

HW2: 39610- Energy Generation and Supply

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Q1]

Data Given:

Velocity	v	100	ft/s
Height	h	200	ft
Mass	m	50	lb
Acceleration due to gravity	g	32	ft/s ²
Work done on the system	W	300	BTU
Net Heat transfer from the system	Q		BTU

Calculations:

$$KE = \frac{1}{2}mv^2 = 0.5 * 50 * 100^2 = 250000 \text{ lb} * \left(\frac{\text{ft}}{\text{s}}\right)^2$$

$$PE = mgh = 50 * 32 * 200 = 320000 \text{ lb} * \left(\frac{\text{ft}}{\text{s}}\right)^2$$

Converting KE, PE to BTU with the following conversion units:

1 lbf	32.2 lb.ft/s ²
1 BTU	778 ft.lbf
1 BTU	25051.6 lb.ft ² /s ²
3.99176E-05 BTU	1 lb.ft ² /s ²

Thus:

$$KE = 9.979 \text{ BTU}$$

$$PE = 12.77 \text{ BTU}$$

Q = -50 BTU (As energy is transferred from the system to the surroundings)

W = -300 BTU (As work is done on the system)

Using Energy Balance:

$$\Delta KE + \Delta PE + \Delta U = Q - W$$

$$\Delta U = Q - W - \Delta KE - \Delta PE$$

Substituting:

$$\Delta U = -50 - (-300) - 9.98 - 12.77$$

$$\Delta U = 227.25 \text{ BTU}$$

Q2]

Data:

Net work output	600 kJ
Energy input by heat transfer	1200 kJ
Hot gas temperature	600 K
Atmospheric temperature	300 K

Calculations:

$$\eta_{HE} = \frac{W_{out}}{Q_H} = \frac{600}{1200} = \mathbf{0.5}$$

$$\eta_{max} = 1 - \frac{T_c}{T_H} = 1 - \frac{300}{600} = \mathbf{0.5}$$

The inventor has to be working in ideal conditions as the actual efficiency equals the maximum efficiency possible.

Q3]

Data:

Q_c	12000	kJ/hr
W_{cycle}	5400	kJ/hr
T_{high}	294.15	K
T_{low}	255.15	K

Calculations:

a)

$$COP_{refrigerator} = \frac{Q_c}{W_{cycle}} = \frac{5400}{12000}$$

$$\text{Thus, } COP_{refrigerator} = \mathbf{2.222}$$

b)

$$COP_{maximum} = \frac{Q_c}{Q_h - Q_c} = \frac{T_c}{T_h - T_c} = \frac{255.15}{294.15 - 255.15}$$

$$COP_{maximum} = \mathbf{6.542}$$

c)

$$\text{Figure of Merit, } F = \frac{COP_{refrigerator}}{COP_{maximum}}$$

$$F = \frac{2.222}{6.542} = \mathbf{0.339}$$

Q4]

Radiation rate	0.18	kW/m ²
Solar collector temperature	590	K
Electricity generation	300	kW
Surrounding temperature	290.15	K

Calculations:

$$\text{Efficiency, } \eta = 1 - \frac{T_{\text{surrounding}}}{T_{\text{collector}}}$$

$$\text{Thus, } \eta = 1 - \frac{290.15}{590} = 0.508$$

For steady state:

When the efficiency of the solar collector is maximum, the area required would be minimum.

Energy from radiation = Electricity generated

Let A be the area of the solar collector

$$\text{Thus, } \text{rate}_{\text{radiation}} * \eta * A = \text{Electricity}_{\text{gen}}$$

$$A = \frac{\text{Electricity}_{\text{gen}}}{\text{rate}_{\text{radiation}} * \eta} = \frac{300}{0.18 * 0.508}$$

$$\text{Minimum area: } A = 3279.42 \text{ m}^2$$

Q5]

Rated capacity of heat pump	66900	Btu/h
COP	3.8	
Cost of power	0.109	\$/kWh
Time of operation	270	hr

Calculations:

a) Energy usage of the system, E:

$$COP = \frac{\text{Energy}_{\text{out}}}{\text{Energy}_{\text{in}}} = \frac{\text{Rated capacity}}{\text{Energy input}}$$

$$E = 66900 / 3.8 = 17605.26 \frac{\text{BTU}}{\text{h}}$$

$$\text{And: } 1 \text{ BTU} = 2.93 * 10^{-4} \text{ kWh}^1$$

$$E = 5.16 \text{ kW}$$

¹ https://www.rapidtables.com/convert/energy/BTU_to_kWh.html

b)

Cost of electricity in a month= (Cost per kWh) *(Number of hours used) * (Energy usage in kW)

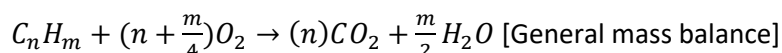
The cost of operating the pump is 0.109 \$/kWh and is operated for 270 hours with a capacity of 5.16kW

$$Cost = 0.109 \frac{\$}{kWh} * 270 \frac{h}{month} * 5.16 kW$$

$$Cost = 151.85 \$/month$$

Q6]

Energy released per kg of CO₂ is calculated by the following method for a general fuel:



Based on this mole balance equation, the amount of energy per kg of CO₂ is tabulated.

Reactions are:

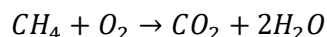
- $C_4 H_{10} + 6.5 O_2 \rightarrow 4 CO_2 + 5 H_2 O$
- $CH_2 O + 1.5 O_2 \rightarrow CO_2 + H_2 O$
- $C_8 H_{18} + 12.5 O_2 \rightarrow 8 CO_2 + 9 H_2 O$
- $C + O_2 \rightarrow CO_2$

The calculations are thus tabulated

Compound	Energy (MJ/kg)	Molecular Weight (g)	Moles (mol/kg)	No. of CO ₂ equivalents	Number of moles of CO ₂ released	Mass of CO ₂ released (kg)	Energy released per kg of CO ₂
Butane	50	58.12	17.20578	4	68.82312	3.028217	16.51136
Wood	10	30.031	33.29892	1	33.29892	1.465153	6.825227
Gasoline	50	114.23	8.754268	8	70.03414	3.081502	16.22585
Coal	30	12	83.33333	1	83.33333	3.666667	8.181818

(e) Based on this, the least amount of energy per kg of CO₂ is released by **wood**.

Q7]



For the combustion of CH₄ in presence of pure oxygen, the adiabatic flame temperature is calculated as follows:

Data:

C_p of CO ₂	57.3 J/mol/K
C_p of H ₂ O	46.1 J/mol/K
Enthalpy of rxn	-802.2 kJ/mol

In this case, 0.75 moles of CH₄ undergo combustion. Thus, in this case:

Heat from enthalpy (J) = -Heat released from products

Thus,

$$LHS = 0.75 \text{ mol} * -802.2 \frac{\text{kJ}}{\text{mol}} = -601.65 \text{ kJ}$$

Moles formed: CO₂: 0.75, H₂O: 1.5

$$RHS = 0.75 \text{ mol} * 57.3 \frac{\text{J}}{\text{mol} * \text{K}} * \Delta T (\text{K}) + 1.5 \text{ mol} * 46.1 \frac{\text{J}}{\text{mol} * \text{K}} * \Delta T (\text{K})$$

Units of RHS are in J

Equating LHS=RHS

$$-601.65 * 10^3 = (0.75 * 57.3 + 1.5 * 46.1) \Delta T$$

$$\Delta T = \frac{601650}{112.125} = 5365.87 \text{ K}$$

$$T_{ad} - T_{ref} = \Delta T$$

We are given that: $T_{ref} = 298 \text{ K}$

$$\text{Thus: } T_{adiabatic} = 298 + 5365.87 = 5663.87 \text{ K}$$

Adiabatic Flame temperature is 5663.87 K