Pearson BTEC Level 5 Higher Nationals in Engineering (RQF)

Unit 63: Industrial Services

Unit Workbook 4

in a series of 4 for this unit

Learning Outcome 4

Refrigeration & Heat Pumps

Contents

INTRODUCTION

Review industrial refrigeration and heat pump systems.

- *Heat Pumps and Refrigeration:*
    - Typical industrial heat pump and refrigeration systems.
    - Application of the second law of thermodynamics.
    - Reversed heat engines: reversed Carnot cycle.
    - Vapour compression cycle.
    - Refrigerant fluids: environmental impact.
    - Refrigeration tables and charts (p-h diagrams).
    - Coefficient of performance for heat pumps and refrigerators.

GUIDANCE

This document is prepared to break the unit material down into bite size chunks. You will see the learning outcomes above treated in their own sections. Therein you will encounter the following structures;

Purpose

Explains *why* you need to study the current section of material. Quite often learners are put off by material which does not initially seem to be relevant to a topic or profession. Once you understand the importance of new learning or theory you will embrace the concepts more readily.

Theory

Conveys new material to you in a straightforward fashion. To support the treatments in this section you are strongly advised to follow the given hyperlinks, which may be useful documents or applications on the web.

Example

The examples/worked examples are presented in a knowledge-building order. Make sure you follow them all through. If you are feeling confident then you might like to treat an example as a question, in which case cover it up and have a go yourself. Many of the examples given resemble assignment questions which will come your way, so follow them through diligently.

Question

Questions should not be avoided if you are determined to learn. Please do take the time to tackle each of the given questions, in the order in which they are presented. The order is important, as further knowledge and confidence is built upon previous knowledge and confidence. As an Online Learner it is important that the answers to questions are immediately available to you. Contact your Unit Tutor if you need help.

Challenge

You can really cement your new knowledge by undertaking the challenges. A challenge could be to download software and perform an exercise. An alternative challenge might involve a practical activity or other form of research.

Video

Videos on the web can be very useful supplements to your distance learning efforts. Wherever an online video(s) will help you then it will be hyperlinked at the appropriate point.

1.1.5 Refrigerant Fluids: Environmental Impact

Typical refrigerant fluids usually have aa severely negative environmental impact, they contribute significantly to the depletion of ozone and an increase in the greenhouse effect. In terms of the greenhouse effect, a rating for refrigerants has been developed to compare how much of an impact they have when compared with carbon dioxide. The Global Warming Potential (GWP) rating indicates how much heat any gas may trap in the atmosphere, using carbon dioxide as a basis, i.e. carbon dioxide has a GWP rating of 1.

There is also another rating which is commonly used, this is the Ozone Depletion Potential (ODP), this system of rating compares any chemical with trichlorofluoromethane (known as CFC-11) in terms of how much it causes the ozone layer to degrade, CFC-11 has an ODP rating of 1.

There are several different types of refrigerants that could potentially be used, they are:

Chlorofluorocarbons (CFCs): This particular type of refrigerant is inexpensive, unreactive, has low toxicity and boiling point, whilst it is relatively easy to store and carries no fire risk. However, it does contain fluorine which means that it is ozone depleting and a greenhouse gas, therefore harmful to the environment. All CFC stock worldwide will be eliminated by the year 2020.

Hydrochlorofluorocarbons (HCFCs): This type of refrigerant was meant as the replacement for CFCs because it depletes the ozone at a much slower rate, however it does still add to depletion and is a harmful greenhouse gas which contributes to an atmospheric chlorine accumulation. HCFCs are currently being phased out of use.

Hydrofluorocarbons (HFCs): This particular form of refrigerant depletes ozone significantly less than CFCs and HCFCs, however they have a high GWP rating.

Natural Refrigerants: Unlike the previously described synthetic refrigerants, it is entirely possible to use naturally occurring fluids, such as water, carbon dioxide, ammonia and some hydrocarbons. These hydrocarbons do contain carbon dioxide, however, as stated, this only has a GWP rating of 1, compared to HFCs and HCFCs whose GWPs are into the thousands. Currently, natural refrigerants are the most environmentally friendly options available.

1.1.6 Refrigeration Tables and Charts (p-h Diagrams)

There are many different refrigerants in common use today, all of which have unique properties and behave in different ways under varying conditions. These properties have been measured and recorded in refrigerant reference tables and charts, which can be easily accessed online, or hard copies attained.

Another way of recording refrigerant behavioural properties is to use a p-h diagram (pressure-enthalpy), which is simply a graph with pressure on the 'y' axis and enthalpy on the 'x' axis. The four stages of evaporation, compression, condensation and expansion can then be represented on such a graph to show how those properties change over the course of the system cycle.

The following video offers an excellent explanation of p-h diagrams and their general use:

Video

https://www.youtube.com/watch?v=u3ixfkzqfMM

In terms of refrigerants, the following video gives an explanation of how the points on a p-h diagram corresponding to the stages of the refrigerant cycle:

Video

https://www.youtube.com/watch?v=eNfgYZCfyE8

Looking at a simple p-h diagram for a common refrigerant call R134a (Tetrafluoroethane), such as the below:

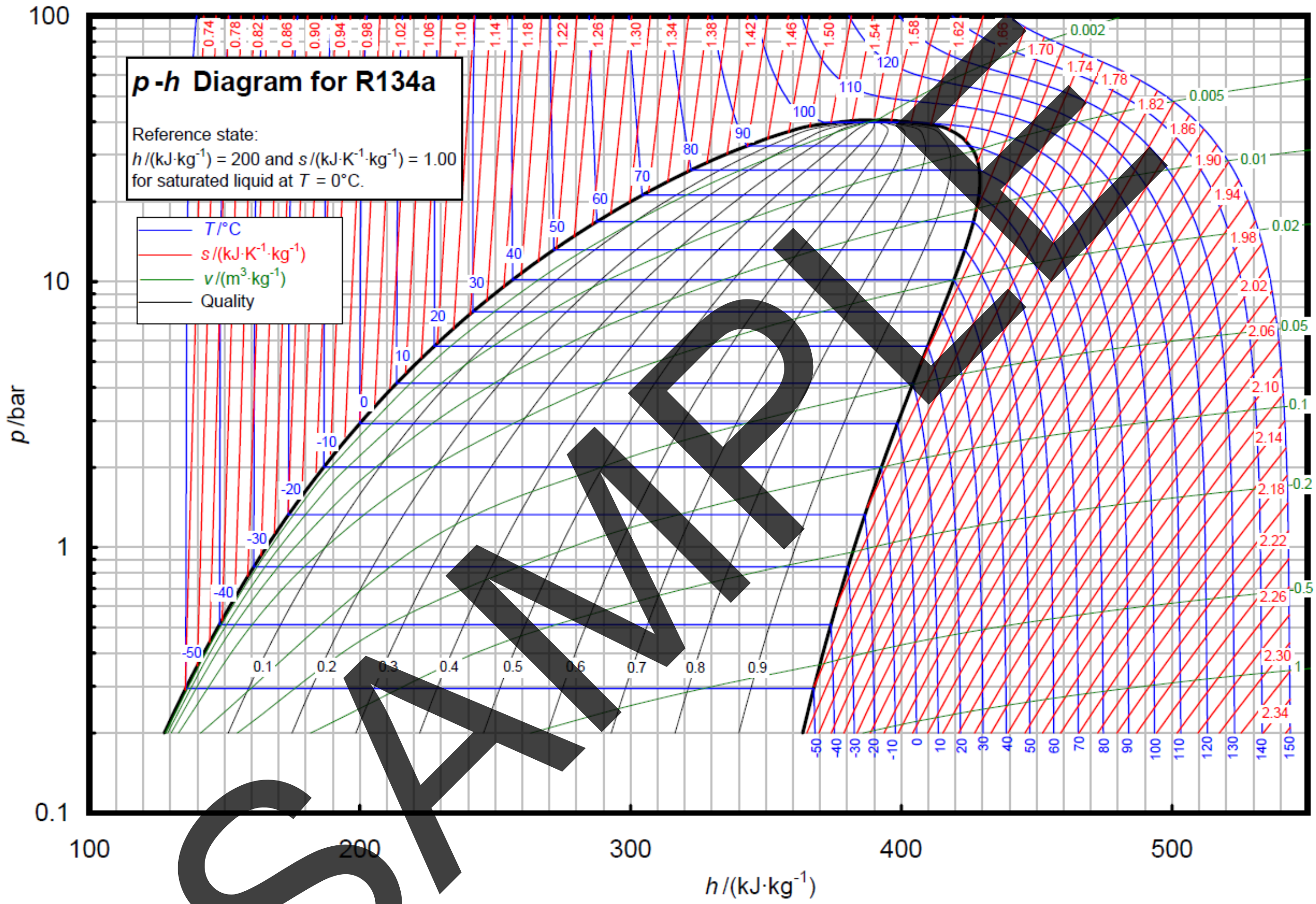

Figure 1.3: *R134a p-h Diagram*

By examining either this diagram or the properties charts for R134a, we are able to determine certain properties:

The 2-phase envelope can be highlighted on the diagram which shows the boundary of the saturated states of the refrigerant. The critical point on the diagram may also be shown, which is the temperature point at which above, the refrigerant cannot be condensed, no matter the pressure, it also signifies the point at which the saturated liquid curve and saturated vapour curve meet.

These items can be seen on the diagram below:

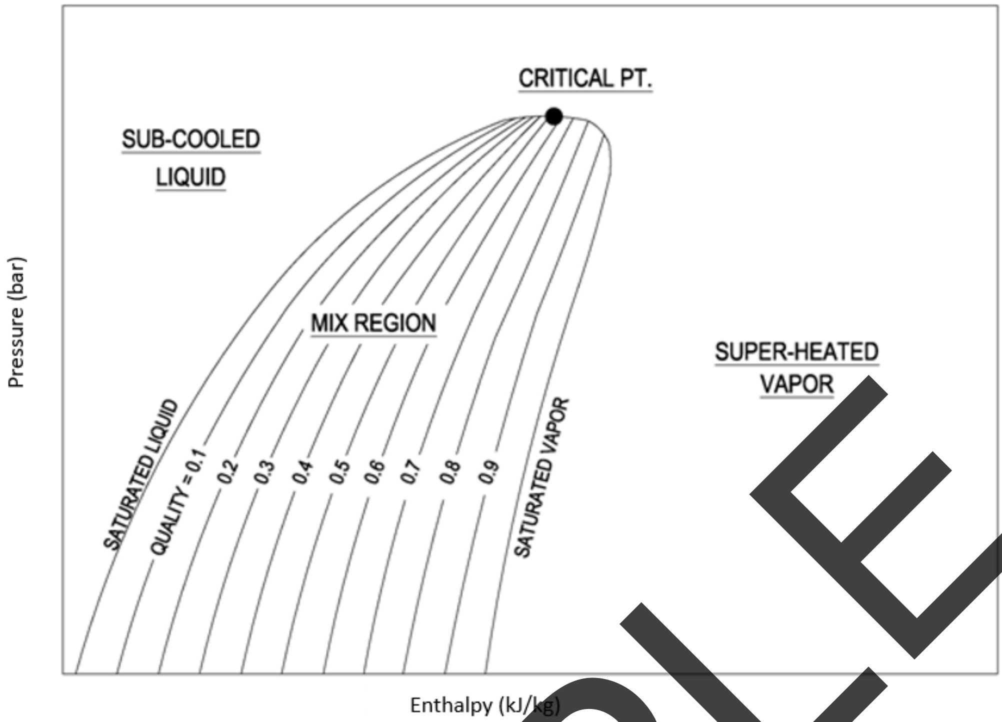

Figure 1.4: *2-Phase Envelope & Critical Point*

We may also identify properties of the refrigerant based on some given aspects, for example: we may highlight the path of a specific temperature, let us take 10°C as an example and show this path, known as an isotherm, on the R134a p-h diagram:

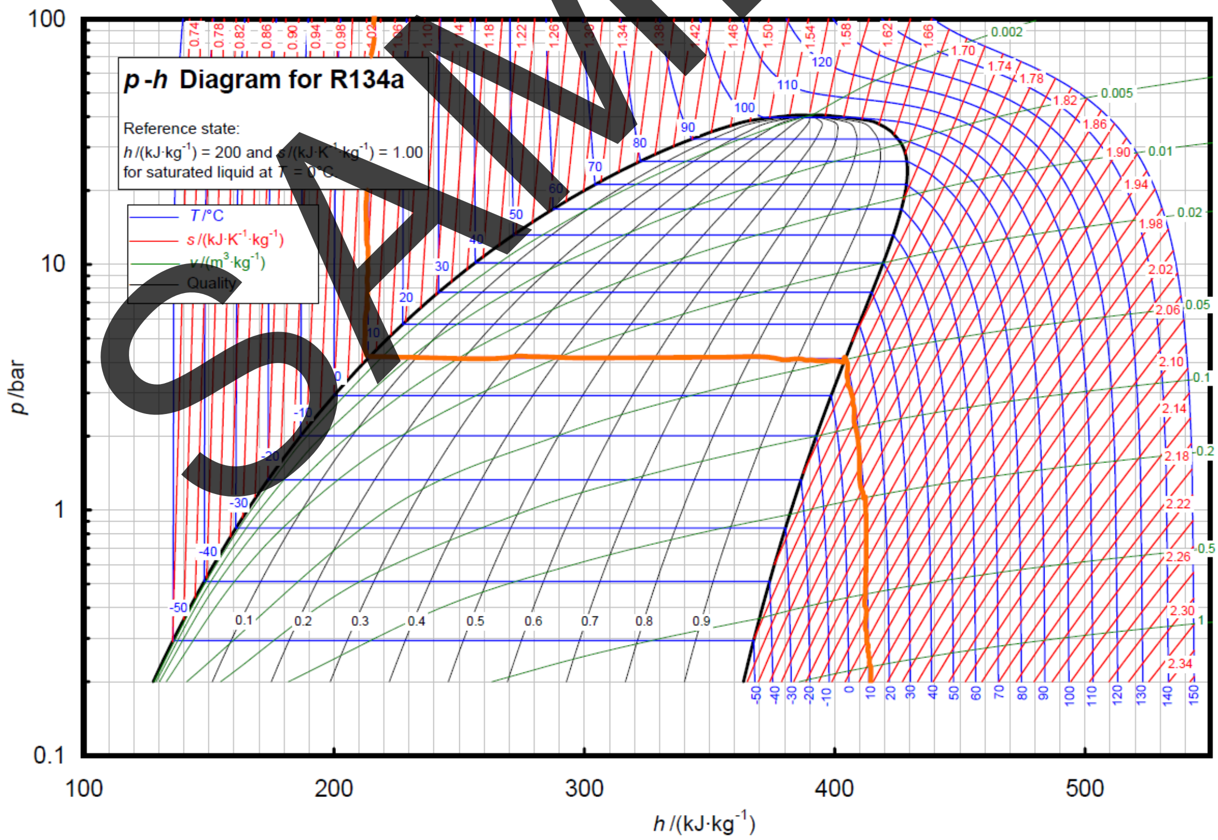

Figure 1.5: *Highlighted 10°C Isotherm*

1.1.7 Coefficient of Performance (COP)

We are now going to consider a worked example of a refrigeration cycle, in order to determine is refrigeration effect and coefficient of performance. The refrigeration effect is defined as the amount of heat that the refrigerant absorbs from the refrigerated space in order to produce useful cooling, normally measured per unit mass. The coefficient of performance is the ratio of refrigeration effect to work done, i.e. it is the heat removed from the cold reservoir divided by the work done to remove the heat.

Before we begin this example, it is useful to familiarise yourself with **linear interpolation**. This is simply a method of finding an unknown value, given some known values either side of the unknown. For an explanation and online calculator see the following link: https://ncalculators.com/geometry/linear-interpolation-calculator.htm. N.B. click the 'Generate Work' button on the website to get the final answer:

Example

A refrigeration system consists of four main components, an evaporator, compressor, condenser and expansion valve. The compressor which has been purchased from an external supplier has a stated mass flow rate of 2.5 kg/s, with suction pressure of 340 kPa and produces a pressure of 1000 kPa. The refirgerant which is going to be used in this system is R134a.

By determining the properties at each stage of this system, you must calculate its refirgeration effect and coefficient of performance (COP). The system is represented in the circuit below, with states 1-4 labelled:

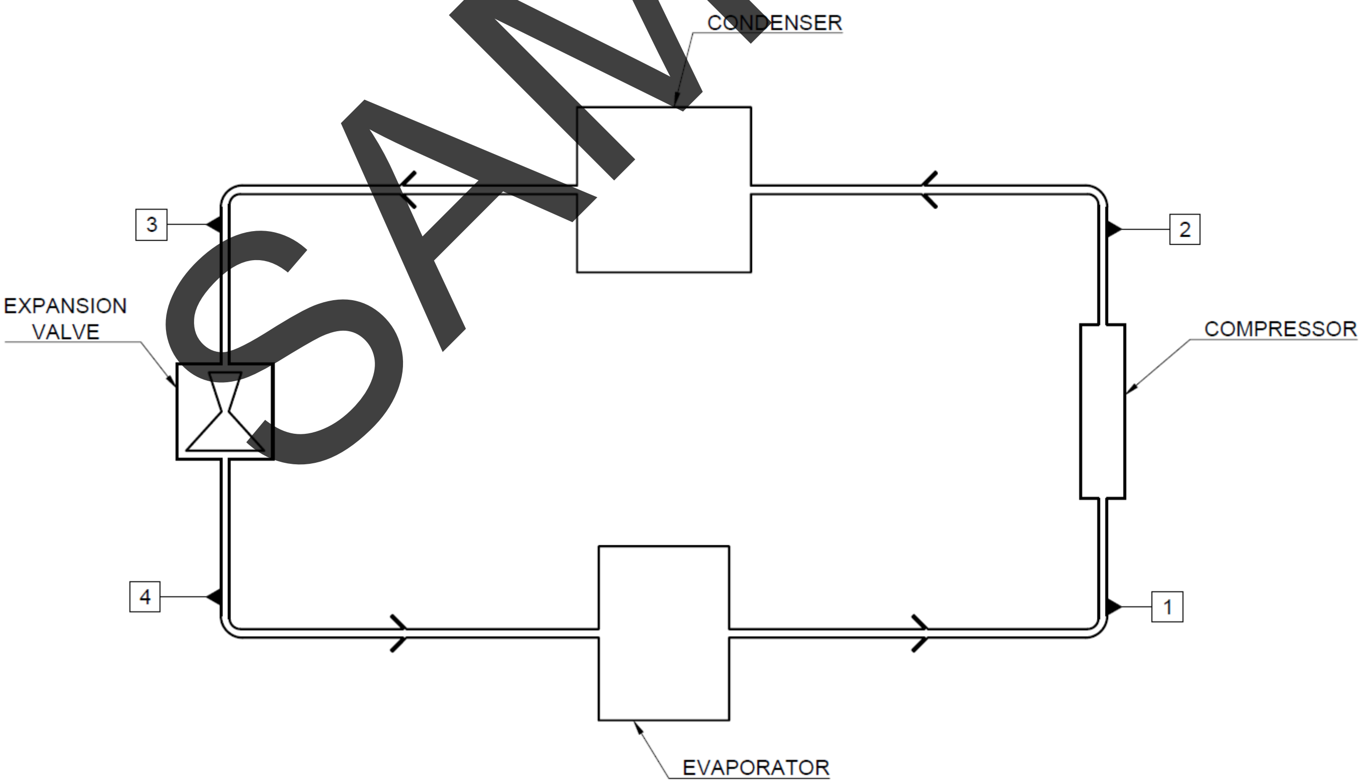

Figure 1.8: *Simplistic Refrigeration Circuit*

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We may assume that the refrigeration cycle is reversible and ideal and can be simply represented on a p-h diagram as follows:

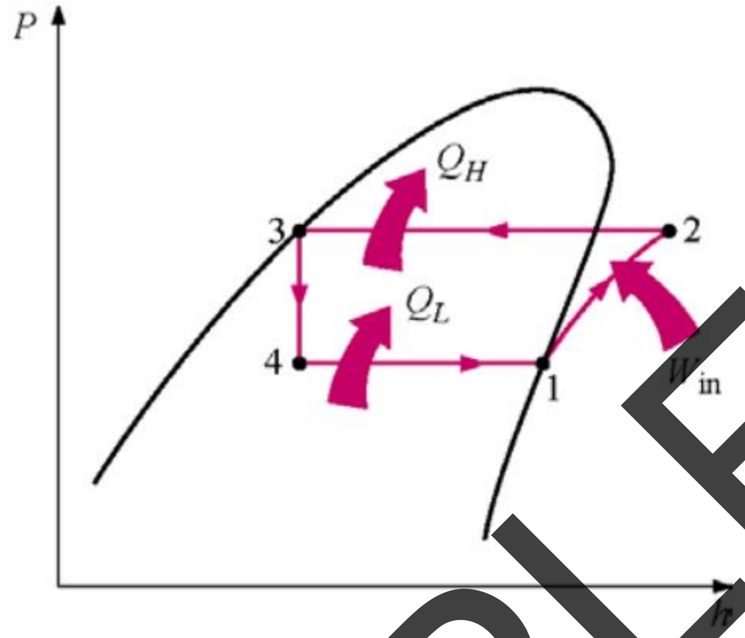

Figure 1.9: *Refrigeration p-h Diagram*

In addition to the pressure-enthalpy diagram, a temperature-entropy diagram may also be utilised and is represented below:

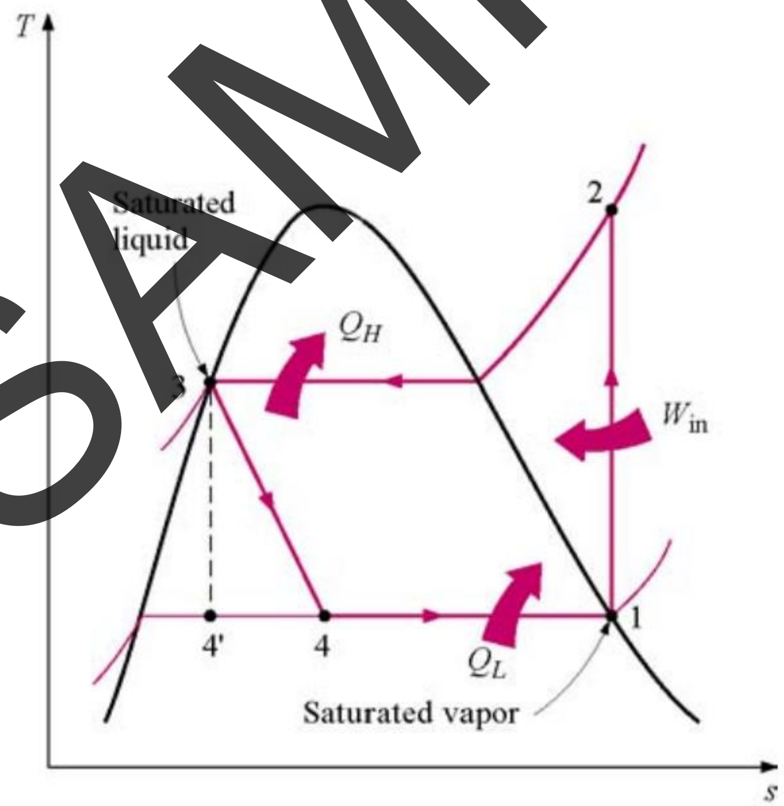

Figure 2.1: *Refrigeration T-s Diagram*

It is useful to specify what we know about each state at this point in the example, we can logically look at the system as well as the accompanying diagrams to determine some properties:

State 1: Between evaporator and compressor, the refrigerant has just been entirely evaporated so is a saturated vapour, its quality is therefore 100% (x=1). We are also told that the compressor suction pressure is 340 kPa and we can confirm from the diagrams that it is at a relatively low pressure as well as being at a low temperature.

State 2: After the compressor and before the condenser, we can logically assume that the refrigerant is going to be at a higher pressure, and we know this to be true because we are also told that the compressor produces 1000 kPa of pressure. We can also tell that this point is at a high temperature and is beyond the saturated vapour line, in fact it is situated in the superheated vapour region, therefore the quality is unknown. The entropy is the same as at state 1.

State 3: After the condenser and before the expansion valve we can tell that the refrigerant is now condensed to the point of being a saturated liquid, i.e. quality is 0% (x=0), from the diagrams we can also see that the temperature is medium and the pressure remains the same as at state 2.

State 4: We can see that the refrigerant has exited the expansion valve and is about to enter the evaporator, the diagrams show us that it is within the 2-phase envelope so we do not know the quality but we know it is a mixture of liquid and vapour. Looking at the diagrams, we can see that the pressure is low, as we would expect after having gone through an expansion valve, we can also see that the temperature is low and the same as at state 1. The enthalpy is the same as at state 3.

Let us now consider each state and determine their properties by examining a properties table for R134a:

At state 1: we look in the saturated refrigerant section for a 340 kPa pressure saturated vapour:

Pressure	Temperature	Specific volume (m^3/kg)		Enthalpy (kJ/kg)		Entropy (kJ/kg.K)	
kPa	°C	Sat Liq vf	Sat Vap vg	Sat Liq hf	Sat Vap hg	Sat Liq sf	Sat Vap sg
320	2.5	0.0007773	0.0636	55.2	251.9	0.2165	0.9301
340	4.2	0.0007808	0.0600	57.5	252.9	0.2248	0.9293
360	5.8	0.0007842	0.0567	59.8	253.8	0.2328	0.9284

For the purposes of this example, we do not need to know the specific volume at any state. However, let us note down the other useful property values:

T_1=4.2 °C, h_1=252.9 kJ/kg, s_1=0.9293 kJ/kg K