Refrigeration

(or Applied Thermodynamics in a Domestic Context)

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Some publicly available material is taken from the Internet and the source is stated. 3 slides (Slides 2, 3 and 4) are taken from the U3A Science Study Group presentation by Ken Derham July 2016. All such information is used with thanks.

First Law of Thermodynamics

- The increase in internal energy of a closed system is equal to the difference of the heat supplied to the system and the work done by the system:
- $\Delta U = Q - W$
- The internal energy of an isolated system obeys the principle of conservation of energy; i.e.
- Energy can be transformed (changed from one form to another) but cannot be created or destroyed

Second Law of Thermodynamics

- **Heat flows from a hotter location to a colder location.**
- There are many versions of the second law, but they all have the same effect, which is to explain the phenomenon of irreversibility of nature.

Enthalpy

- **Enthalpy** is a measurement of energy
- It includes the internal energy (U), which is the energy required to create a system, and the amount of energy required to make room for it by displacing its environment and establishing its volume and pressure
- The enthalpy of a homogeneous system is defined as:

$$H = U + pV$$

where

H is the enthalpy of the system,

U is the internal energy of the system,

p is the pressure of the system,

V is the volume of the system

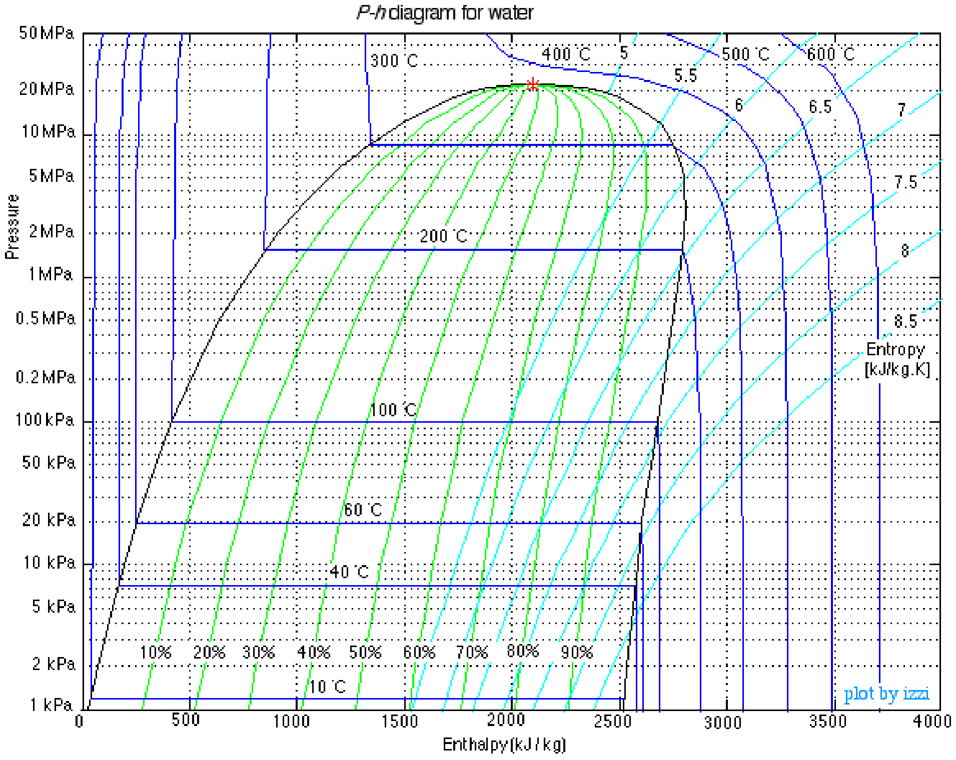
Heating Liquid Water

- Water is not a refrigeration fluid but it is familiar to everyone.
- Water will be used to illustrate the importance of using a change of phase from liquid to vapour and vice-versa to create an efficient refrigeration cycle.
- The SI unit of energy or of enthalpy is the Joule. We will use units of KiloJoules (KJ).
- To raise 1 kg of water from 10 degC to 100 degC (boiling point) requires us to add 1 * 4.219 * 90 = 379.71 KJ of energy (heat). Let’s call it 380 KJ.
- When just at the boiling point the liquid is said to be “saturated”.
- This energy is often called “sensible heat”.

Pressure/Enthalpy Diagram for Water

Absolute Pressure kPa
1 bara = 100 kPa

Standard Atmospheric Pressure



Enthalpy KJ/kg

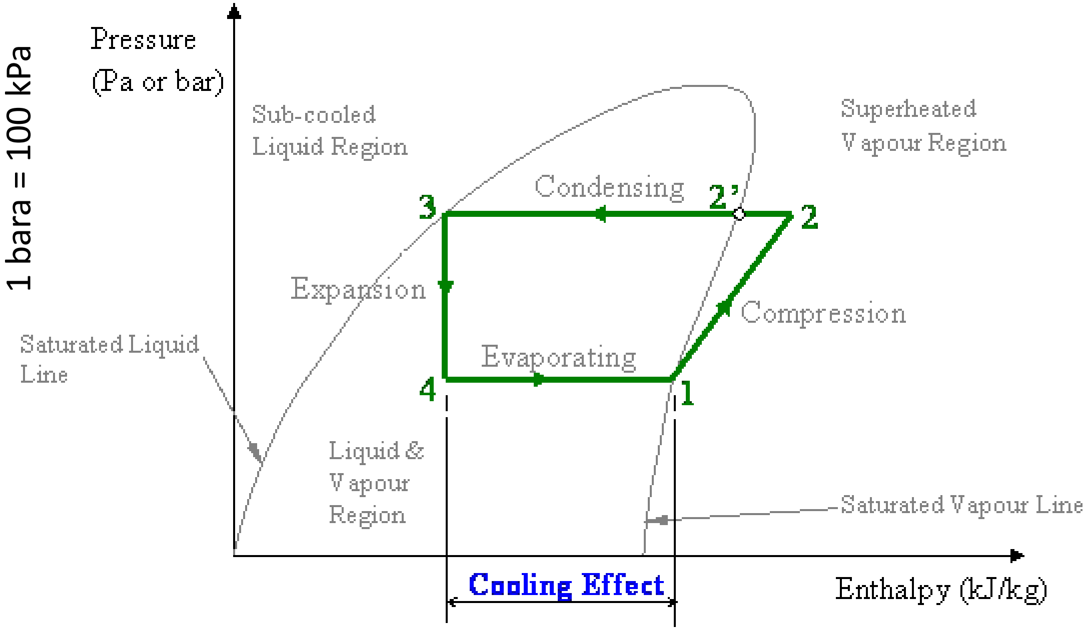
Source: https://www.ohio.edu/mechanical/thermo/property_tables/H2O/ph_water.html

Latent Heat of Water

- To change 1 kg of saturated liquid water at a pressure of 1.01325 bara (standard atmospheric pressure) to saturated water vapour requires (2675.8 – 419.1) KJ = 2256.7 KJ of additional energy.
- To recap: to heat liquid water from 10 degC to boiling point requires 380 KJ of energy.
- Therefore to change the phase of 1kg of water from saturated liquid to saturated vapour (the latent heat) requires nearly 6 times the energy required just to heat it from 10 degC to boiling point (the sensible heat).
- If saturated vapour is condensed to saturated liquid, this energy is released.
- If more heat is added to saturated vapour it becomes superheated and its temperature increases at the same pressure.

Qualitative PH Diagram of Refrigeration

Absolute Pressure kPa
1 bara = 100 kPa

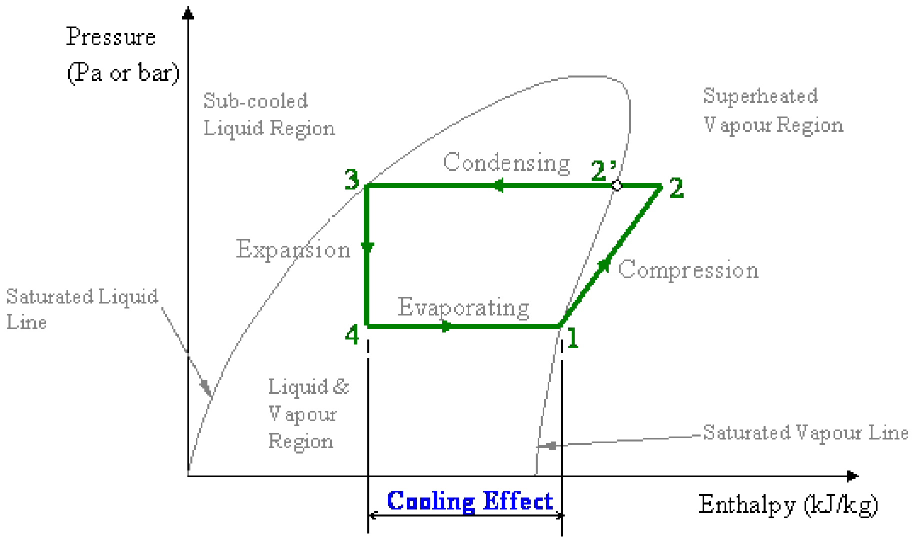


p-H Diagram of Refrigeration Cycle

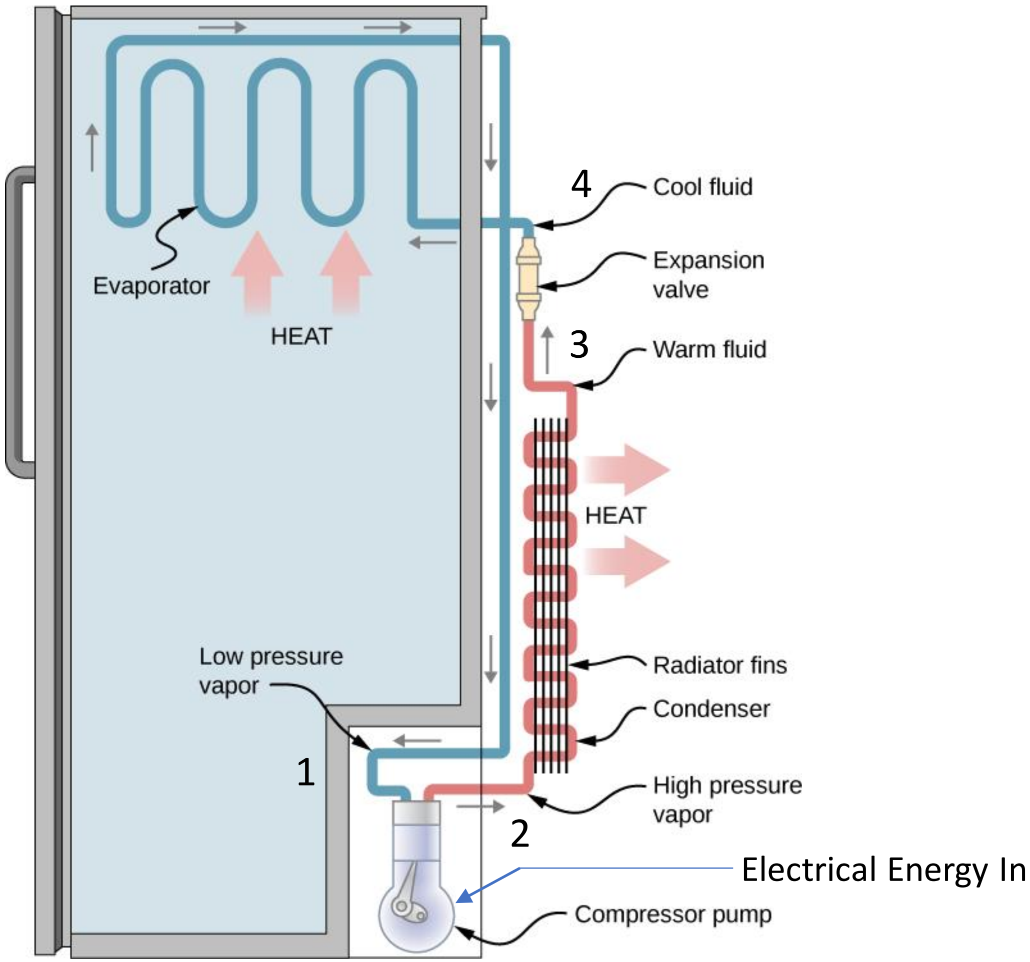
Enthalpy KJ/kg

Source: http://www.arca53.dsl.pipex.com/index_files/phrefrig.htm

Sideways View of a Domestic Refrigerator

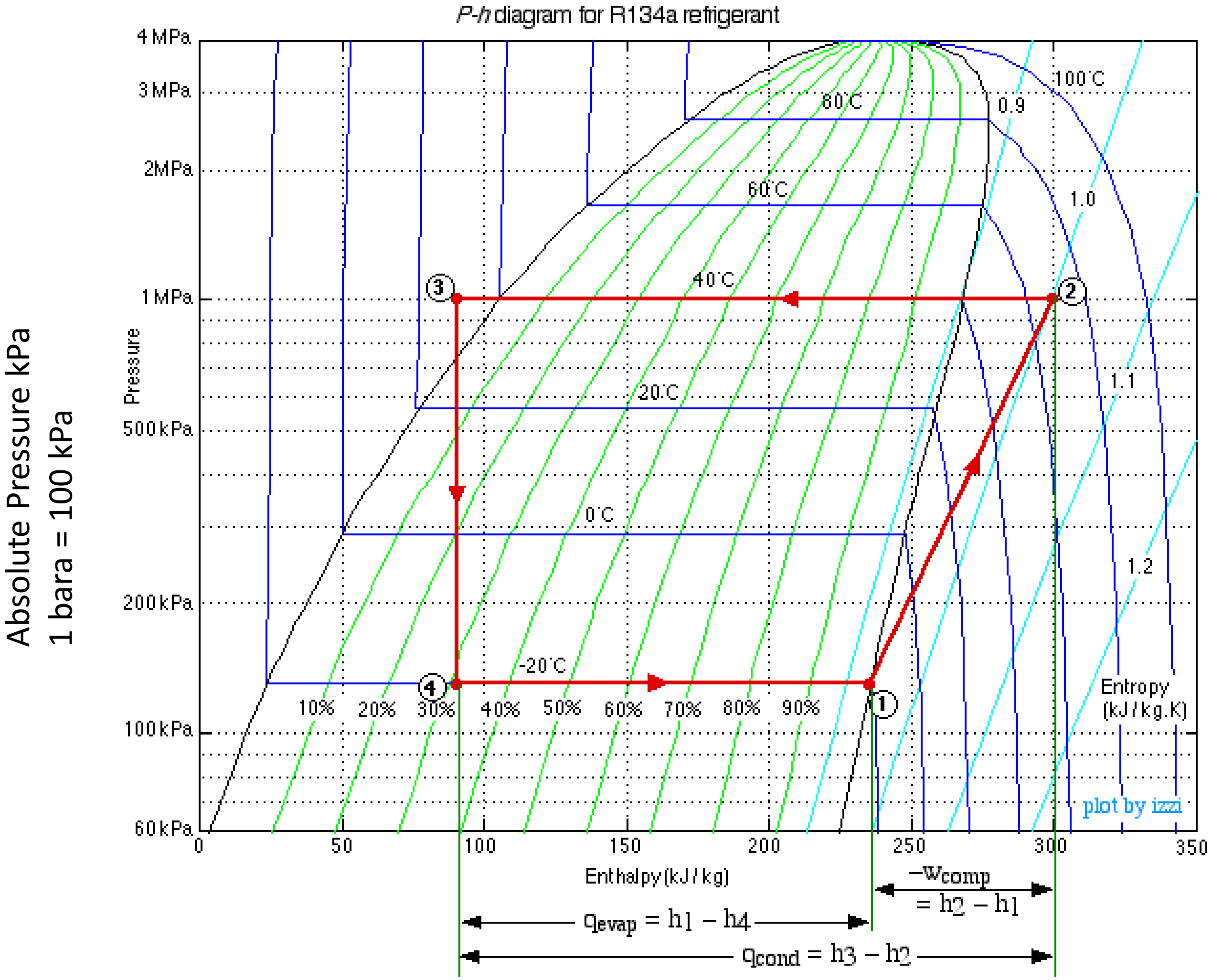


p-H Diagram of Refrigeration Cycle



Source:
https://phys.libretexts.org/TextMaps/General_Physics_Textmaps/Map%3A_University_Physics_(OpenStax)/Map%3A_University_Physics_II_(OpenStax)/4%3A_The_Second_Law_of_Thermodynamics/4.3%3A_Refrigerators_and_Heat_Pumps

Quantitative PH Diagram of Refrigeration



R134A Refrigerant
A Hydrofluorocarbon.
Tetrafluoroethane

Source: https://www.ohio.edu/mechanical/thermo/Intro/Chapt.1_6/Chapter4c.html

Fridges and Freezers

- For a freezer, the refrigeration cycle is designed to produce low temperatures of around -25 deg C.
- For a larder fridge (no ice box), the refrigeration cycle is designed to produce temperatures just above the freezing point of water (~ 3 deg C).
- For a fridge with a cold box or a fridge/freezer, the situation is more complex since there is normally only one (shared) compressor:
  - In most cases, the refrigeration cycle is designed to meet the needs of the freezer alone. Then cold air is bled out of the freezer area to cool the fridge area. This may also be done using a fan.
  - For more expensive fridge/freezers, there may be 2 solenoid valves on the evaporator (cooling coil) to control them separately.

Refrigeration Fluids (1)

- A refrigeration fluid should meet the following criteria:
  - Favourable thermodynamic properties (especially boiling point versus pressure).
  - Non-corrosive, non-toxic and non-flammable.
  - Not cause adverse environmental impacts if released.
- In the early days, sulphur dioxide, methyl chloride and ammonia were used. The first two are very toxic and were quickly dropped. Ammonia still exists in some industrial systems.
- CO2 is also used in industrial systems. It has some advantages but has to operate at very high pressures.
- From the 1950s onwards, Chlorofluorocarbons (CFCs) were the fluids of choice until their ozone depleting properties became known in the 1980s. CFC-12 (R12) was virtually ubiquitous in domestic fridges at this time. It is no longer used.
- Hydrochlorofluorocarbons (HCFCs) also deplete the ozone layer but to a lesser degree than CFCs. HCFCs have also been used as refrigerant fluids but their usage within the EU is now severely restricted.

Refrigeration Fluids (2)

- R134A (Tetrafluoroethane and the subject of the earlier quantified P-h diagram) is a HFC. It does not harm the ozone layer and can be used to replace CFC-12 (R12). However, thermodynamically it is inferior to R12. It also has a large Global Warming Potential and is being phased out. The AC system in my car uses R134A.
- Other fluids are in use but none is completely suitable for reasons of toxicity, flammability or environmental effects. For instance, our fridge at home uses R600A which is iso-butane and highly flammable.
- No perfect refrigerant fluid has so far been identified and research continues in this area to find better candidates.

Summary

- In simple terms you can think of refrigeration as follows:

1. It is effectively a "conveyor belt" for heat, whose motion is driven by the compressor. It collects heat from within the fridge and rejects it to atmosphere at the rear of the fridge.

2. It obeys the Laws of Thermodynamics and gets round the limitations of the 2^{nd} Law.

3. It exploits changes of phase of the refrigeration fluid and the resulting changes in latent heat to make the refrigeration process efficient.

Thank you.

Any Questions?