Lecture 11

April 27, 2012

Some occasionally used special energy units

Toe Tonne equivalent of energy obtained by burning 1 metric tonne of a standard crude. 1000 MToe= 40 Quads	1 Toe	41.87 Giga Joule or 40 x10^6 BTU
Therm Unit used e.g. in power and utilities bills for homes.	1 Therm	10^5 BTU = 29.3 KWh

PG&E Bills

Electricity Usage (March 2012)= 489 Kwh (16/day) Charges: $92.47 (@) $.185 / Kwh

Gas charges = 93 Therms (3/day) Charges: $110.19 @$1. 18/Therm

If we calculate cost of one therm after converting to electricity charges:

$$1\ Therm\ cost\ = 29.3(KWh) \times\ .185\ (Dollar/KWh)\times = 5.4\ Dollars$$

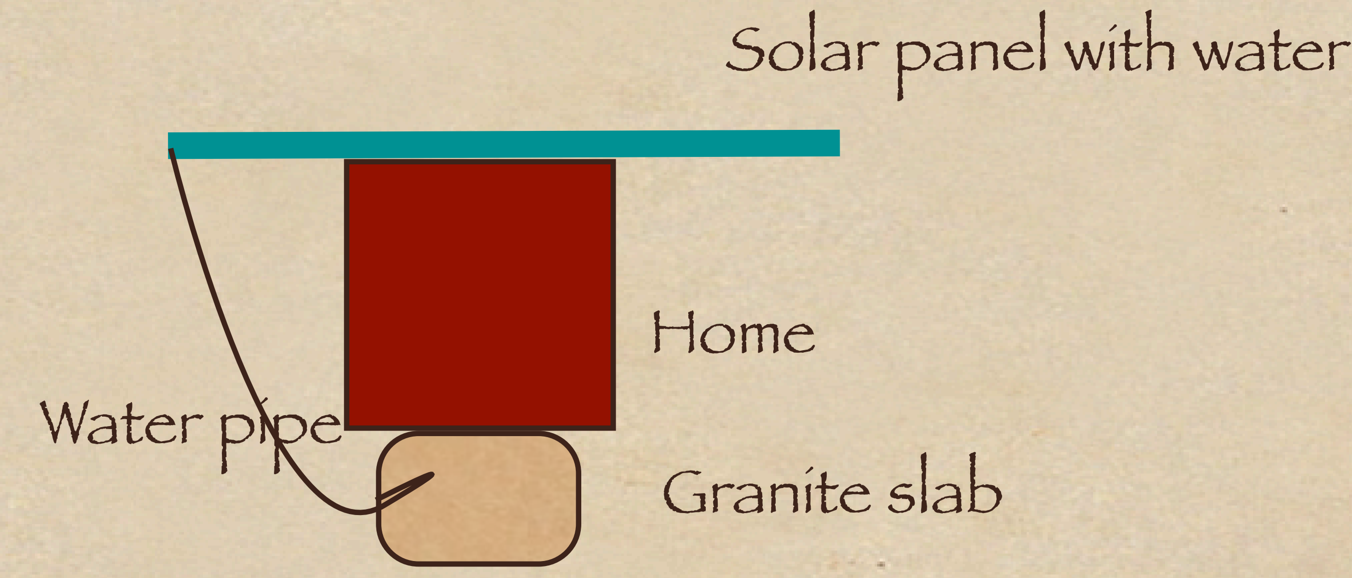
Compared to 1.18 $/Therm for gas itself.

Question:
How many KWh electricity per day do you consume?
And how many therms gas?

A few instructive problems on material so far:

A Heat Storage device from Granite

When water in panel reaches 50°C, pump it through rock at bottom.



Problem: How big should the granite slab be, so that it can store enough energy to heat the house for a whole month?

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Assume house is maintained at 15°C (= 59°F).

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To solve this design issue we will equate the energy need to the energy capacity of granite in broad terms. In details this goes as follows:

1) Energy need:

Since we need energy for a month, the total needed is found by taking the rate (24 KWh/day) times 30 days= 720 KWh

This is expressible in Joules by looking up 1 KWh= 3.6×10^6 J.
(This can also be found from the definitions: 1 KWh= 1000W/Hour and since1 Hour = 3600 Secs, 1KWh= 1000x3600x Joule=3.6×10^6 J
(recall 1 Joule= 1 Watt x1 Second)).

Thus energy requirement ΔE= 720 KWh x 3.6×10^6 Joules/KWg=2.592×10^9J

2) Storage calculation from specific heat.

$$\Delta Q = c\, m\, \Delta T$$

m= (unknown) mass of granite,
c its specific heat=820 J/kG/K

Heat stored in the rock is found from the usual formula. We need to know the temperature difference. Since the home is at 15^{0}C, the granite block is also at that temperature. The hot water is at 50^{0}C, so that the temperature difference corresponding to the heating of the granite block is 35^0 C.

$$\Delta Q = 820J/(kG \times^0 K) \times m(kG) \times (35 \times^0 K) = 2.87 \times 10^4 \times m\ (Joules)$$

Here m is in kG's.

We now equate the storage with the requirement

ΔQ=ΔE

$$(2.87 \times 10^4 \times m(kG))\ (Joules) = (2.592 \times 10^9)\ (Joules)$$

Solving for m we get:

$$m = [2.592 \times 10^9]/[2.87 \times 10^4\ ] = 9.03 \times 10^4 (kG)$$

Since density ρ = m/V, we can find V given the density of granite using V=m/ρ

$$\rho = 2750 kG/m^3$$

$$V = 36m^3 = 6 \times 6 \times 1m^3$$

Answer: Granite slab is appxly 18ft x18ft x3 ft

A coal burning power plant burns coal at 706 ^{0}C and exhausts heat into a river with average temperature 19 ^{0}C. What is the minimum possible rate of thermal pollution (i.e. heat exhausted into the river) if the station generates 125 MW of electricity?

In solving this problem, a few simple ideas are at play.

We notice that we are given the power rating (i.e. rate of energy production) of the plant, rather than the energy produced by itself. The required answer also asks for the rate of thermal pollution.

So the question is can we write the efficiency also in terms of the rates of energy or heat.

The answer is yes. To see further assuming a Carnot machine, this let us assume a unit of time Δt . To fix ideas we can say that Δt = 1 day, but the final answer does not depend upon this choice.

Therefore within the time interval of Δt,
we will write
the heat absorbed from the coal burning as ΔQ_H , (hence the rate of absorption is $\Delta Q_H / \Delta t$)
the heat rejected into the river as ΔQ_L (hence the rate of rejection is $\Delta Q_L / \Delta t$)
and the energy output as ΔE. (power output is $\Delta E / \Delta t$)
If we double Δt, these energies will also double, and that is why the value of Δt is finally immaterial.
Let us now express the Carnot efficiency:

$$\eta = \frac{\Delta Q_H - \Delta Q_L}{\Delta Q_H} \text{ or}$$

$$\eta = \frac{(\Delta Q_H / \Delta t) - (\Delta Q_L / \Delta t)}{(\Delta Q_H / \Delta t)}$$

Thus we can express the efficiency in terms of the rates as well. Solving this we get:

$$(\Delta Q_L / \Delta t) = (\Delta Q_H / \Delta t) \times (1 - \eta)$$

The first calculation we need to do is to figure the efficiency of this engine. Since the operating temperatures (T_H, T_L) are given as

$$T_H = 706^0\ C = 979^0\ K$$

$$T_L = 19^0\ C = 292^0\ K$$

$$\eta = \frac{T_H - T_L}{T_H} = 0.702$$

Now we saw on the last page that

$$(\Delta Q_L/\Delta t) = (\Delta Q_H/\Delta t) \times (1 - \eta)$$

From the first law (energy conservation) we also get

$$\Delta E/\Delta t = (\Delta Q_H - \Delta Q_L)/\Delta t$$

We can eliminate ΔQ_H in favor of ΔQ_L and η to obtain:

$$\Delta Q_L/\Delta t = (1 - \eta)/\eta \times \Delta E/\Delta t$$

Since the power station produces power at the rate of 125 MW, we infer that $\Delta E/\Delta t$ = 125 MJ/Δt. Substituting we get

Therefore $\Delta Q_L/\Delta t = \Delta E/\Delta t\ (1-\eta)/ = 53.1$ MJ/Δt.

This is the amount of heat discharged by the plant, in a time interval Δt, and hence the rate of pollution is 53.1 MW.

2. A jeweller needs to melt a .5 kg block of silver at 20 °C, in order to pour into her molds. How much heat is needed to achieve this in kJ?

We view this in two stages:

First stage is to heat silver to its melting temperature T_M= 960.8 °C from 20°C, using the known heat capacity of silver C= .235 kJ/kg °C,

Second stage to melt it using the latent heat of fusion (melting) 88.3 kJ/kg.

Then add these

$$\Delta Q_{Heating} = C\ m\ \Delta T \qquad \Delta Q_{melting} = L_{melting}\ m$$

$$\Delta Q = \Delta Q_{Heating} + \Delta Q_{Melting}$$

Plugging in the various values, we find in units of kilo Joules

Q= 0.5 kg x 88.3 kJ/kg + .235 kJ/(kG °C) x 0.5 kg x 940.8°C = 155 kJ.