PROBLEM 3

a) energy balance on a mass of water traveling from tank to kettle (system is 200 ml of water)

$$\Delta E = \cancel{Q} - \cancel{W} = 0$$

4 CV
3 1st law
2 properties
1 final answer

$$(E = U + KE + PE)$$

so $\Delta E = \Delta U + \cancel{\Delta KE} + \Delta PE = 0$

(zero velocity in tank & in kettle)

$$= m\left[c(T_2 - T_1) + g(\cancel{z_2} - z_1)\right]$$ ($\Delta U = mc\Delta T$ for inc. substance with const c)

$z_1 = h$

$$\therefore \boxed{T_2 = T_1 + \frac{g}{c}h} = \underline{\underline{25.09\,°C}}$$ (ie. very small change!)

(Closed system: 200ml of H_2O traveling from tank to kettle)

b) $E_{x2} - E_{x1} = \cancel{E_{xq}} - \cancel{E_{xW}} - E_{xd}$ (adiab., no work)

4 CV
4 Exergy balance
2 Properties

$$\Rightarrow E_{xd} = E_{x1} - E_{x2} = U_1 - U_2 + P_0(\cancel{V_1 - V_2}) - T_0(S_1 - S_2) + mg(z_1 - z_2) + \cancel{\Delta KE}^{0}$$

$(V_1 = V_2)$

$$= m\left[c(T_1 - T_2) - T_0\, c \ln\left(\frac{T_1}{T_2}\right) + gh\right]$$

($\Delta S = c \ln \frac{T_2}{T_1}$ for inc. substance with const c)

but $c(T_1 - T_2) = -gh$ from part (a) above

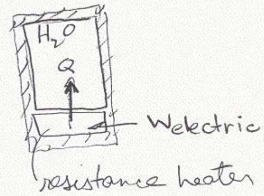
$$\Rightarrow E_{xd} = -mT_0 c \ln\left(\frac{T_1}{T_2}\right) = -mT_0 c \ln\left(\frac{T_0}{T_0 + \frac{g}{c}h}\right) = \underline{\underline{0.075\,kJ}}$$

c) energy balance on water + resistance heater

system: heater + water

$$\Delta E = \Delta E_{water} + \Delta E_{heater} = \not{Q} - W$$ (adiabatic)

5 CV
5 1^{st} law



$$= m_{water} \Delta U_{water} + \not{m}_{heater} \Delta u_{heater} = -W_{ele}$$ (neg.)

$\therefore$ $-W_{elec} = \Delta E_{water}$

100% of electric energy is converted to heat.

d) exergy change of water

$$\Delta E_{x\,water} = \Delta U - T_0 \Delta S + P_0 \not{\Delta V}$$ (incomp.)

6 Δ exergy of water
3 exergy of electricity
1 final answer

$$= m_{water} \left[c(T_2 - T_1) - T_0 c \ln\left(\frac{T_2}{T_1}\right) \right]$$

$$= \underline{\underline{5.96 \text{ KJ}}}$$

exergy input as electric work is $\Delta E_{water} = m c \Delta T$

$= 58.52$

fraction: $\frac{5.96}{58.52} = \underline{\underline{0.102}}$ (~ only 10% of input exergy end up in water!

e) exergy destroyed for filling process:

1 filling
6 ΔE_x water
1 E_{xd}
2 comparison

$$E_{xd_I} = -m T_0 c \ln\left(\frac{T_0}{T_0 + \frac{g}{c} h}\right) = \underline{\underline{0.075 \text{ KJ}}}$$

for heating process: (CV is kettle with water)

$$\Delta E_x = \not{E}_{xq} - E_{xW} - E_{xd}$$

$\Delta E_x = \Delta E_x$ water since mass of heater is neg.

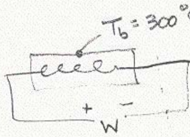
$E_{xW} = -58.52$ KJ from (d) (in is negative!)

$\Rightarrow E_{xd} = 58.52 - 5.96 = \underline{\underline{52.56 \text{ KJ}}}$ (much greater than filling)

f) exergy destroyed in heater

4 CV
4 ΔE_x
1 E_{xd}
1 final

CV: heater



since m=0: $\Delta E_x = 0$

$$\Delta E_x = Q\left(1 - \frac{T_0}{T_b}\right) - W - E_{xd} \quad = \underline{\underline{30.4 \text{ KJ}}}$$

Q: −58.5 KJ (Q_{out} is negative); T_b: 573 K; W: −58.5 KJ (W_{in} is negative)

exergy destroyed in the heat transfer to water is the remainder of E_{xd} calculated in (d):

$$E_{xd,\text{ heat xfer}} = 52.56 - 30.4 = \underline{\underline{22.1}} \text{ KJ}$$

OR with CV = water:

$$\Delta E_x = Q\left(1 - \frac{T_0}{T_b}\right) - E_{xd} \quad \Rightarrow \quad E_{xd} = \underline{\underline{22.1 \text{ KJ}}}$$

ΔE_x: 5.96; Q: 58.5; T_b: 573 K