Problems with solutions**:**

1. A 1-m^3 tank is filled with a gas at room temperature 20°C and pressure 100 Kpa. How much mass is there if the gas is

   a) Air
   b) Neon, or
   c) Propane**?**

Given: T=273K; P=100KPa; M_{air}=29; M_{neon}=20; $M_{propane}$=44;

$$m = \frac{P \times V \times M}{\overline{R} \times T}$$

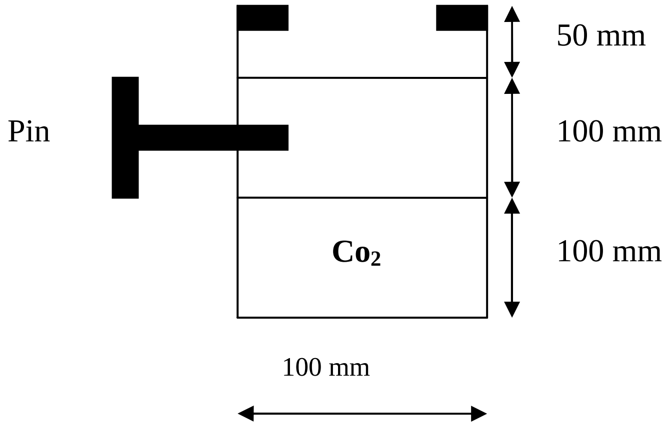
$$m_{air} = \frac{10^5 \times 1 \times 29}{8314 \times 293} = 1.19\ Kg$$

$$m_{neon} = \frac{20}{29} \times 1.19 = 0.82 Kg$$

$$m_{propane} = \frac{44}{20} \times 0.82 = 1.806 Kg$$

2. A cylinder has a thick piston initially held by a pin as shown in fig below. The cylinder contains carbon dioxide at 200 Kpa and ambient temperature of 290 k. the metal piston has a density of 8000 Kg/m^3 and the atmospheric pressure is 101 Kpa. The pin is now removed, allowing the piston to move and after a while the gas returns to ambient temperature. Is the piston against the stops?

Schematic:



Solution:

Given: P=200kpa;

$V_{gas} = \frac{\pi}{4} \times 0.1^2 \times 0.1 = 0.7858 \times 10^{-3} m^3$ **:** T=290 k: V $_{piston}$=0.785×10^{-3}:
m$_{piston}$= 0.785×10^{-3}×8000=6.28 kg

Pressure exerted by piston = $\frac{6.28 \times 9.8}{\frac{\pi}{4} \times 0.1^2} = 7848\ kpa$

When the metal pin is removed and gas T=290 k

$$v_2 = \frac{\pi}{4} \times 0.1^2 \times 0.15 = 1.18 \times 10^{-3} m^3$$
$$v_1 = 0.785 \times 10^{-3} m^3$$
$$p_2 = \frac{200 \times 0.785}{1.18} = 133kpa$$

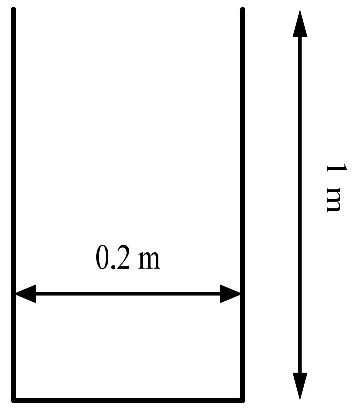
Total pressure due to piston +weight of piston =101+7.848kpa

=108.848 pa

Conclusion: Pressure is grater than this value. Therefore the piston is resting against the stops.

3. A cylindrical gas tank 1 m long, inside diameter of 20cm, is evacuated and then filled with carbon dioxide gas at 25^0c.To what pressure should it be charged if there should be 1.2 kg of carbon dioxide?

Solution: T= 298 k: m=1.2kg:

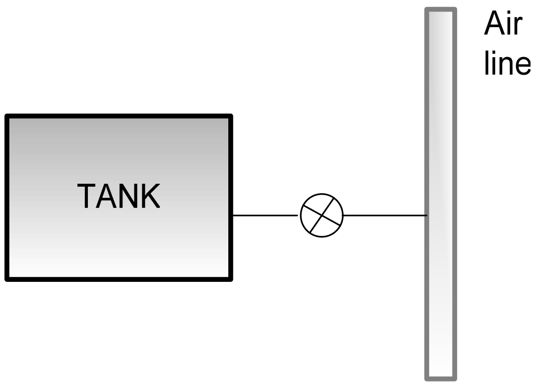


$$p = 1.2 \times \frac{8314}{44} \times \frac{298}{\frac{\pi}{4} \times 0.2^2 \times 1} = 2.15 Mpa$$

4. A 1-m^3 rigid tank with air 1 Mpa, 400 K is connected to an air line as shown in fig: the valve is opened and air flows into the tank until the pressure reaches 5 Mpa, at which point the valve is closed and the temperature is inside is 450 K.

a. What is the mass of air in the tank before and after the process?

b. The tank is eventually cools to room temperature, 300 K. what is the pressure inside the tank then?



Solution:

$P=10^6$ Pa: $P_2=5\times10^6$ Pa: $T_1=400K$: $T_2=450$ k

$$m_1 = \frac{10^6 \times 1 \times 29}{8314 \times 400} = 8.72Kg$$

$$m_2 = \frac{5 \times 10^6 \times 29}{8314 \times 450} = 38.8Kg$$

$$P = 38.8 \times \frac{8314}{29} \times \frac{300}{1} = 3.34Mpa$$

5. A hollow metal sphere of 150-mm inside diameter is weighed on a precision beam balance when evacuated and again after being filled to 875 Kpa with an unknown gas. The difference in mass is 0.0025 Kg, and the temperature is 25^0c. What is the gas, assuming it is a pure substance?

Solution:

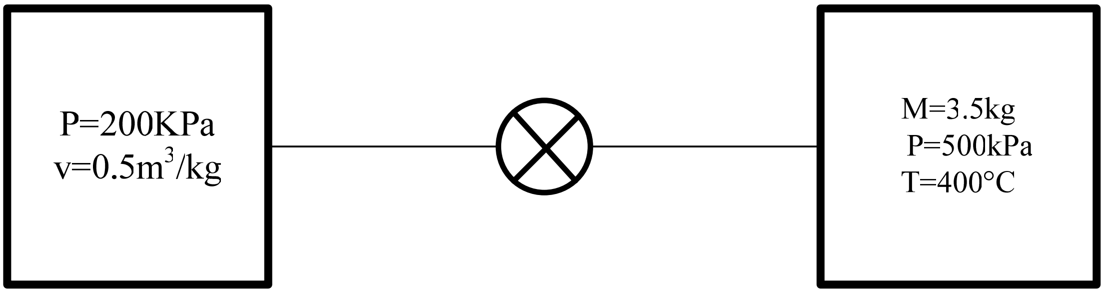
m=0.0025Kg: P=875×103 Kpa: T= 298 K

$$M = \frac{8314 \times 0.0025 \times 298}{875 \times 10^3 \times \frac{\pi}{6} \times 0.15^3} = 4$$

The gas will be helium.

6. Two tanks are connected as shown in fig, both containing water. Tank A is at 200 Kpa,ν=1m^3 and tank B contains 3.5 Kg at 0.5 Mp, 400^{0}C. The valve is now opened and the two come to a uniform state. Find the specific volume.

Schematic:



Known:

V=1m^3
M=2 Kg
ν_f =0.001061m^3/Kg
ν_g =0.88573 m3/Kg

T=400^{0}C
m=3.5 Kg

Therefore it is a mixture of steam and water.

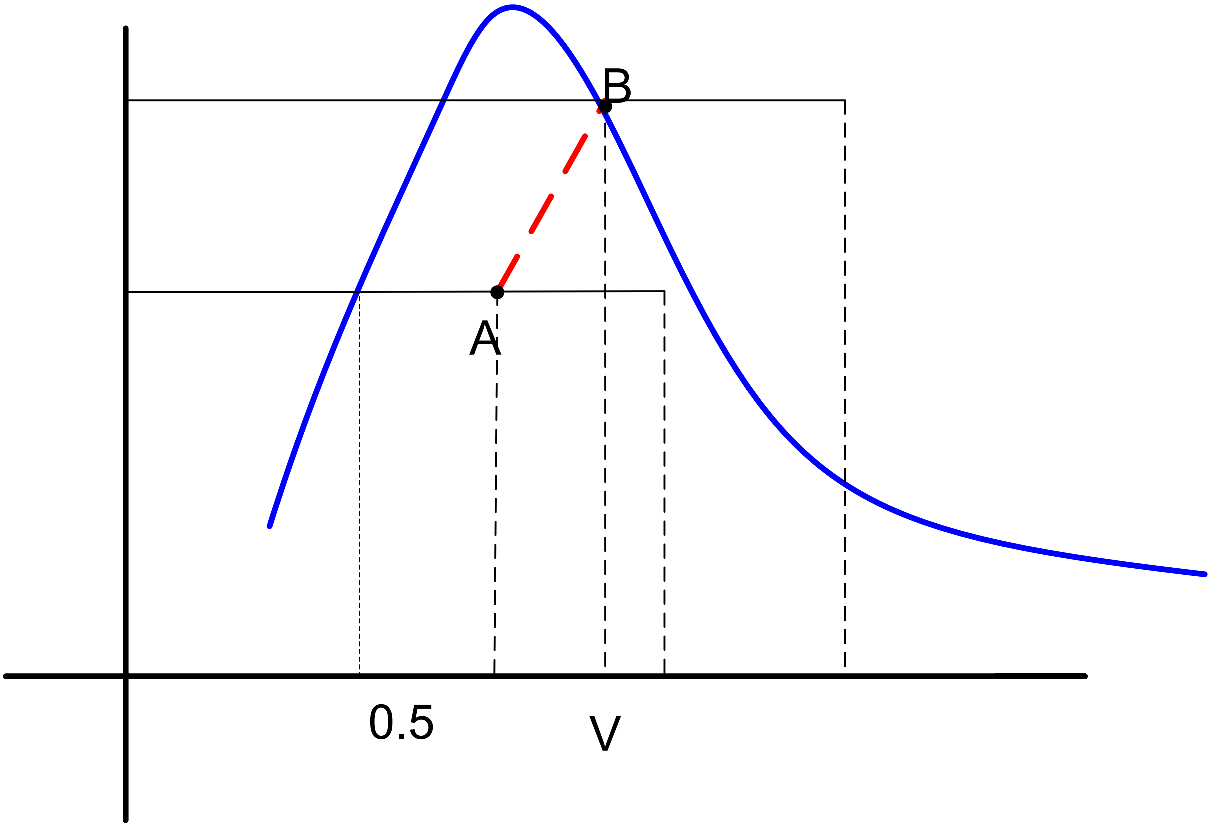
Final volume=2.16+1 =3.16 m^3

Final volume=2+3.5= 5.5 Kg

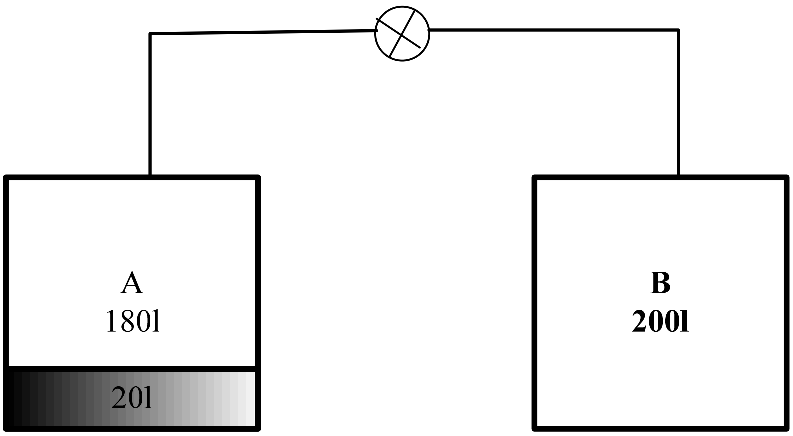
Final specific volume= 3.16/5.5=0.5745 m^3/Kg

$$m_{inA} = \frac{1}{0.5745} = 1.74kg$$

$$m_{inB} = \frac{2.16}{0.5745} = 3.76Kg$$



7.. The valve is now opened and saturated vapor flows from A to B until the pressure in B Consider two tanks, A and B, connected by a valve as shown in fig. Each has a volume of 200 L and tank A has R-12 at 25°C, 10 % liquid and 90% vapor by volume, while tank B is evacuated has reached that in A, at which point the valve is closed. This process occurs slowly such that all temperatures stay at 25 °C throughout the process. How much has the quality changed in tank A during the process?



Solution: Given R-12

P= 651.6 KPa

ν_g= 0.02685 m3/Kg

ν_f = 0.763*10^{-3} m^3/Kg

$$m = \frac{0.18}{0.02685} + \frac{0.02}{0.763*10^{-3}}$$

$$= 6.704 + 26.212 = 32.916$$

$$x_1 = \frac{6.704}{32.916} = 0.2037$$

Amount of vapor needed to fill tank B = $\frac{0.2}{0.02685}$ = 7.448Kg

Reduction in mass liquid in tank A =increase in mass of vapor in B

m_f =26.212 –7.448 =18.76 Kg
This reduction of mass makes liquid to occupy = $0.763\times10^{-3}\times18.76\ m^3 = 0.0143\ m^3$

Volume of vapor =0.2 – 0.0143 =0.1857 L

$$Mg = \frac{0.1857}{0.02685} = 6.916\ Kg$$

$$x_2 = \frac{6.916}{6.916 + 18.76} = 0.2694$$

$\Delta x.\ \uparrow = 6.6\ \%$

8. A linear spring, $F = K_s (x-x_0)$, with spring constant K_s = 500 N/m, is stretched until it is 100 mm long. Find the required force and work input.

Solution:

$F=K_s (x-x_o)$ $\quad\quad$ $x- x_0= 0.1$ m

K_s =500 N/m

F= 50 N

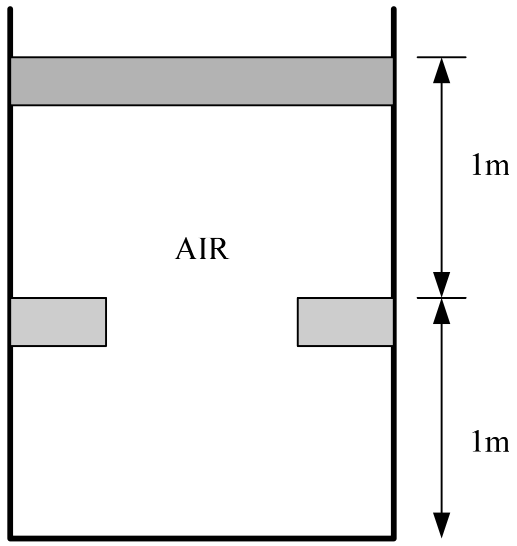
$$W = \frac{1}{2}\mathbf{FS} \quad = \frac{1}{2}\times\mathbf{50}\times\mathbf{0.1} = \mathbf{2.53}$$

9. A piston / cylinder arrangement shown in fig. Initially contains air at 150 kpa, 400°C. The setup is allowed to cool at ambient temperature of 20°C.

a. Is the piston resting on the stops in the final state? What is the final pressure in the cylinder?

b. That is the specific work done by the air during the process?

Schematic:



Solution:

p_1= 150×103 Pa

T_1=673 K

T_2=293 K

$$\frac{P_1 \times V_1}{T_1} = \frac{P_1 \times V_2}{T_2}$$

1. If it is a constant pressure process, $V_2 = \frac{T_2}{T_1} \times V_1 = \frac{293}{673} \times A \times 2 = 0.87m$

Since it is less than weight of the stops, the piston rests on stops.

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

T2 = $\frac{V_2}{V_1} \times T_1$

$$= \frac{1 \times 673}{2} = 336.5K$$

$$\frac{p_3}{T_3} = \frac{p_2}{T_2}$$

$$P_3 = \frac{P_2 \times T_3}{T_2} = 150 \times 10^3 \times \frac{293}{336.5} = 130.6KPa$$

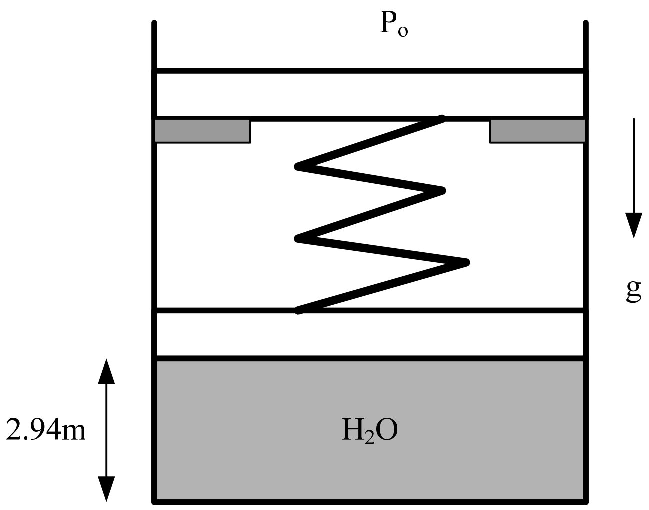
Therefore W = $\frac{-150 \times 10^3 \times A \times 1 \times 8314}{150 \times 10^3 \times A \times 2 \times 29} = -96.5KJ / Kg$

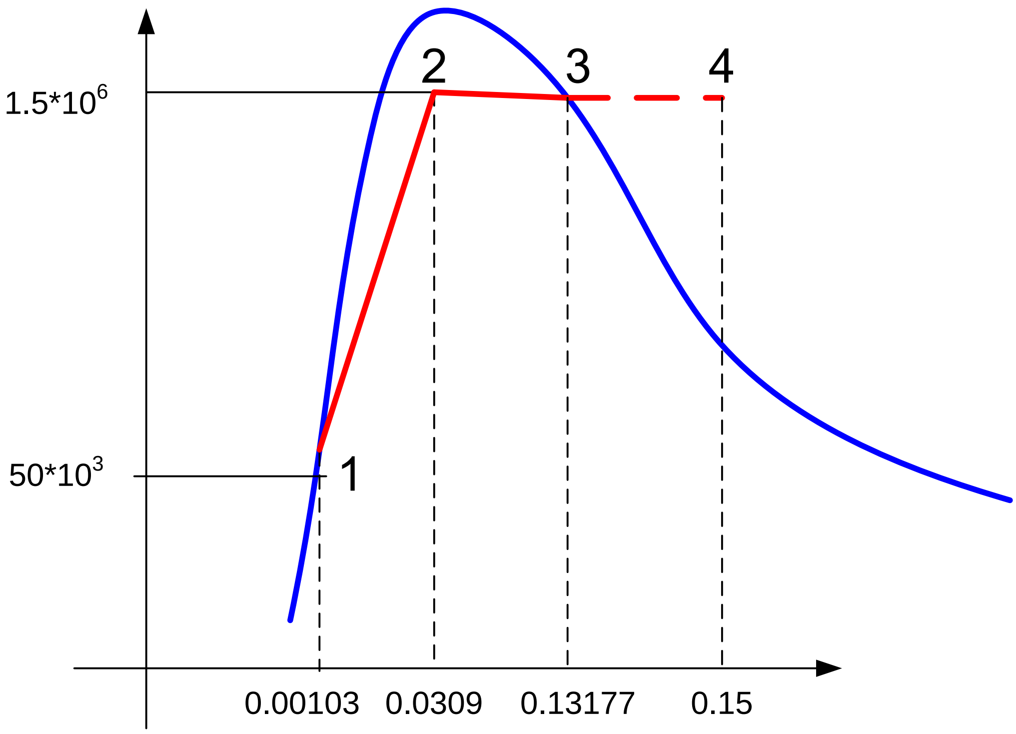
10. A cylinder, A_{cyl} = 7.012cm^2 has two pistons mounted, the upper one, m_{p1}=100kg, initially resting on the stops. The lower piston, m_{p2}=0kg, has 2 kg water below it, with a spring in vacuum connecting he two pistons. The spring force fore is zero when the lower piston stands at the bottom, and when the lower piston hits the stops the volume is 0.3 m^3. The water, initially at 50 kPa, V=0.00206 m^3, is then heated to saturated vapor.

a. Find the initial temperature and the pressure that will lift the upper piston.

b. Find the final T, P, v and work done by the water.

Schematic:





There are the following stages:

(1) Initially water pressure 50 kPa results in some compression of springs.

Force = $50\times10^{3}\times7.012\times10^{-4}$ = 35.06 N

Specific volume of water = 0.00206/2 = 0.00103 m^3/kg

Height of water surface = $\frac{0.00206}{7.012\times10^{-4}}$ = 2.94 m

Spring stiffness = $\frac{35.06}{2.94} = 11.925 N/m$

(2) As heat is supplied, pressure of water increases and is balanced by spring reaction due to due to K8. This will occur till the spring reaction

= Force due to piston + atm pressure

$=981+10^{5}\times7.012\times10^{-4} = 1051$ N

This will result when S = $\frac{1051}{11.925} = 80.134m$

At this average V= $7.012\times 10^{-4} \times 88.134$ =$0.0618 m^3$

P= $\frac{1051}{7.012\times10^{-4}}$ =1.5 Mpa

(3) From then on it will be a constant pressure process till the lower piston hits the stopper. Process 2-3

At this stage V= $0.3\ m^3$

Specific volume = $0.15\ m^3/kg$

But saturated vapor specific volume at 1.5 Mpa = $0.13177\ m^3/ kg$

V=$0.26354\ m^3$

(4) Therefore the steam gets superheated 3-4

Work done = $p_2(v_4 - v_2) + \frac{1}{2}(p_2 + p_1)(v_2 - v_1)$

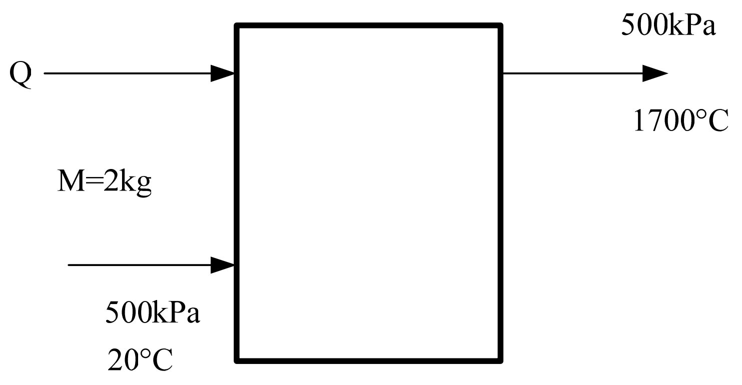
$= 1.5\times10^6(0.15-0.0618) + \frac{1}{2}(1.5\times10^6 + 50\times10^3)(0.0618 - 0.00103)$

= 178598.5 J

= 179 KJ

11. Two kilograms of water at 500 kPa, 20°C are heated in a constant pressure process (SSSF) to 1700°C. Find the best estimate for the heat transfer.

Solution:



$Q = m\ [(h_2\text{-}h_1)]$

$=2[(6456\text{-}85)]$

$=12743$ KJ

Chart data does not cover the range. Approximately h_2= 6456KJ/kg; h_1=85 KJ;

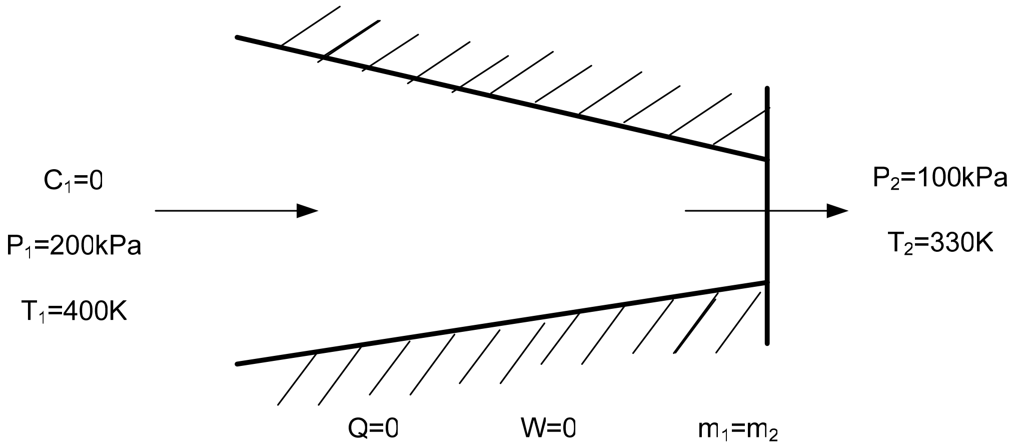
500 kPa 130°C h=5408.57
700°C h=3925.97

Δh = 1482.6 kJ/kg

262 kJ/kg /100°C

12. Nitrogen gas flows into a convergent nozzle at 200 kPa, 400 K and very low velocity. It flows out of the nozzle at 100 kPa, 330 K. If the nozzle is insulated, find the exit velocity.

Solution:



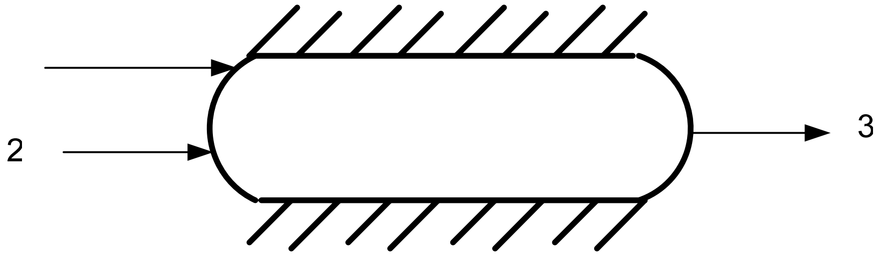
$$h_1 + \frac{c_1^2}{2} = h_2 + \frac{c_2^2}{2}$$

$$\frac{c_2^2}{2} = h_1 - h_2 = 415.31 \times 1000 - 342.4 \times 1000$$

$$c_2 = \sqrt{2(h_1 - h_2} = 381.8 m/s$$

13. An insulated chamber receives 2kg/s R-134a at 1 MPa, 100°c in a line with a low velocity. Another line with R-134a as saturated liquid, 600c flows through a valve to the mixing chamber at 1 Mpa after the valve. The exit flow is saturated vapor at 1Mpa flowing at 20-m/s. Find the flow rate for the second line.

Solution:



Q=0; W=0;

SFEE = $0 = m_3 (h_3) + c_3^2/2 - (m_1 h_1 + m_2 h_2)$

$m_1 = 2$g/s $\qquad$ h_1 (1Mpa, 100°C) = 483.36×10^3 J/kg

$m_2 = ?$ $\qquad$ h_2 (saturated liquid 60°C =287.79×10^3 J/kg)

$m_3 = ?$ $\qquad$ h_3(saturated vapor 1Mpa = 419.54×10^3 J/kg)

$$m_3\left[419540 + \frac{400}{2}\right] = 2\times483360 + m_2(287790)$$

$419.74\ m_3 = 966.72 + 287.79 m_2$

$1.458 m_3 = 3.359 + m_2$

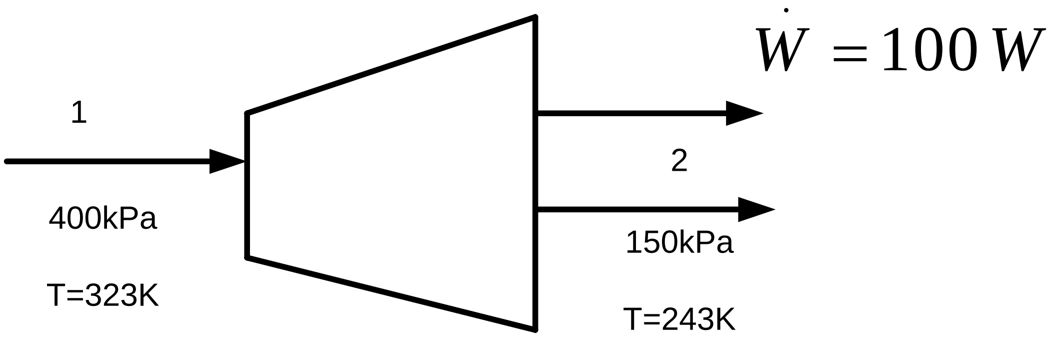
$m_3 = \ \ 2 + m_2$

$0.458 m_3 = 1.359$

$m_3 = 2.967$ kg/s ; $\quad m_2 = 0.967$ kg/s

14. A small, high-speed turbine operating on compressed air produces a power output of 100W. The inlet state is 400 kPa,50°C, and the exit state is 150 kPa-30°C. Assuming the velocities to be low and the process to be adiabatic, find the required mass flow rate of air through the turbine.

Solution:



SFEE : $-100 = \dot{m}\,[h_2 - h_1]$

$h_1 = 243.Cp$

$h_2 = 323.Cp$

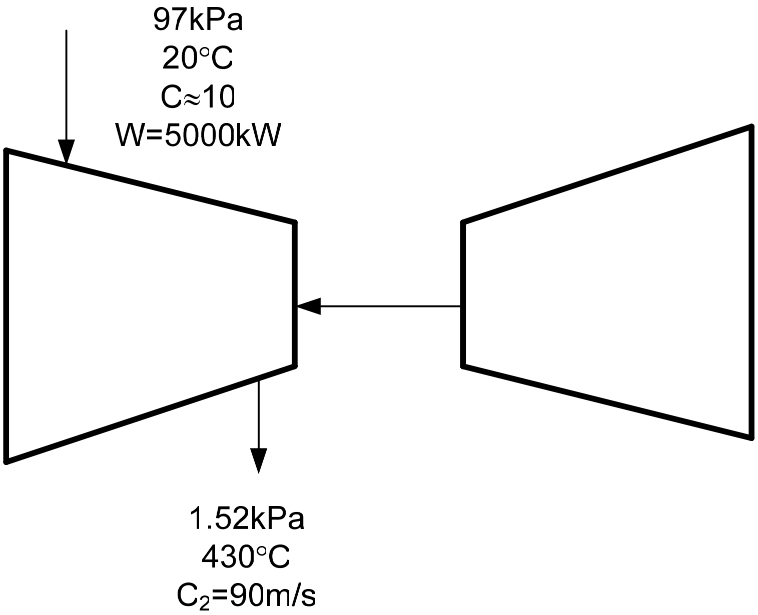
$-100 = \dot{m}\,Cp(243-323)$

$\dot{m}\,Cp = 1.25$

$\dot{m} = 1.25\times10^{-3}$ kg/s

15. The compressor of a large gas turbine receives air from the ambient at 95 kPa, 20°C, with a low velocity. At the compressor discharge, air exists at 1.52 MPa, 430°C, with a velocity of 90-m/s. The power input to the compressor is 5000 kW. Determine the mass flow rate of air through the unit.

Solution:



Assume that compressor is insulated. Q=0;

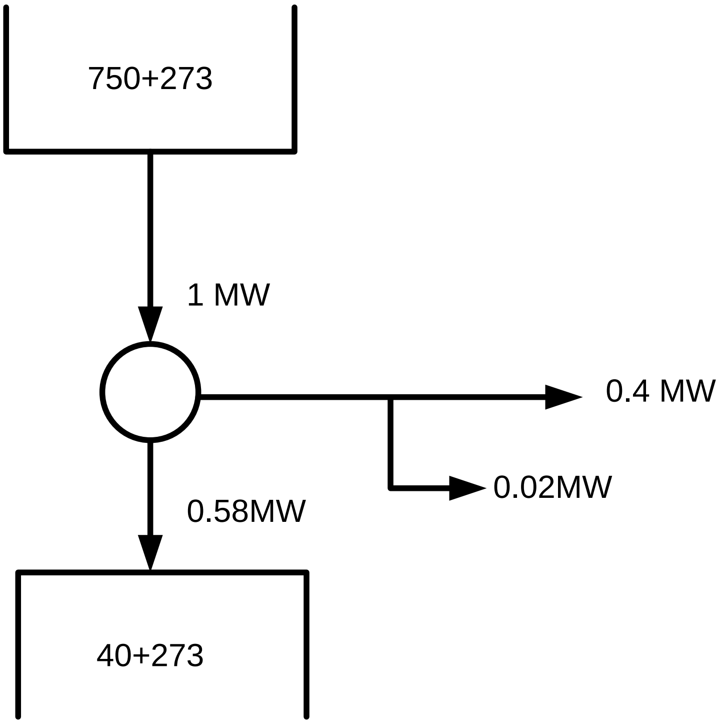
SFEE: $5000\times10^3 = \dot{m}\,[1000*430 + \frac{90^2}{2} - 1000\times 20]$

$5000 = \dot{m}\,[410 - 4.05]$

$\dot{m} = 12.3$ kg/s

16. In a steam power plant 1 MW is added at 700°C in the boiler , 0.58 MW is taken at out at 40°C in the condenser, and the pump work is 0.02 MW. Find the plant thermal efficiency. Assuming the same pump work and heat transfer to the boiler is given, how much turbine power could be produced if the plant were running in a Carnot cycle?

Solution:



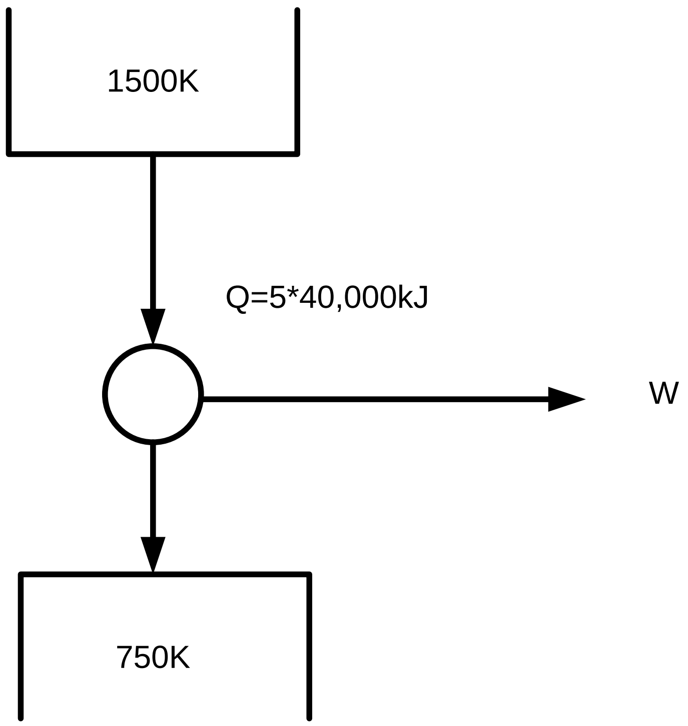
$$\eta = 1 - \frac{313}{1023} = 0.694$$

Theoretically 0.694 MW could have been generated. So 0K on Carnot cycle

Power= 0.694 W

17. A car engine burns 5 kg fuel at 1500 K and rejects energy into the radiator and exhaust at an average temperature of 750 K. If the fuel provides 40000 kJ/kg, what is the maximum amount of work the engine provide?

Solution:



$$\eta = \frac{T_1 - T_2}{T_1} = 50\ \%$$

W= 20,000*5=10^5 KJ=100MJ

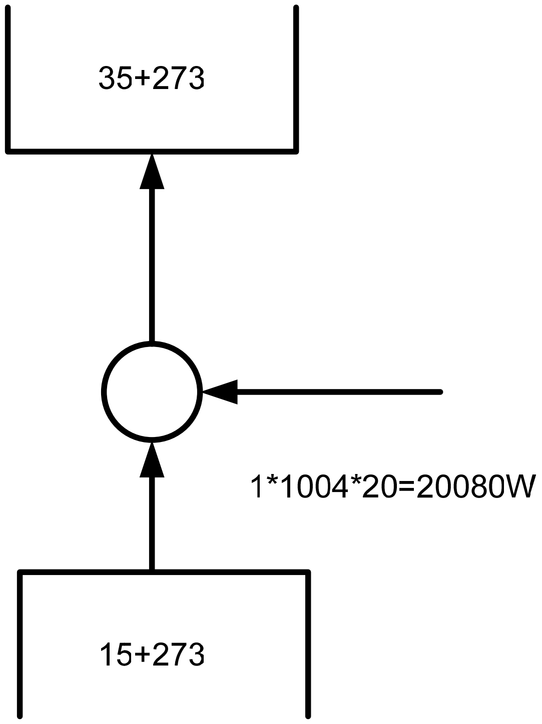
18. At certain locations geothermal energy in underground water is available and used as the energy source for a power plant. Consider a supply of saturated liquid water at 150°C. What is the maximum possible thermal efficiency of a cyclic heat engine using the source of energy with the ambient at 20°C? Would it be better to locate a source of saturated vapor at 150°C than to use the saturated liquid at 150°C?

Solution:

$$\eta_{\max} = \frac{1 - 293}{423} = 0.307 or 30.7\%$$

19. An air conditioner provides 1 kg/s of air at 15°C cooled from outside atmospheric air at 35°C. Estimate the amount of power needed to operate the air conditioner. Clearly state all the assumptions made.

Solution: assume air to be a perfect gas

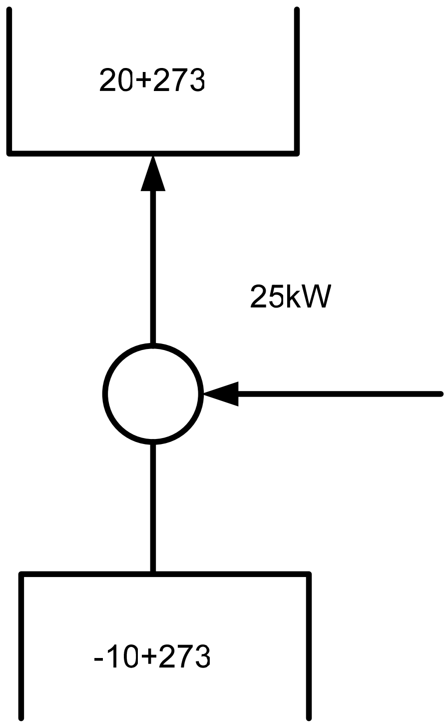


$$cop = \frac{288}{20} = 14.4$$

$$W = \frac{20080}{14.4} = 1390W$$

20. We propose to heat a house in the winter with a heat pump. The house is to be maintained at 20 ^{0}C at all times. When the ambient temperature outside drops at –10 ^{0}C that rate at which heat is lost from the house is estimated to be 25 KW. What is the minimum electrical power required to drive the heat pump?

Solution:



$$cop_{Hp} = \frac{293}{30} = 9.77$$

$$W = \frac{25}{9.71} = 2.56\ KW$$

21.A house hold freezer operates in room at 20°C. Heat must be transferred from the cold space at rate of 2 kW to maintain its temperature at –30°C. What is the theoretically smallest (power) motor required to operating this freezer?

Solution:

$$cop = \frac{243}{50} = 4.86$$

$$W = \frac{2}{4.86} = 0.41 \ kW$$

22. Differences in surface water and deep-water temperature can be utilized for power genetration.It is proposed to construct a cyclic heat engine that will operate near Hawaii, where the ocean temperature is 20^0C near the surface and 5^0C at some depth. What is the possible thermal efficiency of such a heat engine?

Solution:

$$\eta_{\max} = \frac{15}{293} = 5\%$$

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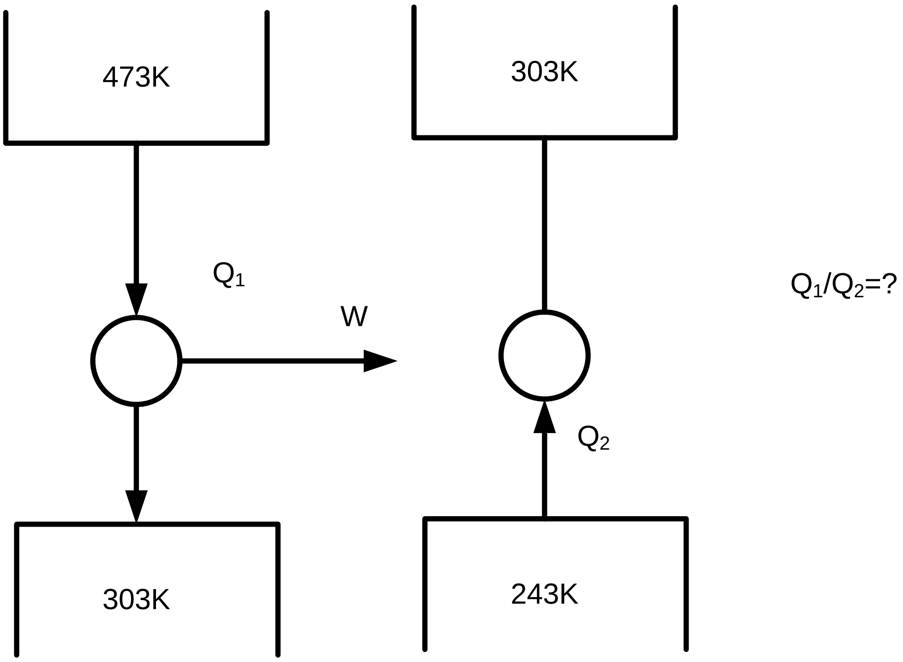
23. We wish to produce refrigeration at –30^{0}C. A reservoir, shown in fig is available at 200 ^{0}C and the ambient temperature is 30 ^{0}C. This, work can be done by a cyclic heat engine operating between the 200 ^{0}C reservoir and the ambient. This work is used to drive the refrigerator. Determine the ratio of heat transferred from 200 ^{0}C reservoir to the heat transferred from the –30^{0}C reservoir, assuming all process are reversible.

Solution:



$$\eta = 0.359 \qquad cop = 4.05$$

$$W = Q \times 0.3594$$

$$Q_2 = W \times 4.05$$

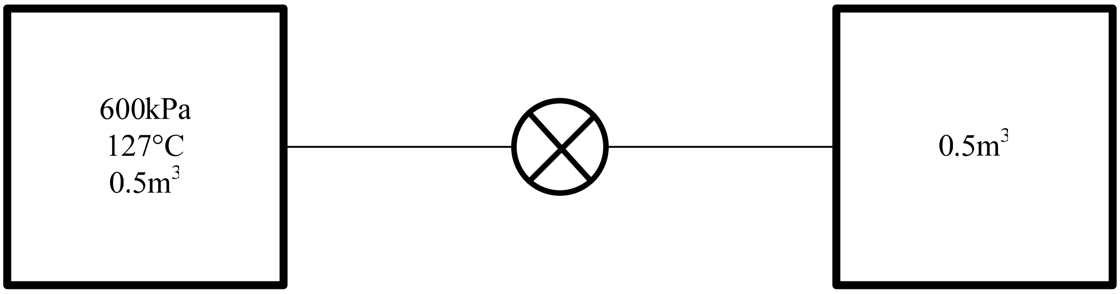
$$W = \frac{Q_2}{4.05}$$

$$Q_1 \times 0.3594 = \frac{Q_2}{6.05}$$

$$\frac{Q_1}{Q_2} = \frac{1}{4.05 \times 0.3594} = 0.69$$

24. Nitrogen at 600 kPa, 127°C is in a 0.5m^3-insulated tank connected to pipe with a valve to a second insulated initially empty tank 0.5 m^3. The valve is opened and nitrogen fills both the tanks. Find the final pressure and temperature and the entropy generation this process causes. Why is the process irreversible?

Solution:



Final pressure = 300 kPa

Final temperature=127 kPa as it will be a throttling process and h is constant.

T= constant for ideal gas

$$m=\frac{10^3\times 600\times 0.5}{\frac{8314}{28}\times 400}=\frac{750\times 28}{8314}=2.5kg$$

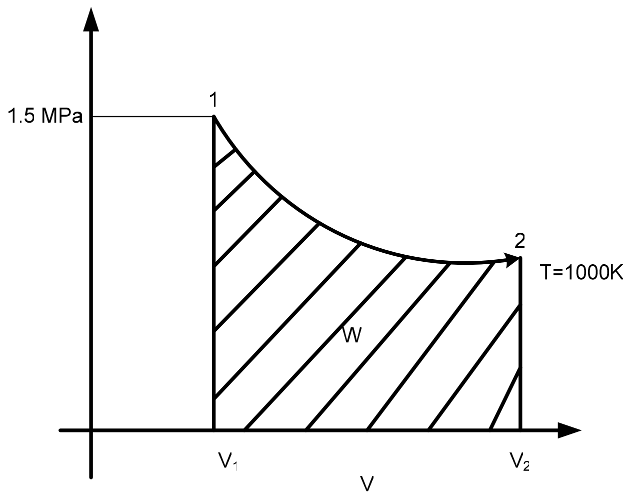
Δs for an isothermal process= $mR \ \ln \dfrac{V_2}{V_1}$

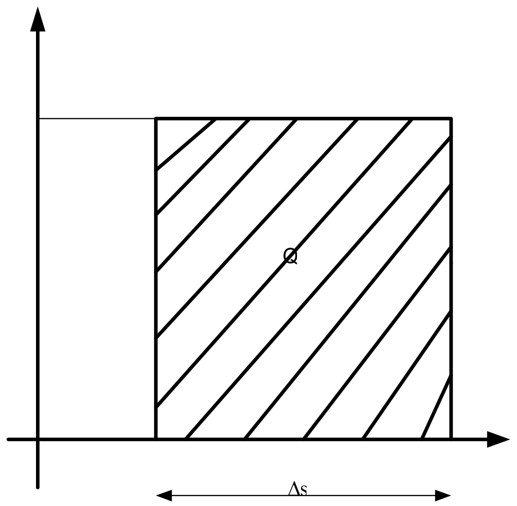
$$=2.5\times\frac{5314}{28}m^2$$

=514.5 J/k

25. A mass of a kg of air contained in a cylinder at 1.5Mpa, 100K, expands in a reversible isothermal process to a volume 10 times larger. Calculate the heat transfer during the process and the change of entropy of the air.

Solution:





$V_2 = 10V_1$

$$Q = W = p_1 v_1 \ln \frac{v_2}{v_1}$$ For isothermal process

$$= mRT_1 \ln \frac{v_2}{v_1}$$

$$= 1 * \frac{8314}{29} * 1000 * \ln 10 = 660127\ J$$

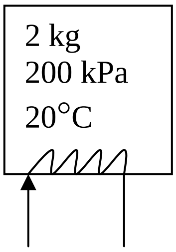
W=Q for an isothermal process,

TΔs=660127;

Δs=660J/K

26. A rigid tank contains 2 kg of air at 200 kPa and ambient temperature, 20°C. An electric current now passes through a resistor inside the tank. After a total of 100 kJ of electrical work has crossed the boundary, the air temperature inside is 80°C, is this possible?

Solution:



$Q=100*10^3$ J

It is a constant volume process.

$$Q = mc_v \Lambda T$$

$=2\times707\times20$

$=83840$ J

Q given 10,000 Joules only. Therefore not possible because some could have been lost through the wall as they are not insulted.

$$\Delta S_{air} = \int_{293}^{353} \frac{mc_v dT}{T} = 2\times703\ln\frac{353}{293} = 261.93 J/K$$

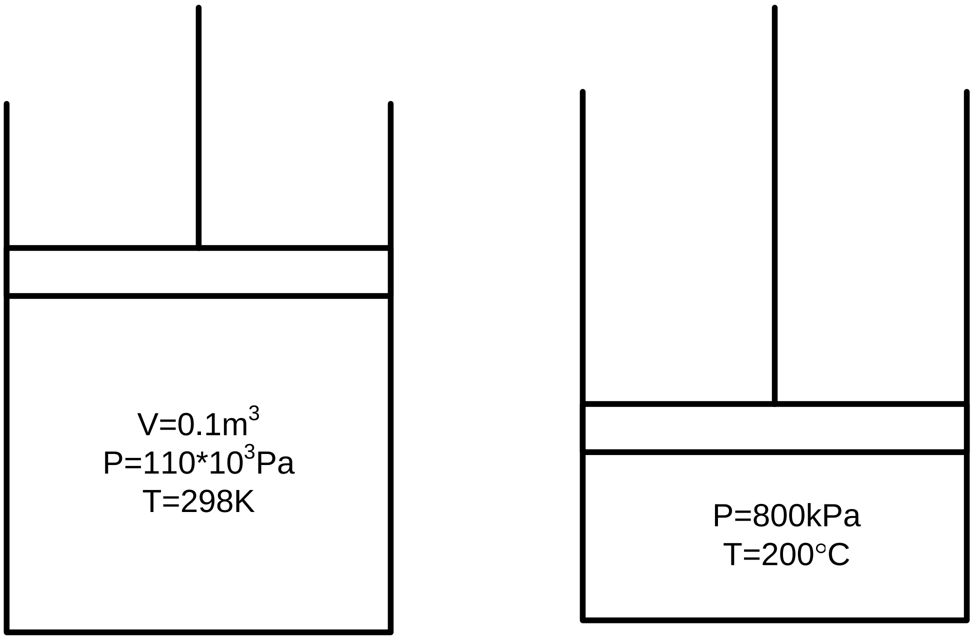
$$\Delta S_{sun} = \frac{-100\times10^3}{293} = -341.3 J/K$$

$$\Delta_{system} + \Delta_{sun} < 0$$

Hence not possible. It should be >=0;

27. A cylinder/ piston contain 100 L of air at 110 kPa, 25°C. The air is compressed in reversible polytrophic process to a final state of 800 kPa, 2000C. Assume the heat transfer is with the ambient at 25°C and determine the polytrophic exponent n and the final volume of air. Find the work done by the air, the heat transfer and the total entropy generation for the process.

Solution:



$$\frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2} = \frac{110\times10^3\times0.1}{298} = \frac{800\times10^3\times V_2}{473} = V_2 = 0.022m^3$$

$$p_1 \times V\gamma_1 = p_2 \times V_2^{\gamma}$$

$$\left(\frac{p_1}{p_2}\right) = \left(\frac{V_2}{V_1}\right)^{\gamma}$$

$$7.273 = (4.545)^{\gamma}$$

$$\gamma = 1.31$$

W= $\frac{p_1V_1 - p_2V_2}{n-1} = \frac{110\times10^3\times0.1 - 800\times0.022\times10^3}{1.31-1} = -21290J$

$$\Delta S = R\ln\frac{V_2}{V_1} + c_v \ln\frac{T_1}{T_2}$$

$$= \frac{8314}{29}\ln\frac{0.022}{0.1} + \frac{8314}{29\times 1.48}\ln\frac{473}{298} = -103J/kgK$$

$$m = \frac{110\times 10^3\times 0.1}{\frac{8314}{29}\times 298} = 0.129kg$$

$$\Delta S = -13.28J/K$$

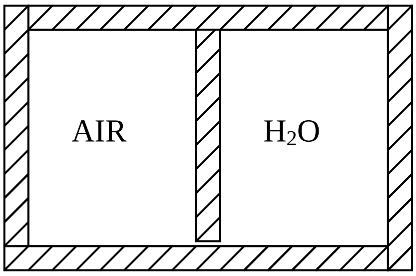
$$\Delta U = 0.129\times\frac{8314}{29\times 0.4}(473-298) = 16180J$$

$$Q - W = \Delta U$$

$$Q = 16180 - 21290 = -5110J$$

28. A closed, partly insulated cylinder divided by an insulated piston contains air in one side and water on the other, as shown in fig. There is no insulation on the end containing water. Each volume is initially 100L, with the air at 40°C and the water at 90°C, quality 10 %. Heat is slowly transferred to the water, until a final pressure of 500kPa. Calculate the amount of heat transferred.

Solution:



State 1:

Vair=0.1m3 $V_{water}=0.1m^3$ Total volume=$0.2m^3$

$t_{air}=40°C$ x=0.1 $t_{water}=90°C$

Initial pressure of air = saturation pressure of water at 90°C = 70.14kPa

$v_g/90°C = 2.360506 m^3/kg$ $v_f/90°C = 0.0010316 m^3/kg$

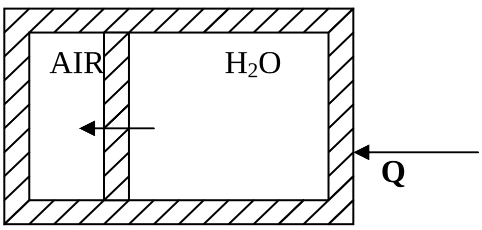
$V = xv_g+(1-x)v_f$

$=0.1*2.36056+0.9*0.0010316=0.237 m^3/kg$

$V=0.1m^3$

$$m_{water} = \frac{V}{v} = \frac{0.1}{0.237} = 0.422kg$$

State 2:



Assume that compression of air is reversible. It is adiabatic

$$p_1V_1^{\gamma} = p_2V_2^{\gamma}$$

$$V_2 = V_1\left(\frac{p_1}{p_2}\right)^{\frac{1}{\gamma}} = 0.1\left(\frac{70.14}{500}\right)^{\frac{1}{1.4}} = 0.0246m^3$$

Volume of water chamber =0.2- 0.0246=0.1754m^3

Specific volume = $\dfrac{0.1754}{0.422} = 0.416m^3/kg$

$$v_g /_{500kPa} = 0.3738m^3/kg$$

Therefore steam is in superheated state.