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Course: MAE 91
Set : #4
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Problem 6,54

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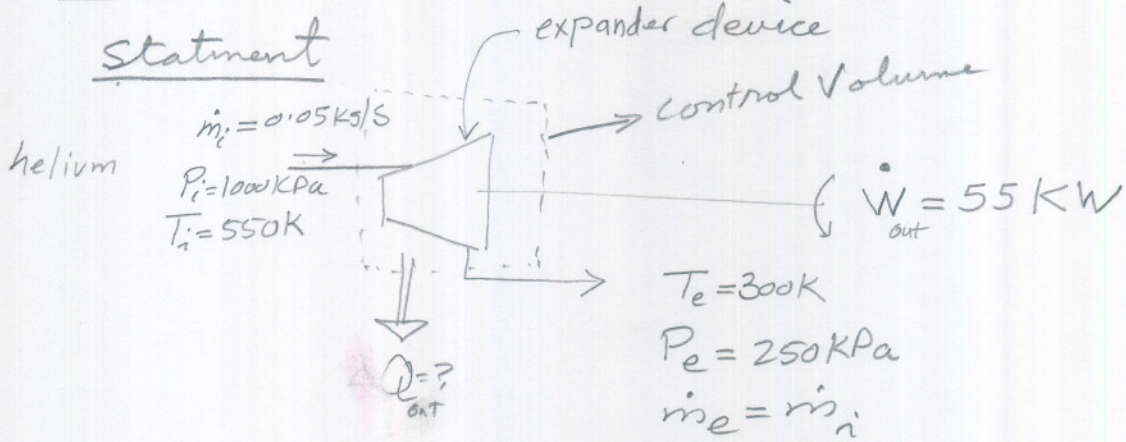
Statment



an expander device with the shown input and output. find $\dot{Q}$ (rate of heat transfer). neglect KE.

Assumptions

steady state $\Rightarrow \frac{d}{dt}(E)_{cv} = 0.$ and $\boxed{\dot{m}_i = \dot{m}_e}$

helium is an ideal gas.

Assume C_p is valid at T_i and T_e as is from Table A.5

Laws

continuity equation $\dot{m}_i = \dot{m}_e$;

$$\dot{Q}_{in} + \dot{W}_{in} + \dot{m}_i(KE+PE+h)_i = \dot{Q}_{out} + \dot{W}_{out} + \dot{m}_e(KE+PE+h)_e + \frac{d}{dt}(E)_{cv}$$

$h = C_p T$ for an ideal gas.

Steps

Simplify the control volume equation, and use $\dot{m}_i = \dot{m}_e$

$$\cancel{\dot{Q}_{in}} + \cancel{\dot{W}_{in}} + \dot{m}_i(\cancel{KE}+\cancel{PE}+h)_i = \dot{Q}_{out} + \dot{W}_{out} + \dot{m}_e(\cancel{KE}+\cancel{PE}+h)_e + \cancel{\frac{d}{dt}(E)_{cv}}$$

$$\Downarrow$$

$$\dot{m} h_i = \dot{Q}_{out} + \dot{W}_e + \dot{m} h_e$$

so $\boxed{\dot{Q}_{out} = \dot{m}(h_i - h_e) - \dot{W}_{out}}$ —— (1)

so $$\boxed{\dot{Q}_{out} = \underbrace{\dot{m}}_{\text{given}} (h_i - h_e) - \underbrace{\dot{W}_{out}}_{\text{given}}}$$

we can find enthalpy on exit and entrance by using the ideal gas relation

$$\boxed{h = C_p T} \text{ --- } (2)$$

look up C_p for Helium from Table A.5 and find h_i, h_e using (2) since we are given T_i, T_e.

Numerical

use (2) to find h_i, h_e.

from A.5, $C_p = 5.193$ KJ/Kg-K.

hence $h_i = C_p T_i = (5.193 \times 10^3)(550) = 2856150$ J/kg

$h_e = C_p T_e = (5.193 \times 10^3)(300) = 1557900$ J/kg.

using (1)

$$\dot{Q}_{out} = \dot{m}(h_i - h_e) - \dot{W}_{out}$$

$$= 0.05 (2856150 - 1557900) - 55 \times 10^3$$

$$= 9912.5 \text{ J/s}$$

$$\cong 9.9 \text{ KJ/S} = \boxed{-9.9 \text{ KW}}$$

-1

problem 6.59

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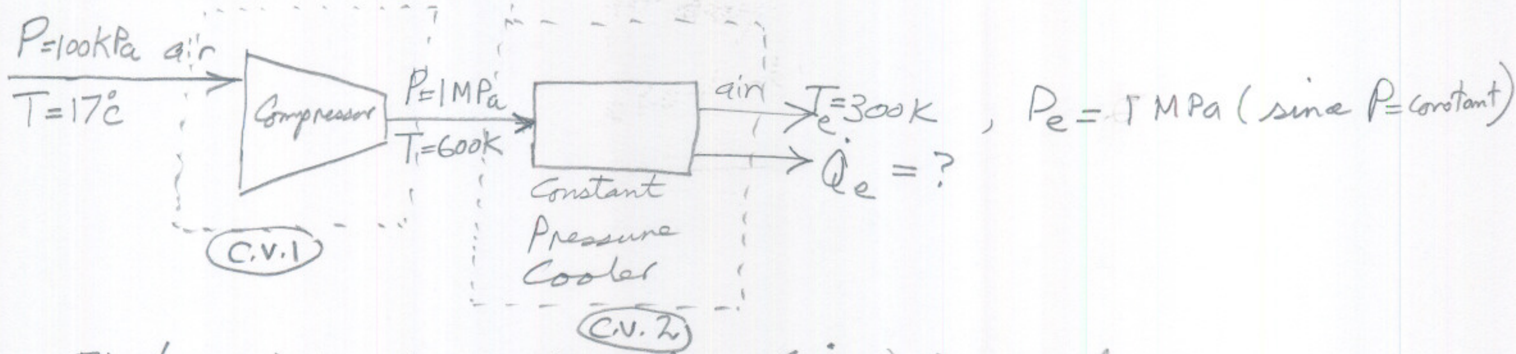
statment



Find specific heat transfer ($\dot{q}_e$) in cooler. and specific compressor work.

Assumption

- Compressor device $Q = 0$. i.e No loss or gain in heat energy.
- assume air is an ideal gas.
- steady state $\Rightarrow \frac{d}{dt}(E)_{cv} = 0$.

Laws

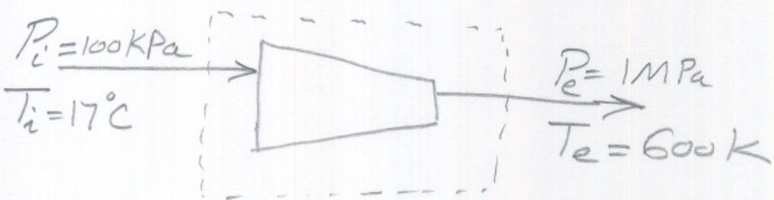
Law of thermodynamics for a control volume.

Continuity equation. $\boxed{\dot{m}_i = \dot{m}_e}$

table A.7 for air h lookup.

Steps for C.V.1

To find work done by compressor, consider it as its own control volume:



$$\cancel{\dot{Q}_{in}} + \dot{W}_{in} + \dot{m}_i(\cancel{KE}+\cancel{PE}+h)_i = \cancel{\dot{Q}_{out}} + \dot{W}_{out} + \dot{m}_e(\cancel{KE}+\cancel{PE}+h)_e + \underbrace{\cancel{\frac{d}{dt}(E)_{cv}}}_{=0}$$

so $(\dot{W}_{in} - \dot{W}_{out}) + \dot{m} h_i = \dot{m}_e h_e$

spcific work.

so $\frac{\Delta \dot{W}}{\dot{m}} = (h_e - h_i) \Rightarrow \boxed{\Delta w = h_e - h_i}$ —— (1)

→

now use relation $h = C_p T$ to find

h_e, h_i.

from table A.7 find h for air at each T.

<u>Numerical for first C.V.</u>

from A.7, $h_i = 290.43\ \text{KJ/Kg}$ (at $T = 290\text{K}$, which is $T = 17^\circ\text{C}$)

from A.7, $h_e = 607.32\ \text{KJ/Kg}$ (at $T = 600\text{K}$).

~~So from~~ (1)

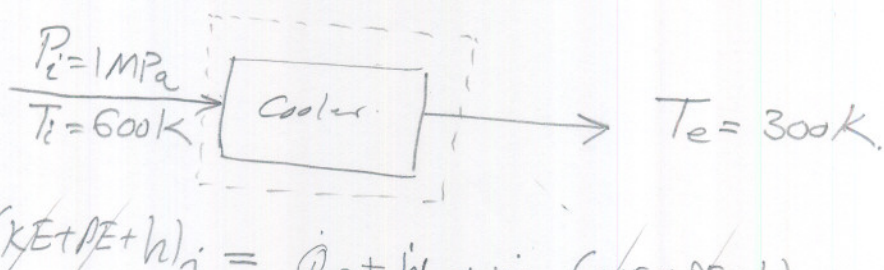
$$\Delta\dot{w} = h_e - h_i = 290.43 - 607.32$$

$$= \boxed{-316.89\ \text{KJ/Kg}}$$

since specific work is negative, then work is being put into the system.

~~steps for second C.V.~~

Now to find heat transfer, treat as a new problem, with Control volume for cooler only.



so $\dot{Q}_i + \dot{W}_i + \dot{m}_i(\cancel{KE} + \cancel{PE} + h)_i = \dot{Q}_e + \dot{W}_e + \dot{m}_e(\cancel{KE} + \cancel{PE} + h)_e + \frac{d}{dt}(E)_{cv}$.

for cooler, there is no work given or taken. so

$\dot{W}_i = \dot{W}_e = 0$

→

so for cooler equation becomes

$$(\dot{Q}_i - \dot{Q}_e) + \dot{m}_i h_i = \dot{m}_e h_e \quad , \quad \text{but } \dot{m}_i = \dot{m}_e = \dot{m}$$

so

$$\boxed{\Delta q = (h_e - h_i)} \quad \text{——— (2)}$$

now use table A.7 to find h_e, h_i for air at T_e, T_i. and solve for Δq.

<u>Numerical for second C.V.</u>

from Table A.7, $h_i = 300.47$ KJ/Kg. at $T = 300K$

$h_e = 607.32$ KJ/Kg at $T = 600K$.

So $\Delta q = 607.32 - 300.47 = \boxed{306.85 \text{ KJ/Kg}}$

Since result is positive, then heat is being input to the system (as would be expected, since this is a cooler!).

Problem 6.110

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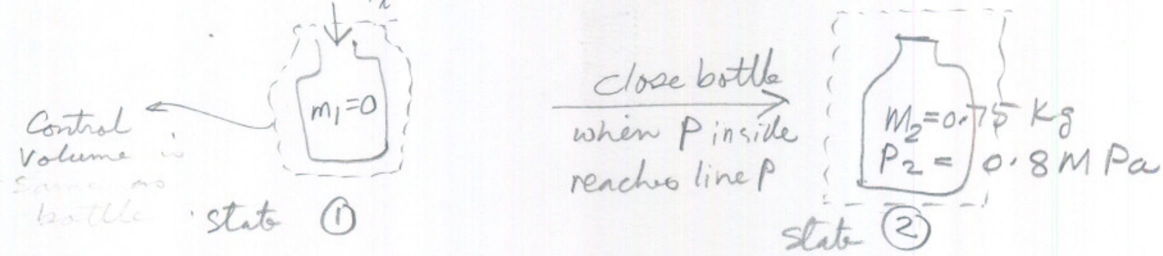
$T_i = 350°C$
$P_i = 0.8\ MPa$



Find final temp of water in bottle when closed and find volume of bottle.

Assumptions

ideal process.
transient process
adiabatic process. $q=0$

Laws

thermodynamic first law for control volume.

$v = \frac{V}{m}$

Steps

$$\cancel{\dot{Q}_{in}} + \cancel{\dot{W}_{in}} + \dot{m}_i (\cancel{KE}+\cancel{PE}+h)_i = \cancel{\dot{Q}_{out}} + \cancel{\dot{W}_{out}} + \cancel{\dot{m}_e}(KE+PE+h)_e + \frac{d}{dt}(E)_{cv}$$

but $\dot{m}_e = 0$ since water only flows in, no water flows out of C.V.

so $\dot{m}_i h_i = \frac{d}{dt}(E)_{cv}$

$$= \frac{d}{dt}(U + \cancel{KE} + \cancel{PE})_{cv}$$

so $\dot{m}_i h_i = \frac{d}{dt}(m_2 u_2 - m_1 u_1)$

but bottle started empty. so $m_1 = 0$.

and $m_i = m_2 \Rightarrow \cancel{\dot{m}_i} h_i = \cancel{\dot{m}_2} u_2 \Rightarrow \boxed{h_i = u_2}$ →

so we can find h_i from (T_i, P_i) and Tables.

so this gives u_2.

now since we are given P_2, we can find T_2 from (P_2, u_2) from Tables.

also can find v_2 from (P_2, T_2) using tables.

but $v = \frac{V}{m}$, so $\boxed{V = vm}$ and bottle volume is found.

Numerical

given $T_i = 350°C = 273.15 + 350 = 623.15\ K$

given $P_i = 0.8\ MPa$.

from B.1.1, we see that for $T = 350°c$, $P_{sat} = 16.514\ MPa$

so $P_{sat} > P_i$ so we have super heated vapor phase.

so use B.1.3.

at $P = 0.8\ MPa$, $T = 350°c$, $\Rightarrow \boxed{h_i = 3161.68\ KJ/Kg}$

so $\boxed{u_2 = 3161.68\ KJ/Kg}$

now given $(P_2 = 0.8 MPa, u_2 = 3161.68\ KJ/Kg)$ find T_2.

phase remain super heated since no change in pressure.

so use B.1.3, interpolate:

$T = 500°C$, $u = 3125.95\ KJ/Kg$.

$T = 600°C$, $u = 3297.91\ KJ/Kg$.

so $\frac{600 - 500}{3297.91 - 3125.95} = \frac{600 - T_2}{3297.91 - 3161.68} \Rightarrow \boxed{T_2 = 520.77°C}$

$\rightarrow$

now find v_2 from same table.

$T = 500\,°C \qquad v = 0.44331 \text{ m}^3/\text{kg}$

$T = 600\,°C \qquad v = 0.50184 \text{ m}^3/\text{kg}$

so $$\frac{600-500}{0.50184-0.44331} = \frac{600-520.77}{0.50184-v_2}$$

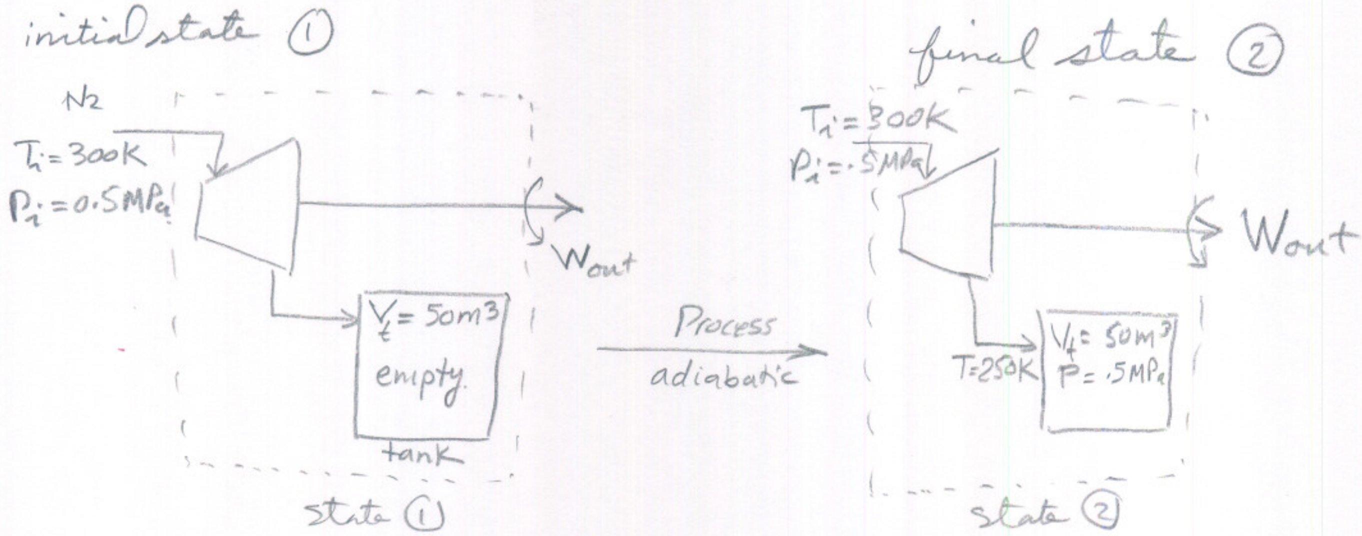
$$\Rightarrow \boxed{v_2 = 0.45546 \text{ m}^3/\text{kg}}$$

so $V = v_2 m = (0.45546 \text{ m}^3/\text{kg})(0.75 \text{ kg})$

$= \boxed{0.3416 \text{ m}^3}$

Problem 6.119 10/10

statment



in state ①, tank is empty. in second state,
$P_{tank} = P_i = 0.5 MPa$.
determine W_{out}.

Assumptions

process is adiabatic. so $Q_{in} = 0$, $Q_{out} = 0$
ideal process.
$m_e = 0$

Laws

First thermodynamics Law for C.V. transient process since there is change of energy inside C.V.
Tables B.6 for N_2; $v = \frac{V}{m}$

Steps

$$\cancel{Q_{in}} + \cancel{W_{in}} + m_i(\cancel{KE} + \cancel{PE} + h)_i = \cancel{Q_{out}} + W_{out} + \underbrace{\cancel{m_e(KE+PE+h)_e}}_{=0} + (E_2 - E_1)_{c.v.}$$

$$m_i h_i = W_{out} + (E_2 - E_1)_{c.v.}$$

$\longrightarrow$

but $(E_2 - E_1)_{c.v.} = m_2 u_2 - m_1 u_1$ (since KE, PE are zero).

so $m_i h_i = W_{out} + (m_2 u_2 - m_1 u_1)$.

since m_1 (mass inside C.V. in state 1) is zero, as we are told that tank is inittially empty.

so $\boxed{m_i h_i = W_{out} + m_2 u_2}$

now all mass entering C.V. went to tank. so

$\boxed{m_i = m_2.}$

so above equation becoms

$$\boxed{m_2 (h_i - u_2) = W_{out}} \quad \text{—— (1)}$$

h_i is found from (T_i, P_i) using B.6.2 table for N_2.
u_2 is found from (T_2, P_2), as well as v_2 from the table as well.

$$\boxed{m_2 = \frac{V_{tank}}{v_2}} \quad \text{—— (2).}$$

so (1) becomes

$$\boxed{\frac{V_{tank}}{v_2} (h_i - u_2) = W_{out}} \quad \text{—— (3)}$$

<u>Numerical</u>

from B.6.2, for $N_2 \Rightarrow P = 0.5\,MPa, T = 250\,K \Rightarrow u_2 = 183.9$ KJ/Kg.
$v_2 = 0.154$ m^3/Kg.

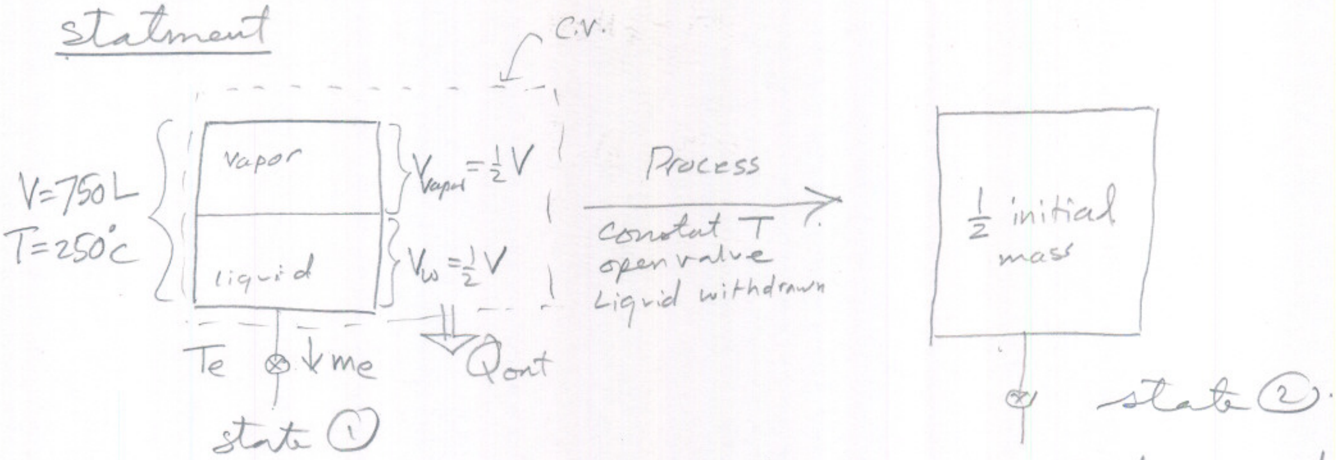
from B.6.2, for $N_2 \Rightarrow P = 0.5\,MPa, T = 300\,K \Rightarrow h = 310.3$ KJ/Kg.
$V_{tank} = 50\,m^3$.

so from (3) $W_{out} = \frac{50\,m^3}{0.154\,m^3/Kg} (310.3 - 183.9)\,KJ/Kg = 40{,}941$ KJ

$\approx \boxed{41\ MJ}$

Problem 6.122 10/10

statment



Find amount of heat transfer required to reach the state when half initial mass withdrawn.

Assumptions

ideal process.
transient process (not steady state inside C.V.)
slowly water is let out ⟹ KE for me = 0.
only water leaves tank, not vapor.

Laws

first Law of thermodynamics for Control volume.

$v = \frac{V}{m} \Rightarrow m = \frac{V}{v}$

$v = v_f + x(v_g - v_f)$, $x = \frac{v - v_f}{v_g - v_f}$

Steps

$$\cancel{Q_{in}} + \cancel{W_{in}} + \cancel{m_i}\,(\cancel{PE}+\cancel{KE}+h)_i = Q_{out} + \cancel{W_{out}} + m_e\,(\cancel{PE}+\cancel{KE}+h)_e + (E_2 - E_1)$$

$$0 = Q_{out} + m_e h_e + (m_2 u_2 - m_1 u_1)$$

but $m_2 = \frac{m_1}{2}$

so $$0 = Q_{out} + m_e h_e + m_1\left(\frac{u_2}{2} - u_1\right)$$

and $m_e = m_1 - m_2 = \frac{1}{2} m_1$

so $$0 = Q_{out} + \frac{1}{2} m_1 h_e + m_1\left(\frac{u_2}{2} - u_1\right) \longrightarrow$$

$$\boxed{0 = Q_{out} + m_1\left(\tfrac{1}{2}h_e + \tfrac{u_2}{2} - u_1\right)} \quad \text{— (1)}$$

So need to find m_1, h_e, u_1, u_2.

$$\boxed{m_1 = \frac{V_{water}}{v_{f_1}} + \frac{V_{vapor}}{v_{g_1}}} \quad \text{— (2)}$$

where v_{f_1}, v_{g_1} are from table B.1.1. at $T = 250°C$.

h_e from table B.1.1. at $T = 250°C$. take it as h_f since we assumed only water leaves tank.

$$\boxed{u_1 = u_{f_1} + x_1 (u_{g_1} - u_{f_1})} \quad \text{— (3)}$$

where u_f, u_g are from table B.1.1 at $T = 250°C$.

and $x_1 = \dfrac{v - v_f}{v_g - v_f}$; $v = \dfrac{V_{tank}}{m_1}$

now to find u_2. this is in state 2.

$u_2 = u_{f_2} + x_2 u_{g_2}$. now need to find x_2.

but in state 2, $m_2 = \dfrac{m_1}{2} \Rightarrow \boxed{v_2 = \dfrac{V_{tank}}{\frac{1}{2}m_1}}$

so since $v_2 = v_{f_2} + x_2 v_{g_2}$, where v_{f_2}, v_{g_2} are found from table B.1.1 at $T = 250°C$.

so $x_2 = \dfrac{v_2 - v_{f_2}}{v_{g_2}} = \dfrac{\frac{V_{tank}}{\frac{1}{2}m_1} - v_{f_2}}{v_{g_2}}$

so $\boxed{u_2 = u_{f_2} + x_2 u_{g_2}}$ — (4) . sub (3),(4),(2) into (1) gives Q

→

Numerical

from table B.1.1, at T = 250

$v_f = 0.001251 \ m^3/Kg.$ $\qquad h_e = h_f = 1085.34 \ KJ/Kg.$

$v_g = 0.05013 \ m^3/Kg.$

$u_f = 1080.37 \ KJ/Kg.$

$u_g = 2602.37 \ KJ/Kg.$

from eq (2), $m_1 = \dfrac{V_{water}}{v_{f_1}} + \dfrac{V_{vapor}}{v_{g_1}} = \dfrac{\frac{1}{2}V_{tank}}{v_{f_1}} + \dfrac{\frac{1}{2}V_{tank}}{v_{g_1}}$

$$= \frac{\frac{1}{2}(750\times10^{-3}\ m^3)}{0.001251} + \frac{\frac{1}{2}(750\times10^{-3}\ m^3)}{0.05013} = \boxed{307.24\ Kg}$$

from (3), $u_1 = u_{f_1} + x\,(u_{g_1} - u_{f_1})$

$$= 1080.37\times10^3 + \left(\frac{\frac{750\times10^{-3}}{307.24} - 0.001251}{0.05013 - 0.001251}\right)(2602.37 - 1080.37)\times10^3$$

$= 1117427.1 \ J/Kg.$

from (4) $u_2 = u_f + x_2(u_{g_2} - u_{f_2})$

$$u_2 = 1080.37\times10^3 + \left(\frac{\frac{V_{tank}}{\frac{1}{2}m_1} - v_f}{v_{g_2}}\right) 2602.37\times10^3$$

$$= 1080.37\times10^3 + \left(\frac{\frac{750\times10^{-3}}{\frac{1}{2}\,307.24} - 0.001251}{0.05013}\right)(2602.37\times10^3 - 1080.37\times10^3)$$

$= 1190616.3 \ J/Ks.$

so from (1) $-Q_{out} = m_1\left(\frac{1}{2}h_e + \frac{u_2}{2} - u_1\right) = 307.24\left(\frac{1}{2}1085.34\times10^3 + \frac{1}{2}1190616.3 - 1117427.1\right)$

$= 6314104.6 \ J$

so $\boxed{Q_{out} \cong -6314\ KJ}$ since Q is −ve, this means it Leaves the system.