UNIVERSITY OF LINCOLN

EGR3030 – Energy systems and conversion 24/25

Basic refrigeration, heat pumps, and air conditioning

Dr Aliyu Aliyu

Aaliyu@lincoln.ac.uk, Room: INB3204

Reference text: Thermodynamics an Engineering Approach by Yunus Cengel (chapter 11)

Outline

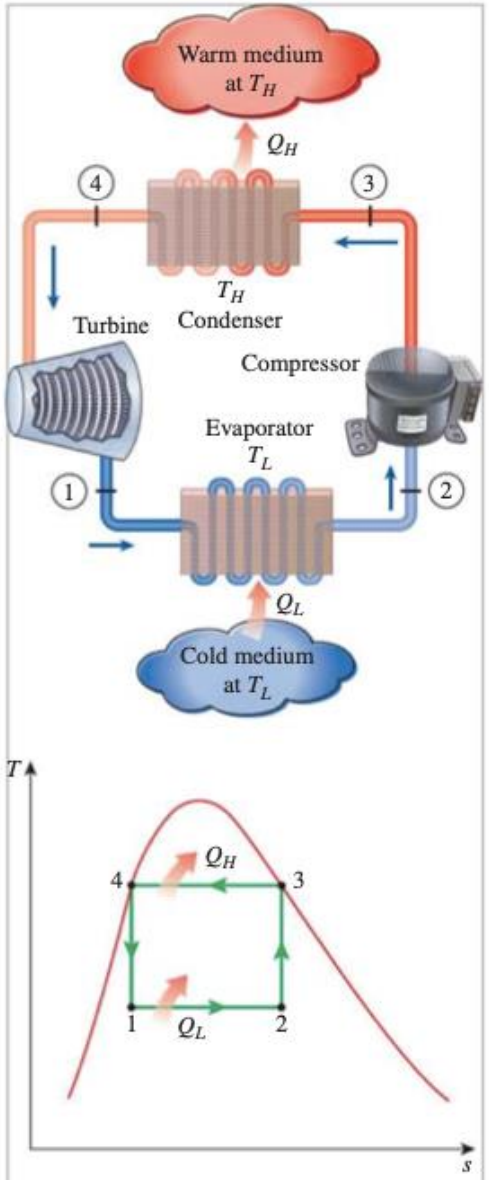
- Introduce the concepts of refrigerators and heat pumps and the measure of their performance.
- Analyse the vapour-compression refrigeration cycle (ideal & real)
- Discuss the operation of refrigeration and heat pump systems.

Refrigeration

- Refrigeration is the transfer of heat from a lower-temperature region to a higher- temperature one.
- Devices that produce refrigeration are called refrigerators. Cycles on which they operate are called refrigeration cycles.
- The most frequently used refrigeration cycle is the vapor-compression refrigeration cycle in which the refrigerant is vaporised and condensed alternately and is compressed in the vapor phase.

Reversed Carnot cycle

- The Carnot cycle is a totally reversible cycle that consists of two reversible isothermal and two isentropic processes.
- It has the maximum thermal efficiency for given temperature limits, and it serves as a standard against which actual power cycles can be compared.
- Reversing the Carnot cycle also reverses the directions of any heat and work interactions. The result is a cycle that operates in the anti-clockwise direction on a *T-s* diagram.
- A refrigerator or heat pump that operates on the reversed Carnot cycle is called a **Carnot refrigerator** or a **Carnot heat pump**.



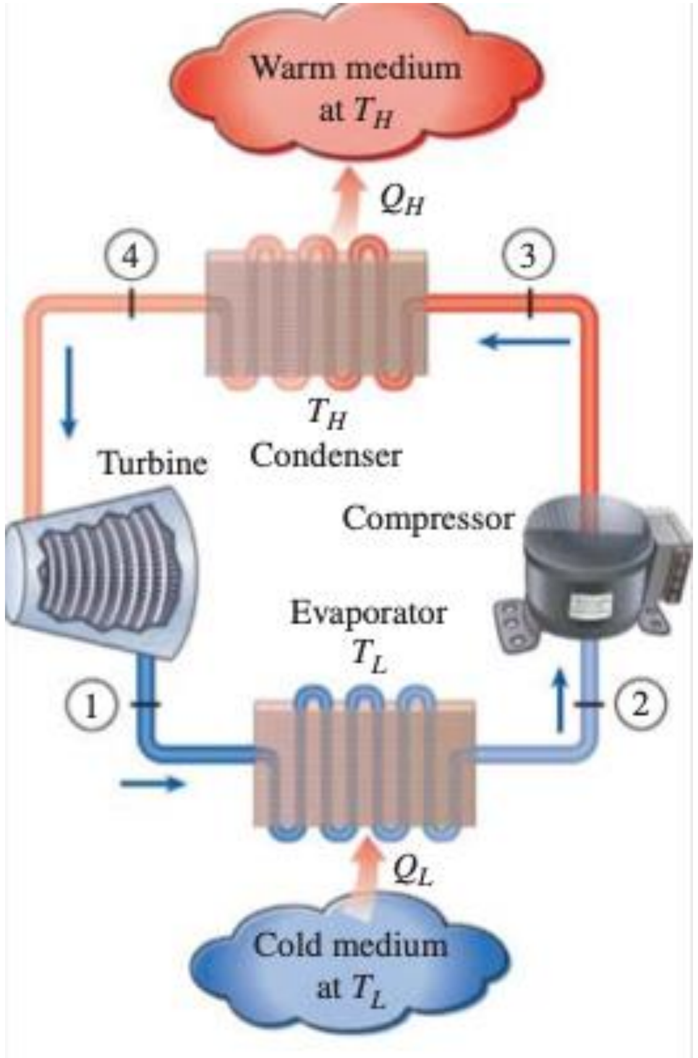
Reversed Carnot cycle cont.

- The coefficients of performance of Carnot refrigerators and heat pumps are expressed in terms of temperatures as

$$COP_{R,Carnot} = \frac{cooling\ effect}{work\ input} = \frac{1}{T_H/T_L - 1}$$

$$COP_{HP,Carnot} = \frac{heating\ effect}{work\ input} = \frac{1}{1 - T_L/T_H}$$

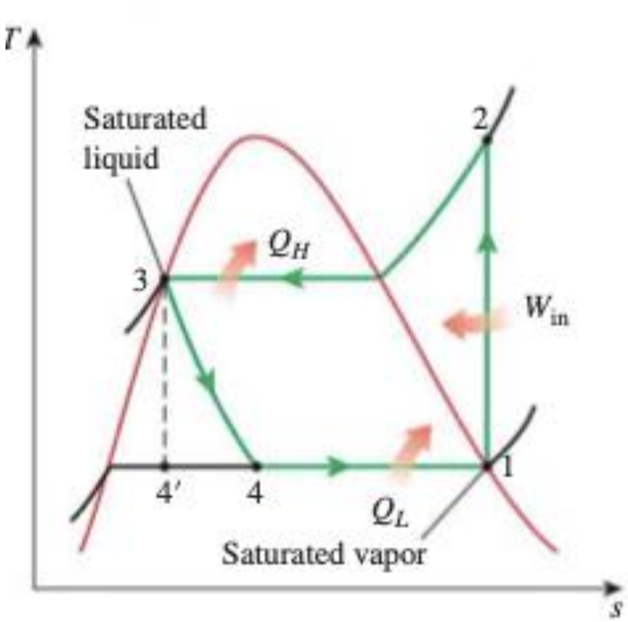
- Both COPs increase as the difference between the two temperatures decreases, that is, as TL rises or TH falls.
- Process 2-3 involves the compression of a liquid–vapor mixture, which requires a compressor that will handle two phases, and process 4-1 involves the expansion of high-moisture-content refrigerant in a turbine.
- Hence, the Carnot cycle is not a suitable model for refrigeration cycles, and cannot be achieved in practice

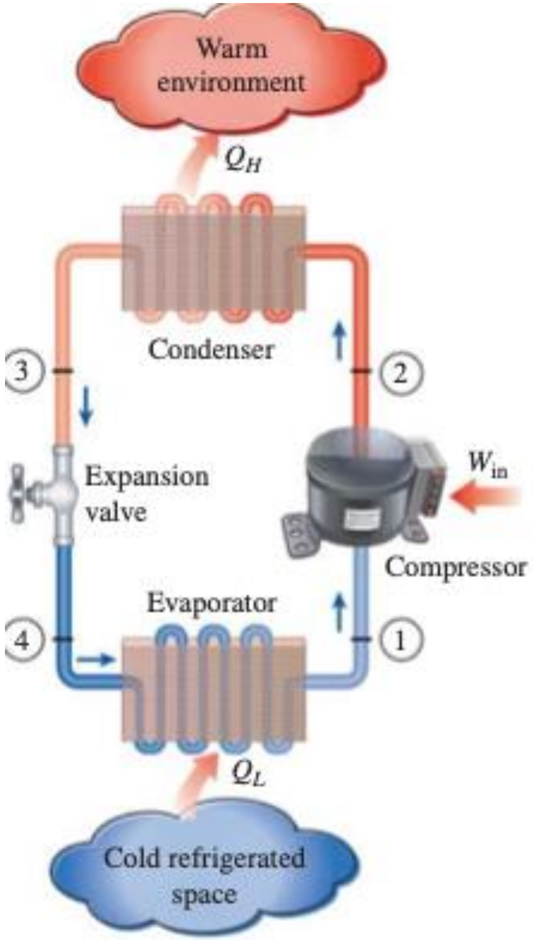


The ideal vapour-compression refrigeration cycle

Many of the impracticalities associated with the reversed Carnot cycle can be eliminated by vaporising the refrigerant completely before it is compressed and by replacing the turbine with a throttling device, such as an expansion valve

- The vapour-compression refrigeration cycle is the most widely used cycle for refrigerators, air-conditioning systems, and heat pumps. It consists of four processes:
  - 1-2 Isentropic compression in a compressor
  - 2-3 Constant-pressure heat rejection in a condenser
  - 3-4 Throttling in an expansion device
  - 4-1 Constant-pressure heat absorption in an evaporator
- A rule of thumb is that the *COP improves by 2 to 4 percent for each °C the evaporating temperature is raised or the condensing temperature is lowered.*

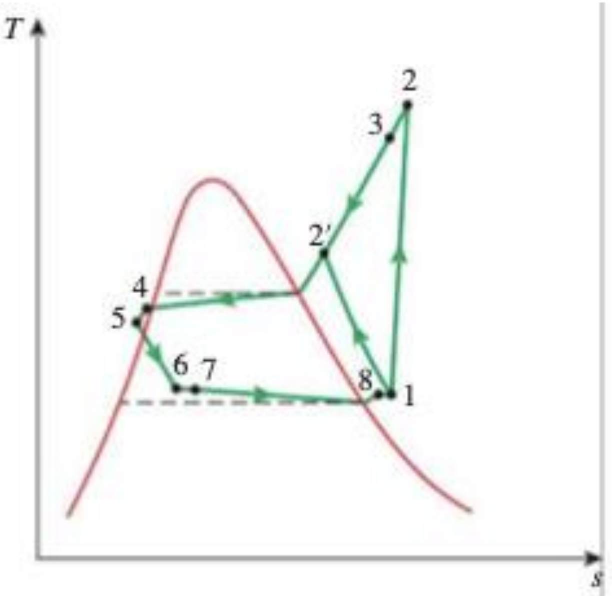


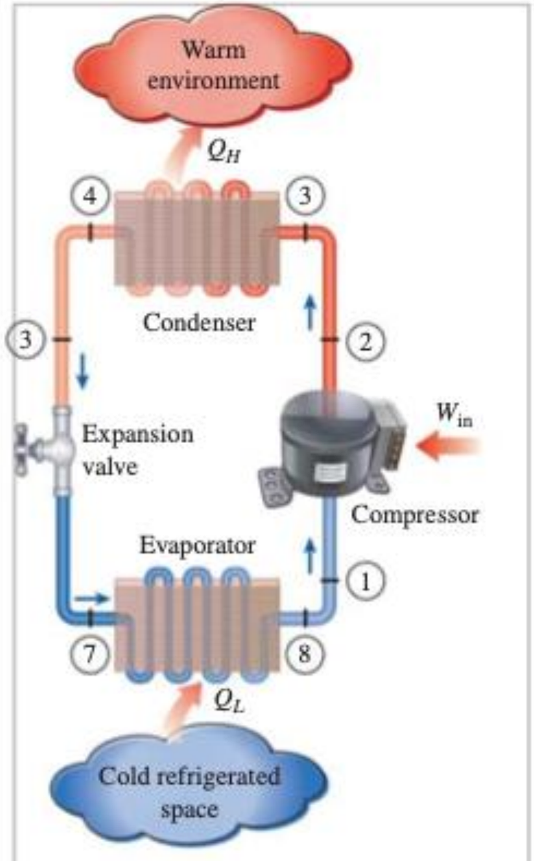


Actual vapour compression refrigeration cycle

- An actual vapor-compression refrigeration cycle differs from the ideal one in several ways, due mostly to the irreversibilities that occur in various com- ponents.
- Two common sources of irreversibilities are fluid friction (causes pressure drops) and heat transfer to or from the surroundings.

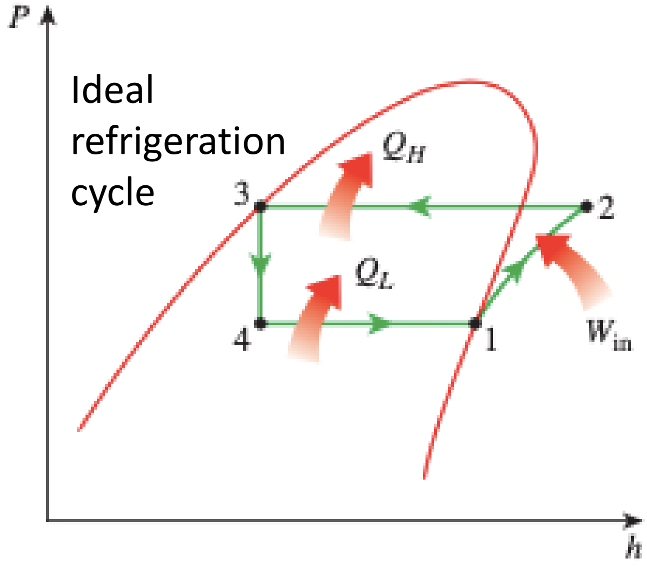
- In the actual cycle, the refrigerant is slightly superheated at the compressor inlet. This slight overdesign ensures that the refrigerant is completely vaporised when it enters the compressor.
- Secondly, in the ideal case, the refrigerant is assumed to leave the condenser as *saturated liquid* at the compressor exit. In reality, there is pressure drop in the condenser as well as in the connecting lines between the condenser, compressor and throttling valve.
- Hence, the refrigerant is somewhat subcooled before entering the throttling valve. The throttling valve and evaporator are usually located very close to each other, to minimise the pressure drop in the connecting line





The P-h diagram

The P-h diagram often used in the analysis of vapor-compression refrigeration cycles is the *P-h* diagram. On this diagram, three of the four processes appear as straight lines, and the heat transfer in the condenser and the evaporator is proportional to the lengths of the corresponding process curves.

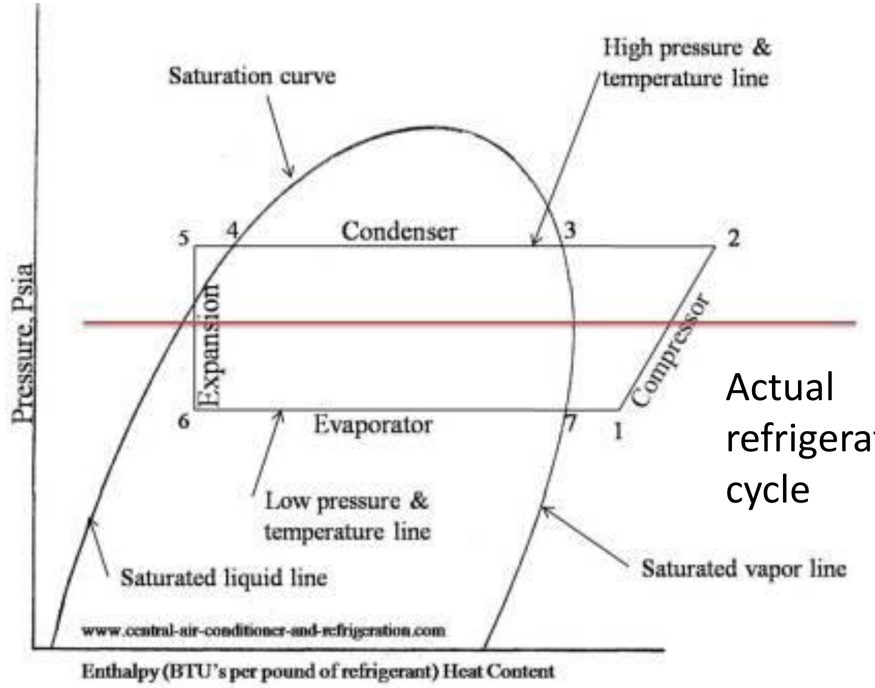


$$COP_R = \frac{q_L}{W_{net,in}} = \frac{h_1 - h_4}{h_2 - h_1}$$

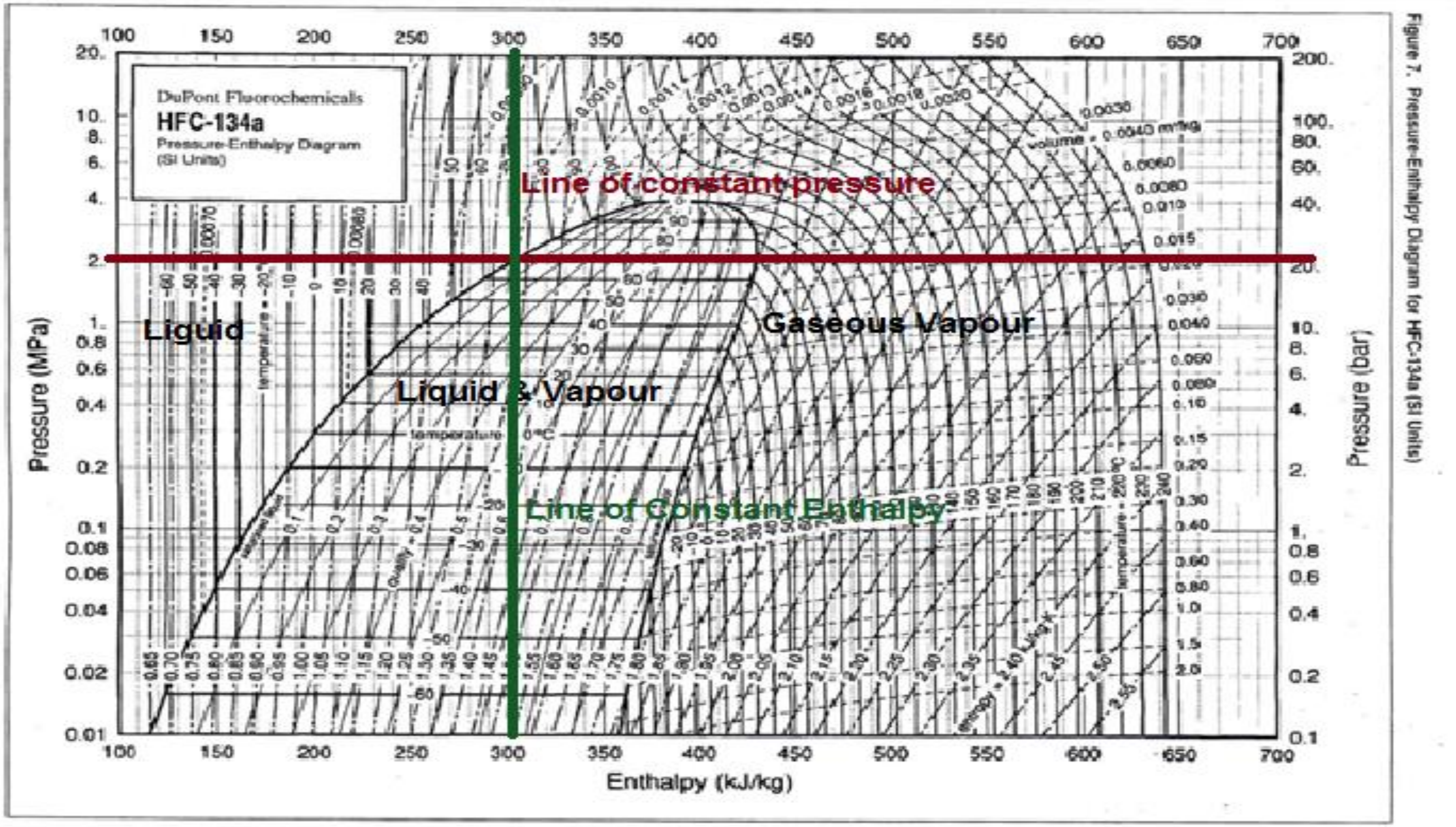
and

$$COP_{HP} = \frac{q_H}{W_{net,in}} = \frac{h_2 - h_3}{h_2 - h_1}$$

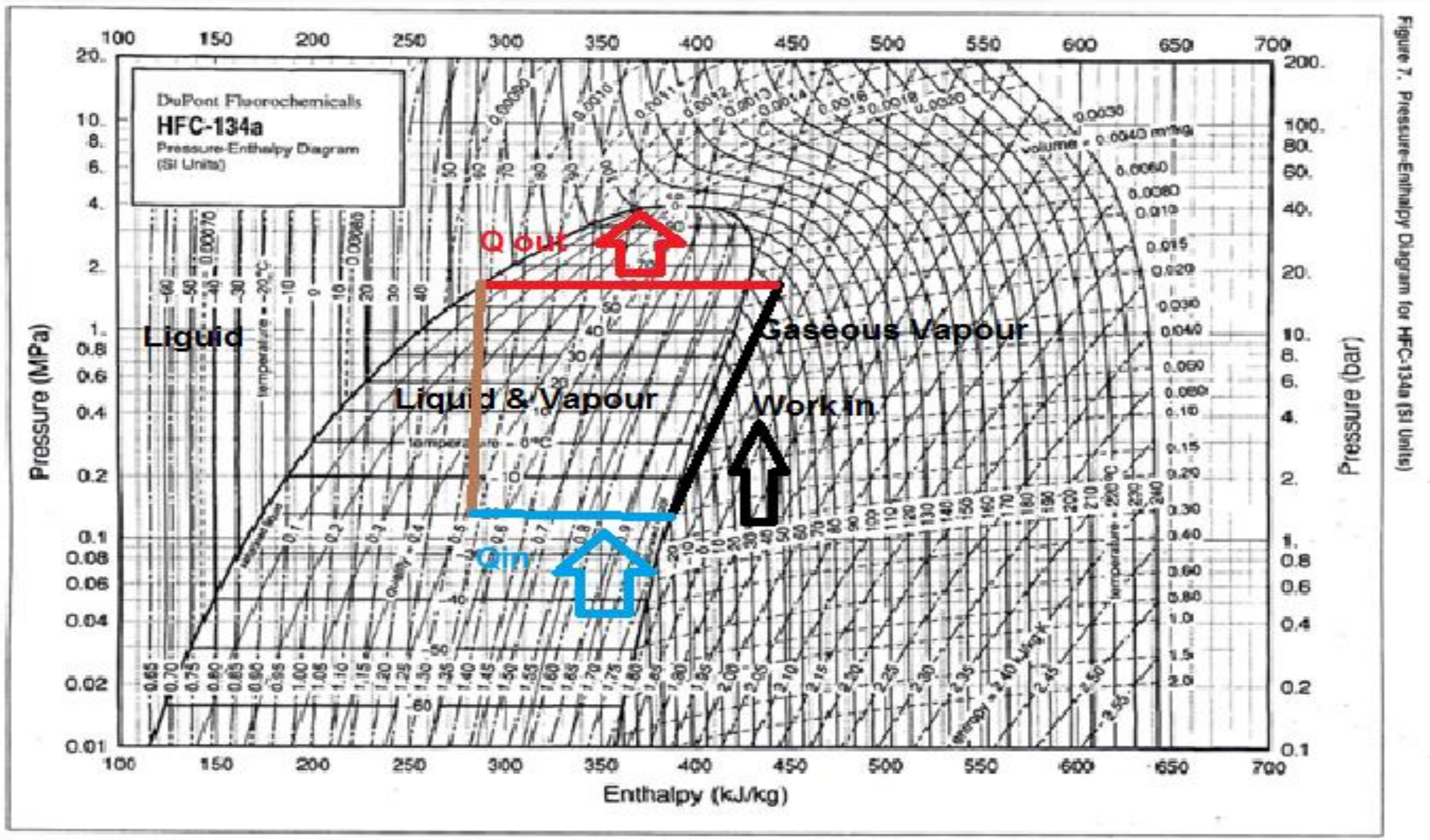
where $h1 = hg$ @ $P1$ and $h3 = hf$ @ $P3$ for the ideal case.



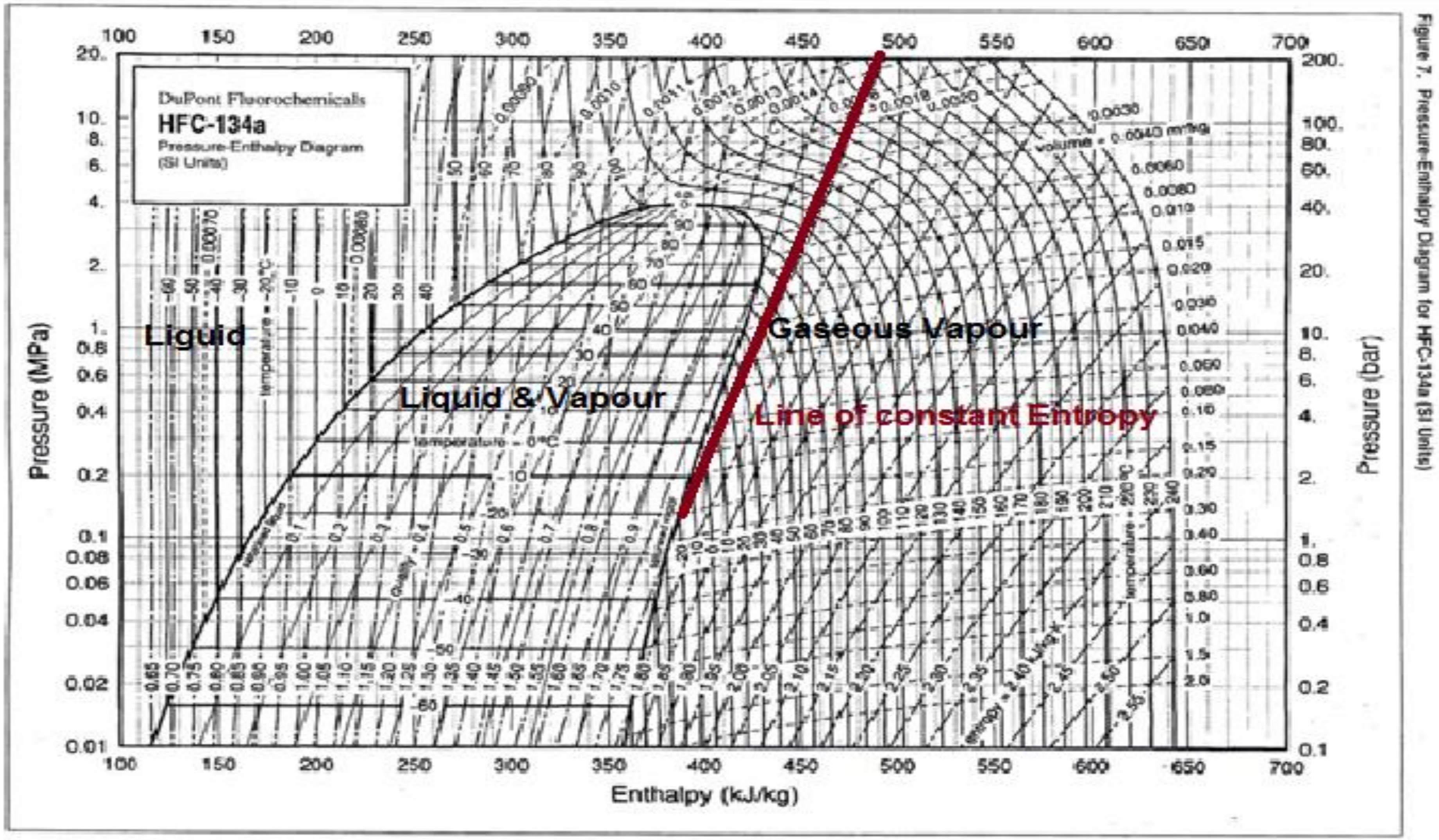
Reading the P-h diagram 1



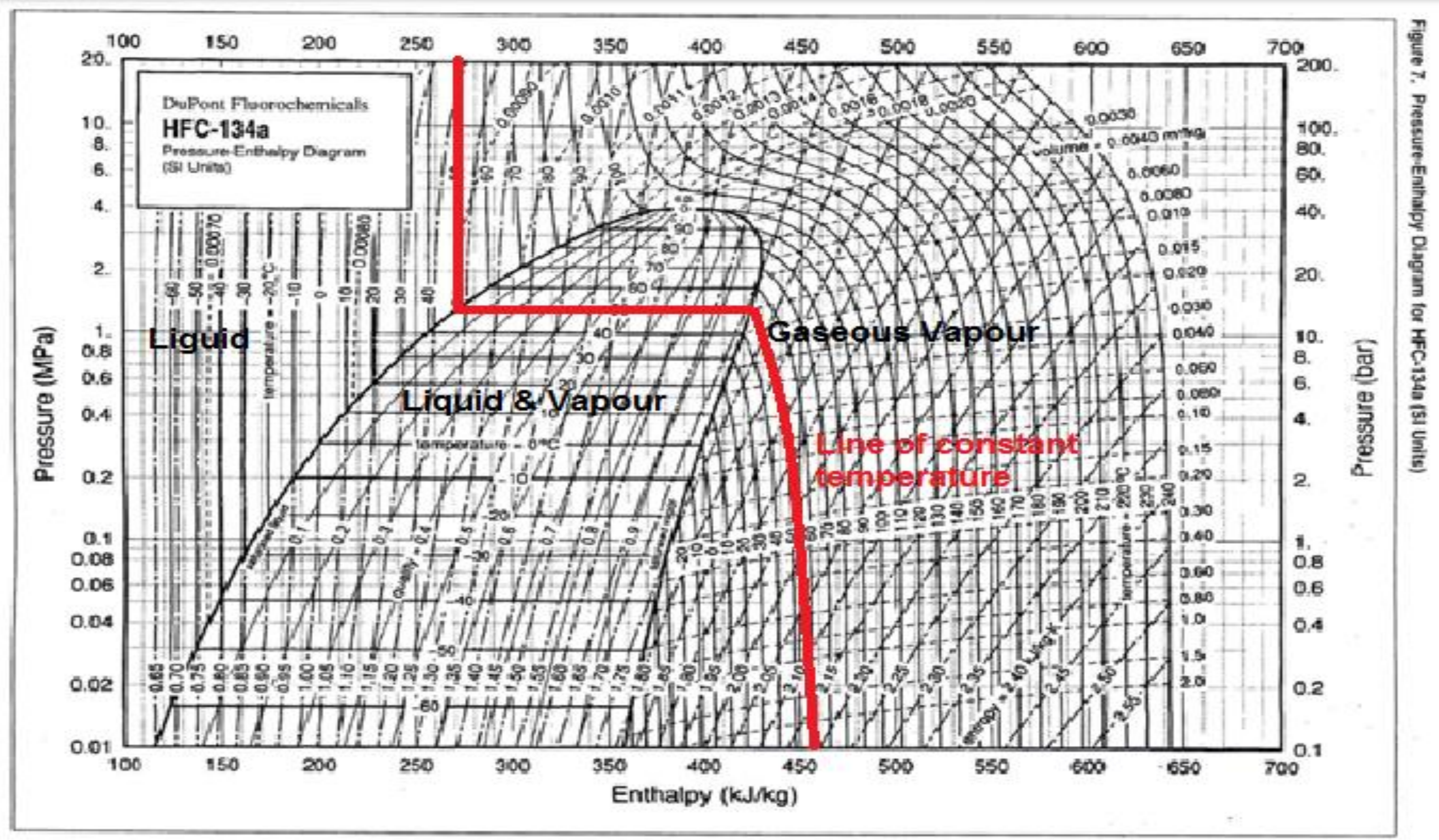
Reading the P-h diagram 2



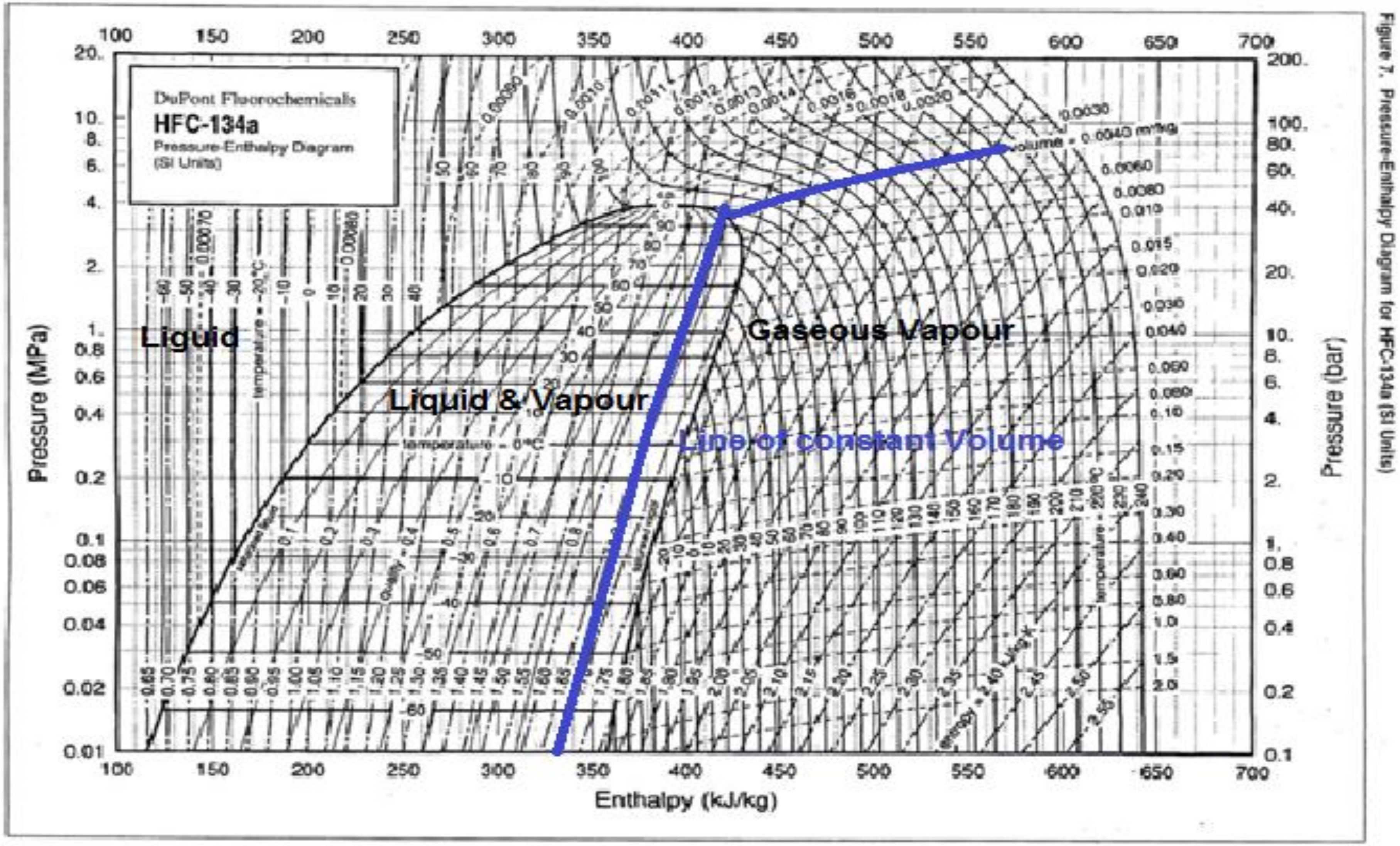
Reading the P-h diagram 3



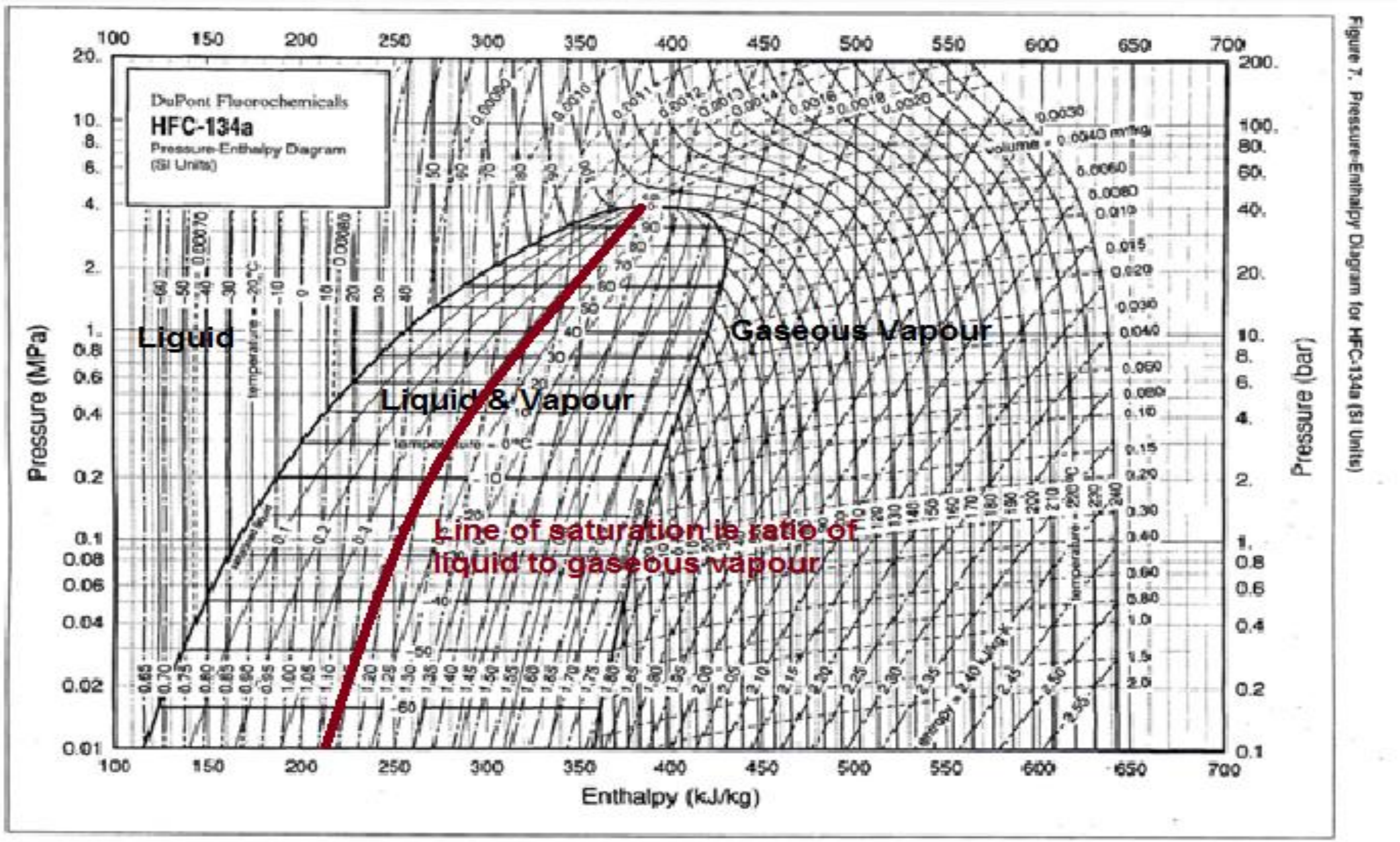
Reading the P-h diagram 4



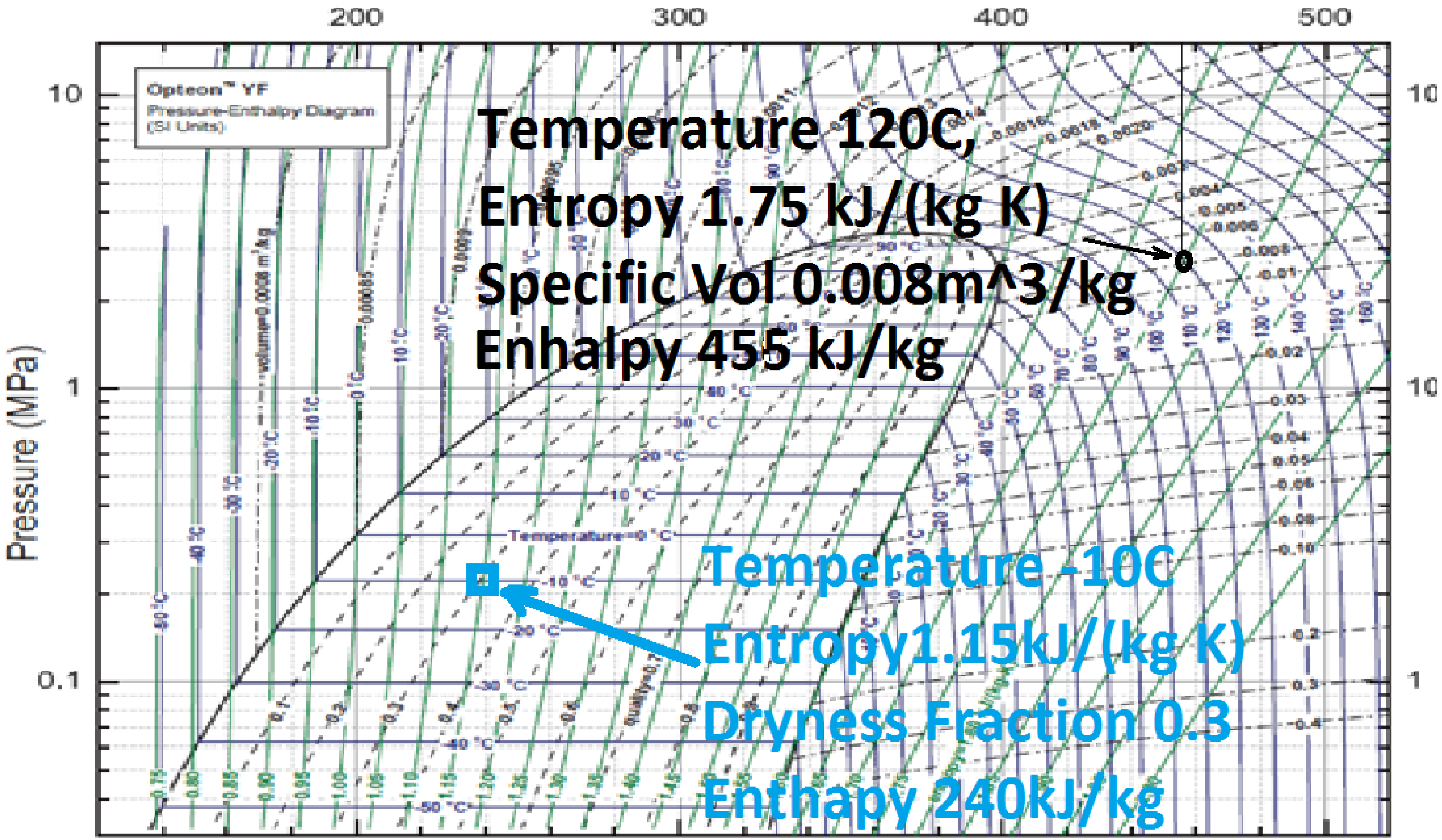
Reading the P-h diagram 5



Reading the P-h diagram 6



Reading the P-h diagram 7

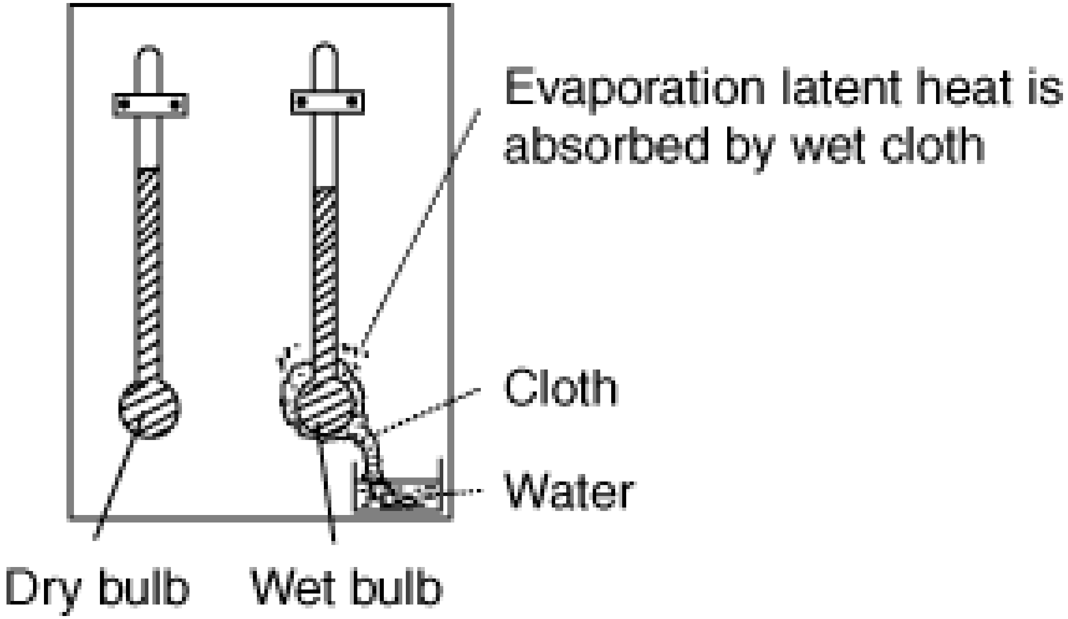


Personal Comfort

Air conditioning

Thermal comfort

Humans are more sensitive to wet bulb rather than dry bulb temperature conditions

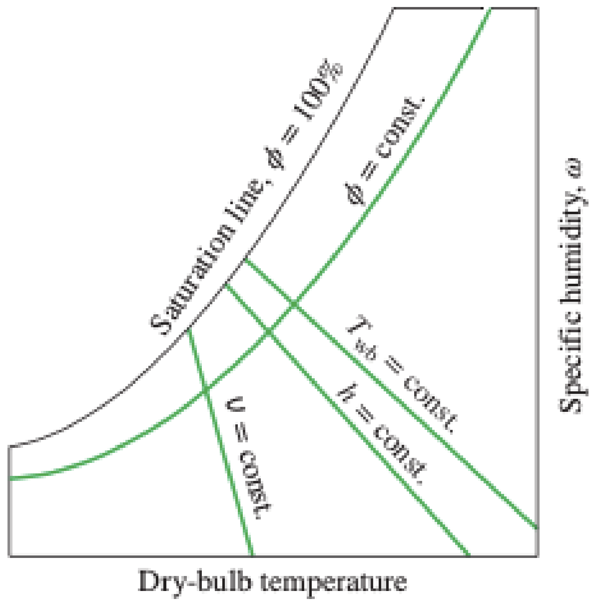


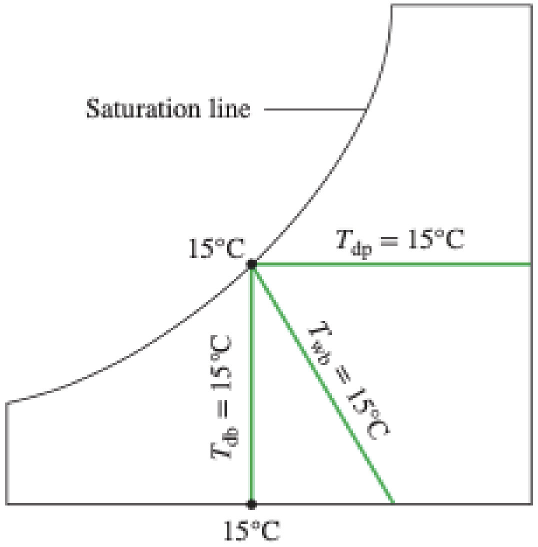
Wet and dry bulb temperatures

- **Wet bulb temperature** is the lowest temperature to which air can be cooled by the evaporation of water into the air at a constant pressure. It is therefore measured by wrapping a wet wick around the bulb of a thermometer and the measured temperature corresponds to the wet bulb temperature.
- When the temperature of the air is mentioned, its **dry bulb temperature** is what is referred to. The Dry Bulb Temperature is basically the ambient air temperature. It is called "Dry Bulb" because the air temperature is indicated by a thermometer not affected by the moisture of the air.

Reading the Psychrometric chart

- The state of the atmospheric air at a specified pressure is completely specified by two independent intensive properties. The rest of the properties can be calculated easily from the previous relations.
- **psychrometric charts** are used extensively in air-conditioning applications. A psychrometric chart for a pressure of 1 atm (101.325 kPa or 14.696 psia) is given in the diagram.
- The psychrometric chart is a valuable aid in visualising air-conditioning processes. An ordinary heating or cooling process, for example, appears as a horizontal line on this chart if no humidification or dehumidification is involved (that is, ω = constant). Any deviation from a horizontal line indicates that moisture is added or removed from the air during the process.





For saturated air, the dry-bulb, wet-bulb, and dew-point temperatures are identical.

Use of the Psychrometric chart – solved tutorial

Consider a room that contains air at 1 atm, 35°C, and 40 percent relative humidity. Using the psychrometric chart, determine

(a) the specific humidity

(b) the enthalpy

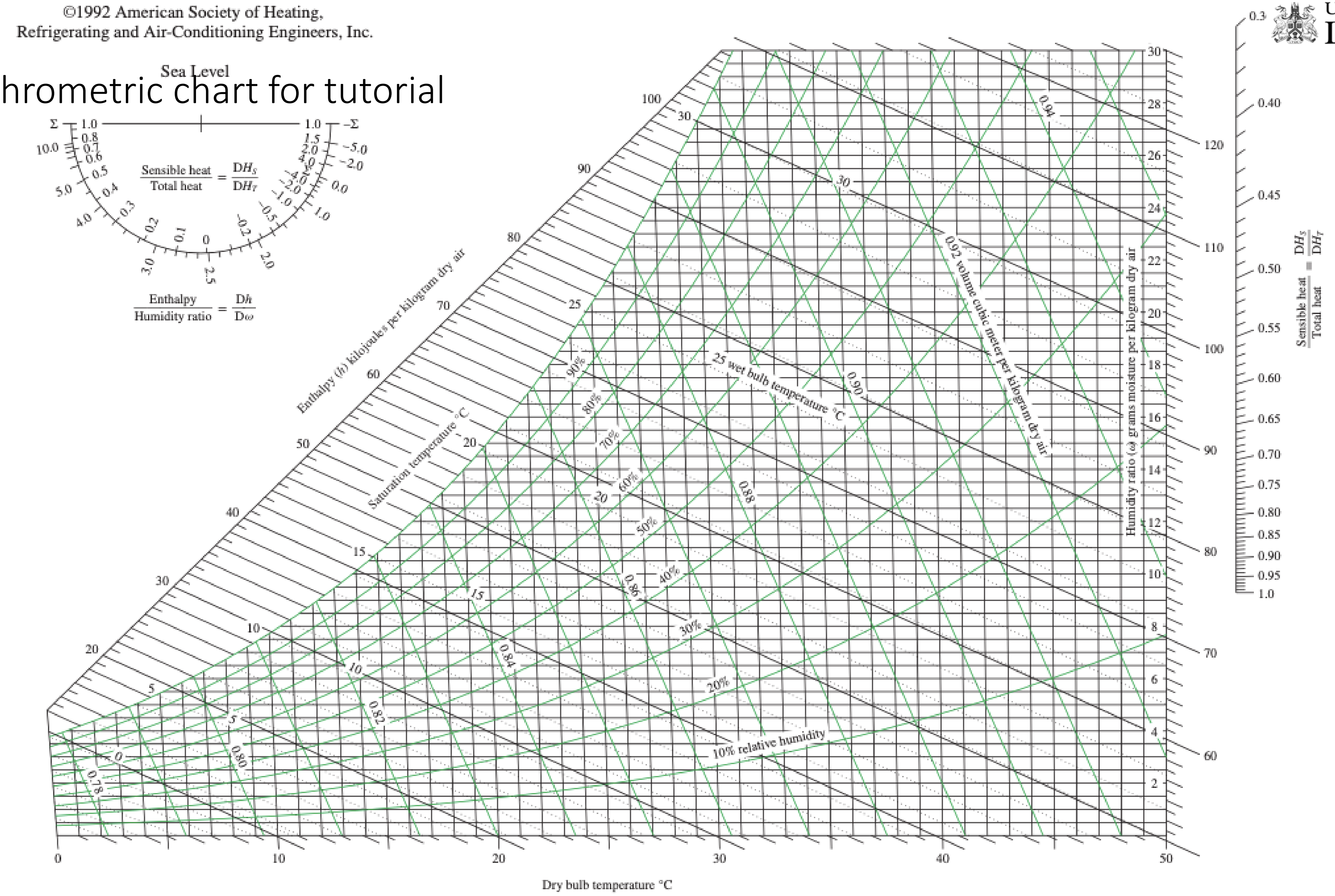
(c) the wet-bulb temperature

(d) the dew-point temperature, and

(e) the specific volume of the air.

Analysis: At a given total pressure, the state of atmospheric air is completely specified by two independent properties such as the dry-bulb temperature and the relative humidity. Other properties are determined by directly reading their values at the specified state.

Psychrometric chart for tutorial



Tutorial solution

(*a*) The specific humidity is determined by drawing a horizontal line from the specified state to the right until it intersects with the ω axis. At the intersection point we read

ω = **0.0142 kg H2O/kg dry air**

(*b*) The enthalpy of air per unit mass of dry air is determined by drawing a line parallel to the *h* = constant lines from the specific state until it intersects the enthalpy scale, giving

h = **71.5 kJ/kg dry air**

(*c*) The wet-bulb temperature is determined by drawing a line parallel to the Twb = constant lines from the specified state until it intersects the saturation line, giving Twb = **24°C**

(*d*) The dew-point temperature is determined by drawing a horizontal line from the specified state to the left until it intersects the saturation line, giving

Tdp = **19.4°C**

(*e*) Specific volume per unit mass of dry air is determined by the distances between the specified state and v = constant lines on both sides of the point. The specific volume is obtained by visual interpolation to be

v = **0.893 m3/kg dry air**

Note: Values from the psychrometric chart inevitably involve reading errors, thus are of limited accuracy.

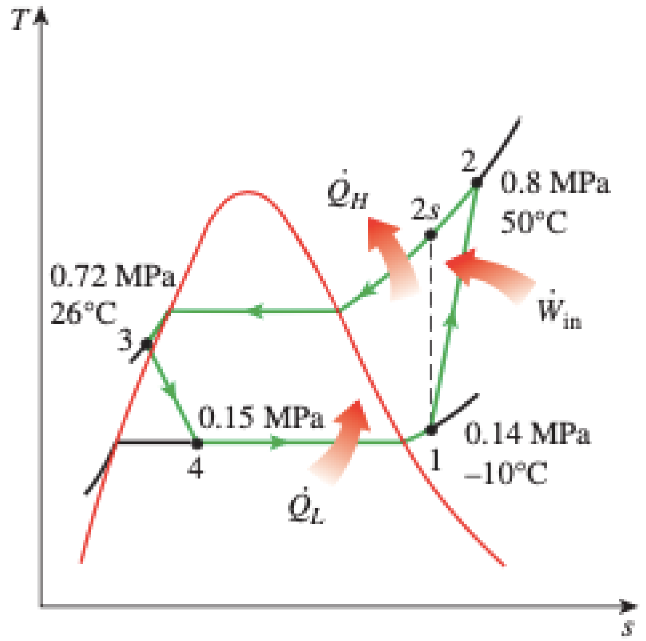
Tutorial

Refrigerant-134a enters the compressor of a refrigerator as superheated vapor at 0.14 MPa and −10°C at a rate of 0.05 kg/s and leaves at 0.8 MPa and 50°C. The refrigerant is cooled in the condenser to 26°C and 0.72 MPa and is throttled to 0.15 MPa. Disregarding any heat transfer and pressure drops in the connecting lines between the components, determine

(a) the rate of heat removal from the refrigerated space and the power input to the compressor,

(b) the isentropic efficiency of the compressor, and

(c) the coefficient of performance of the refrigerator.



See tutorial sheet for solution