Multigas: Airconditioning Basics

Syllabus:
Components :
compressor, reciprocating piston type, swash plate type, vane type
metering device: expansion valve /condenser /evaporator
oil separator/ phase separator.
Accumulator down stream of evaporator.
Liquid receiver down stream of condenser for variable load metering devices
Reversing valve just upstream and downstream of compressor, that is switching the lines before and after compressor,

The refrigeration vapour compression Cycle

The refrigeration cycle in thermodynamics is actually considered as a reverse heat engine. Refrigeration is the reverse of the heat engine because in refrigeration work is inputted (in the form of rotation driven by electric motor driving the compressor) and the output is the movement of heat against the natural tendency. The natural tendency of heat is to move from a high temperature to a low temperature. Refrigeration/airconditioning is capable of moving heat from low temperature to a higher temperature, thus this is movement of heat against the natural tendency. If we can use water as the analogy, water moves naturally from high level to low level but if we want to move water from a low level to a high level we have to put energy input, for example in the form of rotation of a water pump. Therefore we also can appreciate why, correctly so, refrigeration /airconditioning is sometimes called Heat Pump. In reality the terminology refrigeration / airconditioning is used when the desired heat movement is that of extraction of heat from the low temperature reservoir, while the terminology heat pump is used when the desired heat is that of movement of heat into the higher temperature reservoir. So we need to appreciate that the reverse Heat cycle is the same for refrigeration/airconditioning or heat pump, it is what is the desired output that is different.

(The terminology reverse heat engine is correct because it also leads us to the fact that the processes are in reverse to those we have in the heat engine. That is the arrows are in the other direction, and overall the cycle has an anticlockwise rotation.) Thus the upper horizontal line becomes the condenser while the lower horizontal line becomes the evaporator. The principles found from the Carnot process, i.e that the levels of the horizontal lower and upper lines effect the performance are carried over to the refrigeration cycle. However here the gap in height between the two horizontal lines shows the difficulty to transfer heat upwards against the natural tendency (while in the heat engine the gap between the horizontal lines shows the potential of doing work).

The below above refrigeration/airconditioning or heat pump cycle is the most basic vapour compression cycle. Point 1 is the outlet of the evaporator, the working fluid is in vapour form at the saturation condition or slightly superheated. The process 12 is the compression of the vapour that happens in the compressor that is typically driven by the electrical motor. As a consequence of the compression process the pressure rises and so does the temperature. In refrigeration it is very important to always

remember that pressure and temperature are related, if the pressure is increased the temperature increases and also vice versa, if pressure is dropped the temperature drops. Thus the fluid at state 1, when pressurised to 2 ends up with a higher temperature that will be (or needs to be) higher than the heat sink. The fluid at temperature 2 then passes through the heat exchanger 23. The first portion of the heat exchanger drops the temperature of the fluid and brings the fluid down from the superheated condition to the dry saturated condition point 2b (i.e. the point where it hits the dome). The section 2b to 2c is the condenser where the fluid loses its latent heat, condenses and becomes completely liquid. So technically only the portion 2b to 2c is the condenser but in a real system the heat exchanger is a single part that offers the possibility to the working fluid to lose its heat to the sink and it is not possible (nor important) to actually see physically where point 2b or 2c is in the heat exchanger. Hence the whole heat exchanger from 2 to 3 is typically referred to as the condenser. The section 2c to 3 is the subcooling where the liquid is cooled lower than the saturation temperature. The fluid in liquid form at point 3 is still at the higher pressure level. The condenser is not a restrictive path to the fluid, it just offers the possibility to the fluid to reject heat to the sink. The fluid at point 3 is then made to expand down to the lower pressure and this expansion is what generates the drop in temperature. Hence if we consider refrigeration, the condenser will be hotter than the hot outside, while the evaporator will be colder than the cold inside. The evaporator is also a heat exchanger that provides the possibility to the working fluid to get the latent heat from the heat source. It is good to note that in the heat exchangers (condenser and evaporator) heat moves in the natural tendency. Thus in the condenser, the refrigerant has to be hotter than the heat sink for example the air outside of the building. On the other hand, in the evaporator, the refrigerant has to be colder than the cold inside air temperature.
The expansion process 34 is typically done using a capillary tube that acts as the restriction that results in a pressure drop. So it is good to appreciate that the drop in pressure happening across the capillary is 'fought' by the compressor. The term used in the expansion process that happens across the capillary is one that is practically adiabatic (because the capillary does not have much surface area) and no useful work is produced, thus it is referred to as constant enthalpy. The expansion device is also referred to as a throttling device. Throttling is the verb from the noun throttle, and it is good to associate the throttle as that part that restricts air flow into a typical petrol engine.

The compressor work is W_{12}

$$W_{12} = \dot{m}(h_2 - h_1)$$

The heat lost from the condenser is Q_{23}

$$Q_{23} = \dot{m}(h_2 - h_3)$$

The heat extracted by the evaporator from the cold chamber is Q_{14}

$$Q_{41} = \dot{m}(h_1 - h_4)$$

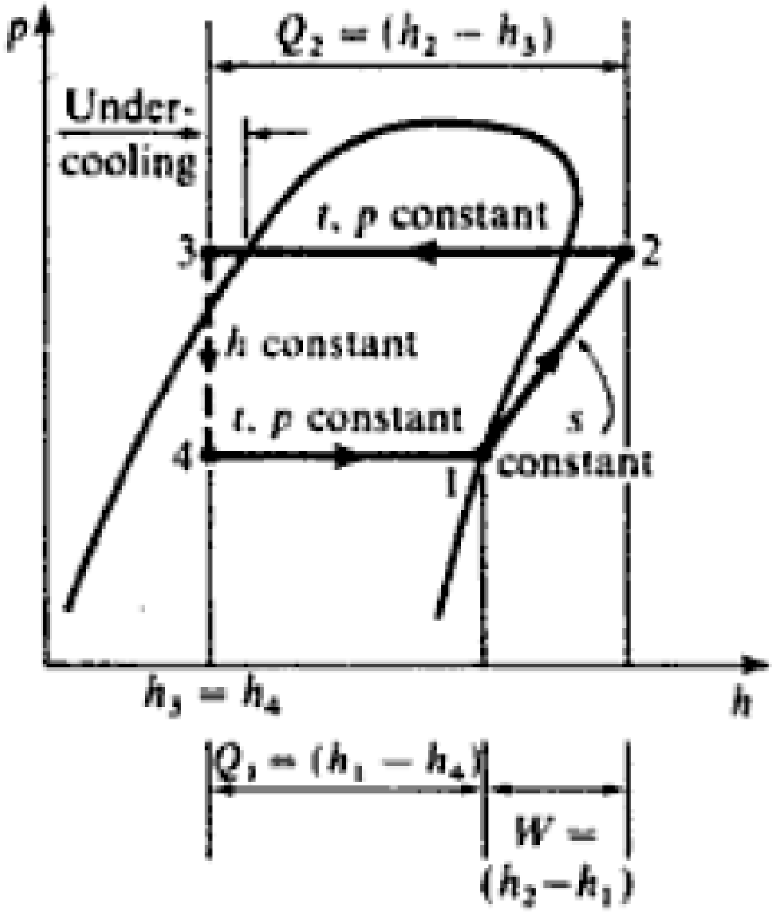


Figure 1

The ph diagram for R134a, very common in cars and also in refrigeration is shown next and then the same diagram with superimposed cycle for condenser at 40 deg C, evaporator at 5 deg C, 4 deg C of Subcooling and 3 deg C of superheat. From the diagram we can see what the pressure in the condenser and evaporator should be. That is around 3.5 bar and just over 10 bar. In reality, when trouble shooting or filling a system, the pressures are the mostly widely measured/used and the lower pressure is by far the more important because it immediately shows if there is loss of gas and it does not vary much with outside temperature. The condenser temperature and hence pressure do vary with outside temperature.

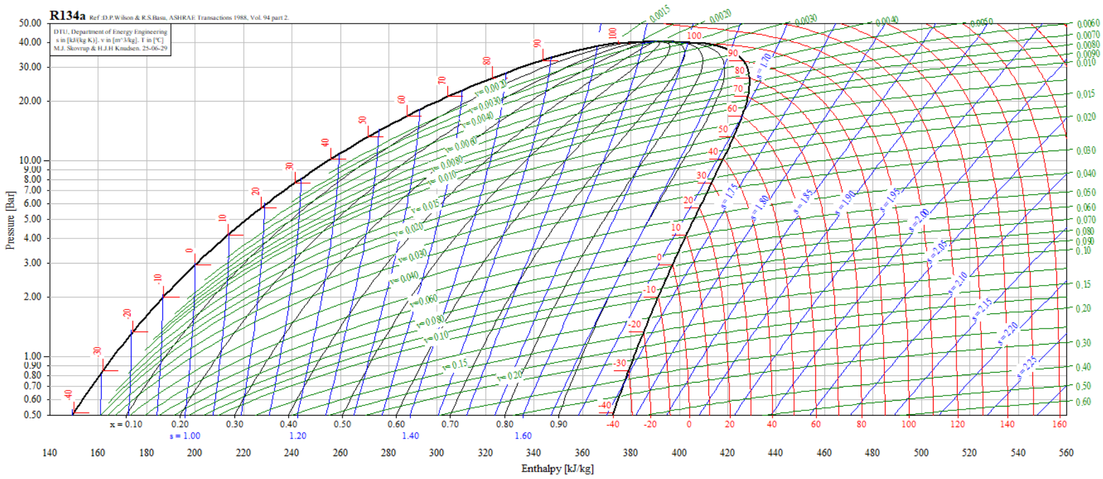


Figure 2

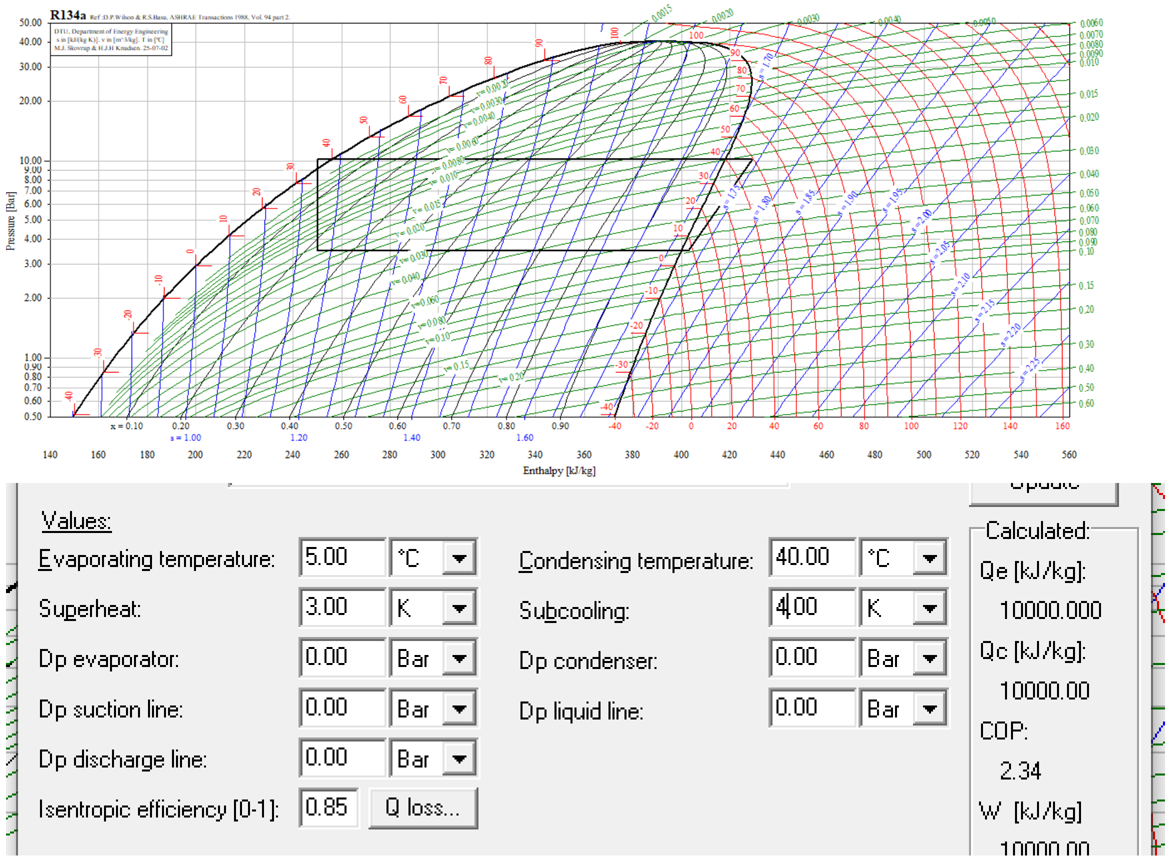
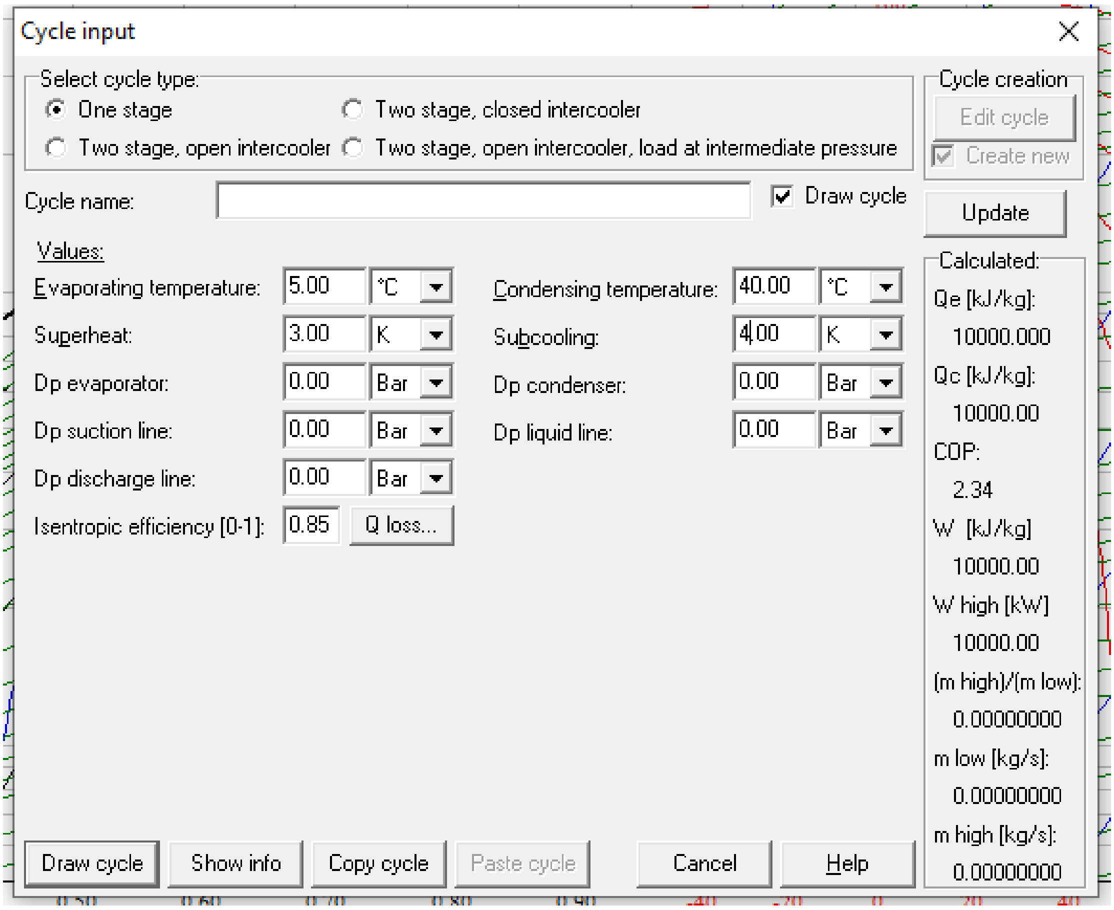


Figure 3



Full table of fig 3

The general or realistic diagram of the refrigeration will have a bit of superheat of the fluid upstream of the compressor and a little bit of subcooling downstream of the condenser. The superheat before the compressor is beneficial to make sure no liquid drops enter the compressor since liquid drops might damage the compressor as it has very low clearances and high compression ratio. While the subcooling in the condenser is beneficial because it lengthens the condensing line and the evaporation line.

As shown above the vapour compression cycle is beneficially drawn on a Pressure enthalpy diagram, ph diagram. Enthalpy, h, is a property that is introduced in thermodynamics because it better quantifies the amount of energy of a fluid in a flow process.
Enthalpy is not measurable by a meter but is calculated from three other properties, pressure p, internal energy u and specific volume v.

$$h = u + pv$$

However we do not really need to calculate h from u, p and v because typically we can find charts or programs that give us the value of h.

The ph diagram is in reality used very often in analysing refrigeration. The reason is that it has three straight lines and just one sloped line! And the points at the end of the processes are easy to pinpoint by means of easy to measure pressure and temperature.

The refrigeration cycle is very ‘efficient’ so much so that it is more than 100% efficient and therefore for refrigeration the terminology Coefficient of Performance is used COP.
The COP is the desired output divided by the Work Input.

So for refrigeration it is

$$Coefficient\ of\ Performance_{refrigeration} = \frac{Heat\ Extracted\ From\ Cold\ Side_{evaporator}}{Compressor\ Work\ Input}$$

While for Heat Pump, i.e. when the desired is the heating effect

$$Coefficient\ of\ Performance_{heat\ pump} = \frac{Heat\ Rejected\ By\ Hot\ Side_{condeser}}{Compressor\ Work\ Input}$$

As can be seen from the ph diagram sketch, the compressor work is smaller than the evaporator line hence the COP refrigeration is bigger than 1, typically 3 or 4.
Also the condenser line is longer than the evaporator line, hence the COP heat pump mode is even bigger than the COP refrigeration mode.

Psychrometric Chart

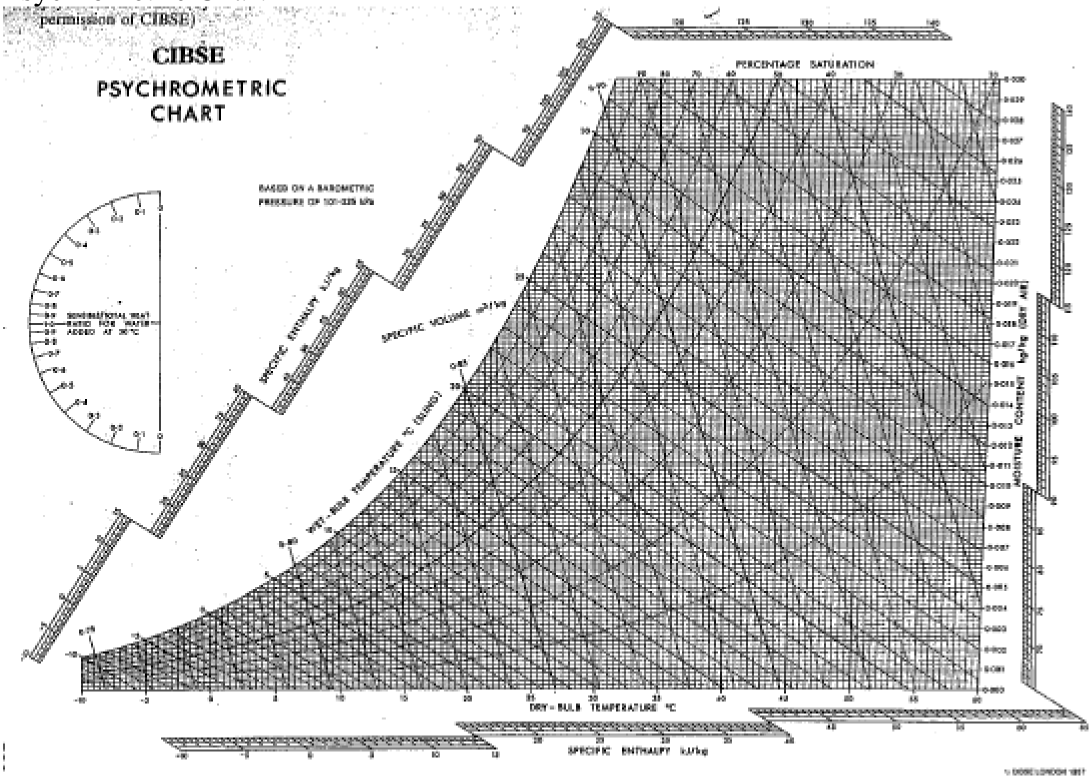


Figure 4

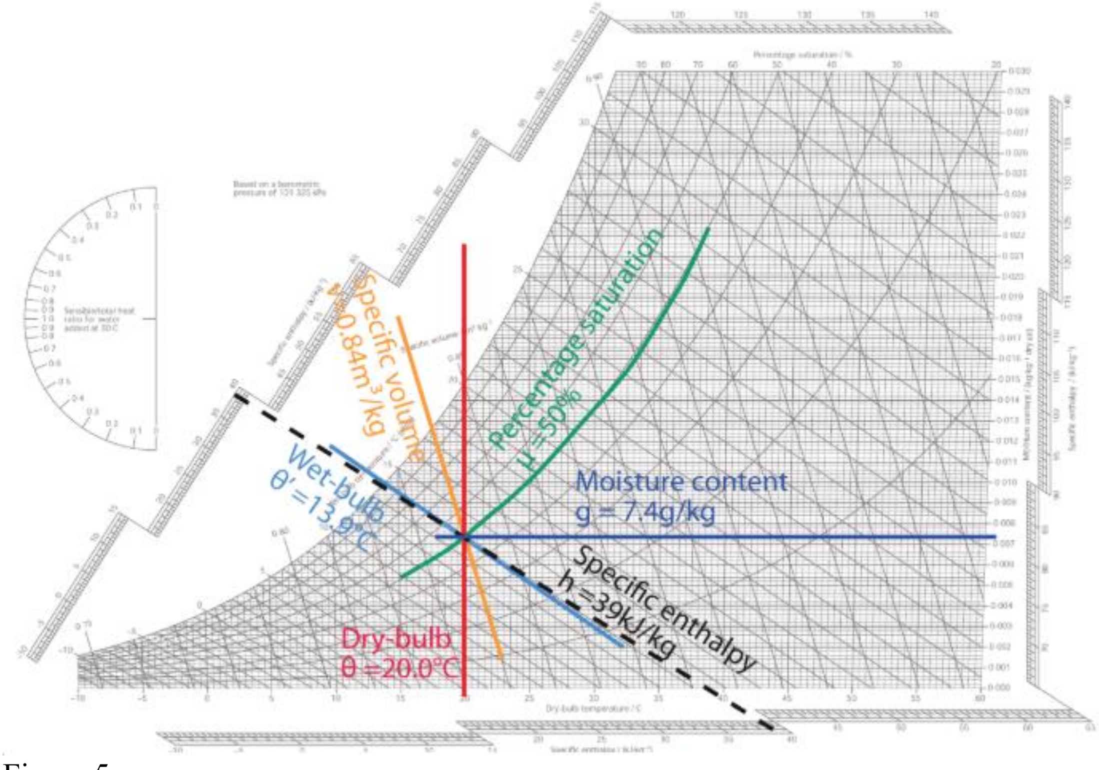


Figure 5

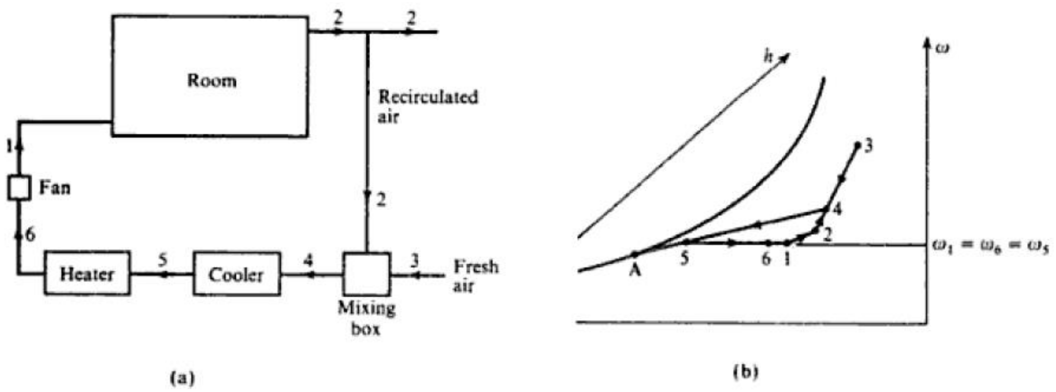


Fig. 15.6 Summer air-conditioning system (a) with the processes on a psychrometric chart (b)

A mass balance of the moisture gives

$$r\omega_2 + (1 - r)\omega_3 = \omega_4$$

Figure 6