

# Lecture 6 -1-

18 Jan 12

Apply Hubbert analysis to Norway

From BP website we extracted oil production rate for each year back to 1971.

This gives  $\frac{dQ_p(t)}{dt}$

we can also calculate  $Q_p(t)$  by merely summing the cumulative oil extracted up to each year.

Finally we can get  $\frac{1}{Q} \frac{dQ_p(t)}{dt}$  by dividing  $\frac{dQ_p}{dt}$  by  $Q$  as shown in next viewgraph

Performing a fit to previous expression, we get

$$k = 0.1685 = \text{"rate constant"}$$

$$Q_\infty = 30 \times 10^9 \text{ bbl} = \text{total estimated reserve}$$

Note: fit is pretty good at later times, not so good initially while production is starting up

Next: using these fit parameters we can plug them into the "logistic function"

$$Q_p(t) = \frac{Q_\infty}{1 + e^{k(t_m - t)}}$$

See next viewgraph (note we have adjusted  $t_m$  to get best fit)

Next we can see how well our fit parameters work in plotting the production rate

Next viewgraph shows production rate vs time

Data are circles.

Fit uses previous expression for

$$\frac{dQ}{dt} = \frac{k Q_0 e^{k(t_m - t)}}{(1 + e^{k(t_m - t)})^2}$$

Note good agreement using  $k = 0.168$   
and  $N_0 = 30 \times 10^9$  bbl

Note = Norway is a special case. Usually don't get such good agreement. Reason: localized offshore field, single extraction technology.  
e.g. US data. Much longer time period. New technologies and discoveries have extended production rate beyond initial Hubbert predictions

see next viewgraph. More recent data for US actually shows a modest increase

# Oil Production Data for Norway (excel spreadsheet excerpt)

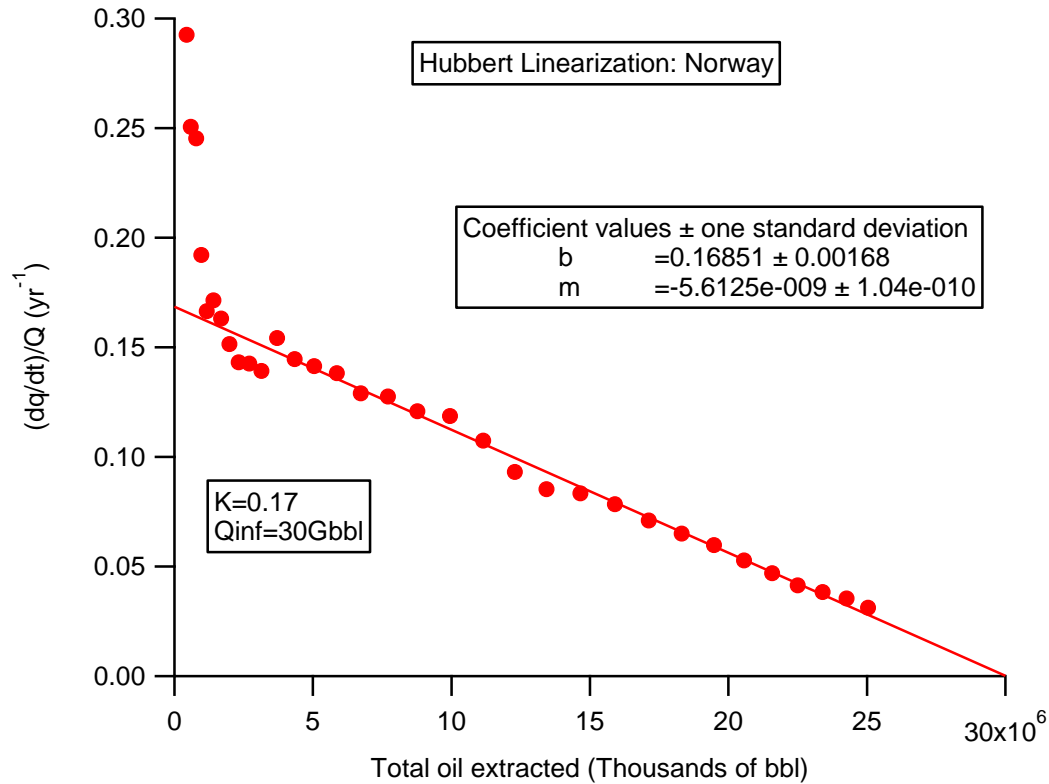
Data from bp.com Statistical Review of Energy

Year	Norway (thousands of bbl/day) dQ/dt	Norway (thousands of bbl/yr) dQ/dt =row B*365	Norway, cumulative (thousands of bbl) Q(t)	Norway 1/Q*(dQ/dt) = row C/D
1971	6	2190	2190	1
1972	33	12045	14235	0.84615385
1973	32	11680	25915	0.45070423
1974	35	12775	38690	0.33018868
1975	189	68985	107675	0.64067797
1976	279	101835	209510	0.48606272
1977	287	104755	314265	0.33333333
1978	356	129940	444205	0.2925226
1979	407	148555	592760	0.25061576
1980	528	192720	785480	0.24535316
1981	512	186880	972360	0.19219219
1982	532	194180	1166540	0.16645807
1983	661	241265	1407805	0.17137672
1984	752	274480	1682285	0.16315904
1985	823	300395	1982680	0.15150957
1986	907	331055	2313735	0.14308251
1987	1054	384710	2698445	0.14256729

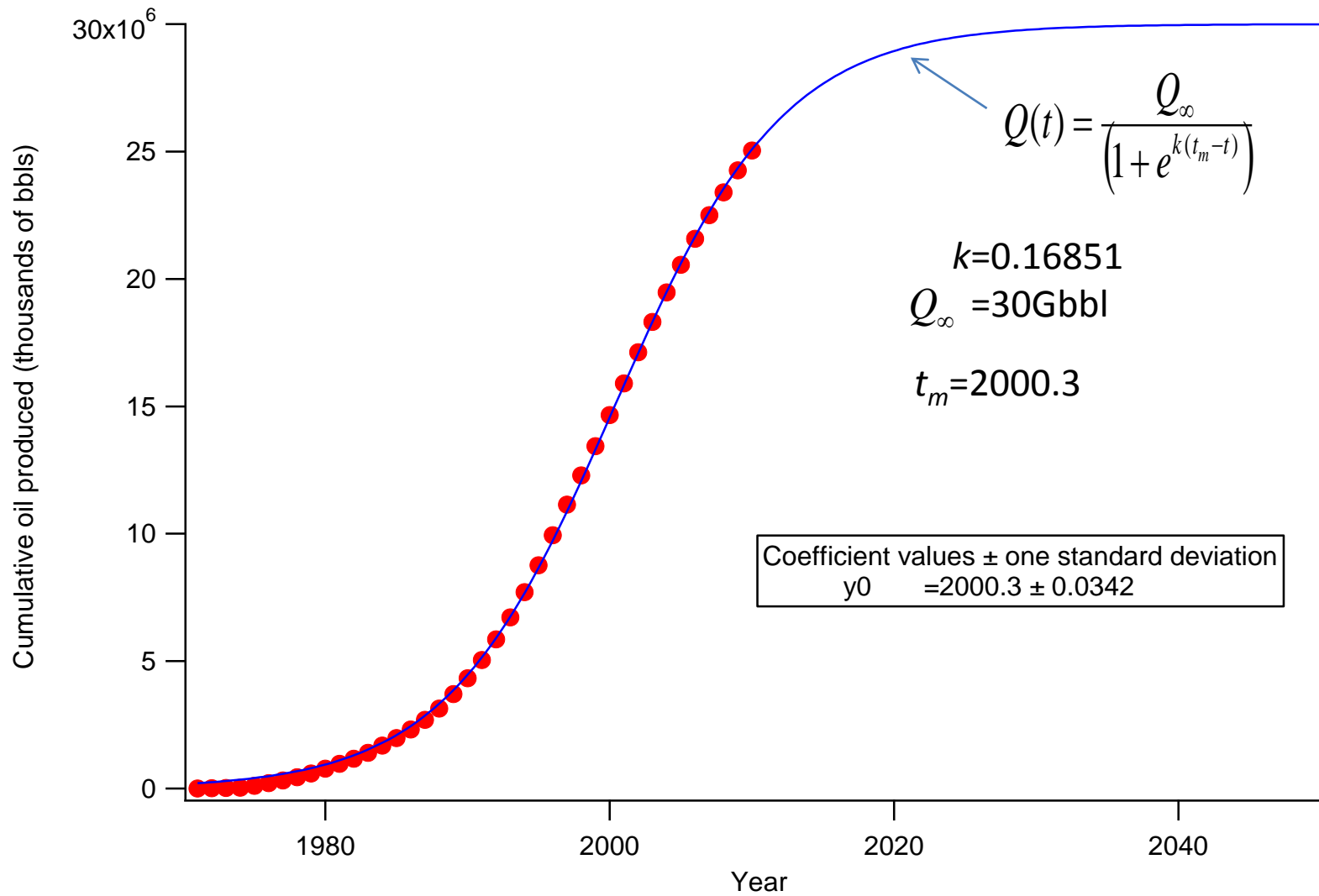
etc.

# Hubbert Linearization

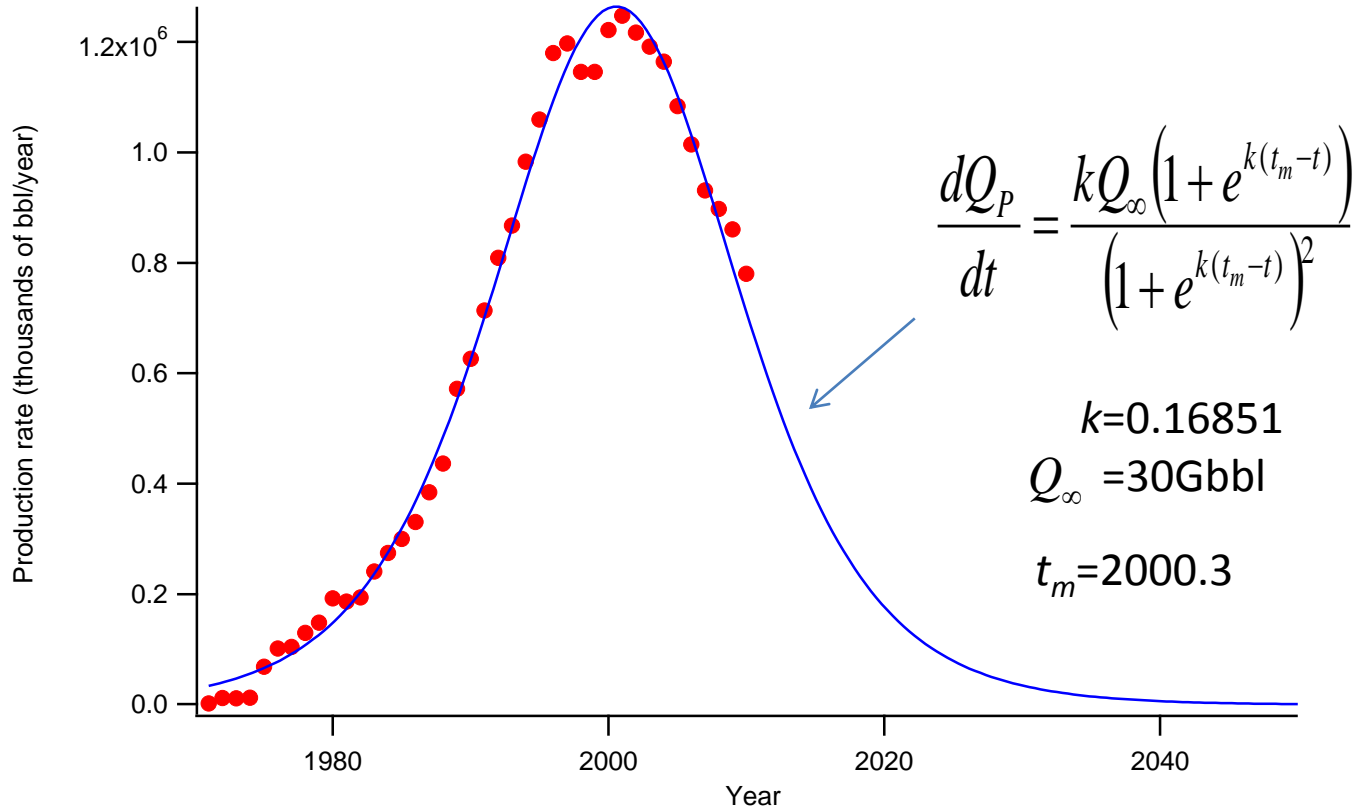
(1/Q)(dQ/dt) vs Q: Norway Data



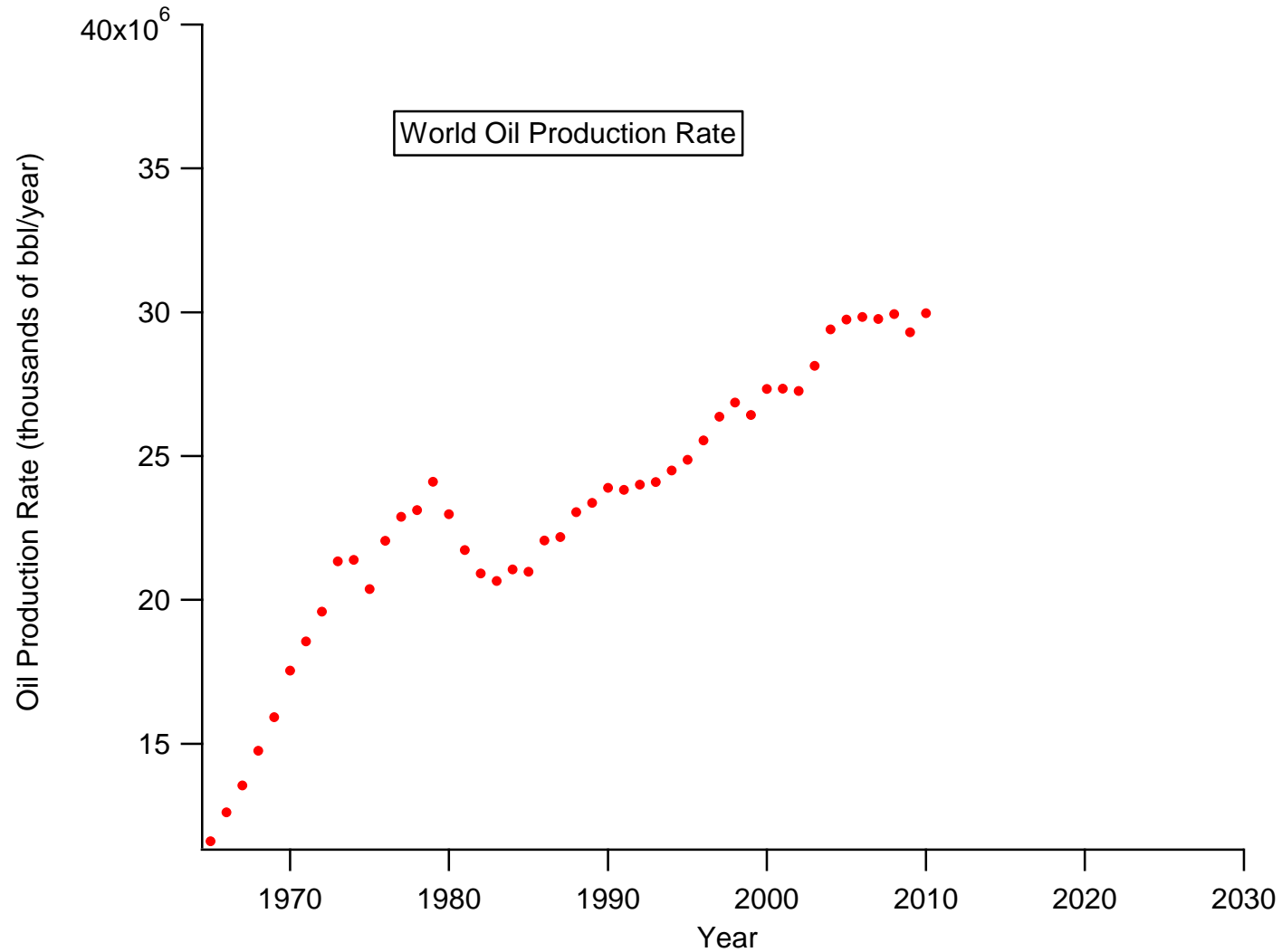
# Cumulative oil produced: $Q_p(t)$ vs. year for Norway



# Production Rate by year: $dQ_p/dt$ vs. time

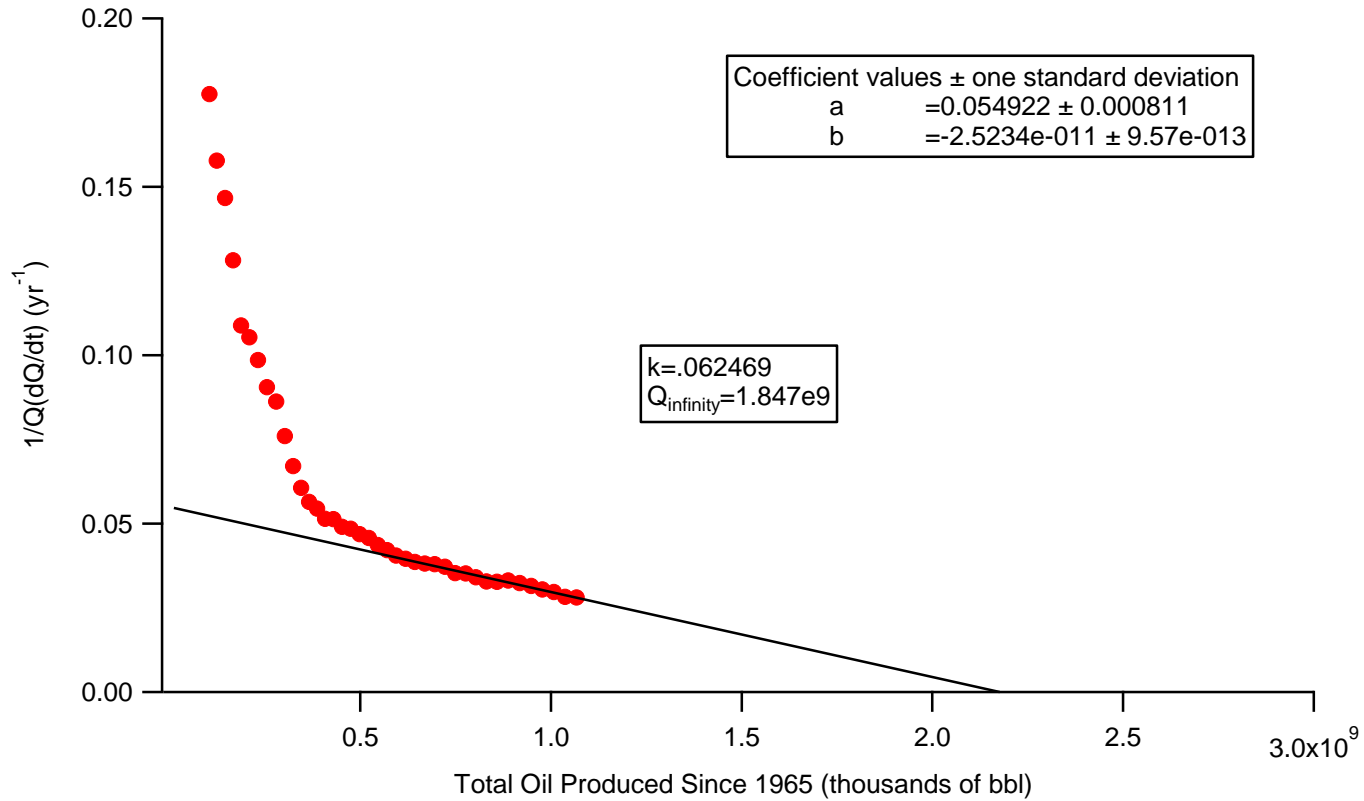


# $dQ/dt$ : world oil consumption/production



Source BP Statistical Review of Energy (2010)

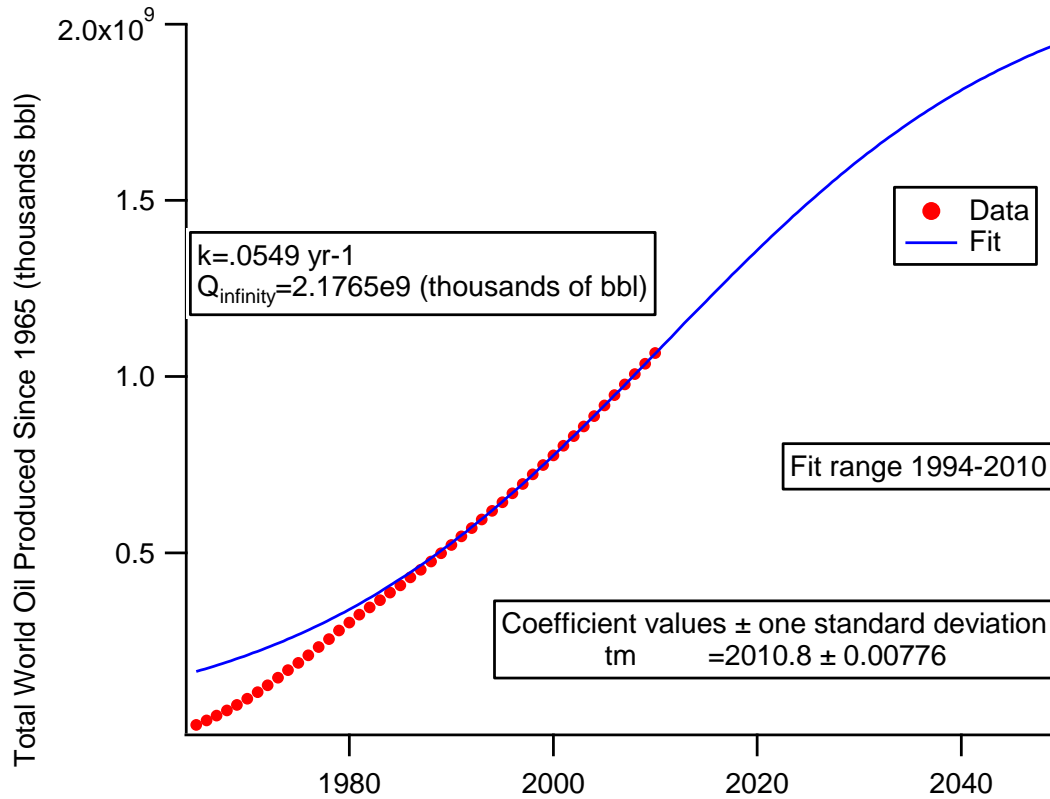
# Hubbert Linearization: world oil



Poor agreement with model



## Cumulative World Oil Produced



$$Q(t) = \frac{Q_{\infty}}{1 + e^{k(t_m - t)}}$$

Conclusion:  
 Hubbert Model is  
 questionable at best  
 for world oil. Too  
 many variables.

Data Source BP Statistical Review of Energy (2010)

# Chapter 4

## Efficiency of energy converters:

### Heat, work and thermodynamics.

- We have qualitative notions of heat, temperature
- Also have general idea of conservation of energy.

If energy can't be destroyed, why do we worry about running out?

\* Answer = all energy eventually gets "degraded" into heat. Laws of thermodynamics tell us under what conditions we may recover this heat for useful things like - mechanical } work  
- electric }

Start w/ concept of temperature:

Simplest conceptual picture is for an ideal gas. In this case  $T$  is a measure of kinetic energy per molecule which is

given by  $KE = \frac{3}{2} kT$  for mono atomic gas (He, Ar)  
 $\frac{5}{2} kT$  for diatomic gas (N<sub>2</sub>, O<sub>2</sub> ...)

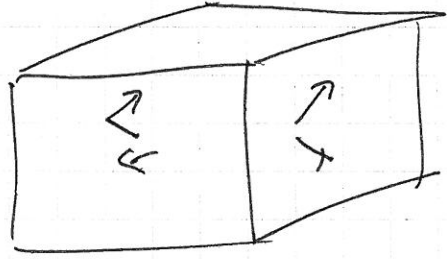
$k =$  Boltzmann's constant  $= 1.381 \times 10^{-23} \text{ J/K}$

Avogadro's number:

1 mole of ideal gas contains  $6.02214 \times 10^{23}$  atoms or molecules

Total KE is  $N_A k = R = 8.314 \text{ J K}^{-1} \text{ mol}^{-1}$   
ideal gas constant

Ideal gas law can be derived from consideration of KE of ideal gas atoms = collisions with walls give rise to pressure on walls



$$PV = nRT$$

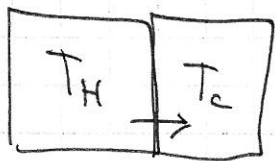
If we fix volume,  $P \propto T$

$P$  increases because KE increases

If we fix  $T$  but decrease  $V$ , the number of collisions per unit area increase  $\Rightarrow P$  increases.

Heat conduction :

If we place two containers at different temps in contact what happens?



transfer of heat from hot to cold until the objects reach equilibrium i.e.

no further changes in  $P, V$

After some time both will have same temp.

hot object lost energy (heat)  
cold object gained (heat)

Heat is the transfer of internal energy by means of temperature difference (as opposed to work)

Heat capacity = If we add heat  $Q$  to an object what happens to the temperature?

For small  $dQ$ ,  $dQ \propto dT$

Proportionality constant is the heat capacity  $C$

① ie  $dQ = C dT$

of  $C = \frac{dQ}{dT}$  units  $\frac{J}{K}$  or  $\frac{J}{^\circ C}$  (same)

In most cases we will assume  $C = \text{constant}$  for a given object (not strictly true)

Usually we will write ① as  $Q = C \Delta T$

where we use  $Q$  rather than " $\Delta Q$ "

Examples:

Substance	$C_p$ ( $J K^{-1} kg^{-1}$ )
lead (Pb)	128
aluminium (Al)	895
liquid water	4186

} note = given in units of  $J K^{-1}$  per unit mass

Note = in this definition  $Q = m C \Delta T$

(Heat capacities are usually defined according to whether process is at const.  $P$ , const  $V$  etc. we will just assume  $C = C_p$  here)

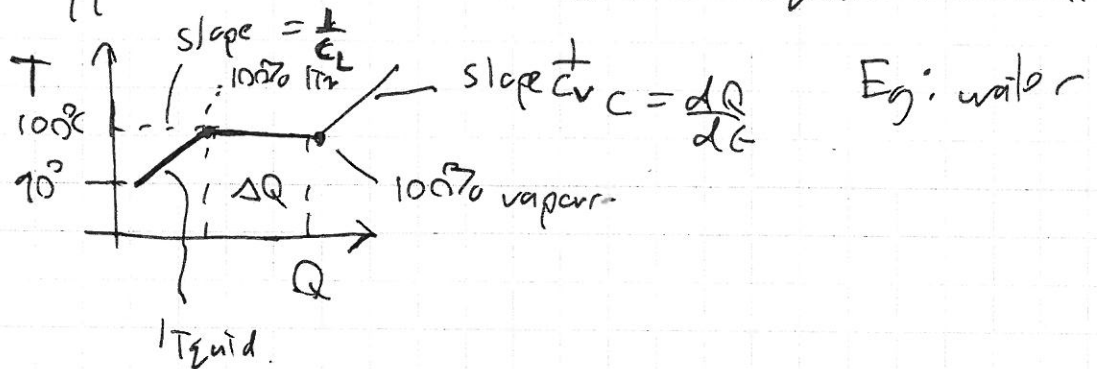
Ex: How much heat is required to raise the temp. of 5 kg of Al by  $100^\circ C$ ?

$$Q = m C \Delta T = (5 kg)(895 J K^{-1} kg^{-1})(100 K) = \underline{4.5 \times 10^5 J}$$

Phase changes = important for heat engines  
heat pumps

we use heat capacities to calculate temp-  
changes for single phase eg. pure liquid, pure solid

what happens when we heat liquid water from 10°C



Initially, water temp increases linearly w/ slope  $\frac{1}{c_L}$   
at 100°C however, some liquid starts to  
convert to steam.

No further temp increase  
Further heat goes into conversion of liquid  
to vapor

Once all liquid is converted to steam,  
the temp. starts to rise with a new slope

$c_v$

Heat required to vaporize all the liquid at 100°C  
is the "heat of vaporization"  
or "latent heat"

eg. water → steam

heat of vap. = $2.2 \times 10^6 \text{ J/kg}$ heat of fusion = $3.33 \times 10^5$
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