ESO Thermodynamics

End Sem (180 minutes); Total points: 150; Closed notes and open minds; April 29th, 2022

Instructions to be read carefully

1) Carry your own ID card, calculators & other accessories. 2) Cell phones/internet enabled watches should not be operated under any circumstances and do not have them with you during the exam. 3) To bring down opportunities to cheat, I suggest that there be no breaks for exchange of any electrolyte/non-electrolyte fluids unless it is critically necessary. You are not in kinder-garden and your bladder can hold on for 3 hrs! 4) Exchange of materials objects/information and misconduct will result in you losing all points for this exam and the matter will be reported to the DOAA for appropriate action. 5) End semester exam will contribute towards 70% of your final grade; 6) You need to show the steps/logic behind your answers to get partial credits 7) If you think the questions lack some information, assume those based on your judgment. State those assumptions explicitly.

Good luck!

Values of gas constant R:8.314J/(K.mol); 2 cal/(K.mol); 8.21x/(K.mol); Specific heat capacity of ideal gas at constant pressure to be 29.1 J/(mol.K); Specific heat capacity of water= 4184 J/(kg °C); Density: 1kg/1liter; Enthalpy of vaporization of water=2255 kJ/kg; 1 liter=0.001 m^3; $g=10 m/s^2$; 1 atm=10^5 Pascal

1) (30 pts) 1.1) A 2 liter plastic soda bottle contains air (assume it to be an ideal gas) at 300 K and 11.5 atm gauge pressure (note: that gauge pressure is the amount by which the pressure exceeds that of the atmosphere). How much work could be done by this gas if you could expand it down to 1 bar 1a) Isothermally and reversibly 1b) adiabatically and reversibly?

1.2) While expanding in the above--mentioned manner, the gas has to push back the atmosphere. Hence, what is the useful work (shaft work) that could be extracted by this 1.2a) isothermal expansion 1.2b) adiabatic expansion

1.3) Find the energy released when a 2 liter plastic soda bottle pressurized to 11.5 atm gauge pressure and 300 K explodes. Clearly state your approximations in analyzing/solving this problem.

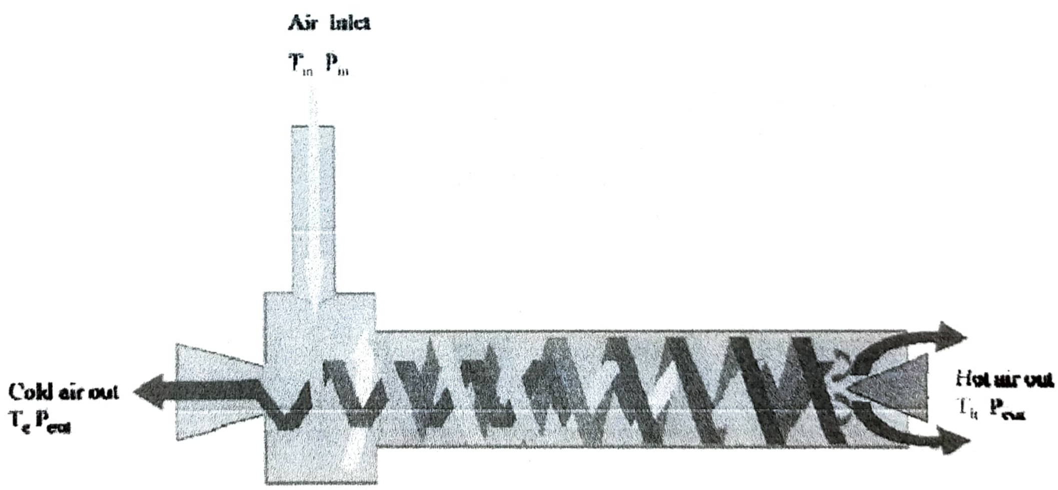
2) (30 pts) 2.1) Shri. Ganesha Ierr pours 1 liter of water at 20 °C into a thermally insulated, electrically heated teapot. The metal of the teapot is equivalent to 200 cm^3 of water. The label on the teapot tells that its heater is rated at 1250 W. 2.2a) How long will Shri. Ganesha Ierr has to wait for the water to boil and for the pot to whistle? 2.2b) How long will the shrill whistling of the teapot last?

2.2) A valve on an evacuated insulated tank is opened. Air (assumed to be ideal gas) rushes in and the pressure equalizes. The valve is then *quickly* closed. What is the temperature of the gas in the tank if the room temperature is 300 K and pressure is 1 bar.

2.3) Theory has it that Earth's atmosphere in the carboniferous period (300 million years ago) was at a much higher pressure than it is today and that it consisted primarily of CO_2. Plants loved it and took up CO_2, grew very well, died, and thereby produced the vast coal deposits that we see today. We are running an experiment today to check this theory by growing plants in a perfectly insulated high-pressure vessel containing 1 m^3 of 96% CO_2 and 4% O_2 at 5 bar and 27°C. Surrounding T=27°C . To clean the unit, we want to lower the pressure to 1 bar by opening the valve. But this would cool the gas (adiabatic reversible expansion). To counter this, we switch on a 150 W light when we let the gas out. A controller adjusts the flow rate of gas so as to keep the temperature unchanged. 2.3a) To keep the vessel at 27°C, what should be the flow rate of gas from the vessel? 2.3b) How long would it take us to lower the pressure from 5 bar to 1 bar?

3) (30 pts) 3.1) Dangers of in-person exams!: Just as a thermo professor, Shri. Ganesha Ierr, was entering the LHC (T=300 K of LHC & its surrounding), a big 20 kg bag of sand {Cp=1000 kJ/(kg.K)} smashed to the ground behind him, just missing him. He looked up and saw that it fell (or dropped?!) 50 m from the roof of the LHC. The first, second and third thoughts that crossed his mind were: 3.1a) What was ΔS of the bag of sand for this event? 3.1b) What was ΔS of the surroundings? 3.1c) What was ΔS_{total} for this process? You have to clearly state your arguments in this analysis.

3.2) Baba Lakshman for the company "Gitanjali" is exploring an interesting surgical "knife," appropriately called "Aruj Astra," which is to be absolutely painless. It works by blowing very, very cold air onto the tissue to be cut. Tissue freezes, feelings disappears, and there is no need for anesthetics! The salesman says the central equipment for this is a "Hilsch tube", a device shown below that splits a stream of high-pressure air (into two equimolar streams, one hot and the other cold, both at lower pressure (. The cold stream is then blown as the surgical "knife", the Aruj Astra. Baba Lakshman is claiming that the cold air should be at 150 K to make the cut.



Baba Lakshman is consulting with the thermo prof Shri. Ganesha Ierr to see if any laws of thermodynamics are violated by Aruj Astra. How do you think Shri. Ganesha Ierr is going to proceed with the analysis. Clearly state the approximations that you are using for your analysis.

4) (30 pts) 4.1) With an ideal heat pump, determine how much energy can be pumped into a home, which is to be kept at 300 K, from a lake bottom whose water is at 280 K, for each kW.hr of electricity used. In effect, calculate the coefficient of performance of this heat pump.

4.2) A little community called Swarnbhoomi (average temperature=300 K) owns an enormous underground reservoir of waste gas (volume of waste gas in the reservoir=10^{12} m^3, Cp= 36 J/(mol.K), p=9.95 atm, T=510 K, MW_{waste}=0.03 kg/mol). The residents feel that there surely should be some extractable energy (and hence, some paise!) in this waste gas and so they hire Shri. Ganesha Ierr as a consultant, to answer the following questions: 4.2a) Ideally, how much useful work can be gotten from this gas? 4.2b) If Swarnbhoomi can sell electricity to the Panki power plant at 5 Rs/(kW.hr), and if the their energy extraction plant is 10% efficient, what is the value of the gas in the reservoir?

5) (30 pts) 5.1) Saudi Arabia, a hot dry country (Average T~ 303 K) plans to drag (assume no melting during transit) icebergs ($h_{-ice} = -333.43\frac{kj}{kg}$; $s_{-ice} = -1.221\frac{kj}{kg.K}$ from Antarctica to Jiddah harbor, melt and store the water at 278 K ($h_W = 20.98\frac{kj}{kg}$; $s_W = 0.0761\frac{kj}{kg.K}$ and thereby supply the country with fresh water. But one can produce work, electricity and air conditioning in addition to freshwater during the melting process. If they do not try to recover this available work, how much power do they waste if they bring in a 10^6 tons iceberg every month (30 days).

5.2) The Swarnbhoomi Institute of Technology has developed compact power plant specifically designed to use agricultural and forest waste as fuel. The central part of this process is a "fluidized bed water boiler" to which solid waste and air are added for the combustion of solid waste with air. The heat generated results in water vapor at 300 °C/573 K (state 6, h_6=3064.2 J, 0.5 MPa) which is sent to a single-stage turbine. The saturated vapor coming out of the turbine is at state 1: 91.78°C and 75 kPa (s_1=7.4599 J/K, h_1=2663 J). This vapor (state 1) enters a condenser and comes out of the condenser as a liquid (state 2) at 91.78 °C (h_2=384.39 J). This liquid is pumped to higher pressure (state 3) which enters the fluidized bed water boiler.

Assuming an ideal Rankine cycle with a saturated power turbine exhaust:

5.2a) Draw a process flow sheet & what is the value of s_6? 5.2b) Sketch the cycle on a T-s diagram marking clearly all relevant states (i.e. states 1 to 6) 5.2c) Assuming negligible shaft work at the pump, determine the efficiency of transformation of heat entering the boiler tubes to work d) Find the efficiency of a Carnot cycle operating between these same two temperature limits.

6) (30 pts) 6.1) Derive a relation for the internal energy change for a gas that obeys the van der waals EOS: $P = \frac{RT}{v-b} - \frac{a}{v^2}$; Assume that in the range of interest $c_v = c_1 + c_2T$, where c_1 and c_2 are constants.

6.2) Show that the internal energy of (a) an ideal gas and (b) an incompressible substance is a function of temperature only