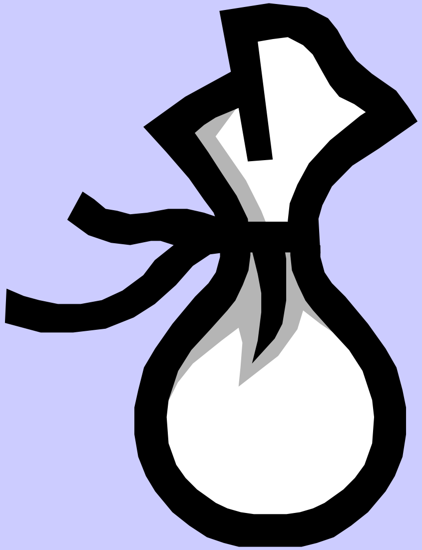
Heat Pumps
and
Refrigeration

GASES

If you have an **amount of a gas** (eg a plastic bag of air), it has:

- volume
- pressure
- temperature

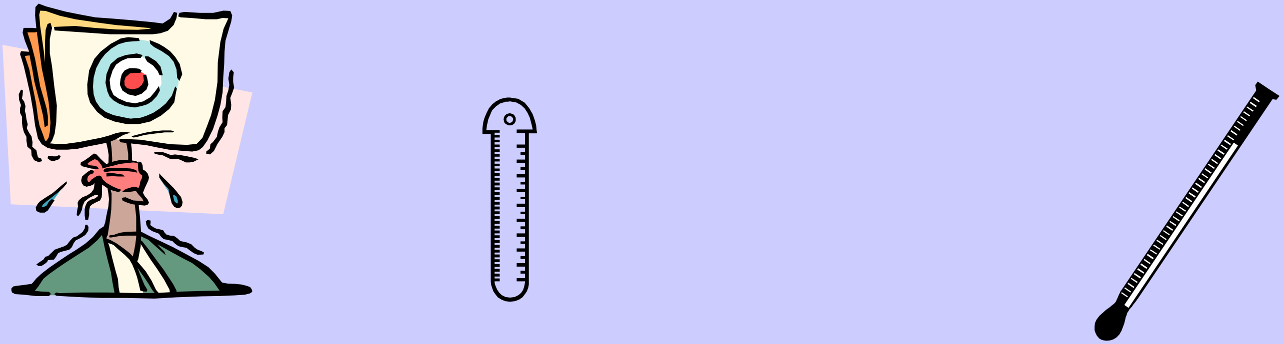


You can **measure** all of these easily.

If you **squash** the bag (compress it):

the volume goes down ↓
the pressure goes up ↑
the temperature goes up ↑
the energy (*enthalpy*) goes up ↑

(*enthalpy* can be easily calculated from a small formula)



The **Pressure, Volume and Temperature** are all found to be connected:

Pressure × Volume = Temperature × Mass × Constant

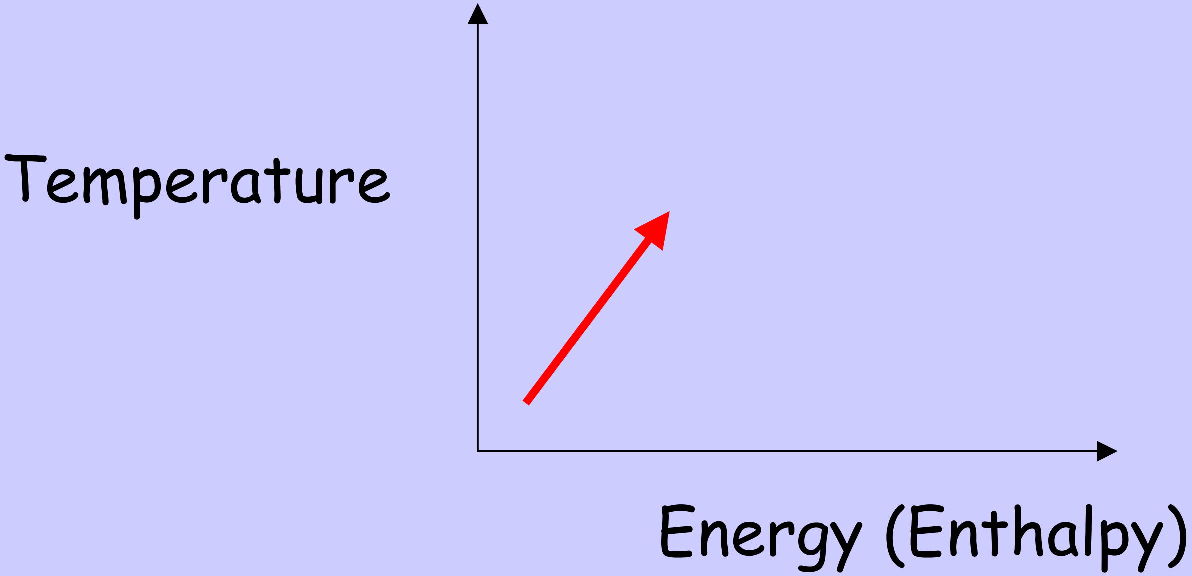
e.g.: If the **temperature** increases, either the pressure or the volume, or both, increase

Or: If the **volume** reduces, the pressure increases for the same temperature

LIQUIDS

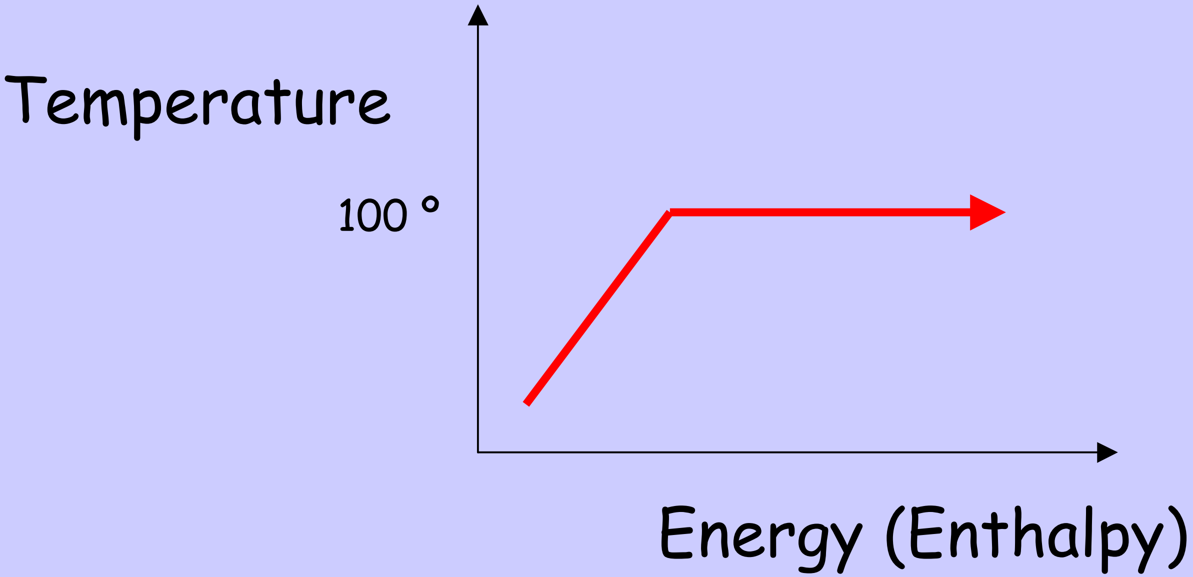
So, if you **heat water** (a liquid) at a constant volume (e.g. a can filled with water), the:

- **Volume** stays the same (of course!)
- But the **Pressure** increases
- And the **Temperature** increases
- And the **Energy** (Enthalpy) increases

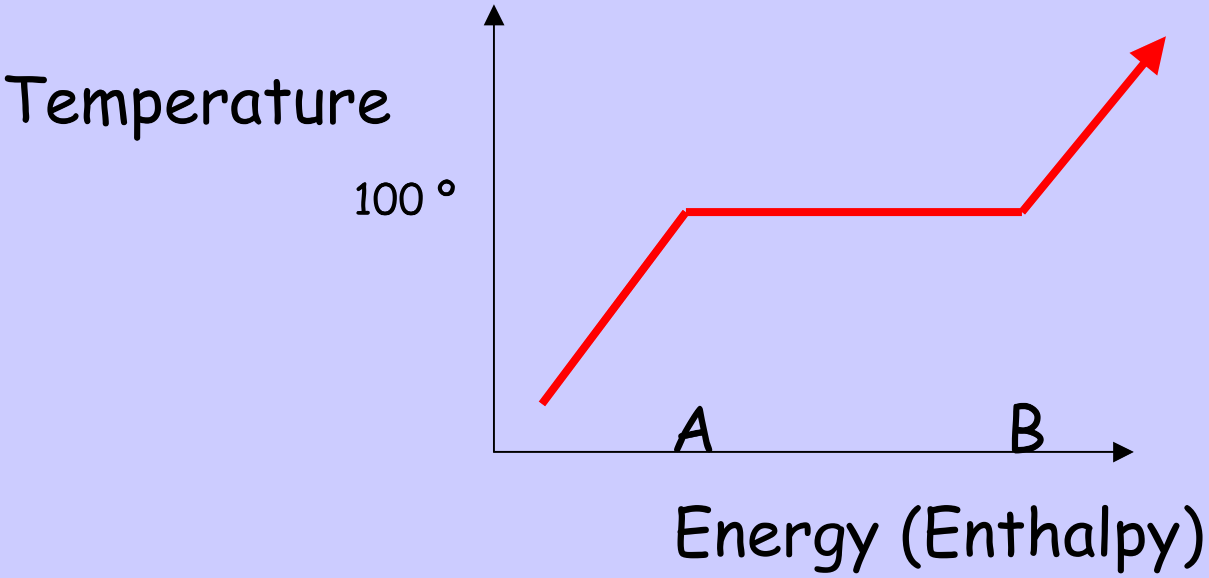


When the temperature gets to 100° (boiling point):

- steam starts to form
- but the temperature stays at 100° until all the water is gone

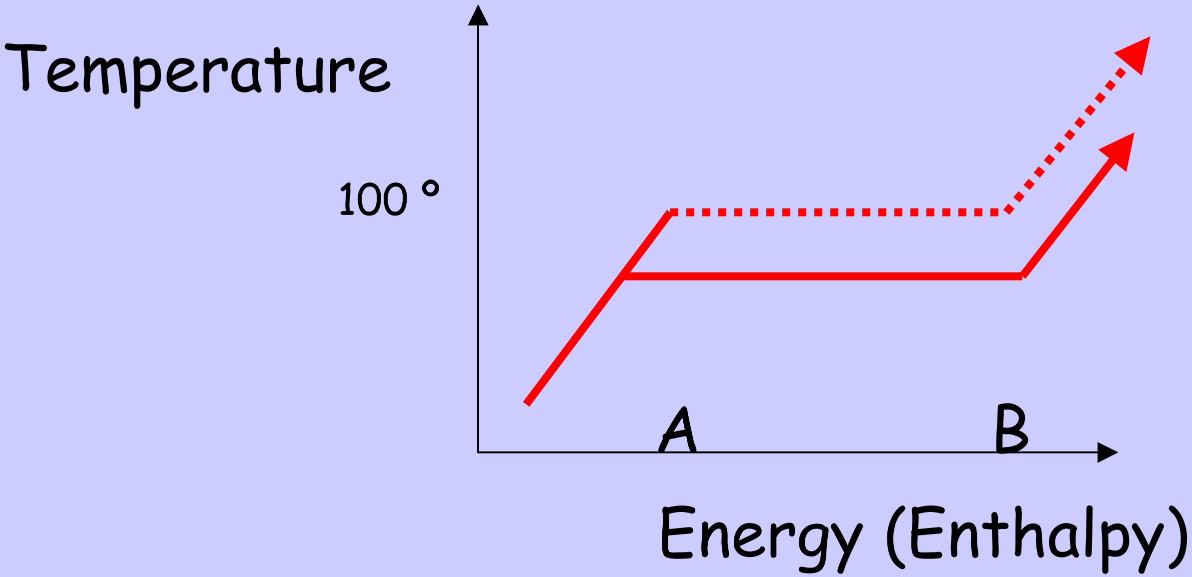


When all the water has turned to **steam**, the temperature and pressure start to rise again

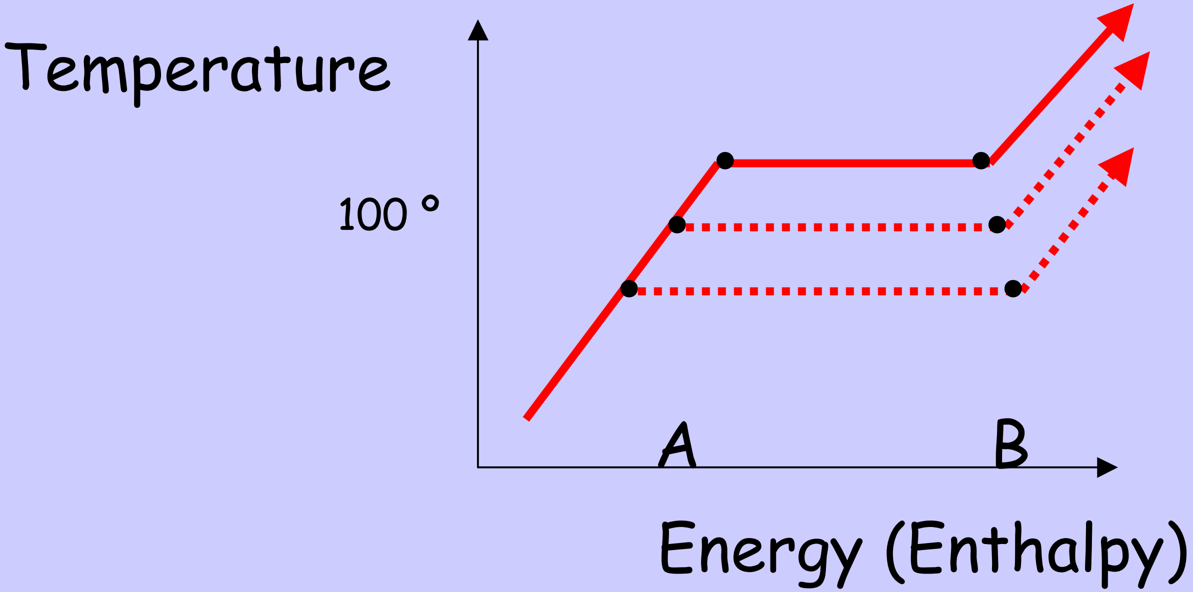


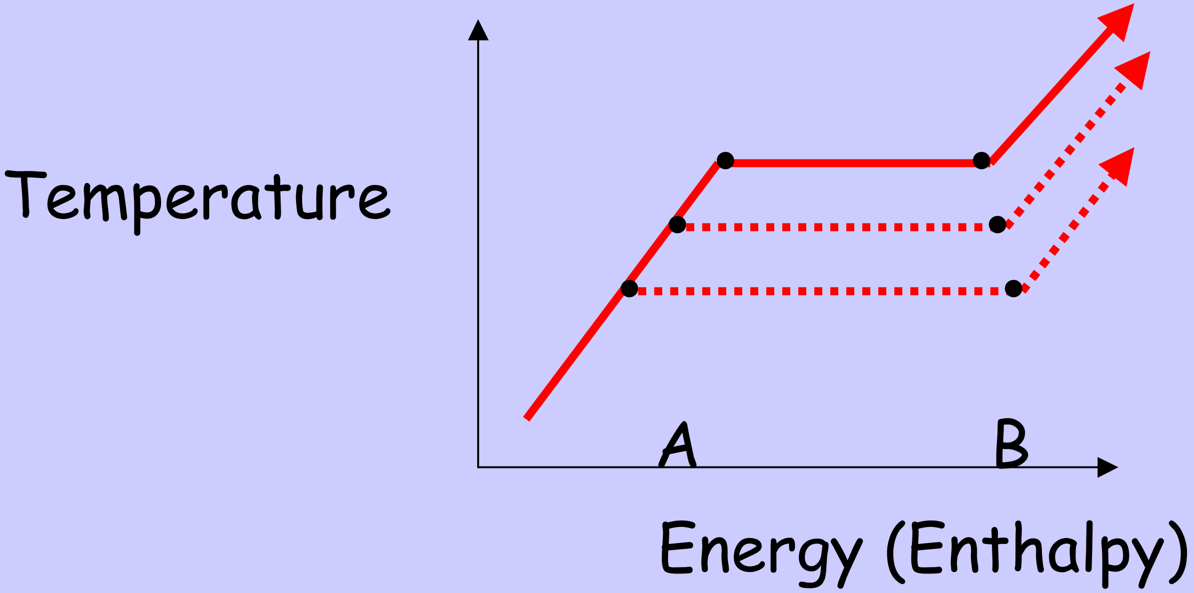
- A-B is called 'latent heat'
- A is still water
- B is all steam. Beyond B it is called 'superheated' steam.
- A-B is vapour: part water, part steam (part liquid, part gas)

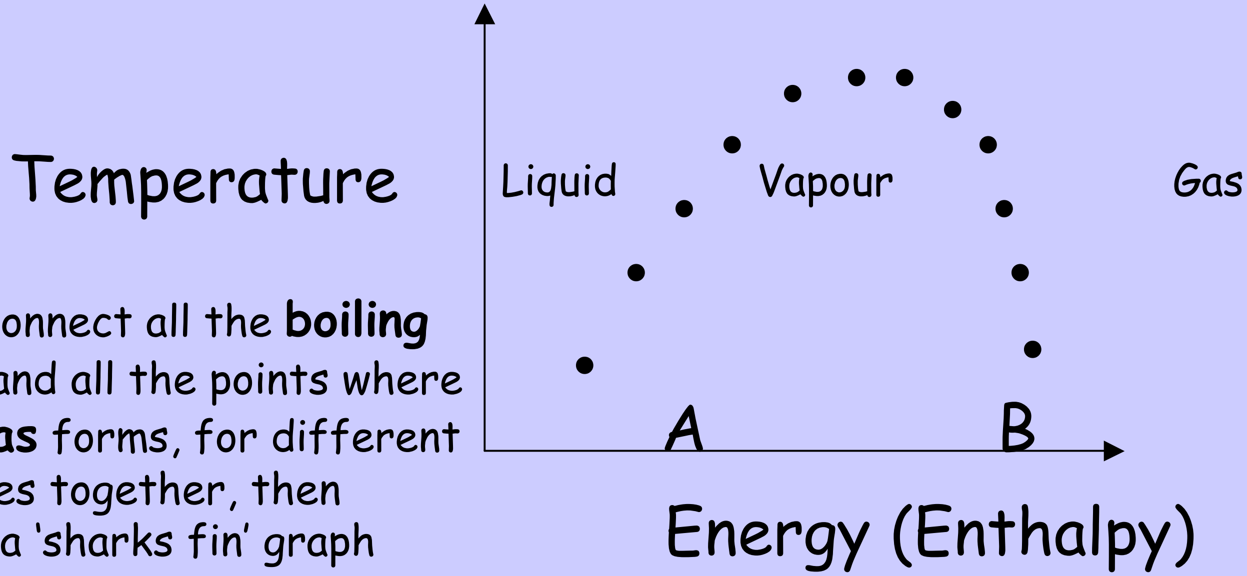
If you go up a **mountain**,the boiling temperature is **lower**.



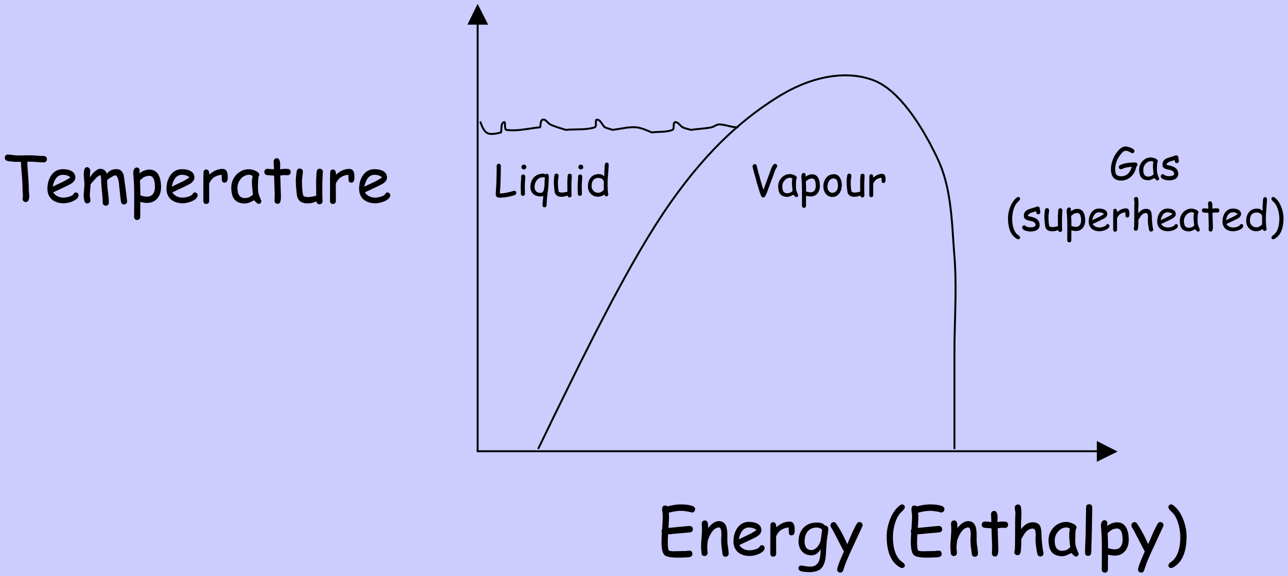
If you went to a place of **high pressure** (eg under the sea) the water would only boil at a **higher temperature**.

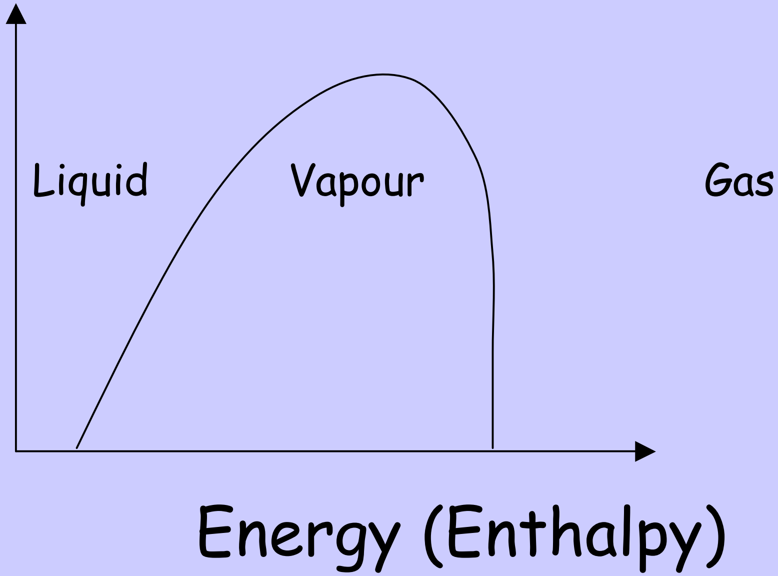






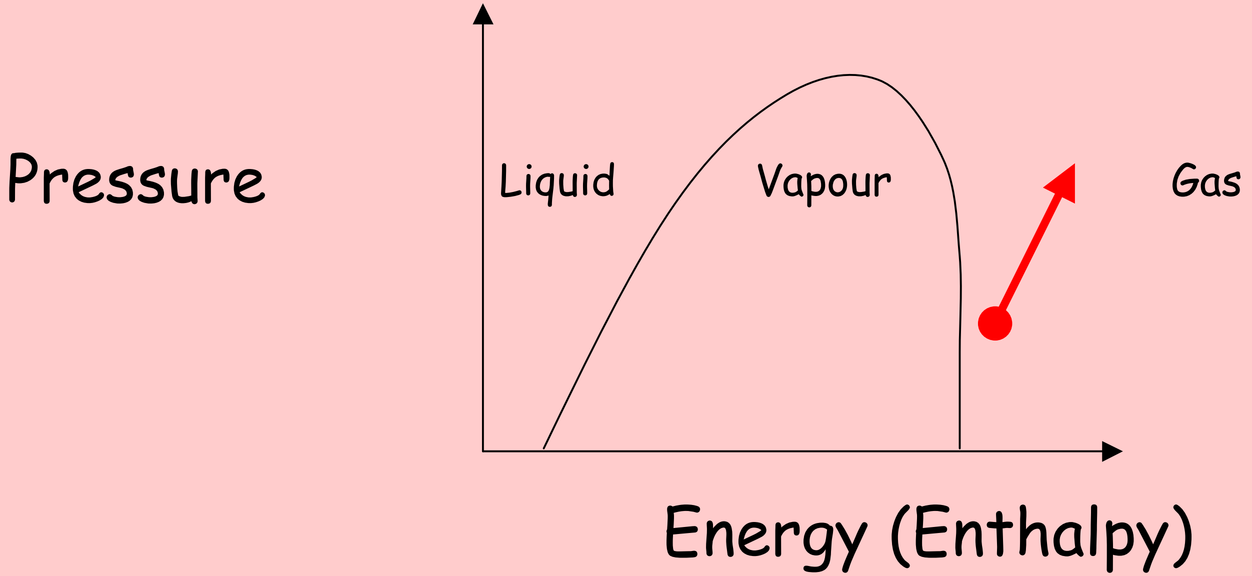
If you connect all the **boiling points**,and all the points where **pure gas** forms, for different pressures together, then you get a 'sharks fin' graph





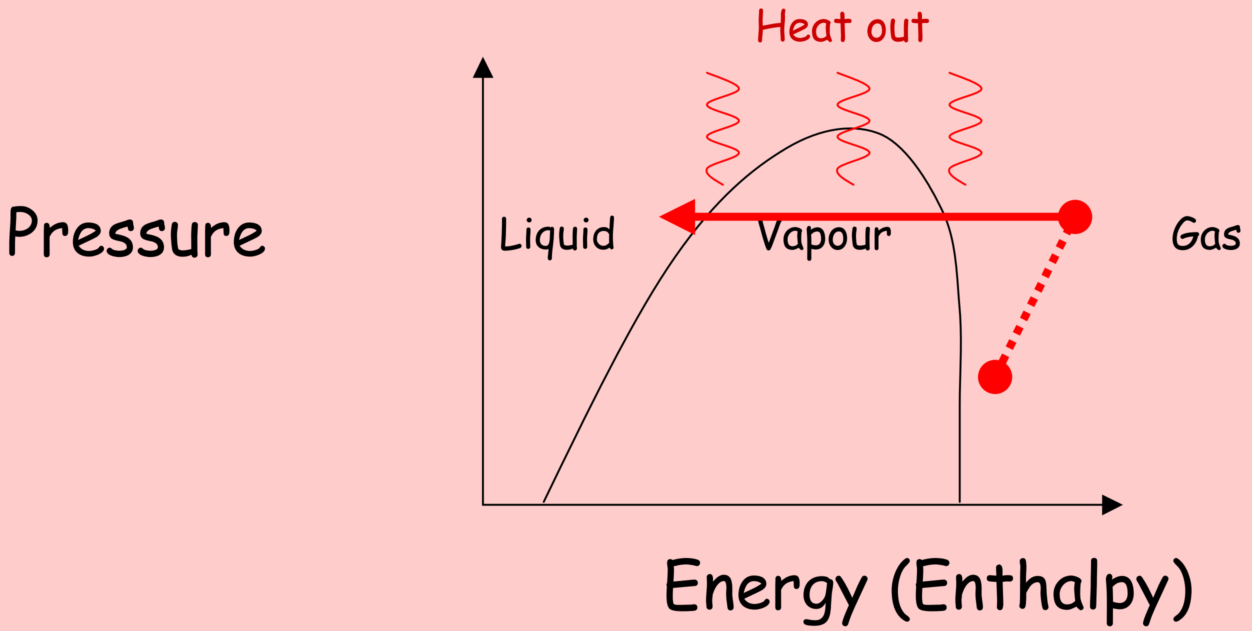
Also, if you plot **pressure** against enthalpy for different temperatures, you get a graph that sort of looks the same as the **temperature**-enthalpy graph

Now, if you take an amount of gas (eg in a plastic bag, or a *compressor*), and compress it, what does it look like on the pressure-enthalpy graph?



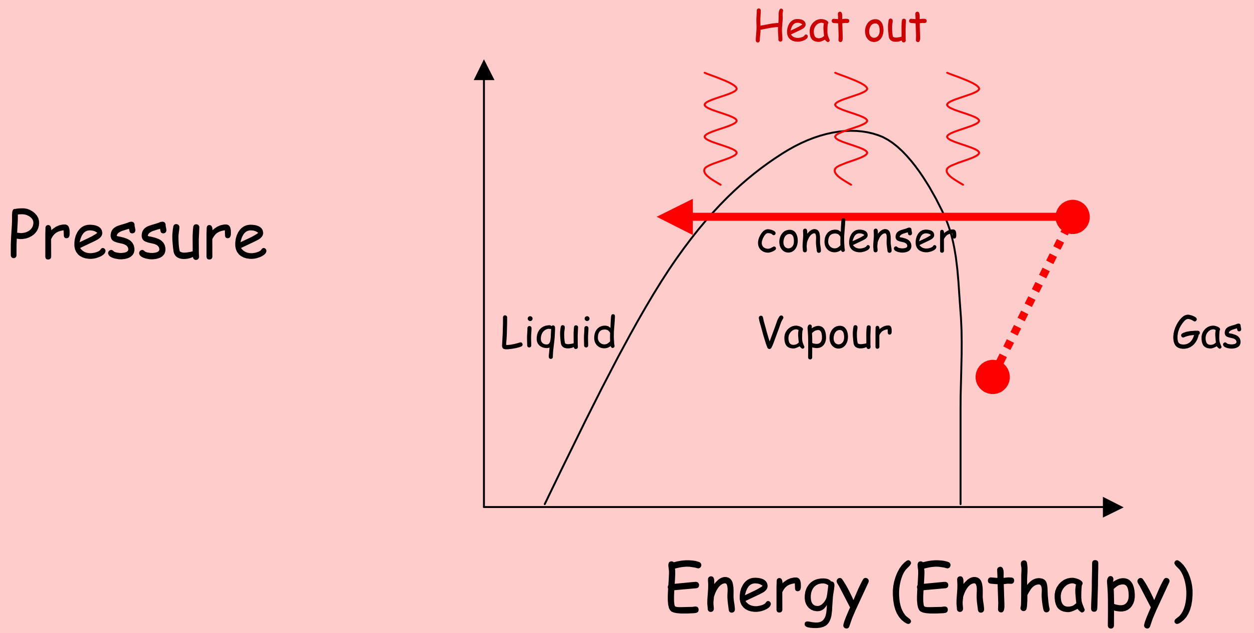
It starts off as a gas, and stays a gas, but the pressure and the enthalpy both go **up**

Now, let the gas lose its heat (without a change in its pressure), e.g. by running it through a pipe where its heat will radiate outwards

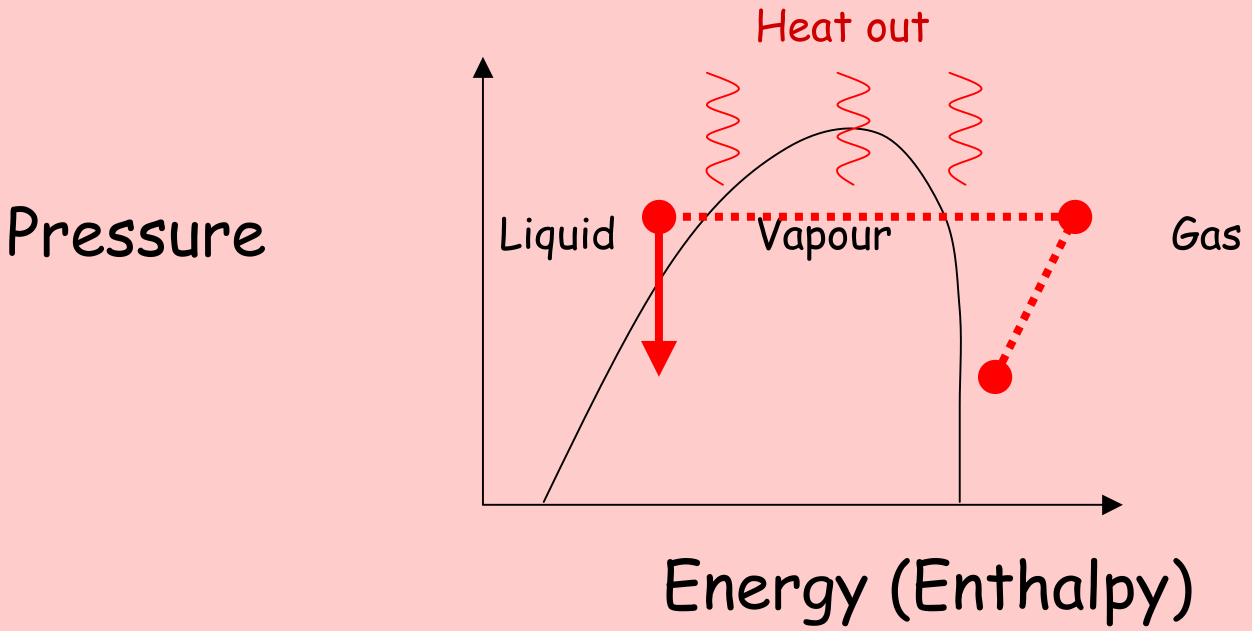


As the **gas** cools, it changes to a **vapour**, then may even become a **liquid** if allowed to cool enough

This step is called condensing, because the gas condenses to a vapour and then a liquid. It does it in a CONDENSER (not surprisingly!) or a HEAT EXCHANGER

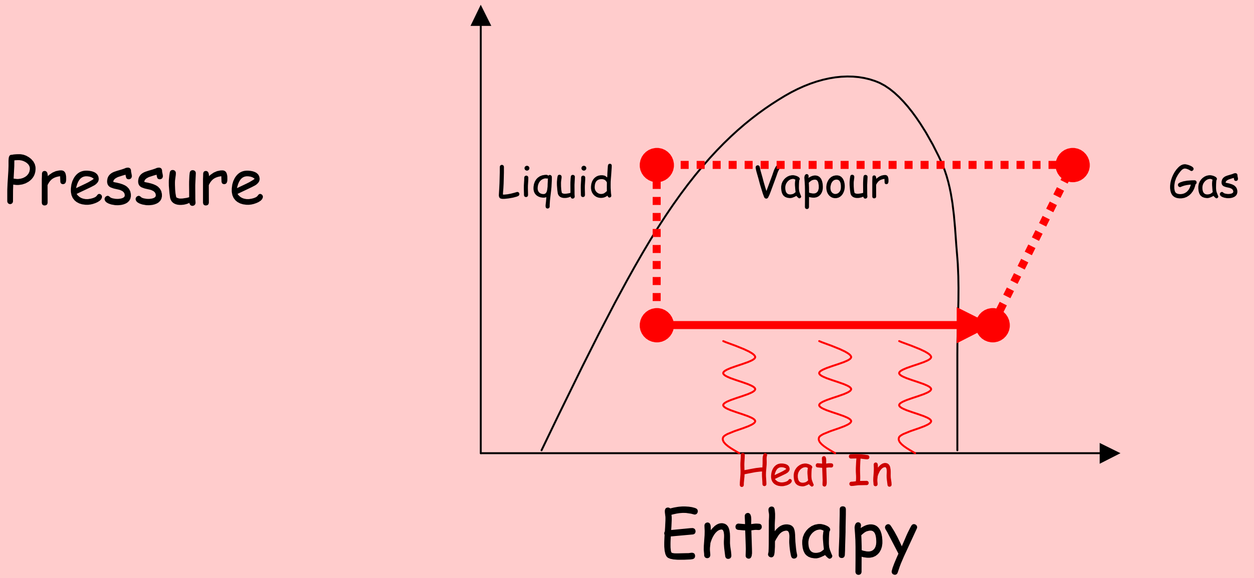


Next, run the liquid through something that causes it to **drop its pressure** (e.g. a *throttle* or *pressure reducing valve*). How will this look on our graph?



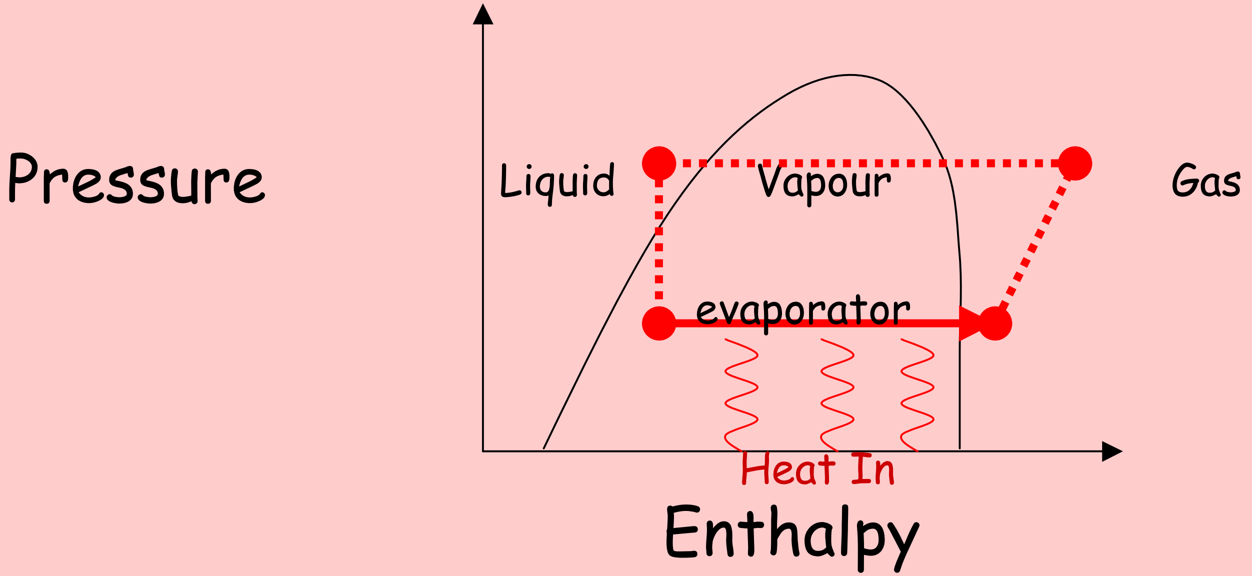
The pressure drops, but the energy doesn't change (no heat is lost or gained). So it changes back from a **liquid** to a **vapour**.

Now, run the low pressure, low heat vapour through another type of heat-exchanger that allows it to take heat IN from the surroundings, at a constant pressure. What happens?



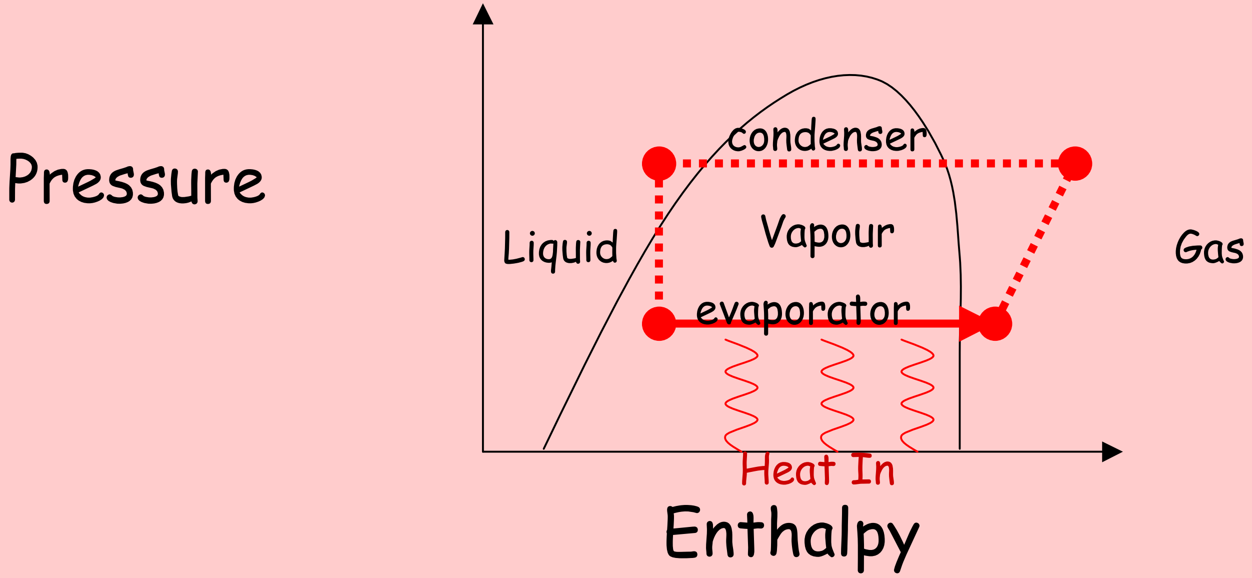
The enthalpy increases, and the vapour may become completely **dry** (a pure gas) again

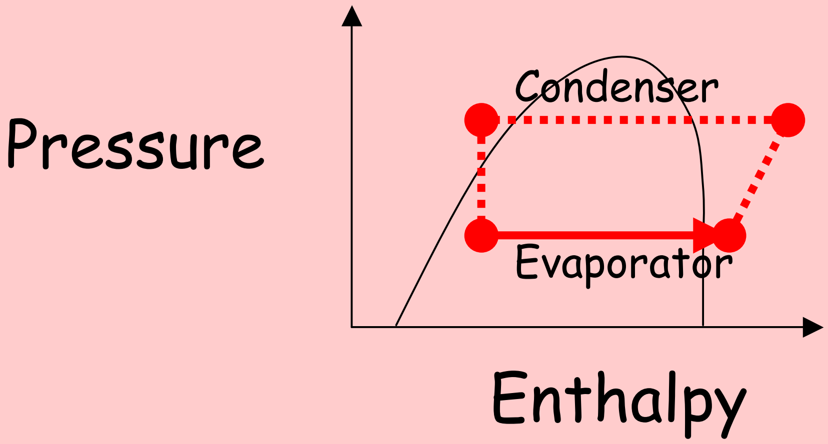
This last step is called EVAPORATION. The Heat Exchanger used here is called an EVAPORATOR

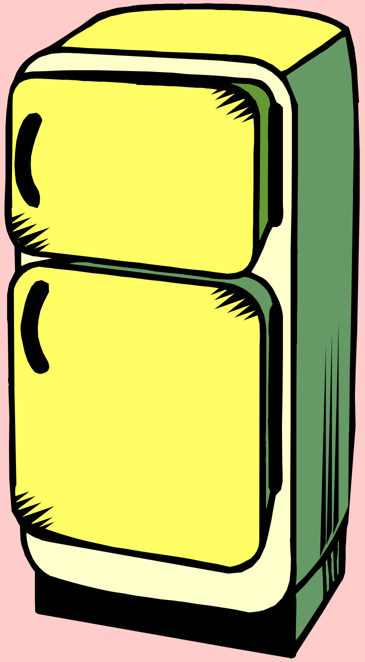


A CONDENSER needs something at a **lower** temperature than its vapour to release its heat out to.

For an EVAPORATOR to work though, it needs something at a **higher** temperature than its vapour to be able to absorb heat from. The vapour in the evaporator is usually pretty cold by now, so it isn't hard to find a source of heat warmer than itself.







In a Refrigerator:

- the **condenser** is the grill at the back of the fridge. It releases its heat to the lower temperature ROOM AIR
- The **evaporator** is the the icebox inside the fridge. The cold, low enthalpy vapour inside, absorbs its heat from the FRIDGE AIR

In a Heat Pump, you mainly want the heating coming from the condenser, rather than the cooling produced by the evaporator.

- The **condenser** may heat up ROOM AIR, or something else such as WATER
- The **evaporator** could be any source of heat, even 'low heat' eg: FRIDGE AIR, or ROOM AIR , or SOIL etc

The Goals:

1. To produce high temperatures (above 60 degrees) solely from a heat pump

2. To get the heat required for this from cheap (preferably free), abundant heat sources

Heat sources are **easy** to find (especially low-temperature heat sources like air, water, ground)

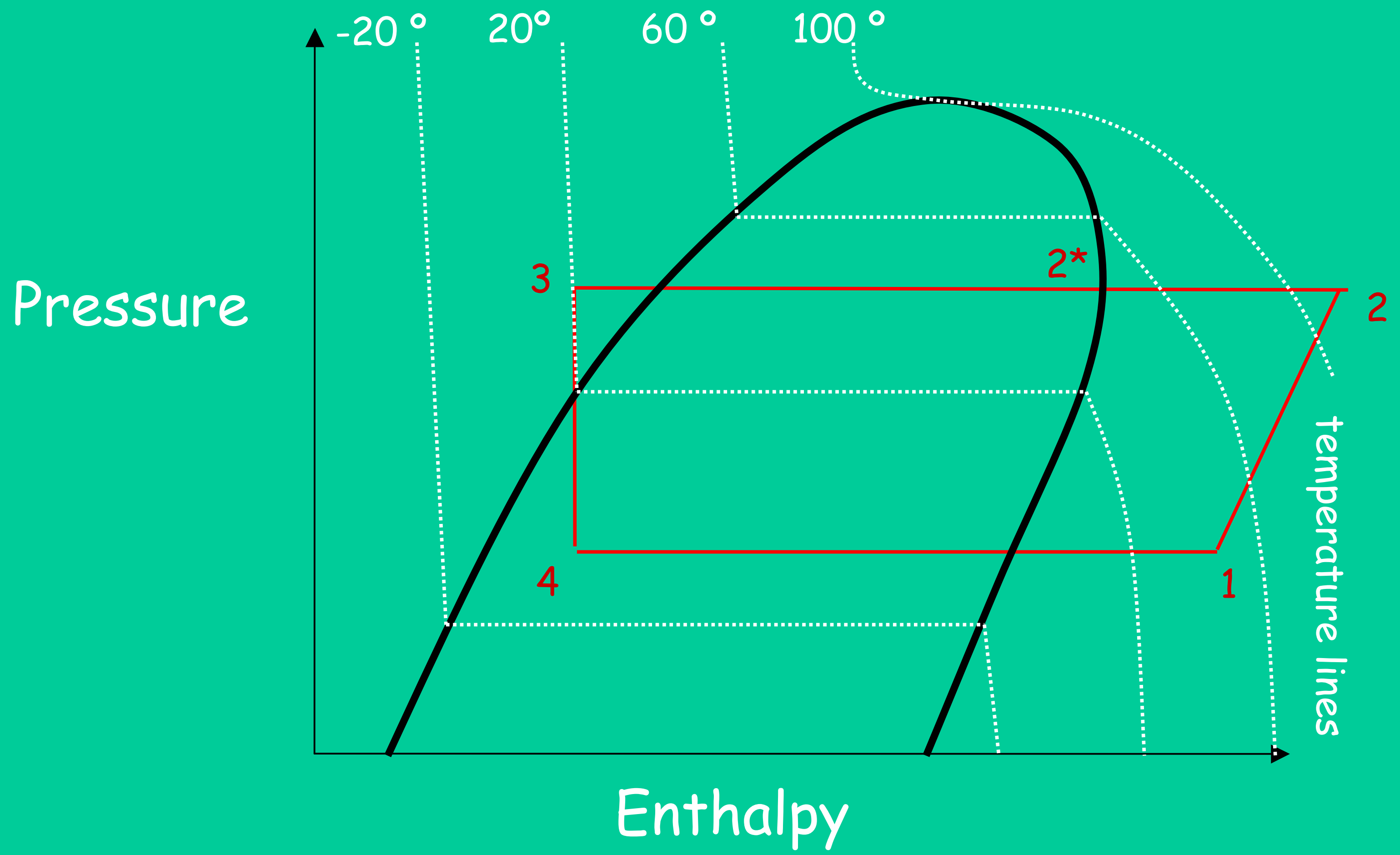
BUT

Producing very high temperatures from them is **harder**

- High temperatures are **very useful** for things such as pasteurising and drying, but before, couldn't be attained just by a heat pump.

- To get high temperatures using a heat pump, you need the **right refrigerant:**
  - water: no good because the boiling point is too high
  - CO2: boiling point too low
  - NH3: too toxic, wrong shark fin
  - R12: ozone depleting

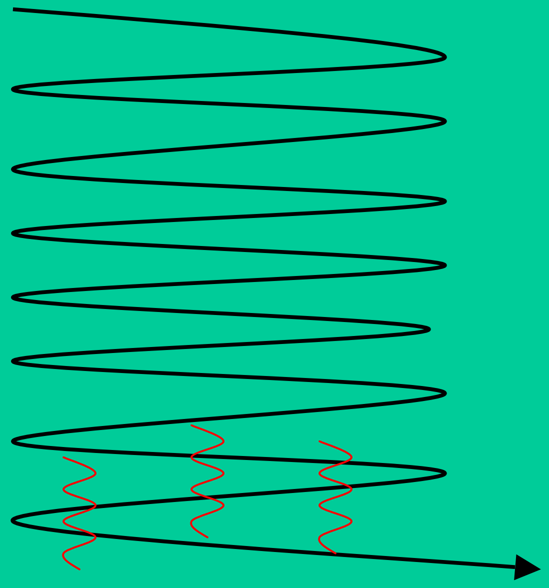
- To keep it economical, it is also best to use **as much heat as available** from the low grade heat source.



- R134a is a good refrigerant for high temperatures
- It can be very hot when it leaves the compressor (2), but is still a gas at low temperatures (4).

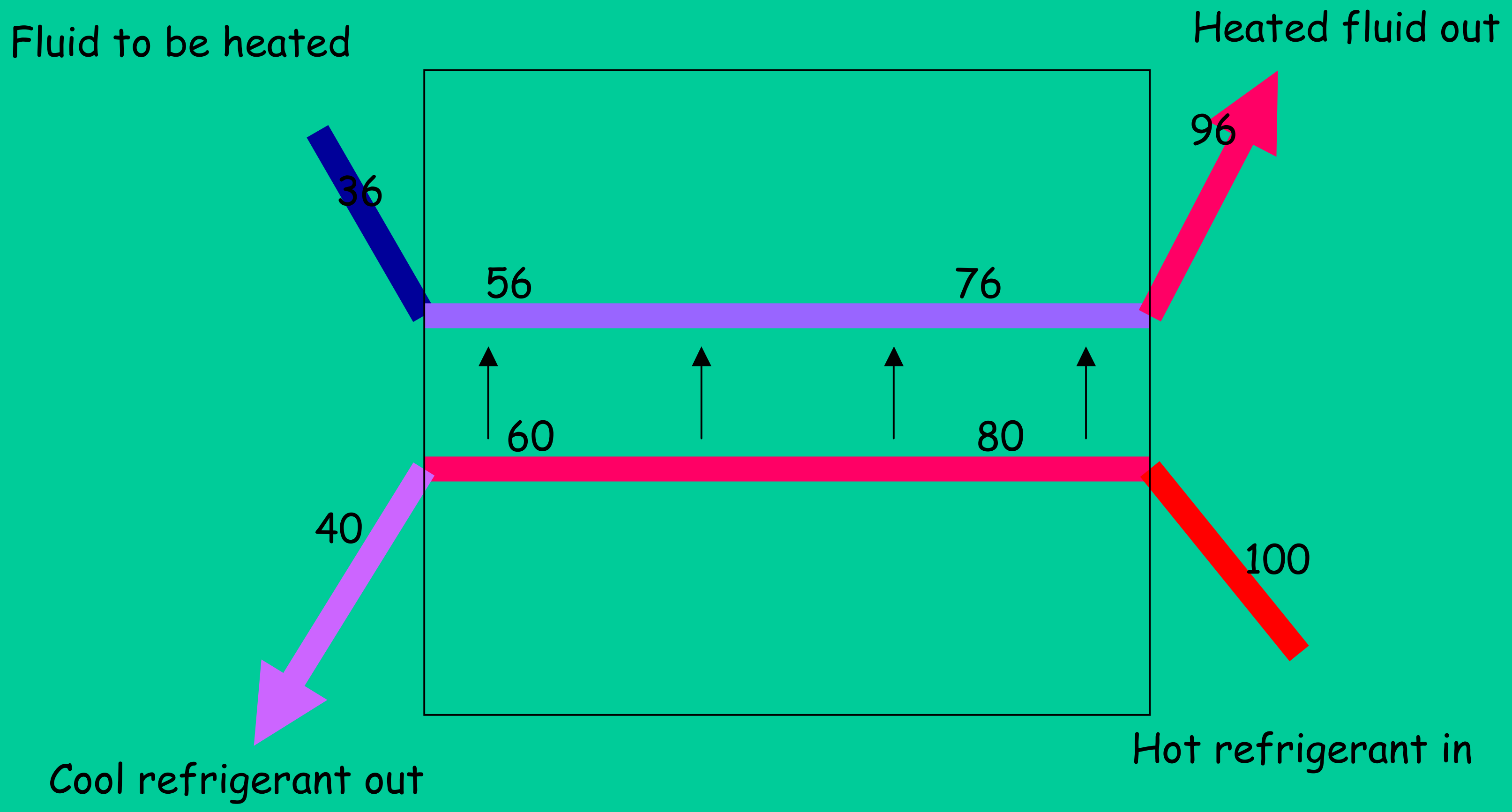
How do different heat exchangers work?

1. **TRADITIONAL** Heat Exchangers: These rely on a big surface area, but the heated fluid rarely gets to the temperature of the heating fluid.



2. **COUNTERFLOW** Heat Exchangers: In nature, the warm blood going down a seagull's thin legs are like a counter-flow exchanger. Heat is transferred to the cold blood coming back up from the ground. So the seagull doesn't lose heat.

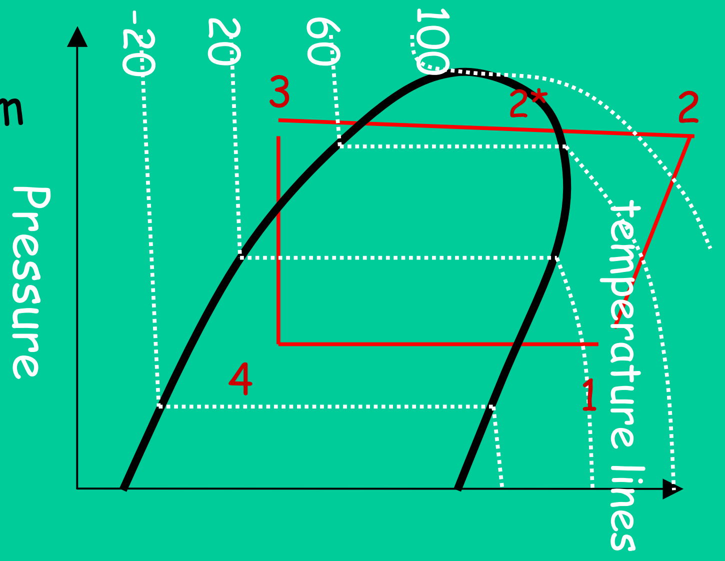
Counter-Flow Heat Exchangers

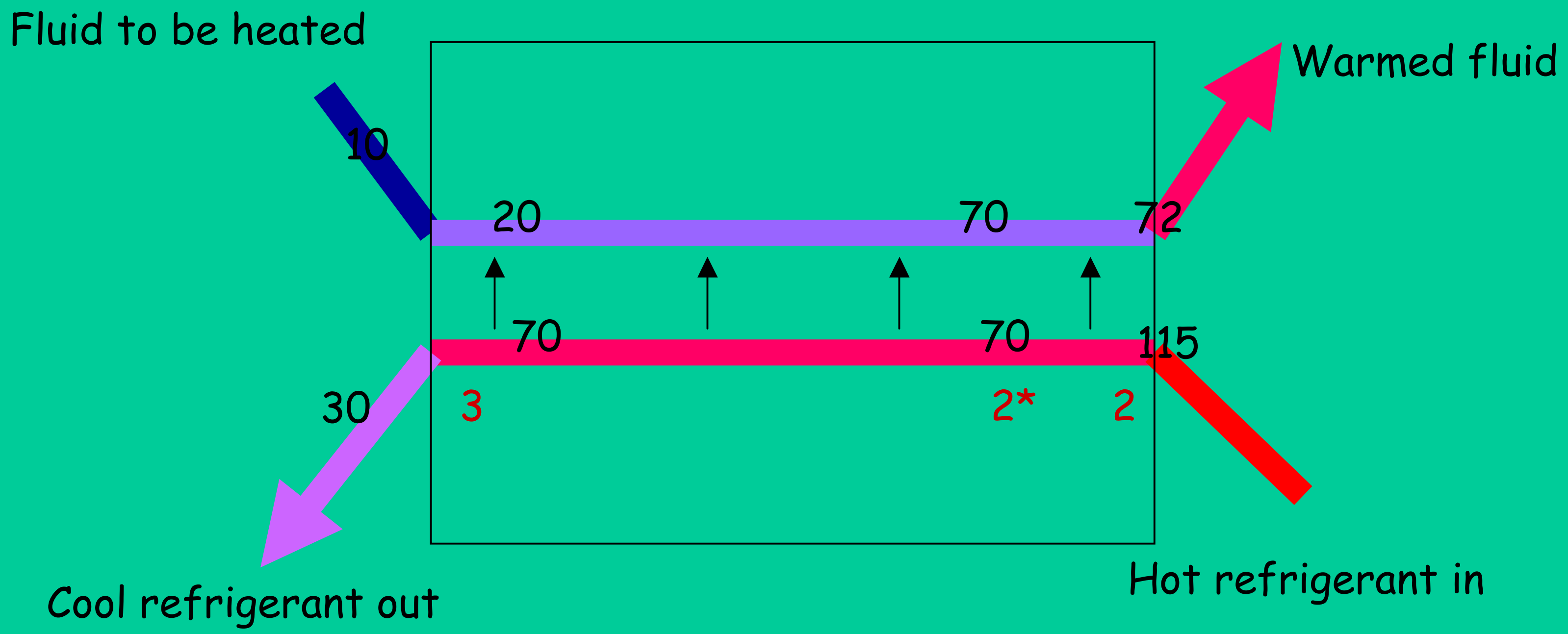


Hot fluid (such as a refrigerant fluid) enters the Exchanger and transfers heat to the cooler fluid travelling in the other direction. The refrigerant continues to transfer heat as it moves along, and in the process cools down itself while the other fluid gets hotter.

A Brazed-Plate **Heat Exchanger** (counter-flow)

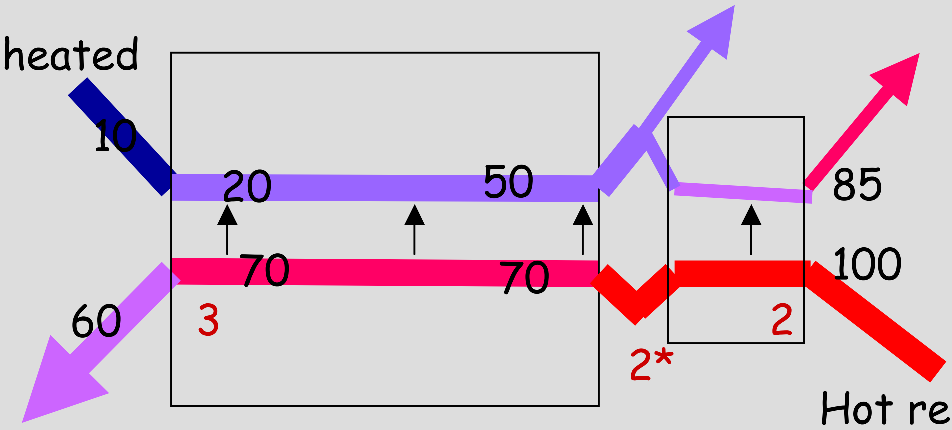
If you put a **Traditional** heat-exchanger from point 2 to point 3, the fluid coming out won't be close to the temperature of the refrigerant at point 2. This is because when you have 'super-heated' refrigerant, the temperature drops so quickly from 2 to 2*, that for a while there is no temperature gradient





In the past, how were higher temperatures obtained?

1. Put in another heat exchanger (de-superheater), with just part of the fluid



Fluid to be heated

10

20

50

85

70

70

100

60

3

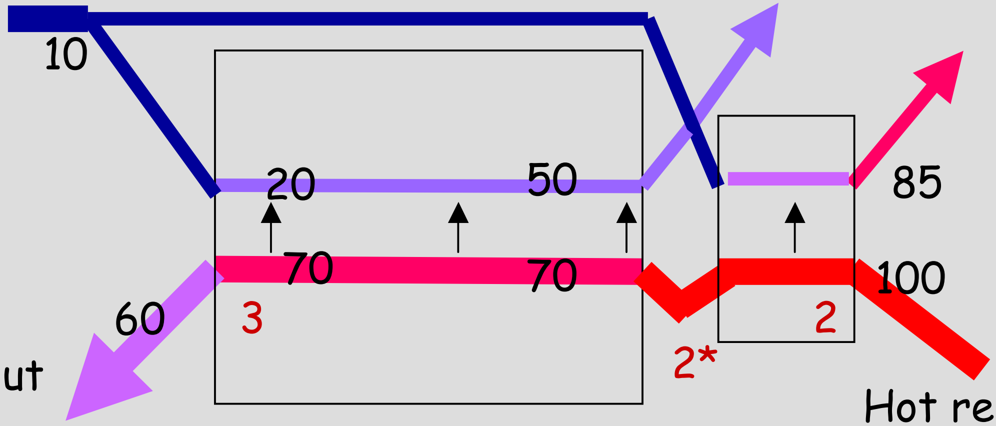
2

2*

Hot refrigerant in

Cool refrigerant out

2. Put in another heat exchanger, but split the fluid earlier.



Fluid to be heated

10

20

50

85

70

70

100

60

3

2

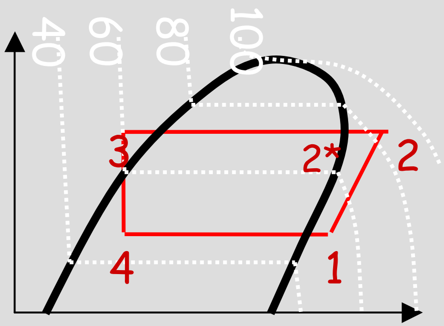
2*

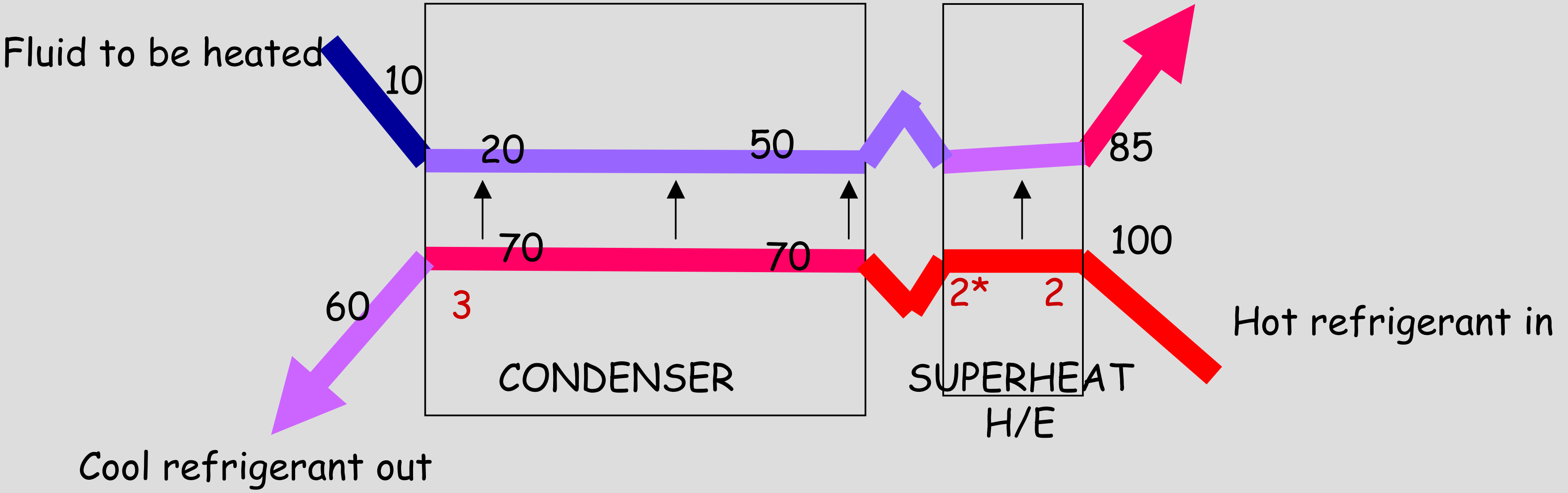
Cool refrigerant out

Hot refrigerant in

In both cases though, heat is wasted

But, by accurately calculating the fluid flow and energy exchange in separate condenser and superheat heat-exchangers, you can ensure there is a temperature difference at all points, thereby ensuring **maximum heat transfer**, and also temperatures higher than the condensing temperature can be obtained

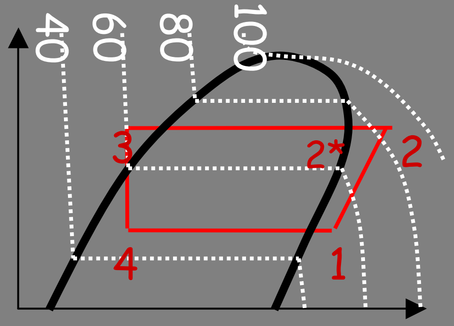




Heat Exchanger duties can be made for a specified **refrigerant**, **flow rate**, **entry and leaving temperatures**.

The heart of the solution:

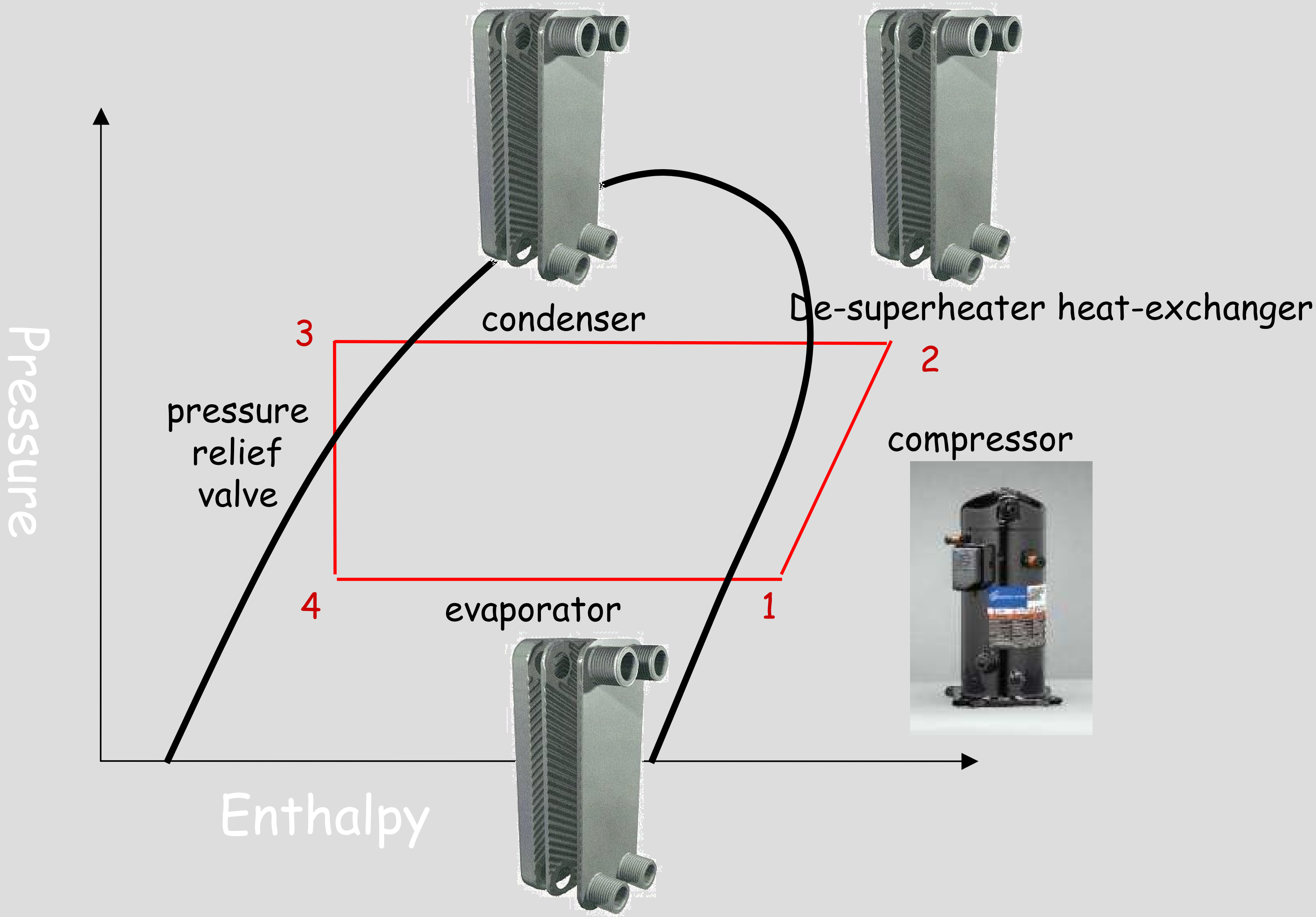
- The counter flow heat-exchanger can take maximum advantage of all the available superheat, IF the fluid Entry-temperature is accurately calculated to ensure there is still a temperature differential in the heat exchangers, at the point vapour starts to appear during condensation (point 2* on the diagram)



Less Power Required

For any Heat Pump (or fridge) you put in a bit of energy with the compressor. Then you use that to turn lots of low grade heat into a smaller amount of higher heat. Often the **enthalpy out is 3-4 times what the compressor puts in**. Likewise for a fridge, the refrigerating effect can be up to 3.5 times what the compressor puts in.

New heat pumps improves on that efficiency by using **more of the available heat** pushed around by the compressor, but also make it available at **higher temperatures**. This means that less electrical or gas power is required to attain the same heating effect.


condenser
De-superheater heat-exchanger
3
2
pressure relief valve
compressor
4
evaporator
1
Pressure
Enthalpy

What Does This All Mean ?

Now, heat pumps are routinely able to produce temperatures well in excess of their condenser's temperature, with higher comparable Coefficient of Performance than previously. 85 degree water is easily attained just by a heat pump.

The new technology means:

- Less waste of the available energy
- Applications traditionally using high temperatures, such as hot water radiators, can be supplied directly without needing extra 'resistance' heating. Systems are therefore simpler and cheaper
- Higher temperatures of water mean smaller storage vessels are required for the same amount of energy.

New technology heat pumps, in various forms, will soon markedly change the way we deal with energy in our homes, and in industry