# Lecture 8

April 21, 2011

## Chapter III of RK

## Heat Engines

1st Law of Thermodynamics:

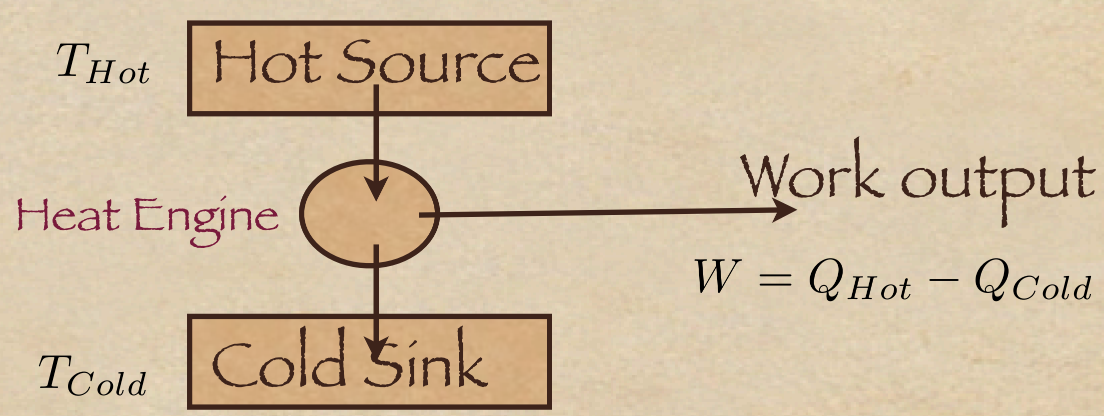
Heat and Work are on the same footing

$$\Delta U = \Delta Q + \Delta W$$

Converting heat into useful work is only possible in a "Lossy" fashion- we lose some heat to unwanted waste.

$$\text{Efficiency} = \frac{\text{Work done}}{\text{energy put into system}} \times 100\%$$

$$\text{Efficiency} = \frac{Q_{Hot} - Q_{Cold}}{Q_{Hot}} \times 100\%$$




$$\text{Efficiency(Carnot)} = \frac{T_{Hot} - T_{Cold}}{T_{Hot}} \times 100\%$$

# Heat Pump≈Refrigerator
# ≈ Heat Engine Run backwards

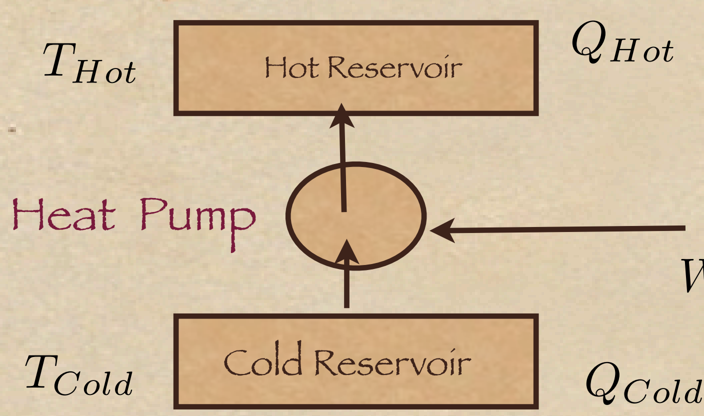
## Coefficient of Performance:

$$COP = \frac{Q_{Hot}}{Q_{Hot} - Q_{Cold}} \times 100\%$$

Often COP > 500% or 600%

Outside temperature of room containing the refrigerator

Warm bedroom inside house




Work input

$$W = Q_{Hot} - Q_{Cold}$$

Cold outside air in winter

Cold milk in refrigerator

Remarkable fact is that $W < Q_{Hot}$, i.e. we are getting $Q_{Hot}$ amount of heat although putting in only W by our external agencies.

Good alternative to space heaters.

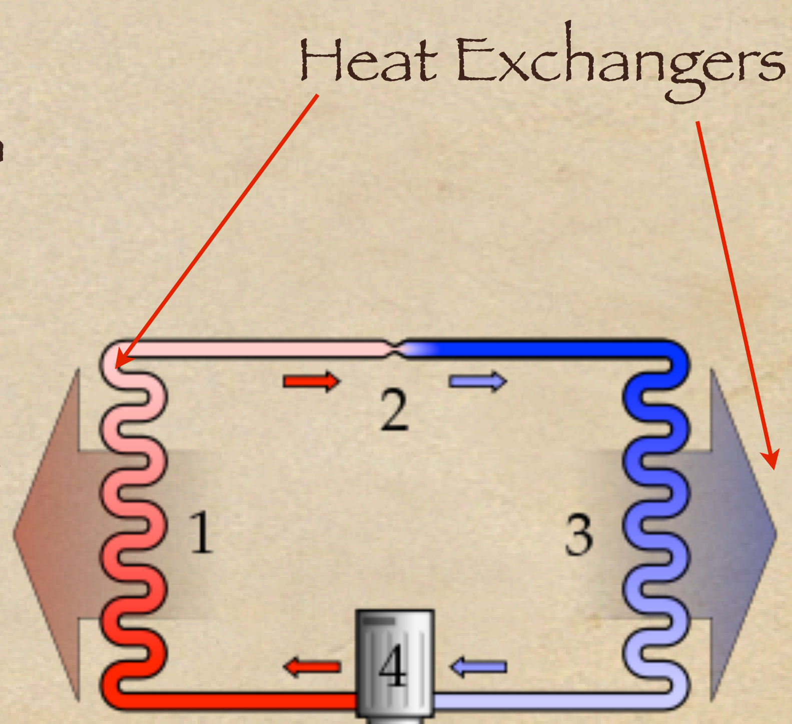
Soleus Air 12,000 BTU Portable Air Conditioner / Heat Pump with HEPA Filtration

$589.00/EA-Each
Free Shipping

http://home.howstuffworks.com/home-improvement/heating-and-cooling/heat-pump1.htm

A simple stylized diagram of a heat pump's vapor-compression refrigeration cycle: 1) condenser, 2) expansion valve, 3) evaporator, 4) compressor.

The working fluid, in its gaseous state, is pressurized and circulated through the system by a compressor. On the discharge side of the compressor, the now hot and highly pressurized gas is cooled in a heat exchanger, called a condenser, until it condenses into a high pressure, moderate temperature liquid. The condensed refrigerant then passes through a pressure-lowering device like an expansion valve, capillary tube, or possibly a work-extracting device such as a turbine. This device then passes the low pressure, (almost) liquid refrigerant to another heat exchanger, the evaporator where the refrigerant evaporates into a gas via heat absorption. The refrigerant then returns to the compressor and the cycle is repeated.



Latent heat issues:

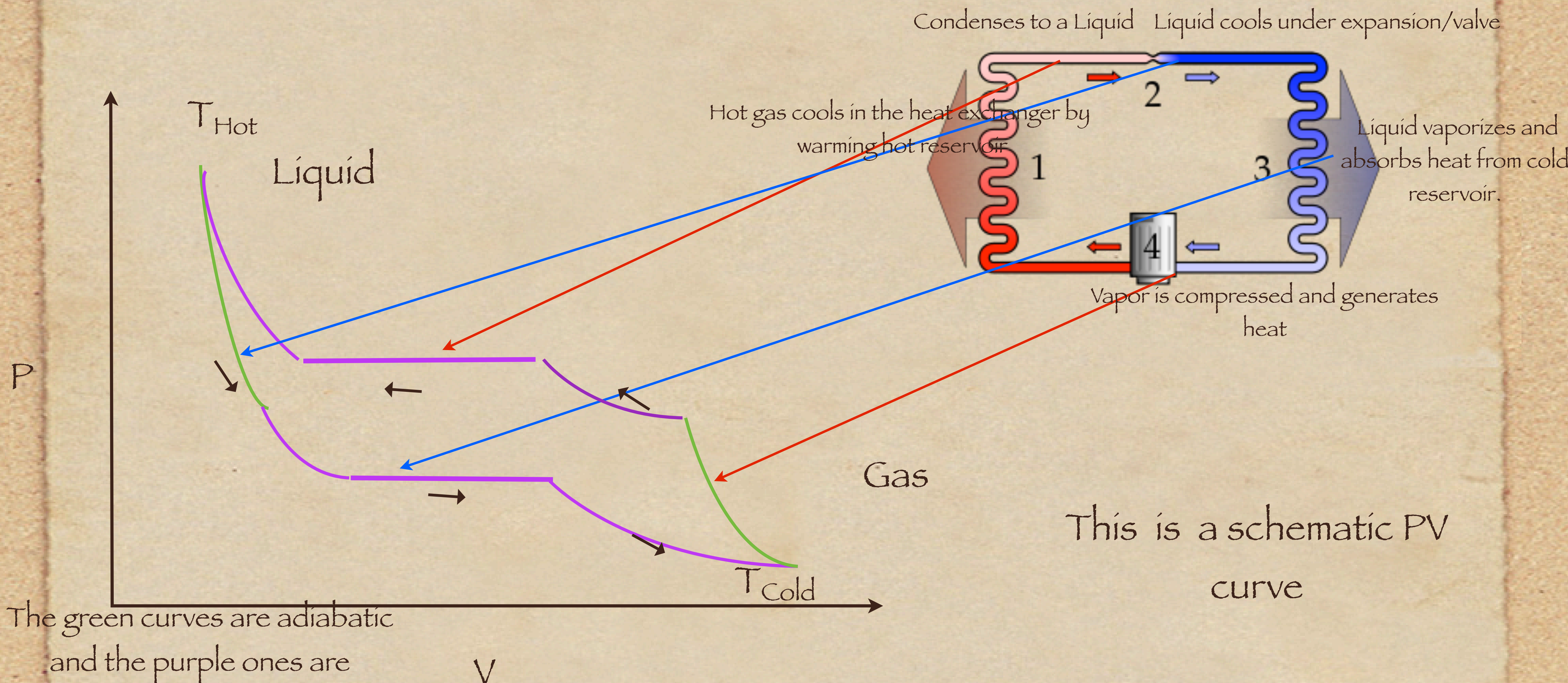
| | | |
|---|---|---|
| Freon evaporates | $\Delta Q<0$ | Need to supply heat f |
| Freon condenses | $\Delta Q>0$ | warms the neighbourhoo |

Freon has a latent heat of vaporization 139 kJ/kg

Boiling point = -29.75°C hence very convenient.

It is also very compressible.

Clean air act has issues with this gas and it is no longer acceptable, however it illustrates the principle well.




This is a schematic PV curve

The green curves are adiabatic and the purple ones are isothermal

Note that the curves in the PV diagram represent a composite process.

This is a closed reversible curve and hence a thermal pump or refrigerator.

Its efficiency will be that of the Carnot cycle between the two temperatures. Losses will make it worse.

Here and in next slide we will omit multiplying by 100
so these are not percentages but fractions instead

Coefficient of performance of heat pump

$$\eta = \frac{Heat\ conveyed\ to\ higher\ level}{Work\ done}$$

$$\eta = \frac{Q_H}{W} \quad = \frac{Q_H}{Q_H - Q_L}$$

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

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Efficiency of a refrigerator

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

$$\eta = \frac{Heat\ removed\ from\ the\ Fridge}{Work\ done}$$

$$\eta = \frac{Q_L}{Q_H - Q_L}$$

Summary:

Given $T_H$ and $T_L$ we may define three functions

Heat Engine Efficiency = $(T_H - T_L)/T_H$

Refrigerator COP = $T_L/(T_H - T_L)$

Heat pump COP = $T_H/(T_H - T_L)$

COP= coefficient of performance

## Example:

$$T_H = 20^0\ C = 293^0\ K$$

$$T_L = -5^0\ C = 268^0\ K$$

$$\eta_{Heat\ Engine} = \frac{25}{293} = .085$$

$$\eta_{Heat\ Pump} = \frac{293}{25} = 11.7$$

$$\eta_{Refrigerator} = \frac{268}{25} = 10.7$$

Second law efficiencies:

Carnot efficiency refers to an ideal reversible engine, in reality we must deal with losses, friction etc. Hence it is useful to define a second law efficiency of an engine as;

second law efficiency= first law efficiency/Carnot efficiency for best process for task

$$\eta_{Second\ Law} = \frac{\eta_{First\ Law}}{\eta_{Carnot}}$$

$$w = cW$$

$w =$ Available work

$W = Q_H - Q_C$

Losses make c<1

$$\frac{w}{W} = \frac{w/Q_H}{W/Q_H} = \frac{\eta_{Firstlaw}}{\eta_{Carnot}}$$

← Read this from right to left

$$\therefore \quad \eta_S = c = \frac{w}{W}$$

# Heat Engine

$$w = cW, \quad c < 1$$

$$\eta_{First\ Law} = \frac{w}{Q_H}$$

$$\eta_{Carnot} = \frac{W}{Q_H}$$

$$\eta_{Second\ Law} = \frac{\eta_{First\ Law}}{\eta_{Carnot}} = c$$

# Refrigerator

$$\eta_{Carnot} = \frac{Q_L}{W}$$

$$w = c\, W, \quad c > 1$$

w= work done on the fridge
W= work done by the best possible machine (Carnot fridge)

$$\eta_{First\ Law} = \frac{Q_L}{w}$$

$$\eta_{Second\ Law} = \frac{\eta_{First\ Law}}{\eta_{Carnot}}$$

$$\eta_{Second\ Law} = \frac{Q_L/w}{Q_L/W} = \frac{W}{w} = \frac{1}{c} < 1$$

Hence second law efficiency always gives us the real picture:
How are we doing relative to the best possible performance.

| | | |
|---|---|---|
| Water heating<br>Electric<br>Gas | First Law<br>.75<br>.5 | Second law efficiency<br>.015<br>.029 |
| Space Heating<br>At room<br>At Furnace<br>Airconditioning | First law<br>.6<br>.75<br>2.0 | Second<br>.028<br>.145<br>.045 |

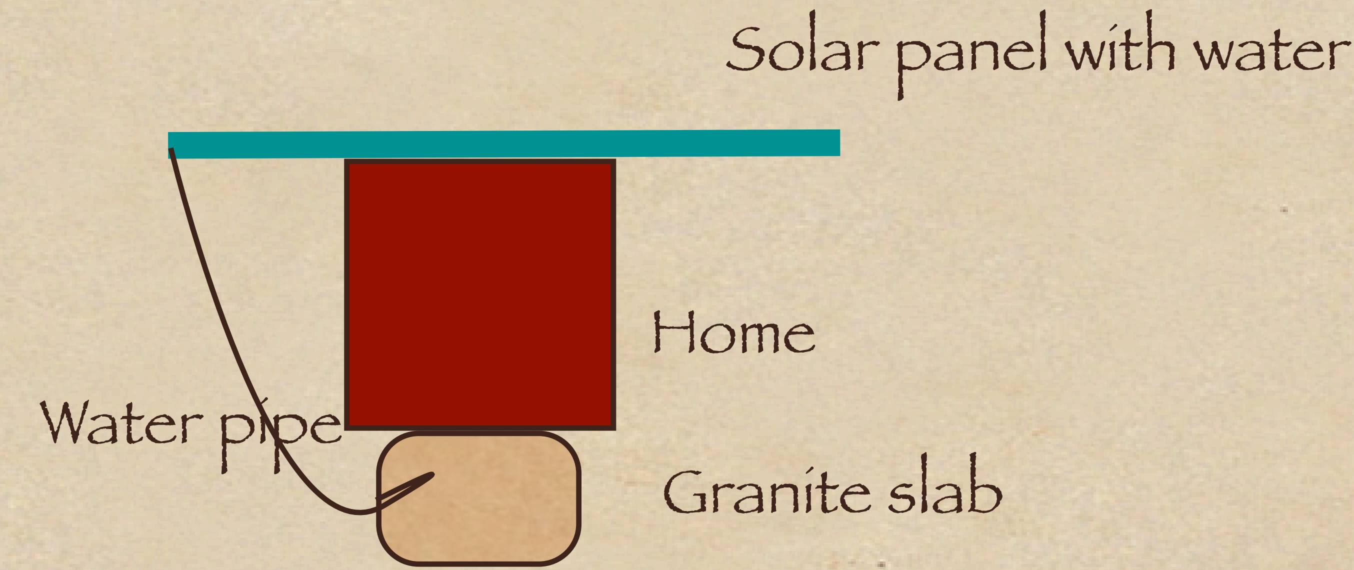
EER is a practical unit often found in ac ads.

**What is an energy efficiency rating?**
Each air conditioner has an energy efficiency rating that lists how many BTU's per hour are used for each watt of power it draws. For room air conditioners, this rating is the Energy Efficiency Ratio, or *EER*. F

The NewAir AC-10000E is one of our most popular portable air conditioners because of its power, compact size and price. This 10,000 BTU AC easily cools down areas up to 250 square feet and comes with a remote, timer and air filter.

# A Heat Storage device from Granite

When water in panel reaches $50^oC$, 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?

Answer: Granite slab is appxly 18ft x18ft x3 ft

A whole month of heating is estimated to be about 24 kWh/day x 30=720 kWh

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

Heat stored in the rock:

$$\Delta Q = Cm\Delta T$$

m= (unknown) mass of granite,

c its specific heat=820 J/kG/K

Heat required, as guessed from electricity consumption data

$$\Delta Q = 720kWh = 720 \times 3.6 \times 10^6 J$$

$$m = \frac{7.2 \times 3.6 \times 10^8}{8.20 \times 3.5 \times 10^3} \sim 100,000kG$$

next we use the density of granite

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

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