

Chapter One

The refrigeration cycle

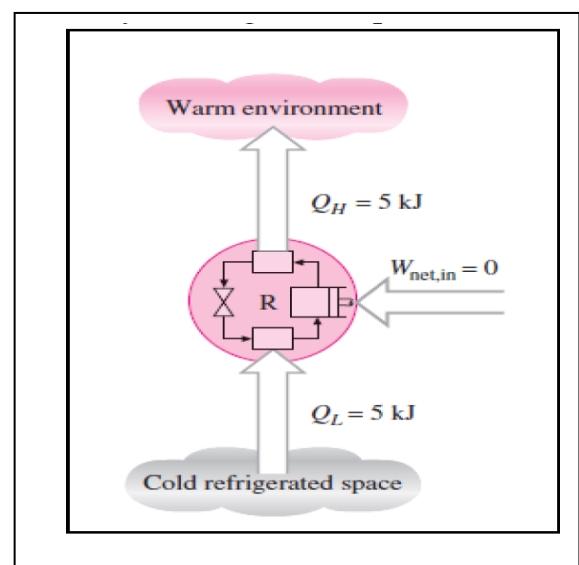
INTRODUCTION

Refrigeration is the process of removing heat, and the practical application is to produce or maintain temperatures below the ambient. The basic principles are those of thermodynamics, and these principles as relevant to the general uses of refrigeration.

A **refrigerant** is a primary working fluid used to produce refrigeration in a refrigeration system. All refrigerants extract heat at low temperature and low pressure during evaporation and reject heat at high temperature and pressure during condensation. A **cooling medium** is a working fluid cooled by the refrigerant during evaporation to transport refrigeration from a central plant to remote cooling equipment and terminals. In a large, centralized air conditioning system, it is more economical to pump the cooling medium to the remote locations where cooling is required. Chilled water and brine are cooling media. They are often called secondary refrigerants to distinguish them from the primary refrigerants.

THE SECOND LAW OF THERMODYNAMICS (Clausius Statement)

It is impossible to construct a device that operates in a cycle and produces no effect other than the transfer of heat from a lower-temperature body to a higher-temperature body

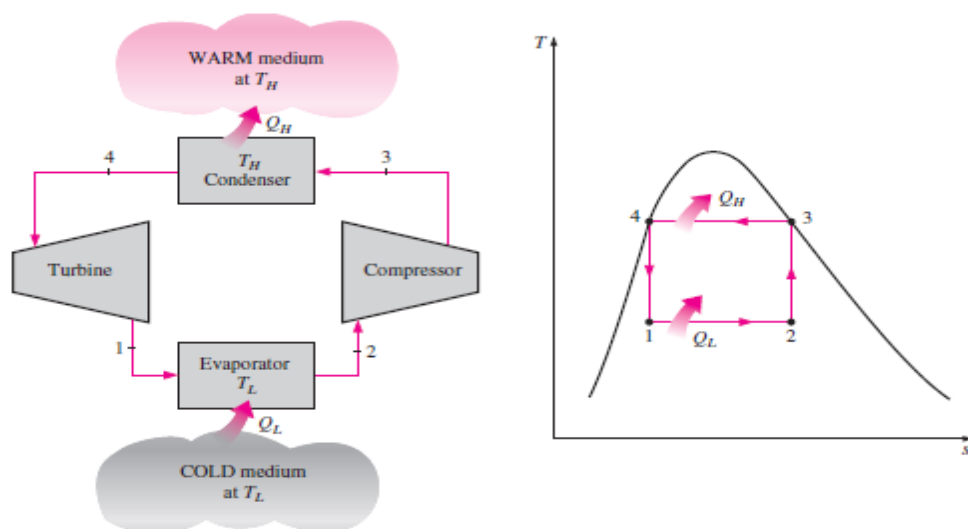




The Reversed Carnot Cycle:

The Carnot heat-engine cycle just described is a totally reversible cycle. Therefore, all the processes that comprise it can be reversed, in which case it becomes the Carnot refrigeration cycle. This time, the cycle remains exactly the same, except that the directions of any heat and work interactions are reversed: Heat in the amount of Q_L is absorbed from the low-temperature reservoir, heat in the amount of Q_H is rejected to a high-temperature reservoir, and a work input of $W_{net,in}$ is required to accomplish all this. The T - s diagram of the reversed Carnot cycle is the same as the one given for the Carnot cycle, except that the directions of the processes are reversed, as shown in below Fig.

- 1- The refrigerant absorbs heat isothermally from a low-temperature source at T_L in the amount of Q_L (**process 1-2**)
- 2- Compressed isentropically to state 3 (temperature rises to T_H) (**process 2-3**),
- 3- rejects heat isothermally to a high-temperature sink at T_H in the amount of Q_H (**process 3-4**),
- 4- Expands isentropically to state 1 (temperature drops to T_L). The refrigerant changes from a saturated vapor state to a saturated liquid state in the condenser during process 3-4.



Schematic of a Carnot refrigerator and T - s diagram of the reversed Carnot cycle.



Basic vapour compression cycle

Refrigeration Processes in an Ideal vapour compression Single-Stage Cycle. An ideal cycle has isentropic compression, and pressure losses in the pipeline, valves, and other components are neglected. All refrigeration cycles covered in this section are ideal. Single stage means a single stage of compression. There are four refrigeration processes in an ideal single-stage vapor compression cycle, as shown in Figure (1.1):

Four major thermal process take place as follows:

1-evaporation

2-compression

3-condensation and

4-expansion

Figure 1. shows a schematic diagram of a basic vapour compression refrigeration system. For better understanding this refrigeration cycle is shown by temperature-entropy (T-s) and pressure-enthalpy (P-h) diagrams as given in figure (1) and figure (2). Along the lines of steps given above. The operation of this system is as follows:

(4-1) reversible heat addition at constant pressure. From expansion valve low pressure refrigerant liquid arrives in the evaporator. It boils here and in the process absorbs heat from the surrounding medium, thereby providing a cooling effect.

(1-2) reversible adiabatic compression. From the compressor, high pressure saturated vapour comes to the compressor and compressed into the condenser by volume reduction and increase pressure and temperature.

(2-3) reversible heat rejection at constant pressure. From compressor, high pressure refrigerant vapour enters the condenser and is liquefied by employing water or air.



(3-4) irreversible expansion at constant enthalpy. From the condenser high pressure saturated refrigerant liquid passes through an expansion valve and its pressure and temperature are reduced.

1. Isothermal evaporation process 4–1 — The refrigerant evaporates completely in the evaporator

and produces refrigeration effect q_{evap} , in kJ/kg:

$$gz_4 + \frac{C_4^2}{2} + h_4 + q_{\text{evap}} = gz_1 + \frac{C_1^2}{2} + h_1 + W$$

$$z_1 \approx z_4 \quad W = 0 \quad C_4 \approx C_1$$

$$q_{\text{evap}} = h_4 - h_1$$

$$q_{\text{evap}} = (h_1 - h_4) \dots\dots\dots(1)$$

where h_1, h_4 = enthalpy of refrigerant at state points 1 and 4, respectively, kJ/kg.

2. Isentropic compression process 1–2 — Vapor refrigerant is extracted by the compressor and compressed isentropically from point 1 to 2. The work input to the compressor W_{in} , in kJ/kg, is

$$gz_1 + \frac{C_1^2}{2} + h_1 - q = gz_2 + \frac{C_2^2}{2} + h_2 - w_{\text{comp}}$$

$$z_1 \approx z_2 \quad q = 0 \text{ isentropic} \quad C_2 \approx C_1$$

$$w_{\text{comp}} = h_2 - h_1$$

$$w_{\text{comp}} = (h_2 - h_1) \dots\dots\dots(2)$$

where h_2 = enthalpy of refrigerant at state point 2, kJ/kg.

The greater the difference in temperature/pressure between the condensing pressure p_{con} and evaporating pressure p_{ev} , the higher will be the work input to the compressor.



3- Isothermal condensation process 2–3 — Hot gaseous refrigerant discharged from the compressor is condensed in the condenser into liquid, and the latent heat of condensation is rejected to the condenser water or ambient air. The heat rejection during condensation, q_{2-3} , in kJ/kg, is

$$gz_2 + \frac{C_2^2}{2} + h_2 - q_{cond} = gz_3 + \frac{C_3^2}{2} + h_3 + W$$

$$z_3 \approx z_2 \quad W = 0 \quad C_3 \approx C_1$$

$$q_{cond} = h_2 - h_3$$

$$q_{cond} = (h_2 - h_3) \dots \dots \dots (3)$$

where h_3 = enthalpy of refrigerant at state point 3, kJ/kg.

4. Throttling process 3–4 Liquid refrigerant flows through a throttling device (e.g., an expansion valve, a capillary tube, or orifices) and its pressure is reduced to the evaporating pressure. A portion of the liquid flashes into vapor and enters the evaporator. This is the only irreversible

process in the ideal cycle, usually represented by a dotted line. For a throttling process, assuming that the heat gain from the surroundings is negligible:

$$h_3 = h_4 \dots \dots \dots (4)$$

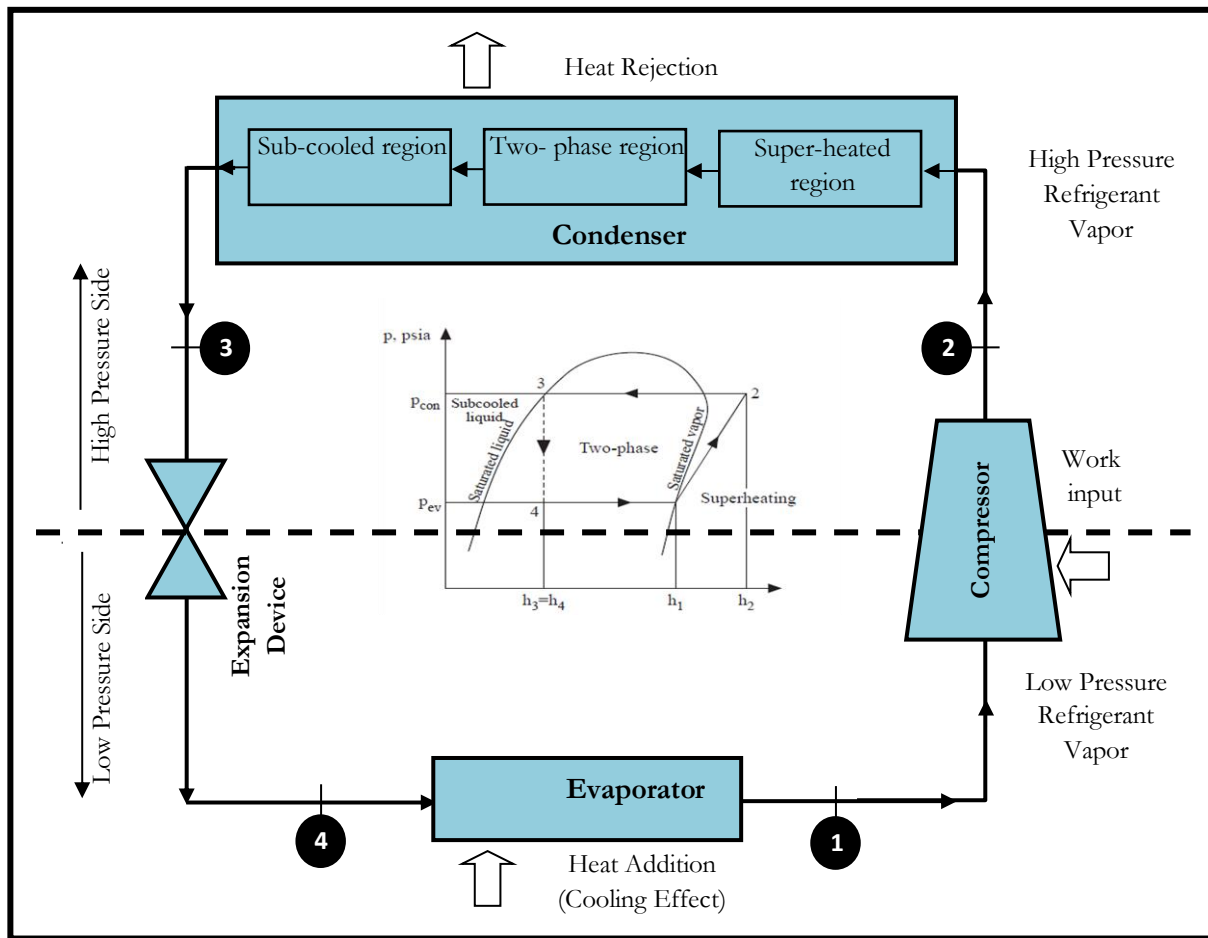


Fig.1.1 the P-h diagram and the components of the VCRS.

Coefficient of Performance of Refrigeration Cycle

The coefficient of performance (COP) is a dimensionless index used to indicate the performance of a thermodynamic cycle or thermal system. The magnitude of COP can be greater than 1.

- If a refrigerator is used to produce a refrigeration effect, COP_{ref} is

$$COP_r = \frac{q_{eva}}{w_{comp}} \dots \dots \dots (5)$$

- If a heat pump is used to produce a useful heating effect, its performance denoted by COP_h is

$$COP_h = \frac{q_{cond}}{w_{comp}} \dots \dots \dots (5)$$

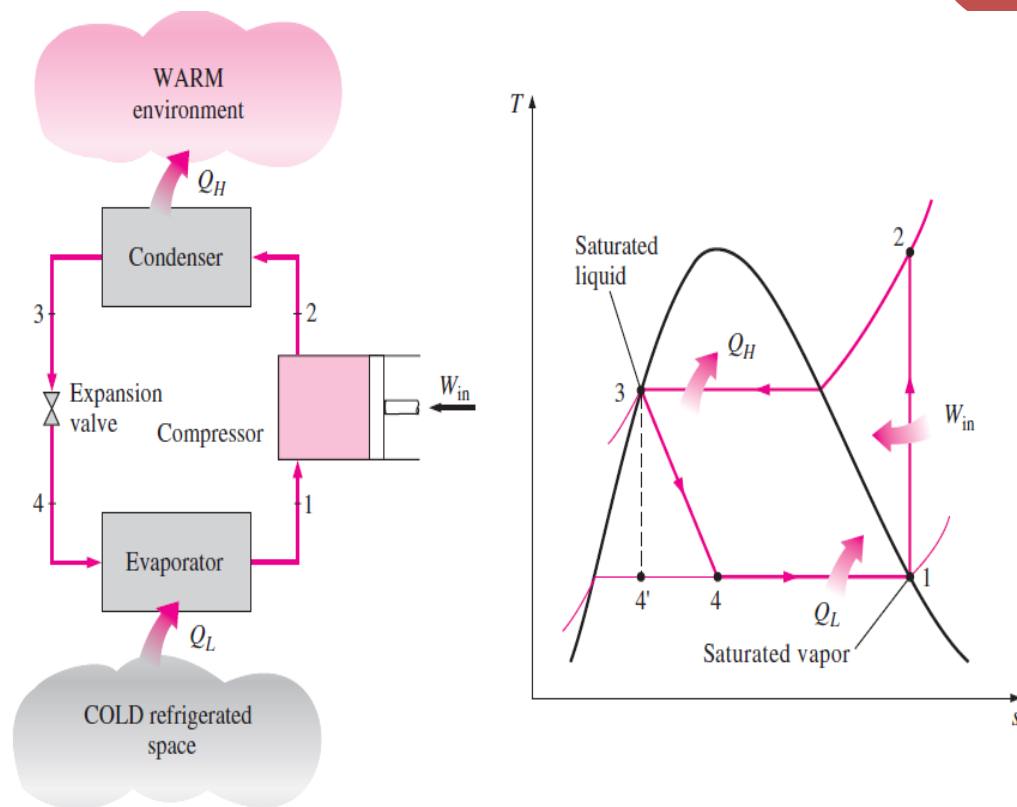
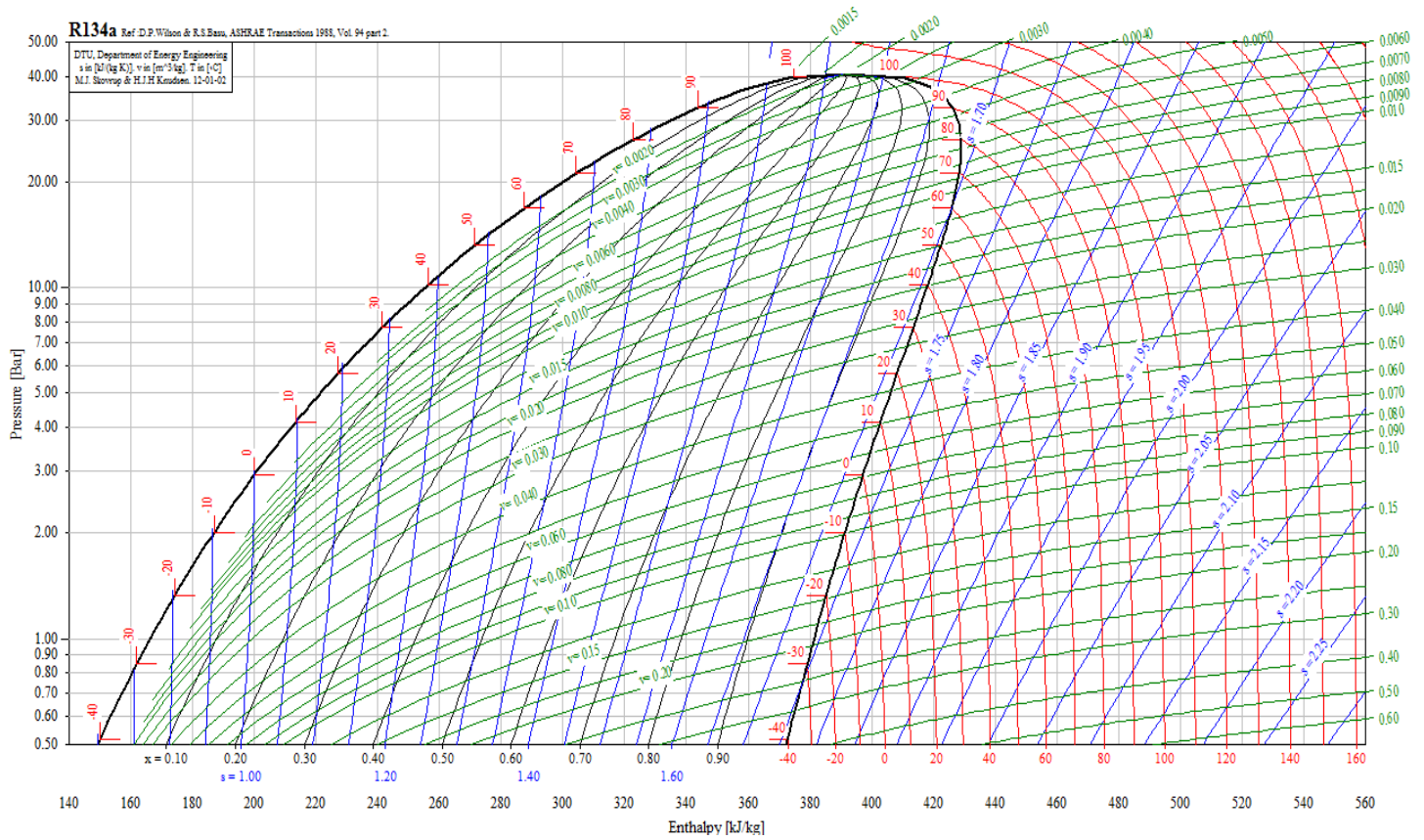
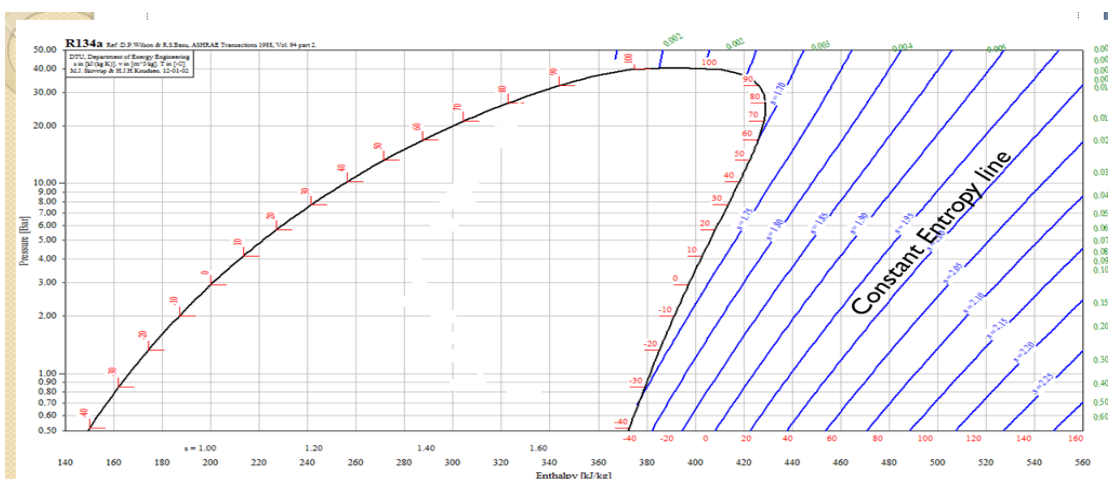
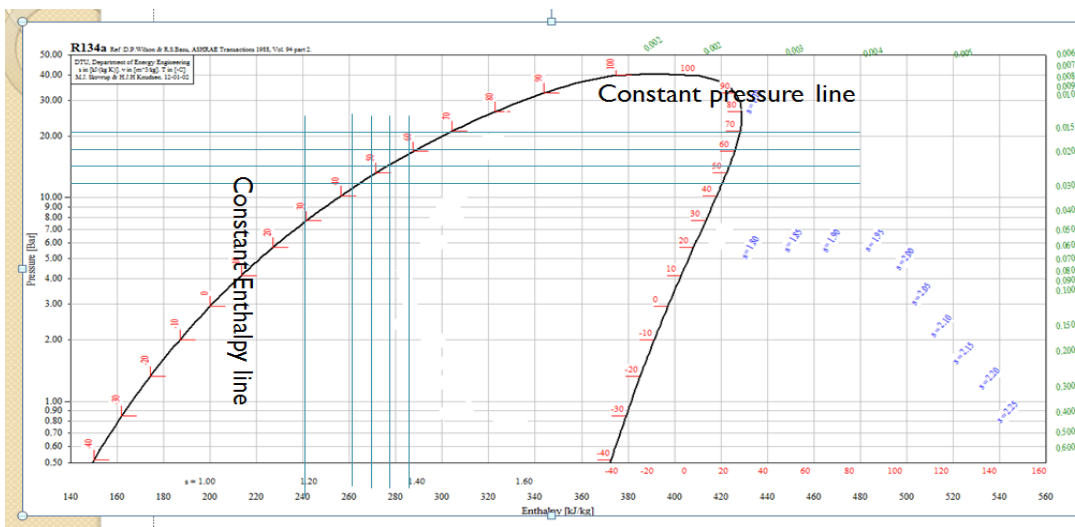
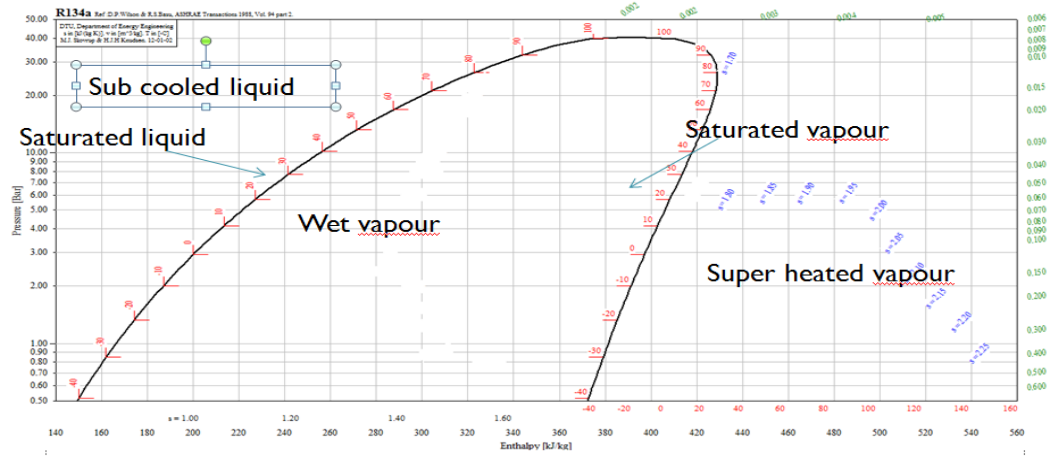


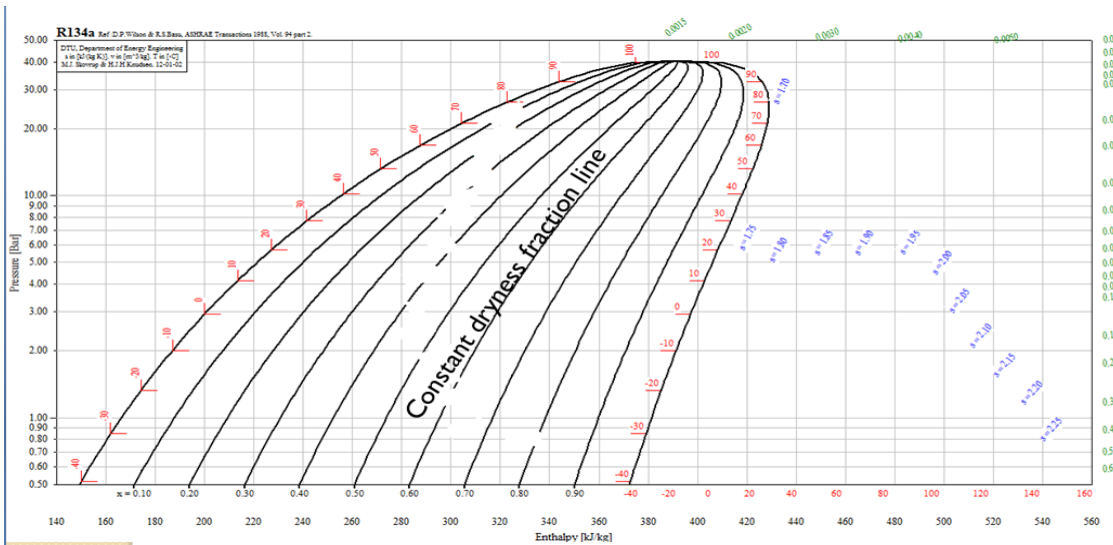
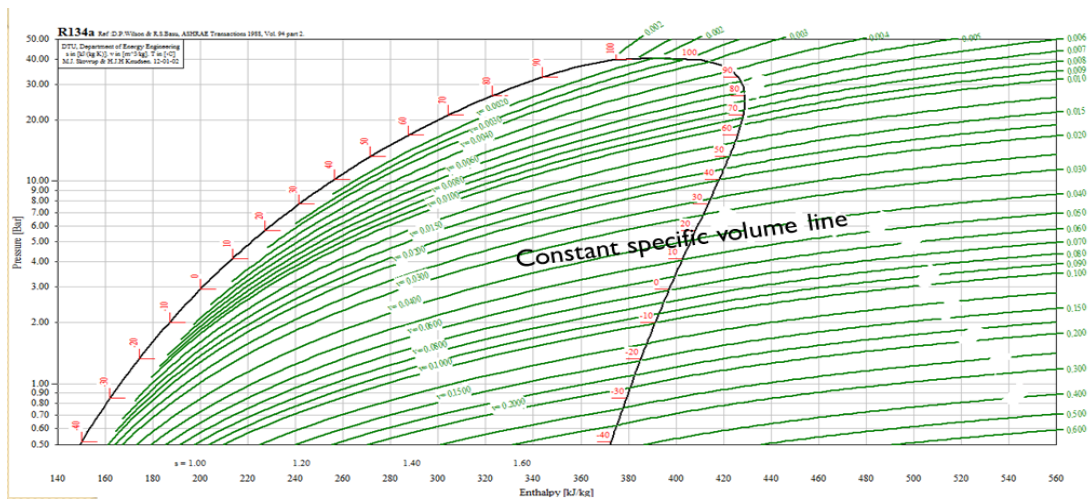
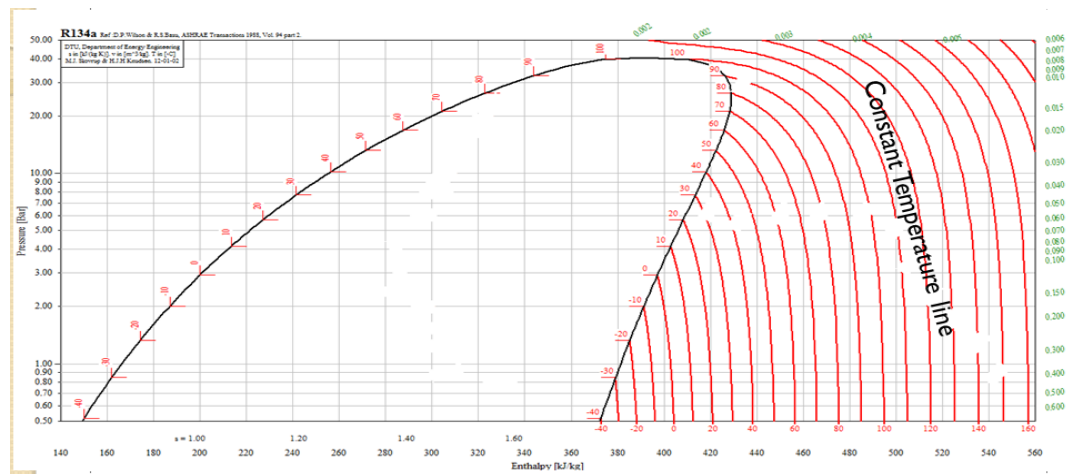
Fig.(2) shows schematic and T-s diagram for the ideal vapor-compression refrigeration cycle.



Pressure Enthalpy diagram (P-h diagram):









EX1/ A refrigerator uses refrigerant-134a as the working fluid and operates on an vapor-compression refrigeration cycle between 2 and 8 bar. If the mass flow rate of the refrigerant is 0.05 kg/s, where the refrigerant enters to the compressor as saturated vapour and the refrigerant exits of the condenser as saturated liquid determine:

- (a) The rate of heat removal from the refrigerated space
- (b) The power input to the compressor;
- (c) The rate of heat rejection to the environment, and
- (c) COP of the refrigerator.

Sol/

By using P-h diagram for R134a and depending on condenser and evaporator pressure will drawing the cycle.

$$h_1 = 390.909 \text{ kJ/kg}$$

$$s_1 = s_2$$

$$h_2 = 421.818 \text{ kJ/kg}$$

$$h_3 = 243.63 \text{ kJ/kg}$$

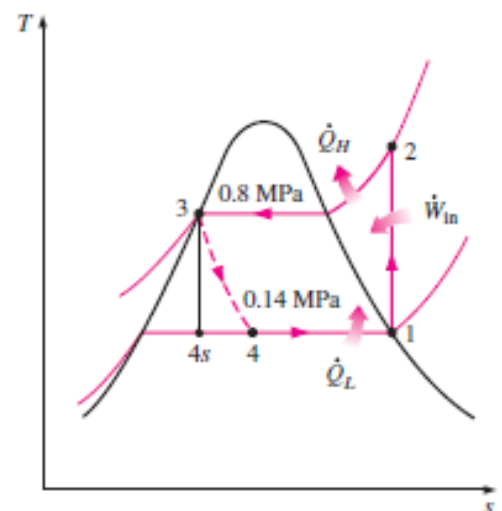
$$h_3 = h_4$$

$$Q_{\text{evap}} = m_r(h_1 - h_4)$$

$$Q_{\text{evap}} = 0.05 \cdot (390.909 - 243.63)$$

$$Q_{\text{evap}} = 7.363 \text{ kW}$$

$$W_{\text{comp}} = m_r(h_2 - h_1)$$





$$W_{comp} = 0.05 \times (421.818 - 390.909)$$

$$W_{comp} = 1.545 \text{ kW}$$

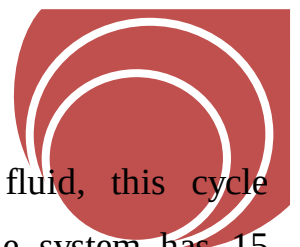
$$Q_{cond} = m_r(h_2 - h_3)$$

$$Q_{cond} = 0.05 \times (421.818 - 243.63)$$

$$Q_{cond} = 8.909 \text{ kW}$$

$$\text{COP}_r = \frac{Q_{eva}}{W_{comp}}$$

$$\text{COP}_r = 7.363 / 1.545 = 4.76$$



Example2/ A vapour compression system used R12 as a working fluid, this cycle operate at condenser temperature of 40 °C and evaporator of -5 °C the system has 15 TR. Find the following:

- 1- Refrigerating effect,
- 2- The mass flow rate of refrigerant,
- 3- Volume flow rate of refrigerant at inlet compressor (suction condition),
- 4- Work done by the compressor,
- 5- Heat removed by condenser, and
- 6- COP of the system.

Sol/

$$h_1 = h_g \text{ at } -5^\circ\text{C}$$

$$\therefore h_1 = 349.3 \text{ kJ/kg}$$

$$s_1 = s_2 = s_g \text{ at } T = -5^\circ\text{C}$$

$$\therefore h_2 = 372.2 \text{ kJ/kg}$$

$$h_3 = h_4 = h_f \text{ at } T = -5^\circ\text{C}$$

$$\therefore h_3 = h_4 = 238.53 \text{ kJ/kg}$$

1- Refrigerating effect is given by :

$$q_{\text{evap}} = h_1 - h_4$$

$$q_{\text{evap}} = 349.3 - 238.53$$

$$q_{\text{evap}} = 110.77 \text{ kJ/kg}$$

2- Refrigerating capacity(Q_{evap}) is given by :



$$Q_{evap} = m_r(h_1 - h_4)$$

Refrigerating capacity in kW = 15 TR*3.5167 = 52.75 kW

$$m_r = \frac{Q_{evap}}{(h_1 - h_4)}$$

$$m_r = \frac{52.75}{110.77} = 0.476 \text{ kg/s}$$

3- Volume flow rate is given by

$$V = \dot{m} * v_1$$

v_1 from P – h diagram at evaporator pressure P = 2.6 bar

$$v_1 = 0.06497 \text{ m}^3/\text{kg}$$

$$\therefore V = 0.476 * 0.06497 = 0.0309 \text{ m}^3/\text{s}$$

4- Work done by the compressor is given by:

$$w_{comp} = h_2 - h_1$$

$$w_{comp} = 372.2 - 349.3 = 22.9 \text{ kJ/kg}$$

$$\text{Consumption power}_{\text{compressor}} = m_r * (h_2 - h_1)$$

$$\text{Consumption power}_{\text{compressor}} = 0.476 * 22.9 = 10.9 \text{ kW}$$

5- Heat removed by condenser is given by:

$$Q_{cond} = m_r(h_2 - h_3)$$

$$Q_{cond} = 0.476 * (372.2 - 238.53) = 63.63 \text{ kW}$$

$$6- \text{COP} = \frac{\text{refrigerating effect}}{w_{comp}} = \frac{110.77}{22.9} = 4.837$$



References:

1- A. R. Trott and T. Welch, "Refrigeration and Air-Conditioning"

2 – "مبادئ هندسة تكييف الهواء والتثليج" ، الدكتور خالد احمد الجودي، كلية الهندسة جامعة البصرة ، ١٩٩٨

3-ASHREA hand book 1997

4-air condition and refrigeration

Shan K. Wang



تواريخ مهمة في تاريخ التبريد والتكييف

التاريخ الميلادي	الحدث
١٧٥٥م	البروفيسور كلين (Cullen)، أستاذ الكيمياء بجامعة ايدنبرج، ينجح في توليد الثلج صناعياً عن طريق تبخير الأثير لتبريد الماء.
١٨٠٠م	توماس موور (Thomas Moore) يستخدم مصطلح ثلاجة.
١٨٣٤م	يعقوب بيركنز (Jacob Perkins) يعطي وصفاً مدعماً بالوثائق لدورة التبريد بانضغاط البخار باستخدام الأثير.
١٩٠٢م	قام وليس كاريير بتصميم وبناء أول نظام لتكييف الهواء للتحكم في الرطوبة ودرجة الحرارة للهواء الداخلي لمطبعة.
١٩٠٦م	استخدام مصطلح تكييف الهواء لأول مرة في التاريخ بواسطة ستيفورت كرامر.
١٩١٣م	إقامة أول معرض دولي متخصص للتبريد (شيكاغو، أمريكا).
١٩١٧م	تكييف هواء أول مسرح (مونتجمري، الاباما، أمريكا).
١٩١٧م	عملت آلات التبريد الأتوماتيكية عندما صنع صمام التمدد وضمت آلة التبريد أيضاً ترموستات لتشغيل وإيقاف الضاغط تبعاً لدرجة حرارة الحمل الحراري.
١٩٣٠م	نجاح ميدجلي (Midgley) بالولايات المتحدة الأمريكية بإنتاج مبردات الهالوكربونات التي تعرف تجارياً باسم: فريون.
١٩٣٠م	تقديم الضواغط المغلقة، حيث ضم الضاغط والموتور في علبة واحدة مغلقة.



التاريخ الميلادي	الحدث
١٩٨٤م	اكتشف بروفيسور رولاند (Roland) ودكتور مولينا (Molina) بجامعة كاليفورنيا: أن بعض مشتقات الهالوكربونات، وخاصة مبرد ١١ ومبرد ١٢، تمثل تهديداً لطبقة الأوزون المحيطة بالكرة الأرضية.
١٩٨٧م	توقيع الأمم المتحدة بروتوكول مونتريال؛ لحظر استخدام الهالوكربونات لحماية طبقة الأوزون للكرة الأرضية.