Subject: Refrigeration	**الموضوع : تجميد**
Weekly Hours :Theoretical: 2 Tutorial:1	**الساعات الأسبوعية: نظري:2 مناقشة:1**
Experimental : 1	**عملي :1**
Units: 5	**عدد الوحدات:5**

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CHAPTER ONE
REFRIGERATION

1.1 Definition

Refrigeration : Is the transfer of heat from one place to another by a change in state of a liquid. Without a change in state, however, the result are not refrigeration because there is no refrigerant effect.

Cold : is a relation term to describe the energy level or temperature of an object or area compared to a known energy level or temperature.

" Absolute Zero " The removal of all heat energy (molecular movement) from space or object. Theoretically it is -273.16 °c or -459.69 °F

Mechanical Refrigeration: Is the use of work energy in mechanical components as arranged in a "Refrigeration System" to obtain the desired results.

Refrigerant: are chemical compounds that are used to absorb heat by evaporation or boiling from the liquid state to the vapor state and reject heat from the vapor state to the liquid state by condensation

Tone of refrigeration: is a production of heat Energy same as the melting of one ton of ice at 0°C (32°F) over a 24 hour period.

1.0 ton of ICE = 2000 lb

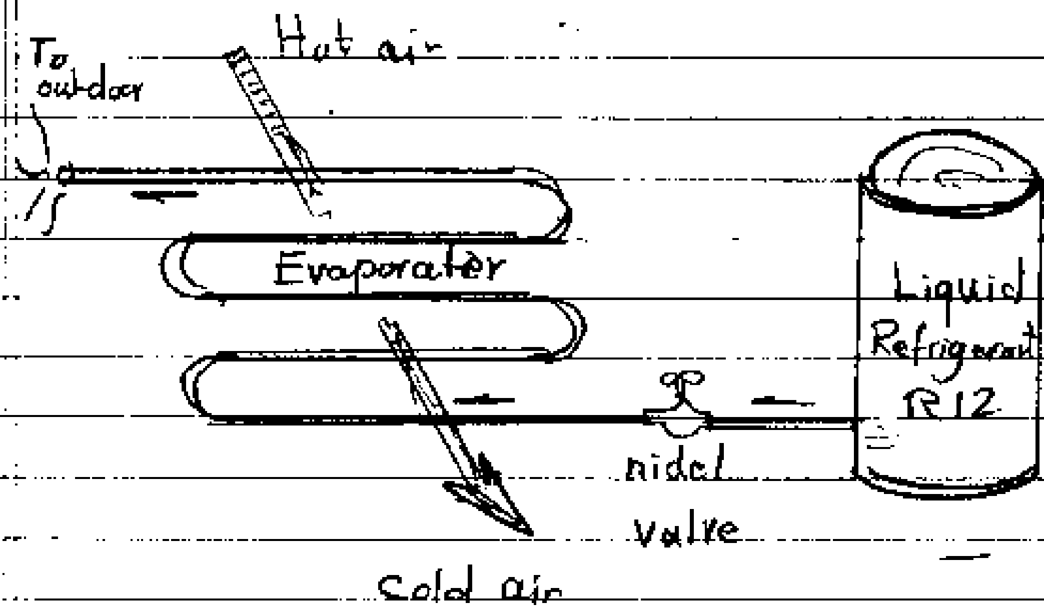
1.0 pound of 32°F ICE melts it absorbs 144 Btu.

$$\therefore \text{ One ton of Refrigeration} = \frac{2000 \times 144}{24 \text{ hr}}$$

One Ton of Refrigeration = 12,000 Btu/hr
= 3.5 KW

Refrigeration Theory

. Simple system (Theoritical).



The refrigerant must be delivered to the evaporator or cooling coil as a liquid because it can absorb het only by vaporizing.

Disadvantage of Simple system

1. The refrigerant is lost contumusly (becomes vary expansive operation)

2. Pullotion of the envirments

3. The refrigerant boiling temperature in this Case at atmospheric pressure (-31°c) whic is not desired in many application.

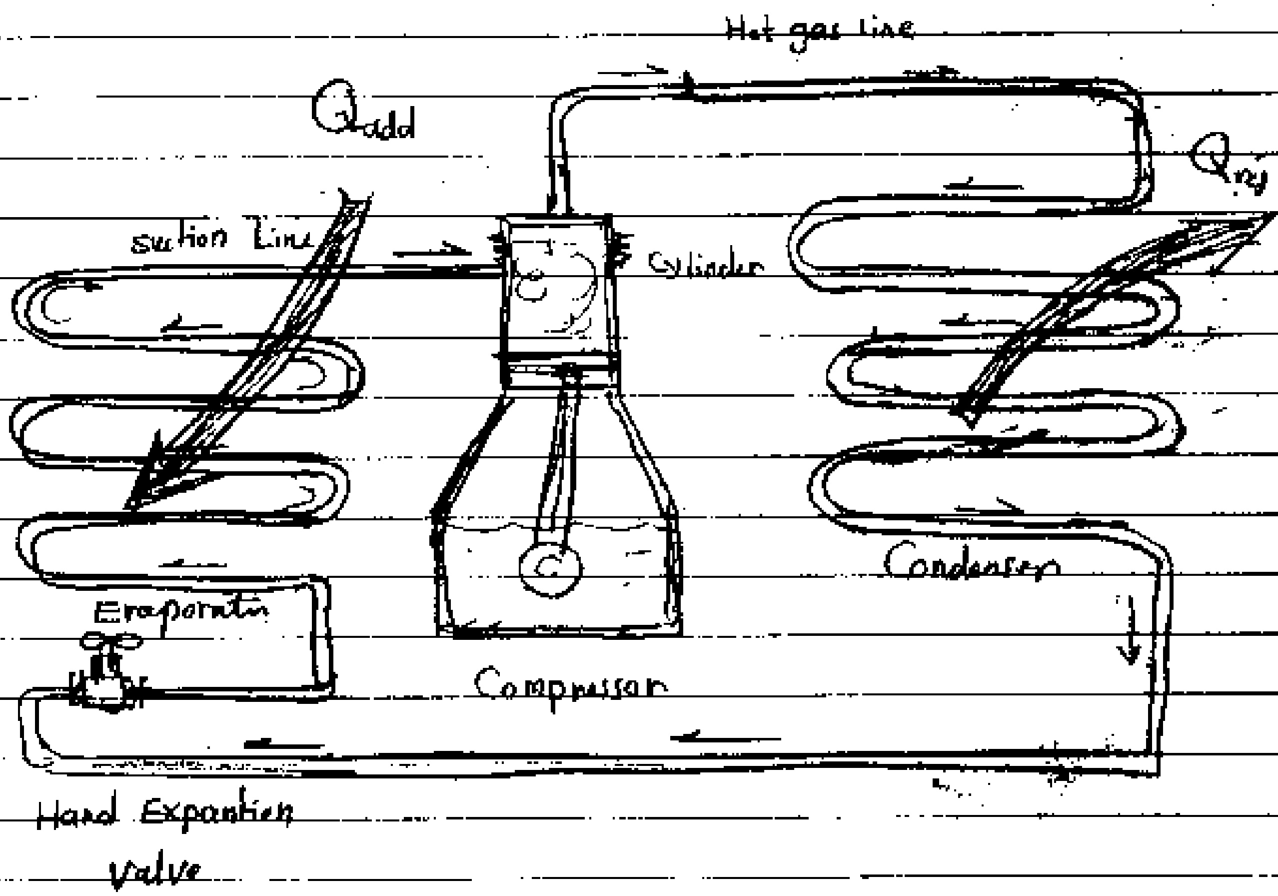
Refrigerant leaving the coil in the form of vapor, it must be reduced to a liquid befor it can be used again. The simplest way of accomplishing this would be condense the vaporized refrigerant as it leaves the cooling coil.

To condense the refrigerant vapor, the latent heat surrendered by the vapor during condensation must be transfered to some other medium. For this purpose, water or air is ordinarily used. The water or air must be at a temperature lower than the condensing temperature of refrigerant.

* In order to condense the vapor, its pressure must be increased to such a point that its condensing temperature will be above the temperature of water or air available for condensing purposes.

* The only reason that the compressor and Condenser are introduced into the system is to enable the same refrigerant to be used over and over again.

A complete refrigerating system is illustrated diagrammaticlly in Figure 1.2



CHAPTER TWO

REFRIGERANT

Refrigerants are the vital fluid in refrigeration System they absorb heat from the place where is not wanted and expel it elsewhere. The evaporation or boiling of the liquid refrigerant absorbs the heat that is released by the condensation of the vapor

Any substance that undergoes phase change from liquid to vapor, and vice versa may function as the refrigerant in vapor Compression type system. However, only those substances that undergo these changes at commercially useful temperature and pressure levels are of practical value.

2.1 Pressure Temperature Relationship

The most important to understand when dealing with the action in refrigeration system is the "boiling point" of the liquid (Refrigerant) in the system

* boiling point (Evaporation) must be < Chilling Substance (water,)

※ boiling point (condenser) must be $<$ cooling media (air or water)

In reality, the boiling point of a liquid will change in the same direction as the pressure to which the liquid is subjected. This is important basic law of physics. Fig. 2.1 gives example of the boiling point of water at sea level (212 °F, 100 °C) and water can be raised to 276 °F (°C) with pressure of 2 bar (30 psig) or lower to 40 °F (4 °C) at pressure of 29.67 in Hg (

Figure 2.1

2.2 Refrigerants type & Classification

1- **Hydro Carbon:** The refrigerant of this group are flammable.

Methane (CH_4), Ethane (C_2H_6), Propane (C_3H_8).

2 **Halocarbons (HFC):** Replac one or more hydrogen atoms in either of the hydrocarbons by halogens [Cl, F, Br]

R11 (CCl_3F), R12 (CCl_2F_2), R22 ($CHClF_2$)

3- **Inorganic Compounds:**

Amonia R717 (NH_3), Water R718 (H_2O)

Air R729, Carbon dioxide R744 (CO_2)

4- **Unsaturated Organic Compounds:**

Ethylene R1150 (C_2H_4), Propylene R1270 (C_3H_6)

2.3 Characteristics of Refrigerants

The desirable properties of the refrigerant are subdivided into three main groups:

A Safe Working Properties:
Refrigerant should be
- chemically stable
- non-explosive
- non-flammable
- non-toxic
- not react with lubricating oil

B. Thermodynamic Properties:
Should have
- very low boiling temperature
- Low freezing temperature
- evaporating and condenser pressure above atmosphere (preferiable) to prevent the leakage in, but not too high
- High critical temperature
- Compression ratio (π) small as possible.
- Latent heat of vaporization large as possible

C. Pysical Properties:

- Low specific volume at the suction line
- Low specific heat of liquid and high specific

heat of vapour.
- High thermal conductivity
- less Viscosity
- No electrical conductive.
- have same color
- Cheap in cost & available.

2.4 Refrigerant Numbering System

Because the chemical names of typical refrigerants are long and complex a method of referring to refrigerants by number was developed by DuPont. The numbering system was released for general use in 1965.
[ASHRAE Standard 34-1989]

A * Numbering system of Halocarbons & Hydrocarbons. And Unsaturated Organic

4	3	2	1
Number of saturated Carbon-Carbon bonds (not used when zero)	Number of carbon atoms - one (not used when zero)	Number of hydrogen atoms + one	Number of fluorine atoms

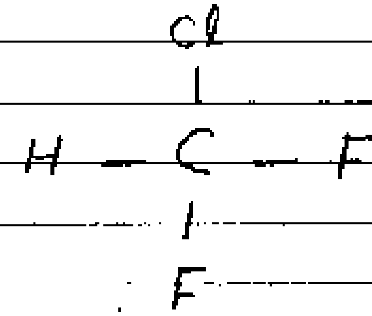
Notes

* when bromin is presents in place of all or part of chlorine, the same rules apply except that the capital letter "B" after the designation.

* The lower-case letter that follows the refrigeration designation refers to the form of molecule when different forms (isomers) possible, with the most symmetrical form indicated by the number alone. As the form becomes increasingly unsymmetrical, the letters a, b, c (lower case) are appended (Example HFC-134a).

Example 1. $CHClF_2$

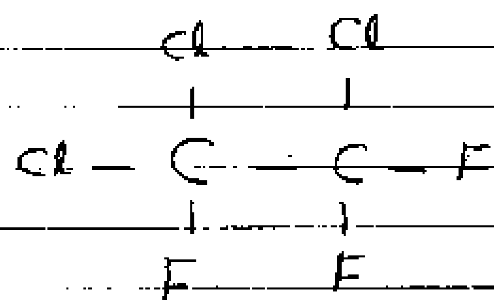
- Number of F atoms = 2
- Number of H = 1
- Number of C = 1
- Number of unsaturated carbon - carbon.



Digit [1] = 2
Digit [2] = 1+1 = 2
Digit [3] = 1-1 = Ø (Not use)
Digit [4] = Ø (Not use)

* The refrigerant is designated HCFC-22 (R22)

Example 2 CCl_2FCClF_2

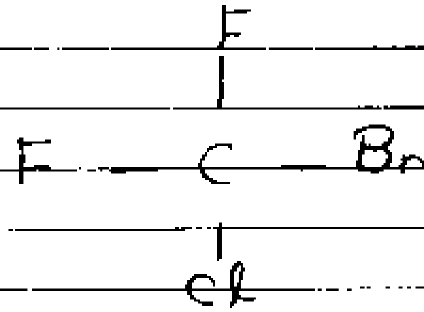


Digit [1] = 3
" [2] = Ø + 1 = 1
" [3] = 2 - 1 = 1
" [4] = Ø (Not used)

* CFC 113 (R113)

Example 3 $CBrClF_2$

Digit [1] = 2
" [2] = Ø + 1 = 1
" [3] = 1 − 1 = Ø (Not use)
" [4] = Ø (Not use)

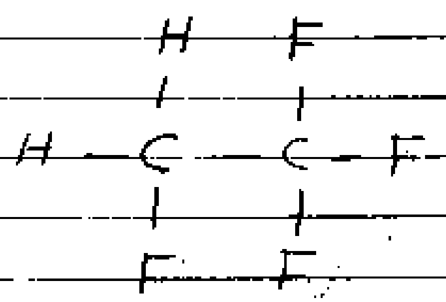


* One atom of Bromine = B1

∴ R12B1

Example – 4 CH_2FCF_3 (Tetrafluoroethane)

Digit [1] = 4
[2] = 2 + 1 = 3
[3] = 2 − 1 = 1
[4] = Ø Not use

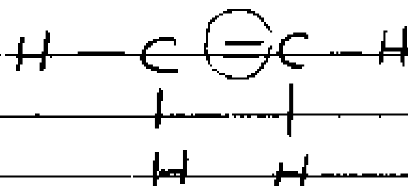


* The molecule (isomers) is unsymmetrical form the letter "a" is added

∴ R 134 a

Example 5 C_2H_4

Digit [1] = Ø
[2] = 4+1 = 5
[3] = 2−1 = 1
[4] = 1 (bond Carbon Carbon)



∴ R 1150

※ Numbering System For Inorganic Compound

It take number (700) plus the molecular weight

Example 1 Ammonia NH_3

- molecular weight = 14 + 3×1 = 17
∴ R 717

Example 2 Water H_2O

- molecular weight = 2×1 + 16 = 18
∴ R 718

CHAPTER 3

Vapour Compression Cycle

The vapour - Compression cycle is the most widely used refrigeration cycle in practice.

3.1 Carnot Refrigeration Cycle

The carnot cycle is one whose efficiency can not be exceeded when operating between two given temperature. The carnot cycle operating as a heat Engine. (Figure 3.1 a & 3.1 b) The carnot heat engine received energy at a high level of temperature, converts a portion of it into work and discharges the remained to a heat sink at a low level of temperature.

The Carnot refrigeration cycle performs the reverse effect of the heat engine because it transfer energy from a low level temperature (evaporator) to a high level of temperature. The refrigeration cycle requires the addition of external work for its operation. See Figure 3.2 a and 3.2 b.

The processes which constitute the cycle are:

1-2 Adiabatic compression

2-3 Isothermal rejection of heat
3-4 Adiabatic expansion (isentropic)
4-1 Isothermal addition of heat

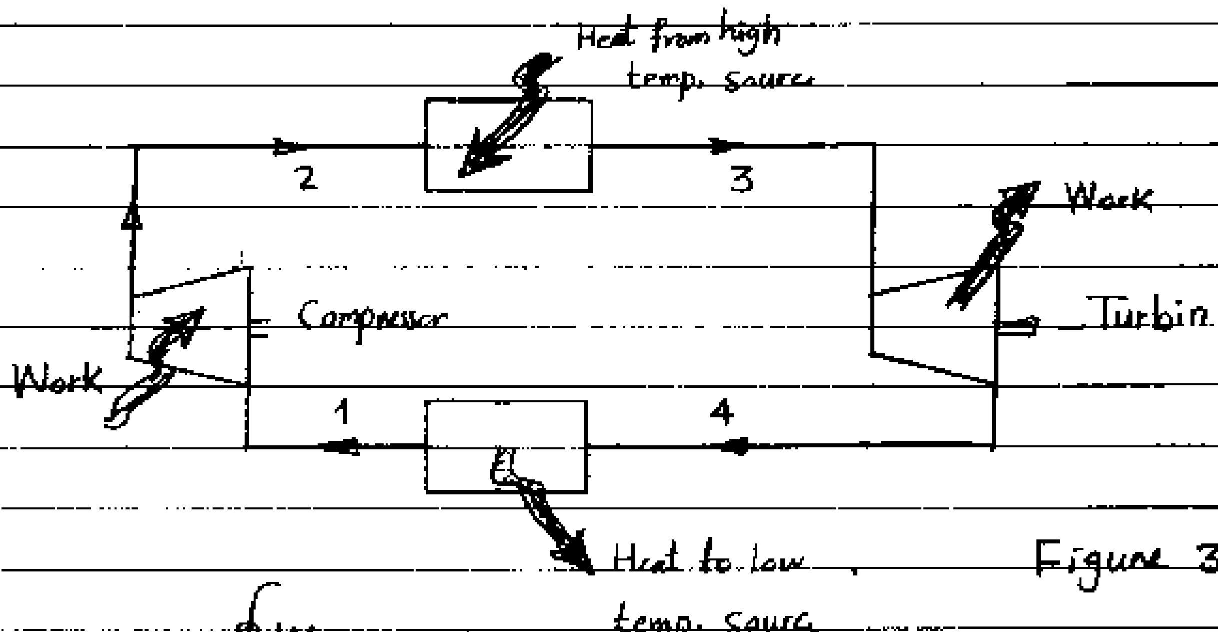


Figure 3.1.a

$$※\ \eta_{carnot} = \frac{\oint W}{Q_{in}} = \frac{W}{Q_{in}}$$
$$= \frac{Q_{in} - Q_{out}}{Q_{in}} = 1 - \frac{Q_{out}}{Q_{in}} = 1 - \frac{T_L(S_4 - S_1)}{T_H(S_3 - S_2)}$$
$$= 1 - \frac{T_L}{T_H}$$

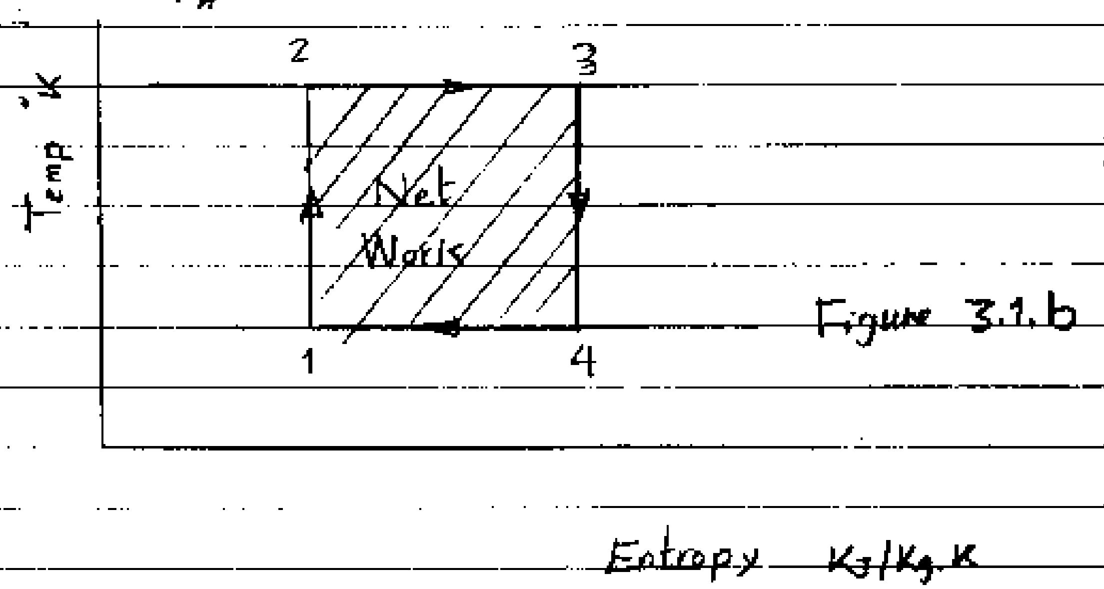


Figure 3.1.b

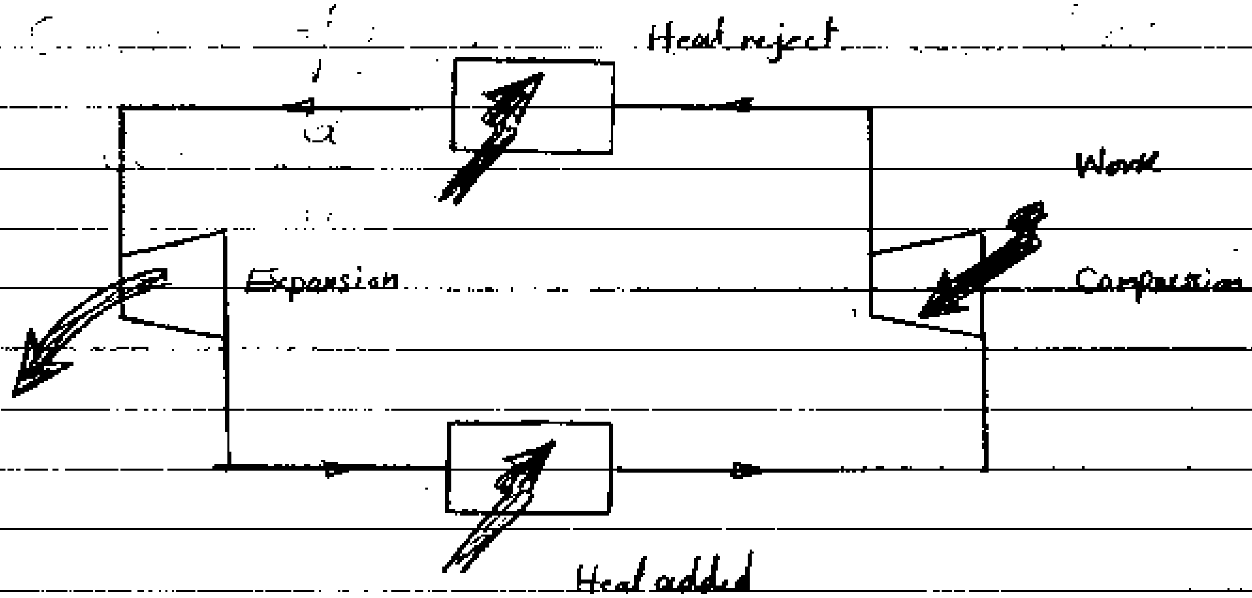
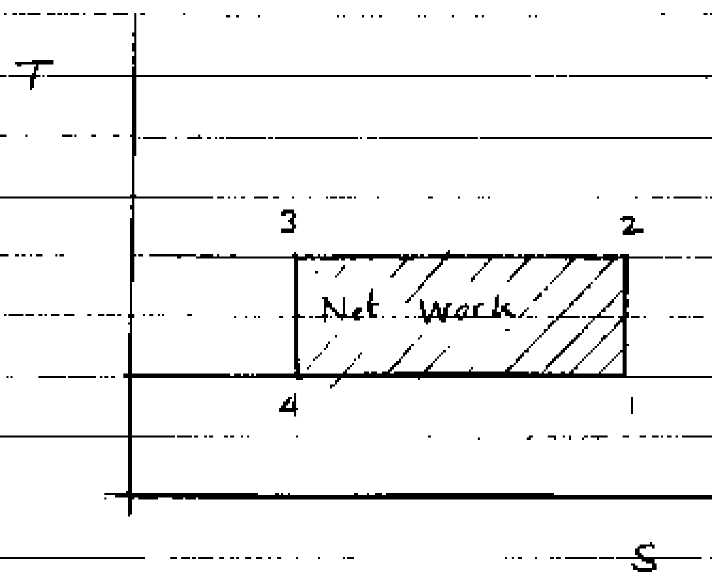


Figure 3.2_a



COP=

Figure 3.2_b

.2 P-h chart

The p-h chart, or pressure enthalpy chart is quit helpful in the study of refrigeration cycles, On the p-h chart several of the physical properties of a refrigerant are plotted on the two scales of pressure (P) and enthalpy (h). Figure 3-3 & Figure 3.4 are p-h chart for Refrigerant-12 and Refrigerant-22.

The p-h chart is divided into three general areas by the saturated liquid line and saturated vapour line. The area to the left of the saturated liquid line is called the subcooled region The area to the right of the saturated vapour line is called the superheated region and the area between the saturated liquid and vapour lines is called the "Wet" region or mixture region.

In Figure 3.5 there are four components of the refrigeration cycle: Expansion valve, evaporator, compressor, and condenser. The four components of the refrigeration cycle can be identified on the p-h chart by the four processes of Expansion, evaporation, compression, and condensation. Figure 3.6 shown the refrigerant cycle on ph chart

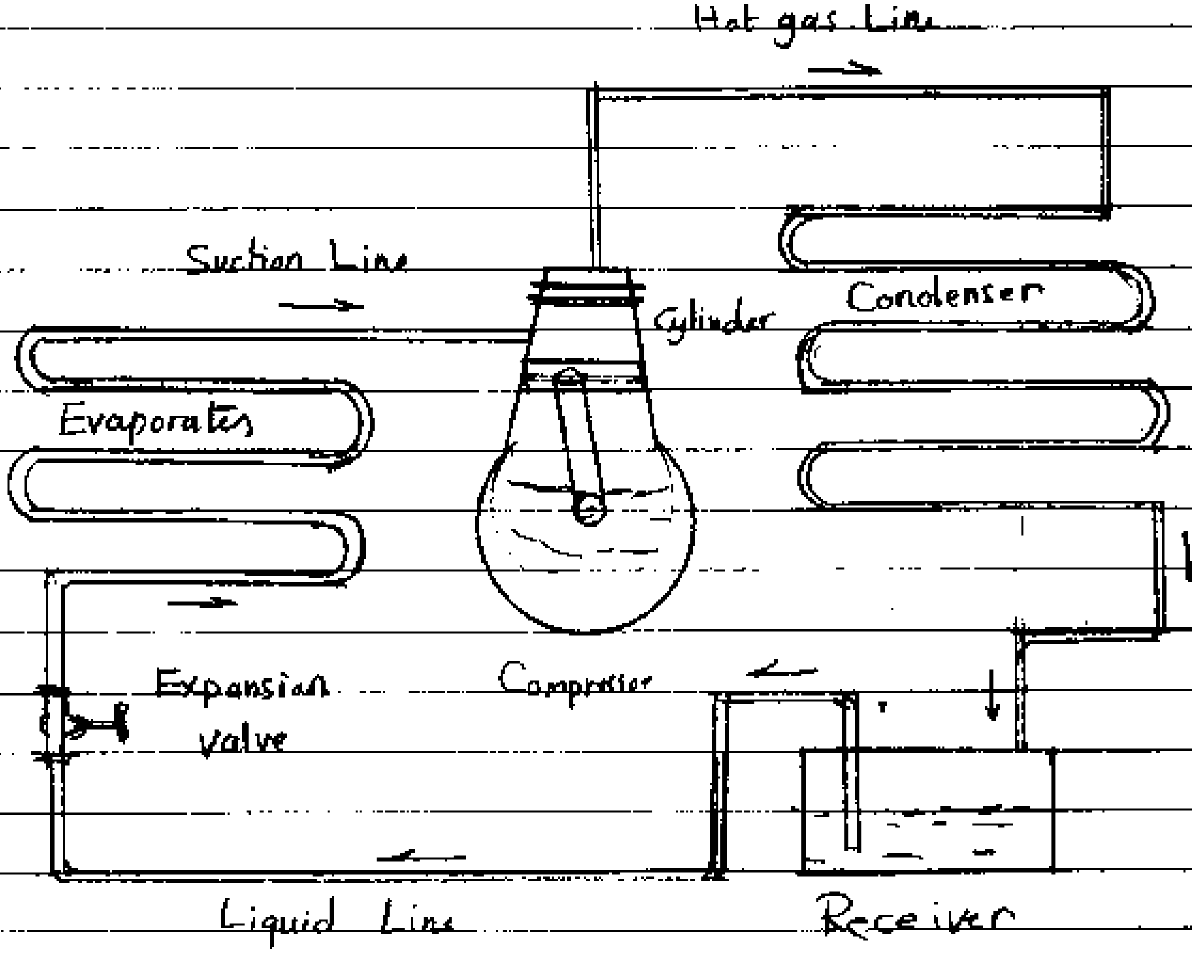


Figure 3.5

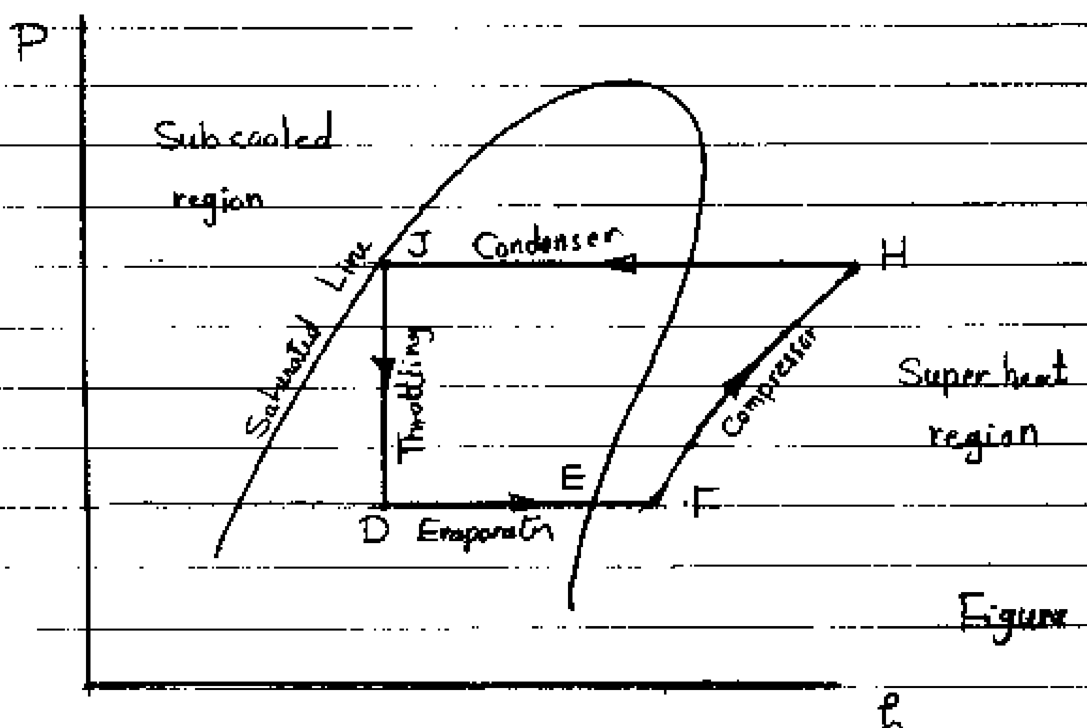


Figure 3.6

3 Refrigeration Effect

The quantity of heat that each Kg of refrigerant absorbs while flowing through the evaporation is known as the refrigeration effect.

The heat added to each (Kg) of refrigerant in the evaporator is the difference between the enthalpy of the vapor leaving the evaporator and the enthalpy of the liquid - vapor mixture entering the evaporator

Example

What is the refrigerating effect (RE) of one kilogram of refrigerant - 12 if the pressure in the evaporator is 2.55 bar (255 KN/m^2) and the temperature of the liquid approaching the expansion value is 26.7 °c.

Solution

Referring to table 3-1

- Temperature of vaporizing refrigerant in the evaporator at 4.4 °c on 255 KN/m^2
- Enthalpy of each Kg of vapor leaving the evaporator (No super-heat) at 4.4 °c = 353.3 KJ/kg

$$\dot{m} = \frac{3.5}{128} = 0.0273 \text{ Kg/s} \quad \text{per ton}$$

$$\cong 1.64 \text{ Kg/min}$$

(b) mass flow rate to 15 ton = 15 × 1.64
= 24.6 Kg/min

Circulated in a 15 ton plant.

.5 Cofficient of performance

The cofficient of performance, abbreviated COP, is the ratio of the refrigerating effect to work supplied, with the refrigerating effect and work each expressed in the same thermal units. The COP is a useful means of comparing the performance of various cycles.

$$COP = \frac{RE}{Work}$$

Example

A water chiller using Refrigerant 22 has a nominal rating of 60 tons when the evaporator temperature is 4.4 °c and condensing temperature is 37.8 °c. Assume the following conditions:

where

$$Q = q \times \dot{m}_{rf}$$

$$= 185 \times 1.32$$

$$= 244.2 \quad KW$$

(d) $$COP = \frac{R.E}{Work}$$

$$= \frac{160}{25} = 6.4$$

▲ Therefor (theoretical) 6.4 Kw can be removed from the evaporator for the expenditure of only 1.0 KW power input.

3.6 Superheated Refrigerant Vapor

When liquid refrigerant is addmitted to a cooling coil it will usually be completely vaporized befor it reaches the outlet connection. As much as the liquid is vaporized at low temperature, the vapor is still cold after the has completely evaporated. As the cold vapor flows through the coil it continues to absorb heat and become superheated, (Sensible heat).

On the one hand, the capacity of refrigeration system is increased when superheating of the vapor take place because the refrigerating effect of each pound of vapor removed has been increased by the sensible heat add during the superheating. On the other hand, the refrigerant capacity of the system is decreased because of the decrease in density during superheating. The effect of these two opposing tendencies must be computed in order to determine whether or not the refrigerating capacity of system is increased by superheating the vapor in the cooling coil.

However, superheating of the vapor often takes place after it leaves the evaporator. The vapor may absorb sensible heat while it is flowing through the suction line which connects the evaporator to the compressor.

3.7 Subcooling

Subcooling is a term used to describe the cooling of a liquid refrigerant at constant pressure, to a point below the temperature at which it was condensed. The effect of subcooling will be illustrated in the following example.

3.8 Actual cycle;

The actual vapor Compression cycle suffers from inefficiencies compared with the standard cycle. There are also other changes from the standard cycle, which may be intentional or unavoidable.

The essential differences between the actual and the standard cycle are:

1. Pressure drop in the evaporator ($\bar{4}$-1)
2. Pressure drop in the suction line from evaporator to compressor. (1'-1)
3. Pressure drop in the suction valve. ($\acute{1}$-1")
4. Non Isintropic Compression. (1"-$\acute{2}$)
5. Pressure drop in discharge valve of compressor ($\acute{2}$-2")
6. Pressure drop in the condenser piping. (2"-3)
7. Pressure drop in the liquid line (the line connecting the evaporator with the expansion valve). (3-$\acute{3}$)
8. Non adiabatic Expansion in expansion valve. ($\acute{3}$-4)

Figure 3- shows a p-h representation of an actual cycle. The effect of pressure drop in evaporator and suction valve (4'-1-$\acute{1}$, 1") decrease the temperature of inlet vapor in the compressor and increase the specific volume therefore decrease the mass handled by the compressor. Also pressure drops in piping, evaporator, condenser, receiver and valves causes an increase in the overall pressure ratio of the compression and to increase the work done per kg of refrigerant compressed.

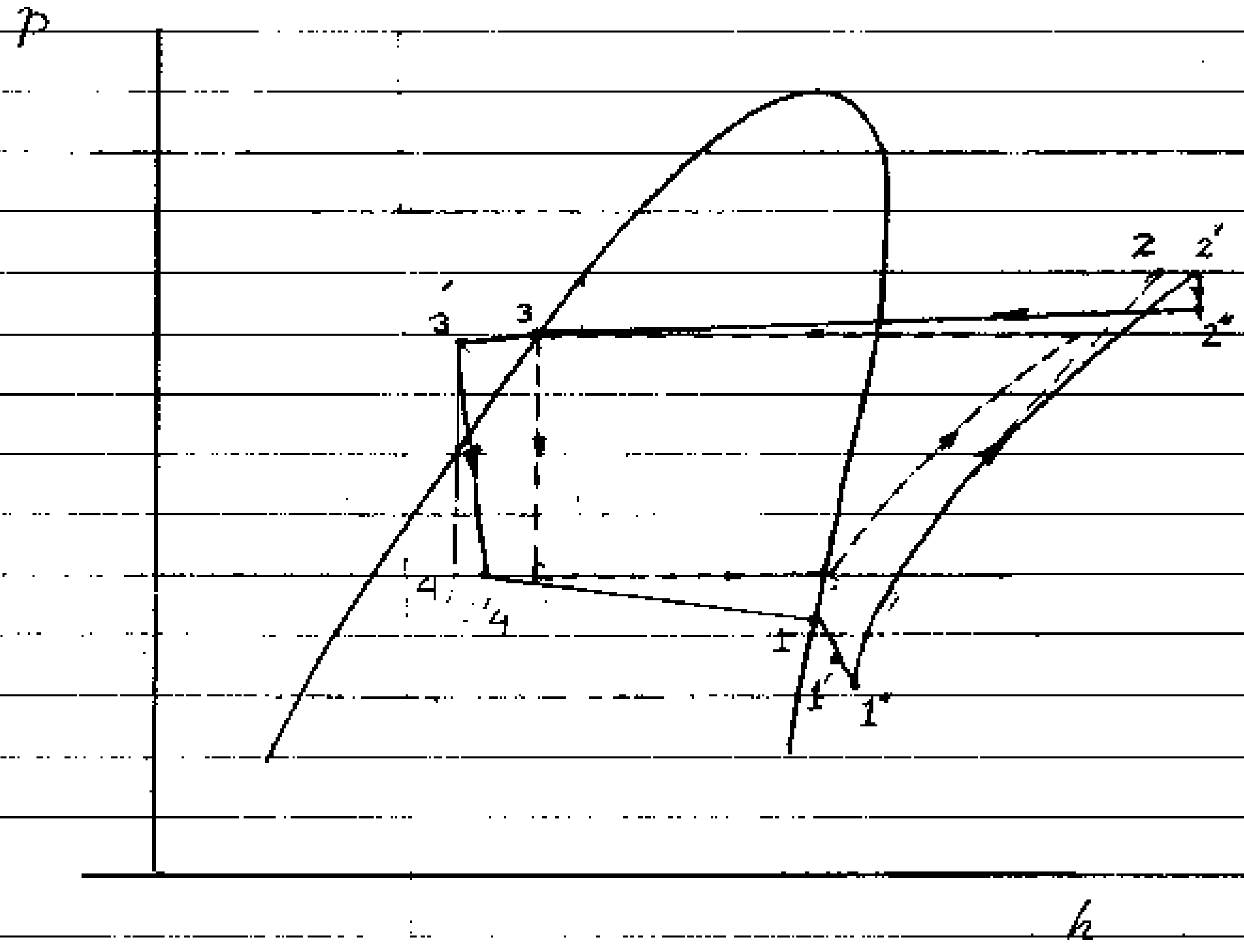


Figure 3.

The dotted line represent the ideal vapor compression cycle

9 Multistage System

Multistage System are used when ultralow temperatures are desired but cannot be obtained economically through the use of a single-stage System. This is because the compression ratios would be too high to get the necessary evaporating and condensing vapor temperatures. and the staging of refrigerant compression (with inter cooler) reducing the compression work done per kg of refrigerant circulated.

Stage of Compression with inter-cooler

The low pressure compression draws the refrigerant vapor from the evaporator and compresses it to some intermediate pressure and discharge it to intercooler. The gas in the intercooler is cooled by water or Flash gas. The gas is then led to high pressure compressor (cylinder) and compressed to condenser Pressure.

A/ Multi Compression system with water intercooler

This system is shown in the Figure 3-

CHAPTER 4

Compressor

Compressor is the heart of the vapor-compression system. The function of the compressor is to pump refrigerant vapor from the evaporator ~~to the~~ (Low pressure) to condenser (high pressure). its often the costliest component ~~system~~ (typically 30 to 40 percent of total cost)

Classification of compressors

The compressor may be classified in ~~many~~ several ways.

1. According to (Based) the method of compression
   - (a) Reciprocating compressor
   - (b) Rotary "
   - (c) Centrifugal "
2. According to ~~type~~ Idea or (Principle) of compression
   - (a) positive displacement compressors
   - (b) Kinetic compressor (roto-dynamic)

3. According to number of stage

(a) Single-stage (cylinder) compressor

(b) Multi-stage (cylinder) compr

4. According ~~to a stage~~ to arrangement of compressor motor

(a) open type compressor

(b) Semi hermatic "

(c) hermatic compr

4.2 Reciprocating Compressor

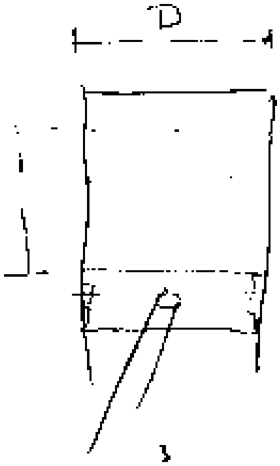
It is a positive displacement compression. in which the vapour refrigerant is compressed by the reciprocating motion of piston. ~~These compressor are used for~~ refrigerants

- low volume per Kg
- large differential pressure (R12, R22, Amonia)

The compressor usually have their cylinders arranged vertically radially or in V or W form.

4.3 ~~Work Done~~ Piston Displacement (strocks volume) or ~~displacer~~

It is the volume swept by the piston when it moves from its top dead position to bottom position during any certain interval of time. For one cylinder



$$V_P = \frac{\pi}{4} D^2 * L \quad \text{(Theoretical)}$$

where

V_P : Piston Displacement volume (m^3)

D : Piston or Cylinder Diameter (m)

L : Length of piston stroke (m)

Example 4.1

Find the theoretical refrigerating capacity of a single cylinder compressor ~~operating under the condition saturated vapor at 4.4°C & saturated liquid at 22°C~~.

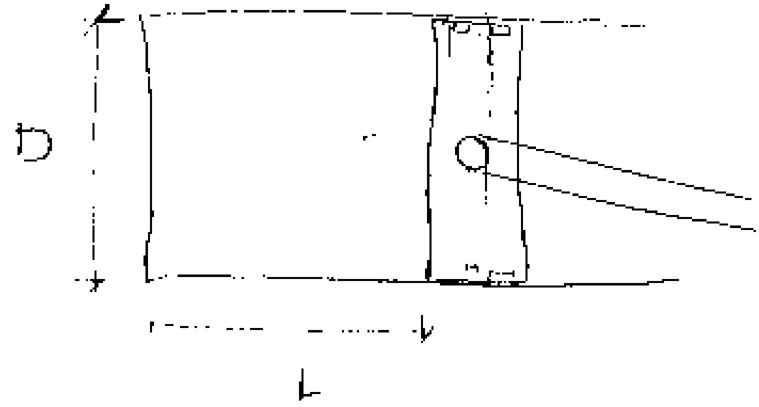
The compressor has 7 cm bore and 5 cm stroke. The compressor runs at speed of 1750 rpm.

Solution

$$V_p = \frac{\pi}{4} D^2 \times L$$

$D = 7$ cm
$= 0.07$ m

$L = 5$ cm
$= 0.05$ m



$$\therefore V_p = \frac{\pi}{4}(0.07)^2(0.05)$$
$$= 1.92 \times 10^{-4} \; m^3$$

Each revolution produce 1.92×10^{-4} m^3

$\therefore$ for 1750 revolution per minute

$$Q : \text{Discharge} = \frac{V_p \times rpm}{60}$$

$$= \frac{1.92 \times 10^{-4} \times 1750}{60} = \underline{\underline{0.0058 \; m^3/s}}$$

$$= 5.6 \; l/s$$

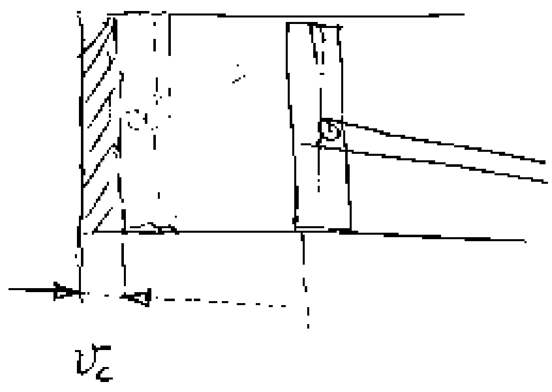
Most reciprocating compressors are multicylinder usually having ~~to~~ two to eight cylinders. The total piston displacement of such a compressor is found by multiplying the piston displacement of one cylinder by the number of cylinders.

4.3 Clearance factor (C)

It is the ratio of clearance volume (V_c) to the displacement volume (V_p)

$$C = \frac{V_c}{V_p}$$

This clearance is approximately 0.0375 − 0.75 cm



4.4 Volumetric Efficiency

It is the ratio of the actual compressor capacity or the suction volume (V_s) to the piston displacement volume (V_P) (theoretical)

$$\eta_v = \frac{V_s}{V_P} \quad \text{or} \quad \frac{m_{actual}}{m_{theoretical}}$$

It was assumed that at each stroke of piston the cylinder would fill completely with vapor at exactly the same pressure and temperature at which it left the evaporator. This is not true of actual compressor. The volume and therefor the weight of refrigerant that flows into a cylinder, is always less than this theoretical amount for several reasons.

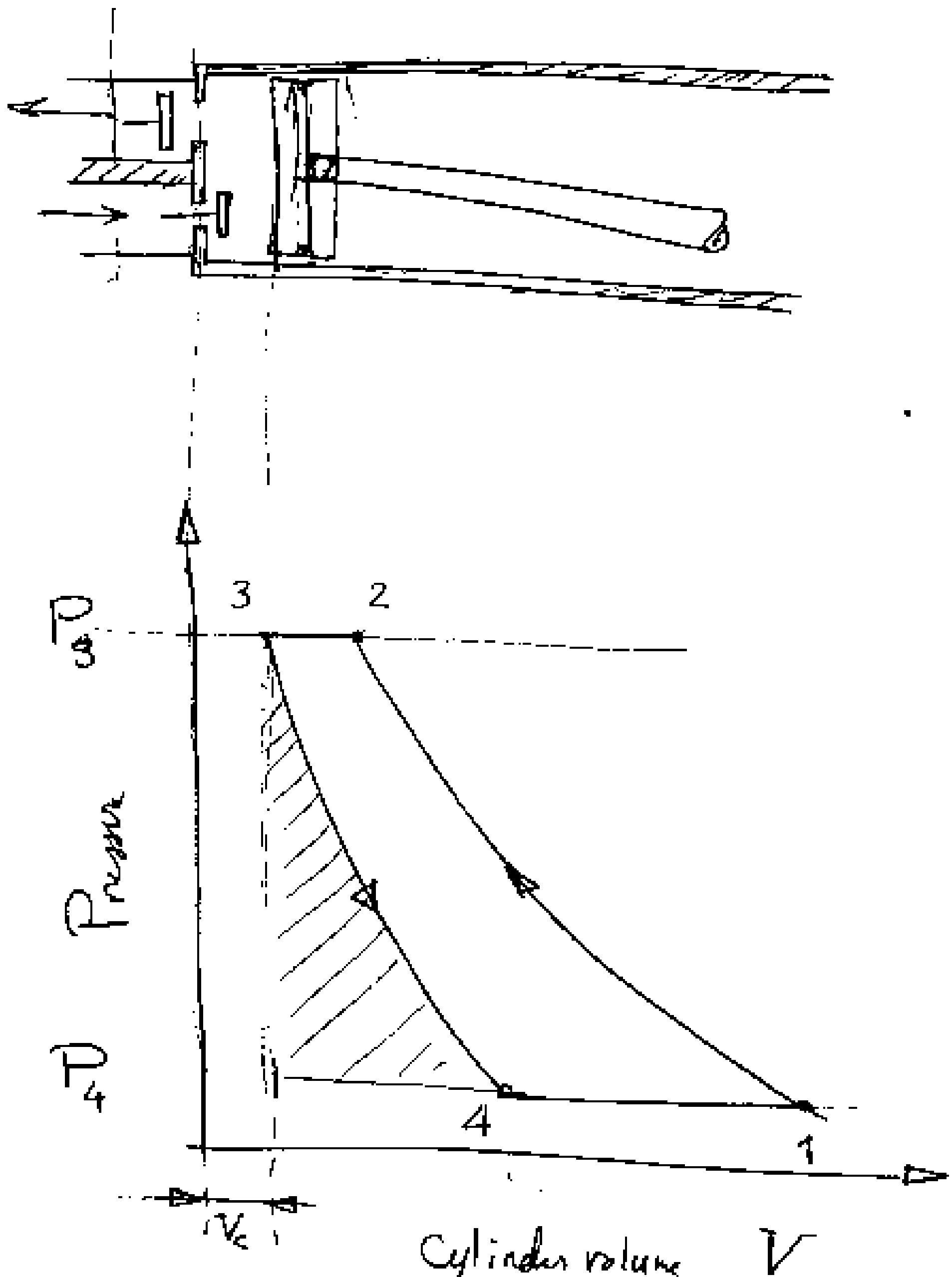
I/ Walls of the compressor cylinder are considerably ~~warm~~ warmer than the cold vapor leaving the evaporator
" change in specific volume "

II/ The pressure inside the cylinder is always somewhat
" change in specific vol "
lower than the ~~cylinder~~ pressure in the evaporator and in the suction pipe.

III/ All reciprocating compressor are built with slight clearance between the top of the piston an the cylinder head.

The volumetric Efficiency of any compressor is not a constant quantity. It depends on what is known as the

For reciprocating compressor, assumed the pressure is constant during the exhaust process $P_2 = P_3$ and during the intake process $P_1 = P_4$



(Figure 4-2)

Volumetric efficiency (η_{Vol}) Calculation

We have already noted that the induced volume is less than the swept volume. To enable this effect to be evaluated we define Volumetric efficiency (η_{Vol}) as:

$$\eta_{Vol} = \frac{\text{Induced volume}}{\text{Swept volume}} = \frac{\text{Suction Vol.}}{\text{Discharge Vol.}}$$

$$= \frac{V_1 - V_4}{V_p}$$

but $P_3 V_3^n = P_4 V_4^n \implies \left(\frac{V_4}{V_3}\right)^n = \left(\frac{P_3}{P_4}\right)$

$$\therefore \quad V_4 = V_3 \left(\frac{P_3}{P_4}\right)^{\frac{1}{n}}$$

$$= V_3 (r)^{1/n}$$

V_3 is the clearance volume (V_c), and

$$V_1 = V_c + V_p$$

$$\therefore \eta_{vol} = \frac{V_c + V_p - V_c \pi^{1/n}}{V_p}$$

$$= \frac{V_c}{V_p} + 1 - \frac{V_c}{V_p} \pi^{1/n}$$

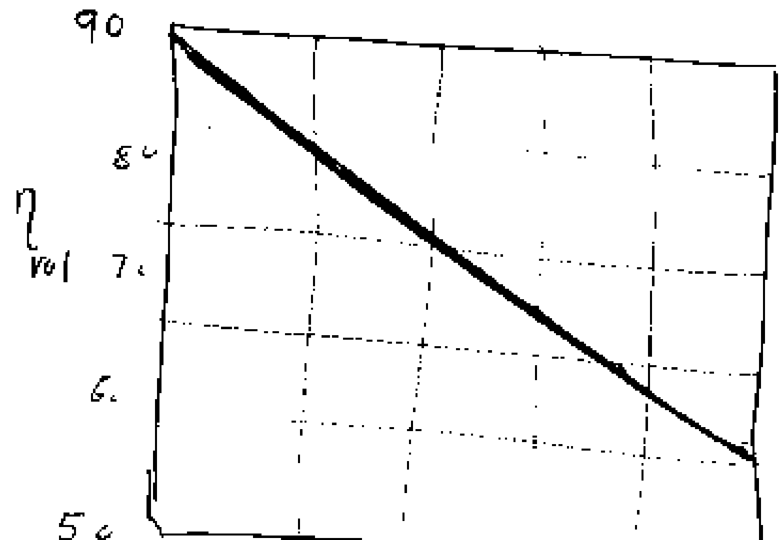
$$= \frac{V_c}{V_p} - \frac{V_c}{V_p} \pi^{1/n} + 1$$

$$\boxed{\eta_{vol.} = 1 - \frac{V_c}{V_p} \left(\pi^{1/n} - 1 \right)}$$

The

Figure 4.3 shown the average volumetric efficiency of reciprocating compressor using R-12 or R-22 and running at 1750 rpm

Figure 4.3



Also $\frac{V_c}{V_p}$ = Clearance factor (C)

$$\therefore \eta_{vol} = 1 - C\,(\pi^{1/n} - 1)$$

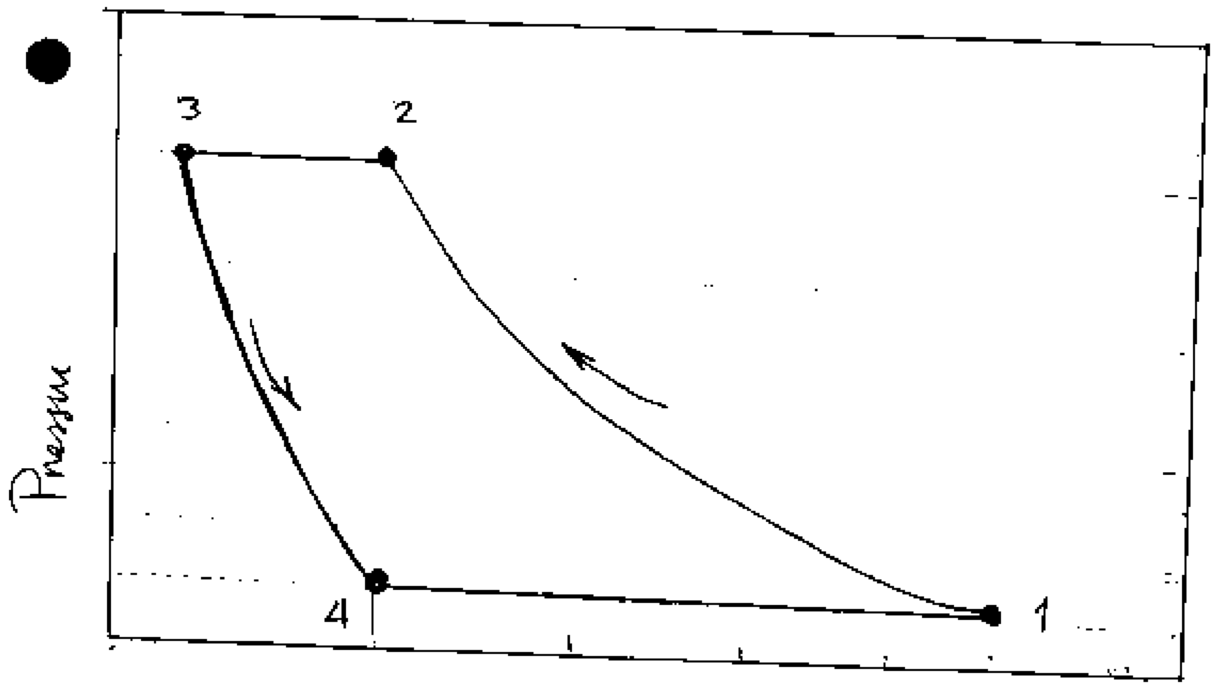
The three main factor that influence the volumetric efficiency in Eqn above.

1. Clearnce factor (4 – 16 %)
2. Compression ratio π
3. polytropic exponent n

Work input to the Compression

The cycle may be analysed as two non-flow (compression and expansion) processes and two flow processes (delivery and induction or suction)

	PROCESS	GROSS WORK
1 → 2	Compression	$\frac{P_2 V_2 - P_1 V_1}{n-1}$
2 → 3	Delivery	$p_2 (V_2 - V_3)$
3 → 4	Expansion	$\frac{P_4 V_4 - P_3 V_3}{n-1}$
4 → 1	Suction	$p_1 (V_4 - V_1)$.



Assume polytropic compression and expansion ($PV^n = \text{Constant}$)

The work per cycle is given by: $\sum$ gross Work

$$\text{Work per cycle} = \frac{P_2V_2 - P_1V_1}{n-1} + P_2(V_2 - V_3) + \frac{P_4V_4 - P_3V_3}{n-1} + P_1(V_4 - V_1)$$

$$= \frac{P_2V_2}{n-1} - \frac{P_1V_1}{n-1} + P_2(V_2 - V_3) + \frac{P_4V_4}{n-1} - \frac{P_3V_3}{n-1} + P_1(V_4 - V_1)$$

\# Rearanged

$$= \frac{P_4V_4 - P_1V_1}{n-1} + P_1(V_4 - V_1) + \frac{P_2V_2 - P_3V_3}{n-1} + P_2(V_2 - V_3)$$

but $P_1 = P_4$ & $P_2 = P_3$

$$\therefore \text{Work per cycle} = \frac{P_1(V_4 - V_1)}{n-1} + P_1(V_4 - V_1) + \frac{P_2(V_2 - V_3)}{n-1}$$

$+ P_2 (V_2 - V_3)$

$$= P_1 (V_4 - V_1)\left(1 + \frac{1}{n-1}\right) + P_2 (V_2 - V_3)\left(1 + \frac{1}{n-1}\right)$$

but mass discharge = mass induced

using Universal Law of gases

$$PV = mRT \Rightarrow \frac{P_1 V_1}{RT_1} = \frac{P_2 V_2}{R.T_2}$$

$$\therefore \frac{P_2 (V_2 - V_3)}{R T_2} = \frac{P_1 (V_1 - V_4)}{R T_1}$$

$$P_2 (V_2 - V_3) = P_1 (V_1 - V_4) \frac{T_2}{T_1}$$

$$\text{Work per cycle} = P_1 (V_4 - V_1)\left(1 + \frac{1}{n-1}\right) + P_1 (V_1 - V_4)\frac{T_2}{T_1}\left(1 + \frac{1}{n-1}\right)$$

$$= P_1 (V_1 - V_4)\left(\frac{T_2}{T_1}\right)\left(\frac{n}{n-1}\right) - P_1 (V_1 - V_4)\left(\frac{n}{n-1}\right)$$

$$= P_1 (V_1 - V_4)\left[\left(\frac{T_2}{T_1}\right)\left(\frac{n}{n-1}\right) - \left(\frac{n}{n-1}\right)\right]$$

If we plot the specific work against the polytropic index n we obtain

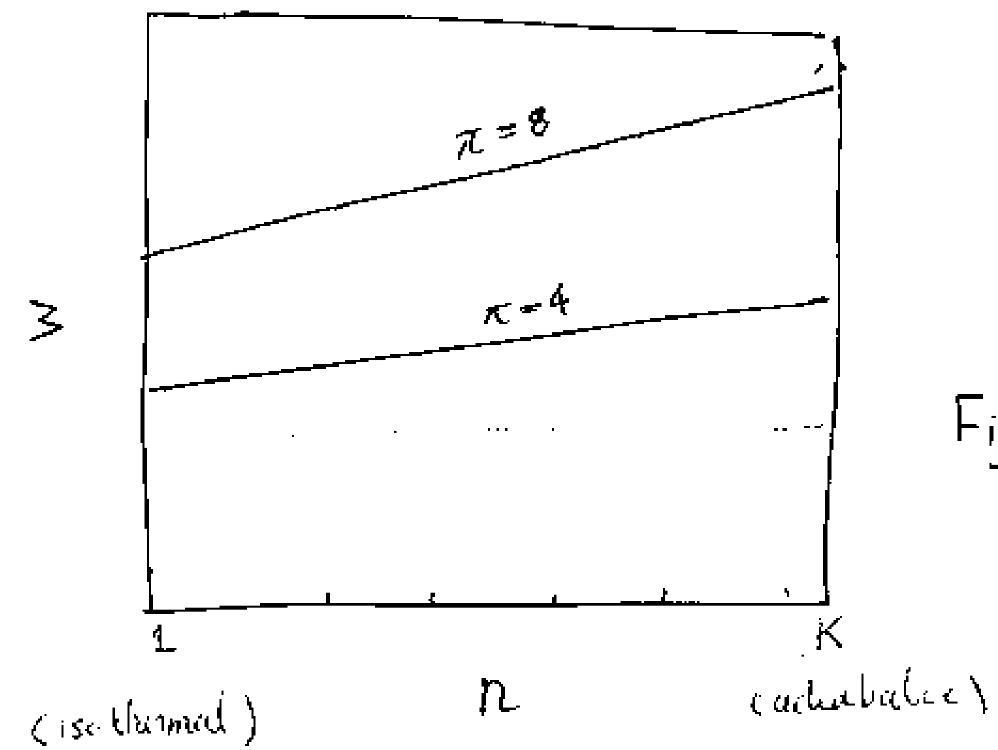


Fig 4-5

where $K = \gamma$ or c_p/c_v

Figure 4.6 Shows on Pv and Ts diagrams for a gas three different reversible compression paths between state 1 and the same final Pressure P_2

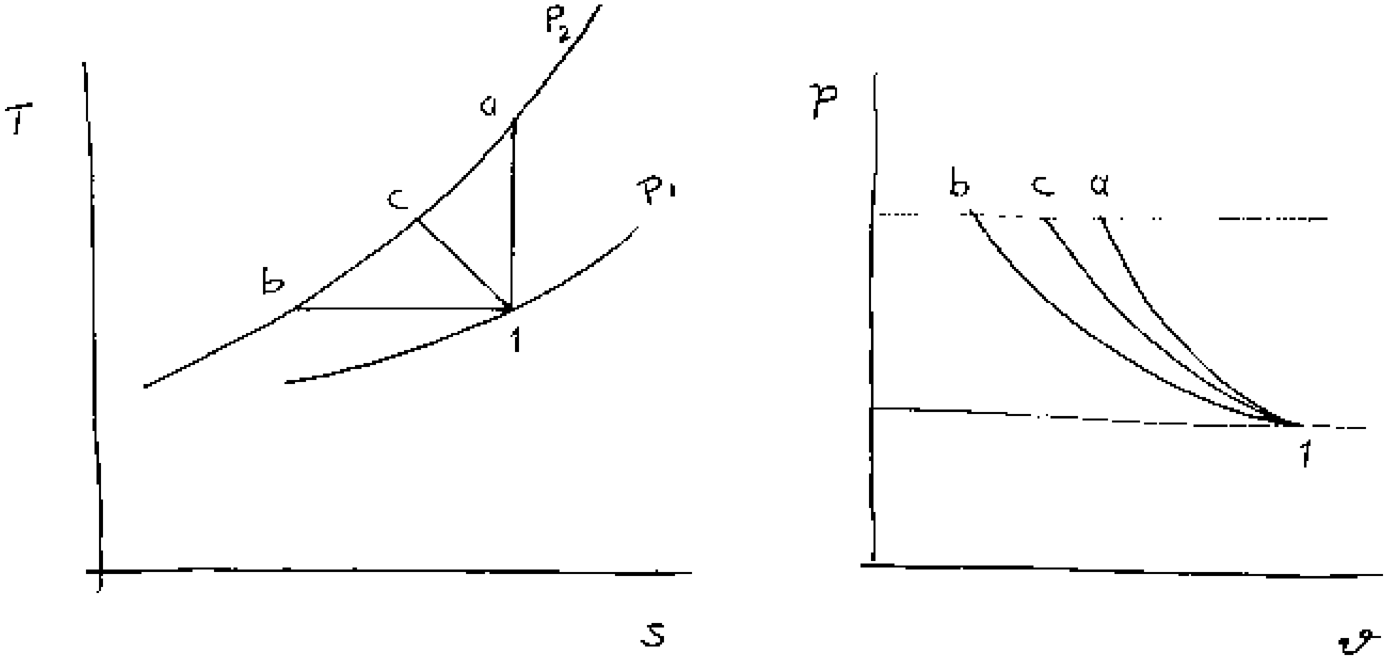


Fig 4-6

- 1-a is reversible adiabatic compression

$$n = K$$

1-b is reversible isothermal compression

$$n = 1$$

1-c is reversible compression with some heat remove but not hold the temperature constant. might be polytropic process :

$$1 < n < K$$

※ In an actual machine, the amount of heat that can be transferred during the compression process is limited by both the small surface area available for heat transfer and short length of time required for the gas to pass through the machine. In actual cooled compressor is a polytropic process with n closer to k than to 1

We can therefore define compressor efficiency

- as

$$\eta_{isoth.} = \frac{\text{Isothermal Work}}{\text{Actual Work}}$$

$$W = \frac{n}{n-1} R T_{in} \left\{ \pi^{\frac{n-1}{n}} - 1 \right\}$$

fr isothermal

- $$W = P_1 V_1 \ln (P_1/P_2)$$

$$\therefore \eta_{isoth} = \frac{\ln \pi}{\frac{n}{n-1}\left(\pi^{\frac{n-1}{n}} - 1\right)}$$

※ One way of improving efficiency, especially at higher compression ratio (π) and speed, is to go

$$= P_1 (V_4 - V_1)\left(1 + \frac{1}{n-1}\right) + P_2 (V_2 - V_3)\left(1 + \frac{1}{n-1}\right)$$

but mass discharge = mass induced

using Universal Law of gases

$$PV = mRT \Rightarrow \frac{P_1 V_1}{RT_1} = \frac{P_2 V_2}{R.T_2}$$

$$\therefore \frac{P_2 (V_2 - V_3)}{RT_2} = \frac{P_1 (V_1 - V_4)}{RT_1}$$

$$P_2 (V_2 - V_3) = P_1 (V_1 - V_4) \frac{T_2}{T_1}$$

$$\text{Work per cycle} = P_1 (V_4 - V_1)\left(1 + \frac{1}{n-1}\right)$$

$$+ P_1 (V_1 - V_4) \frac{T_2}{T_1} \left(1 + \frac{1}{n-1}\right)$$

$$= P_1 (V_1 - V_4)\left(\frac{T_2}{T_1}\right)\left(\frac{n}{n-1}\right) - P_1 (V_1 - V_4)\left(\frac{n}{n-1}\right)$$

$$= P_1 (V_1 - V_4)\left[\left(\frac{T_2}{T_1}\right)\left(\frac{n}{n-1}\right) - \left(\frac{n}{n-1}\right)\right]$$

$$= P_1(V_1 - V_4)\left[\frac{n}{n-1}\right]\left[\frac{T_2}{T_1} - 1\right]$$

for a polytropic process:

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} = (\pi)^{\frac{n-1}{n}}$$

where

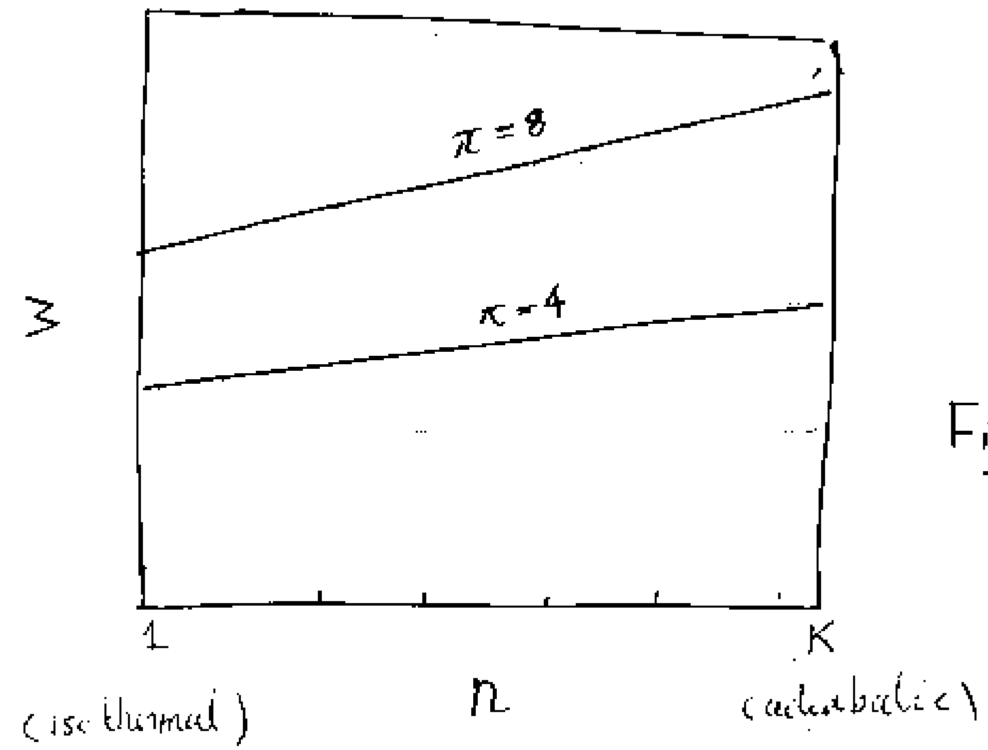
n : polytropic index

π : Compression ratio

Noting that $(V_1 - V_4)$ is the suction volume ($V_{act.}$) and P_1 is the suction pressure. (P_e) we may re-arrange and write:

$$\text{Work per cycle} = \frac{n}{n-1} P_{suc} V_{act.} \left(\pi^{\frac{n-1}{n}} - 1\right)$$

if we plot the specific work against the polytropic index n we obtain



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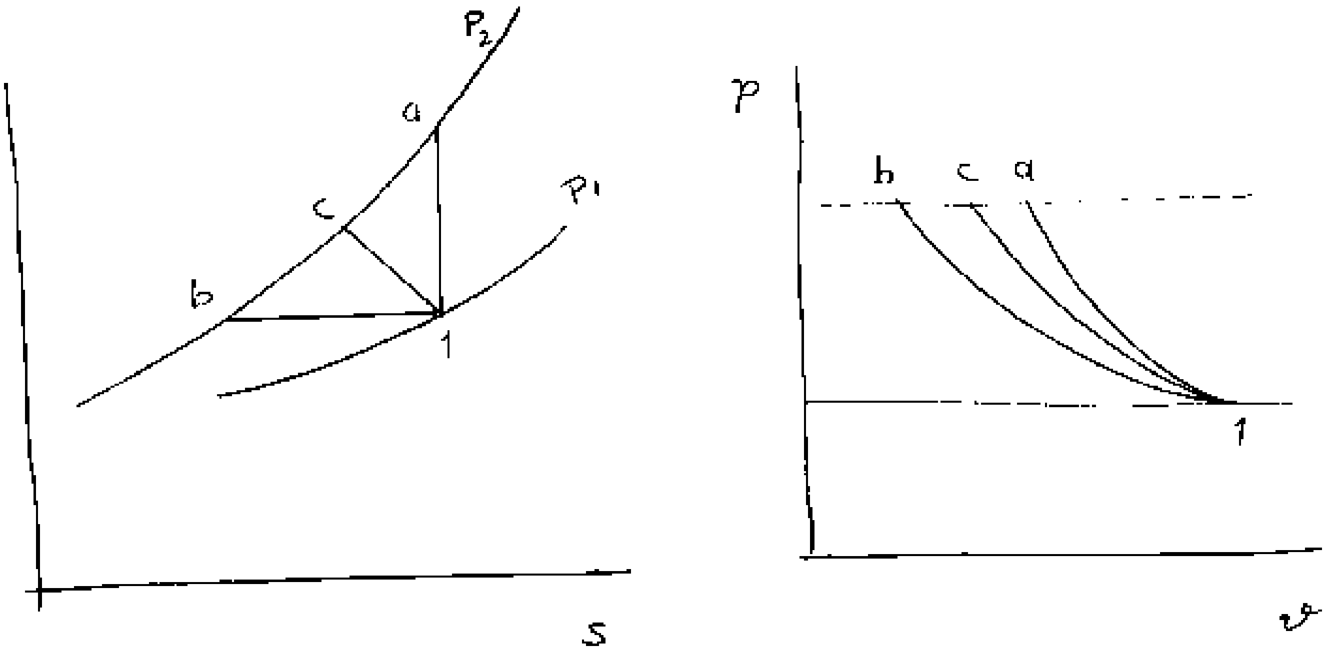

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1-a is reversible adiabatic compression

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$$1 < n < K$$

In an actual machine, the amount of heat that can be transferred during the compression process is limited by both the small surface area available for

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We can therefore define compressor efficiency as

$$\eta_{isoth.} = \frac{\text{Isothermal Work}}{\text{Actual Work}}$$

$$W = \frac{n}{n-1} R T_{in} \left\{ \pi^{\frac{n-1}{n}} - 1 \right\}$$

for isothermal

$$W = P_1 V_1 \ln (P_1/P_2)$$

$$\therefore \eta_{isoth} = \frac{\ln \pi}{\frac{n}{n-1} \left(\pi^{\frac{n-1}{n}} - 1 \right)}$$

* One way of improving efficiency, especially at higher compression ratio (π) and speed, is to go

to multistage compression with cooling of the gas between each stage.

※ The polytropic exponent (n) must be determined experimentally, it may be approximated by the isentropic exponent (K) or (γ) when other data are not available.

Table 4.1 gives some representative value of (K)

	Refrigerant		
	R-12	R-22	Ammonia
vapor temperature °C	10	30	21
$K = \gamma = C_p/C_v$	1.13	1.16	1.31