage increase of COP.

e) Why are turbines not placed in refrigeration cycles?



[ans: (a) $x_4 = \mathbf{0.32}$, (c) $\dot{Q}_{14} = \mathbf{7.36\ kW}$, (d) COP = 3.41 (6.56% increase)]