CO$_2$ molecules
@ 17°C
@ 5 kPa

C.V.
$V = 0.5\,m^3$
$M = 44 \frac{kg}{kmol}$

$$m = ? = \frac{pV}{RT} = \frac{5\cdot 10^3 [Pa] \cdot 0.5 [m^3]}{\frac{8.314\cdot 10^3 \left[\frac{J}{kmol\,K}\right]}{44 \left[\frac{kg}{kmol}\right]} \cdot 290 [K]} = \underline{0.046\,kg}$$

NOTE: T $\underline{\text{must}}$ be an absolute temperature unit!

STATE ① $V = 0.5\,m^3$, $M = 44 \frac{kg}{kmol}$ ($CO_2$), $T_1 = 17°C$, $p_1 = 5\cdot 10^3\,Pa$

STATE ② $V = const \therefore V_2 = V_1$ $\quad T_2 = 117°C = 117 + 273 = 390\,K$

$$pV = mRT \therefore \quad m = const = \frac{pV}{RT} = \frac{p_1 V_1}{RT_1} = \frac{p_2 V_2}{RT_2} \therefore \quad p_2 = p_1 \frac{T_2}{T_1} = 5\cdot 10^3 [Pa] \left(\frac{390 [K]}{290 [K]}\right)$$

$$p_2 = 6.7\,kPa$$

$\Delta s = ?$

$$T ds = du + p dv = c_v dT + p dv \quad \therefore \quad ds = c_v \frac{dT}{T} + \frac{p}{T} dv \qquad pv = RT$$

$$T ds = dh - v dp = c_p dT - v dp \qquad ds = c_p \frac{dT}{T} - \frac{v}{T} dp \qquad \frac{p}{T} = \frac{R}{v}$$

Therefore:

$$ds = c_v \frac{dT}{T} + R \frac{dv}{v} \qquad \frac{v}{T} = \frac{R}{p}$$

$$\int ds = \Delta s = s_2 - s_1 = \int_1^2 c_v \frac{dT}{T} + R \int_1^2 \frac{dv}{v}$$

$$\Delta s = c_v \ln \frac{T_2}{T_1} + R \ln \frac{v_2}{v_1}$$

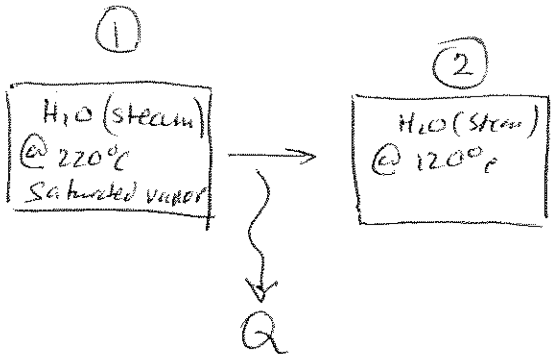
Also

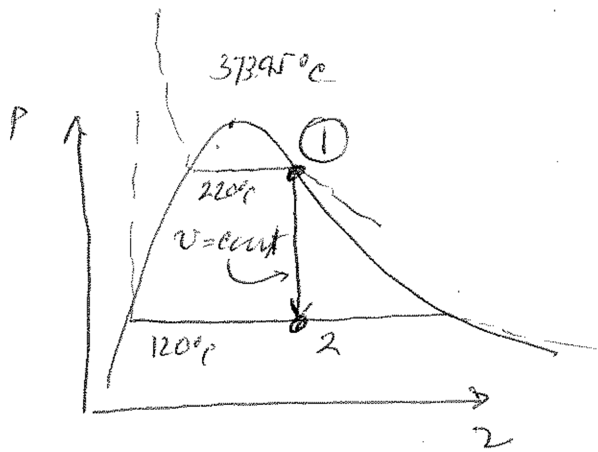
$$\Delta s = \int c_p \frac{dT}{T} - R \ln \frac{p_2}{p_1} = c_p \ln \frac{T_2}{T_1} - R \ln \frac{p_2}{p_1}$$

Since $v_2 = v_1 \therefore \frac{v_2}{v_1} = 1$ $\quad \ln(1) = 0 \therefore \quad \Delta s = c_v \ln \frac{T_2}{T_1}$

$c_v = 0.652 \cdot 10^3 \frac{J}{kgK}$ $\qquad \Delta s = 0.657 \ln \frac{390}{290} = \underline{0.20 \cdot 10^3 \frac{J}{kg}}$

P2




$\Delta u = q - w = u_2 - u_1$

$u_1$ @ saturation line @ 220°C — DEFINED STATE $\therefore u_1 = 2602.4 \cdot 10^3 \frac{J}{kg}$

$u_2$ @ 120°C but p does not define with T the state, $u_2 = ?$

$u_2 = u_f + x(u_g - u_f) = u_f + x(u_{fg})$

known $u_f = u$ (saturated Liquid @ 120°C) $= 503.5 \frac{kJ}{kg}$

$u_{fg} = 2025.8 \frac{kJ}{kg}$

$u_g = 2529.3 \cdot 10^3 \frac{J}{kg}$

BUT $x_2 = ?!$

How to find $x_2$!

NOTE $v_2 = v_1$ $\quad v_2 = v_{2f} + x_2 v_{fg}$

@ saturated vapor Line

$v_2 = v_1 = 0.0861 \frac{m^3}{kg}$

$v_{2f} = 0.00106 \ m^3/kg$

$v_g = 0.8919 \ m^3/kg$

$$x_2 = \frac{v_2 - v_{2f}}{v_{fg}} = \frac{v_2 - v_{2f}}{v_g - v_f} = \frac{0.0861 - 0.00106}{0.8919 - 0.00106} = 0.0956$$

so

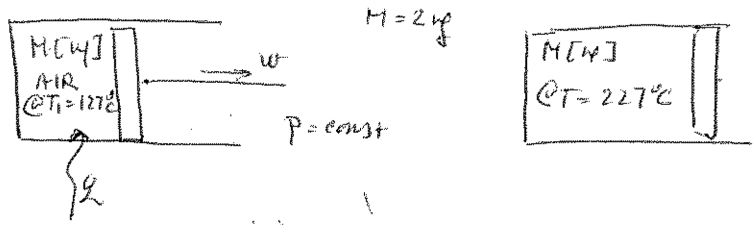
$u_2 = u_{f2} + x_2 u_{fg} = 503.5 \frac{kJ}{kg} + 0.0956 \cdot 2025.8 \frac{kJ}{kg}$

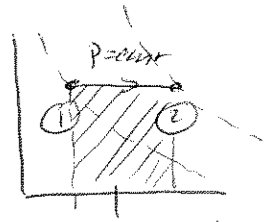
$u_2 = 697 \cdot 10^3 \frac{J}{kg}$

$q = \Delta u = u_2 - u_1 = (697 - 2602.4) \cdot 10^3 \frac{J}{kg} = -1905 \cdot 10^3 \frac{J}{kg}$

NOTE $q < 0$ (convention: heat is removed ∴ so, the result is logical

# P3




$$\int dw = \int p\,dv = p\int dv = p(v_2 - v_1) \qquad p = \text{const}$$

BUT $T \uparrow \therefore Q$ must be added as well !!

$$du = dq - dw$$

$$dq = du + dw$$

for reversible "quasistatic" change of state

$$dw = p\,dv$$

$$dq = du + p\,dv \qquad \text{if } p \text{ const}$$

$$q = \int dq = \int du + \int p\,dv = u_2 - u_1 + p(v_2 - v_1)$$

$$q = (u_2 + p v_2) - (u_1 + p v_1) = (u_2 + p_2 v_2) - (u_1 + p_1 v_1)$$

NOTE $p_1 = p_2 = p$

$$q = h_2 - h_1 \qquad \text{because } h \triangleq u + pv \quad (\triangleq \text{ by definition})$$

$$dh = c_p\,dT$$

$$\Delta h = \int dh = h_2 - h_1 = \int c_p\,dT = c_p \int_1^2 dT = c_p(T_2 - T_1)$$

$c_p = \text{const}$ (AIR I.G.)

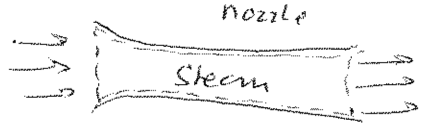
$$q = c_p(T_2 - T_1)$$

$$Q = m c_p (T_2 - T_1)$$

$$Q = 2\,[kg] \cdot 1\left[\frac{kJ}{kg\,K}\right](500 - 400)\,[K]$$

$$Q = 200\ kJ$$

P4




$P_1 = 0.4\,MPa$

$T_1 = 300°C$

$V_1$ - velocity "small"

i.e., $V_1 \ll V_2$ !

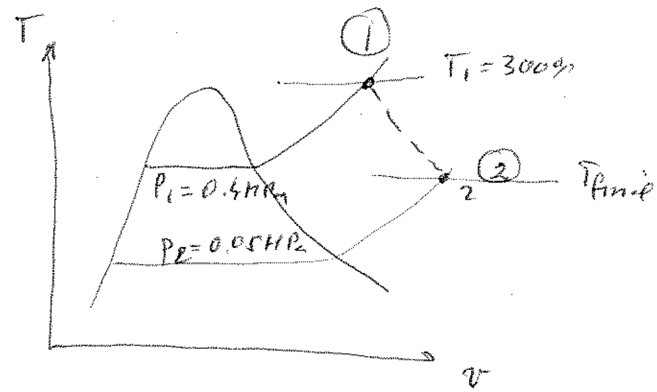
$P_2 = 0.05\,MPa$

Velocity $V_2 = 300\,m/s$

$h_2 = ??$

$\downarrow \vec{g}$

$\uparrow z_1 = z_2$




$P_1\,(P = 0.4\,MPa,\ T = 300°C)$

from steam tables

$h_1 = 3066.8\,\frac{kJ}{kg}$ @ $P_1, T_1$

Conservation of energy - OPEN SYSTEM !

$$\sum \dot{E}_i = \dot{H}_{1,in} - \dot{H}_{2,out} + \cancel{\dot{Q}_{in}}^{\,0} - \cancel{\dot{W}_{out}}^{\,0} = 0$$

$\dot{Q}_{in/out} = 0$ adiabatic

$\dot{W} = 0$ no work performed

$$\dot{H}_{1,in} = \dot{m}_1\left(h_1 + \underbrace{\cancel{\frac{V_1^2}{2}}}_{0} + \cancel{gz_1}^{\,z}\right) \rightarrow$$

$$\dot{H}_{2,out} = \dot{m}_1\left(h_2 + \underbrace{\frac{V_2^2}{2}}_{\neq 0} + \cancel{gz_2}^{\,z}\right)$$

$|g(z_1 - z_2)| \cong 0$

$\Delta$ potential energy $\sim 0$

CONSERVATION of MASS

$\sum \dot{m}_i = \dot{m}_1 - \dot{m}_2 = 0!$

$\dot{m}_1 = \dot{m}_2$

Therefore

$$h_2 = h_1 - \frac{V_2^2}{2}$$

$$h_2 = 3066.8\,\frac{kJ}{kg} - \left(\frac{300^2}{2}\right)\frac{m^2}{s^2}$$

NOTE: $J = N.m$

$$h_2 = 3021.8\,\frac{kJ}{kg}$$

$\frac{m^2}{s^2} = \frac{Nm}{kg} \ldots \frac{J}{kg}$