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/s2
Work done on the system	W	300	BTU
Net Heat transfer from the system	Q		BTU

Calculations:

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

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

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 BTU

PE= 12.77 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:

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

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

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)

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

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)

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

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

Q4]

Radiation rate	0.18	kW/m2
Solar collector temperature	590	K
Electricity generation	300	kW
Surrounding temperature	290.15	K

Calculations:

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

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

Thus, $rate_{radiation} * \eta * A = Electricity_{gen}$

$A = \frac{Electricity_{gen}}{rate_{radiation} * \eta} = \frac{300}{0.18 * 0.508}$

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

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:

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

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

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

$\boldsymbol{E = 5.16\ kW}$

[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 CO_2 is calculated by the following method for a general fuel:

$C_nH_m + (n + \frac{m}{4})O_2 \rightarrow (n)CO_2 + \frac{m}{2}H_2O$ [General mass balance]

Based on this mole balance equation, the amount of energy per kg of CO_2 is tabulated.

Reactions are:

a. $C_4H_{10} + 6.5O_2 \rightarrow 4CO_2 + 5H_2O$
b. $CH_2O + 1.5O_2 \rightarrow CO_2 + H_2O$
c. $C_8H_{18} + 12.5O_2 \rightarrow 8CO_2 + 9H_2O$
d. $C + O_2 \rightarrow CO_2$

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 CO_2 is released by **wood**.

Q7]

$$CH_4 + O_2 \rightarrow CO_2 + 2H_2O$$

For the combustion of CH_4 in presence of pure oxygen, the adiabatic flame temperature is calculated as follows:

Data:

$C_p of\ CO_2$	57.3 J/mol/K
$C_p of\ H_2O$	46.1 J/mol/K
Enthalpy of rxn	-802.2 kJ/mol

In this case, 0.75 moles of CH_4 undergo combustion. Thus, in this case:

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

Thus,

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

Moles formed: CO_2: 0.75, H_2O: 1.5

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

Units of RHS are in J

Equating LHS=RHS

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

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

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

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

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

Adiabatic Flame temperature is 5663.87 K