Total Pressure

![Diagram of fan with static and velocity pressure](image)

\[ \text{total pressure (P_t)} = \text{static pressure (P_s)} + \text{velocity pressure (P_v)} \]

The total amount of pressure generated by a fan has two components: velocity pressure and static pressure. The velocity pressure is due to the momentum of the air as it moves axially through the duct, while the static pressure is due to the perpendicular outward "push" of the air against the duct walls.

The total pressure is the sum of the velocity pressure and the static pressure.

Fan Performance Curve

![Graph showing fan performance curve](image)

When a series of points is plotted, a curve can be drawn. The resulting curve graphically illustrates the performance of this fan when it is operated at a constant speed.

Notice that the curve extends from blocked-tight static pressure, with a corresponding zero airflow, to wide-open airflow, with a corresponding zero static pressure.
7.3: Fans laws:

\[
\frac{\text{Airflow}_2}{\text{Airflow}_1} = \frac{\text{Fan Speed}_2}{\text{Fan Speed}_1}
\]

\[
\frac{\text{Static Pressure}_2}{\text{Static Pressure}_1} = \left(\frac{\text{Fan Speed}_2}{\text{Fan Speed}_1}\right)^2
\]

\[
\frac{\text{Input Power}_2}{\text{Input Power}_1} = \left(\frac{\text{Fan Speed}_2}{\text{Fan Speed}_1}\right)^3
\]

Static Efficiency

\[
\text{Static Efficiency (SE)} = \frac{\text{Power Out}}{\text{Power In}}
\]

\[
\text{SE} = \frac{\text{Airflow} \times \text{Static Pressure}}{\text{Constant} \times \text{Input Power}}
\]

7.4: Air Duct design methods:

The essential economics of an air transmission system is achieved by a proper balance between the initial cost and operating cost for the given flow rate of air. The initial cost is determined by the cost of the duct system which is depends on duct sizes. The operating cost is determined by the fan power consumption which depend on the pressure drop in the air handling equipments and duct system. The pressure drop can be reduced by increasing the sizes of the ducts but this will increase the initial cost. Hence the need for a proper balance. A few general rules are stated in reference (1) which should be followed in the design of ducts.

There are three common methods for sizing of ducts, they are:

a- Equal friction method
b- Velocity reduction method
c- Static regain method.
7.2: Fans connections

**System Resistance**

![Diagram of System Resistance]

**System Static-Pressure Control**

![Diagram of System Static-Pressure Control]
The first method will be used for its simplicity. In this method the frictional pressure drop per unit length of the duct is maintained constant throughout the duct system. The procedure is to select a suitable velocity in the main duct from sound level consideration or to choose a suitable value for the pressure drop (1.0-1.5 Pa/m). Knowing the air flow rate and the velocity or pressure drop the size are determined from charts. This method of sizing the duct system automatically reduces velocity in the direction of flow.
LECTURE No. 16 & 17

DESIGN OF PIPING SYSTEMS:

Types of piping system: The piping systems are divided into two types:

Closed system: In a closed system chilled or hot water flowing through the coils, heater, chiller, boiler or other heat exchanger forms a closed recirculating loop as shown in the figure below. In close system water is not exposed to the atmospheric during its flowing process. The purpose of recirculating is to save water and energy.

Open system: In an open system the water is expose to the atmosphere as shown in the figure below. For example, chilled water come directly into contact with the cooled and dehumidified air in the air washer and condenser water is exposed to atmosphere in the cooling tower. Recirculation of water is used to save water and energy.
The close systems are consists of the following components:

1- Load unite which represents the terminal unite as cooling or heating coils or radiators

2- Source unite which represent the chiller in cooling system or the boiler and furnace in heating systems.

3- Distribution systems which represents the piping and fitting of the piping systems.

4- Pump that used to circulate the water in the cooling or heating systems. It is usually of a centrifugal types with constant flow rates (0.3 l/s with 20 kPa up to hundreds of l/s and appropriate pressures).

5- Expansion tanks which are of two types

Types of closed systems:

1- One pipe system: A single pipe connect all the system components i. e. the pipe started from the source unit through the pump to the load units and then return to the source. The disadvantage of this system is that the efficiency of the last units are low because the return cold or hot water of all units is added to the same pipe that supply the end units.

2- Two pipe system: This system has a two pipes one to the supply water and the other to the return water. In this system the disadvantage of the one pipe system is overcome. This is the most popular system in use because it is simple and cheep.
3- Three pipe system: This system can be used in central air conditioning units that used for cooling and heating in the same time. It has one pipe to supply hot water, the other to supply cold water and the third is a common return pipe i.e. the third pipe is used to return cold and hot water to the chiller and boiler. The disadvantage of the system is the waste of heat in the third common return pipe.

4- Four pipe system: The disadvantage of the three pipe system (i.e. the common third return pipe) is overcome in this system by adding a fourth pipe. The four pipe system can be used in central air conditioning plant with cold and hot circuits separated as shown in the figure below.
Direct return or Reverse return:

In a direct-return water system, the various branch piping circuits such as ABGHA and ABCFGHA are not equal in length (figure a- direct return b- reverse return). Careful balance is often required to establish the design flow rates for a building loop when a direct return distribution loop is used. In a reverse-return system the piping length for each branch circuits, including the main and branch pipes are almost equal.

Procedure for sizing pipe systems

The recommended procedure for sizing piping systems is outlined below:

1. Sketch the main lines and branches and indicate the locations of terminal units and the rate of flow of each unit. Use as short as possible runnes.
2. Choose a suitable velocity in the main pipe or riser (1.0 - 2.5 m/s), and 1.25 m/s for branch pipes for D= 50 mm or less.
3. Point out the locations of valves, drainage and air-vent openings. The drainage should be located at the lowest point while the air-vent should be at the highest point in the system.
4. Design the pipe sizes using charts and tables. Do not use an equal pressure drop as in duct system.
5. Determine the equivalent length for the main pipes branches, fittings, coils heat exchangers plus any static head given in open circuits.
6. Calculate the pump total head or total pressure and the pump power required to deliver the required flow rate. Always use a stand by pump for emergency.
Example -1

Determine the pressure drop in 90 elbow of 25 mm diameter. The water is flowing at mass flow rate of 0.5 kg/s and temperature of 60 c.

Example -2

Size the piping required to carry water mass flow rates such as (1, 10, 30, 50 kg/s) at temperature of 5 c.

Water pumps:

The total head of a given pump may be determined by:

\[ H_{\text{pump}} = \{ H_d + 0.5 \times (V_d)^2 / g - ( H_s + 0.5 \times (V_s)^2 / g ) \} \]

Where \( H_{\text{pump}} \) in meter of water and subscripts \((d)\) for discharge and \((s)\) for suction sides.

\[ P_{\text{pump}} = \{ P_d + 0.5 \times P \times (V_d)^2 - ( P_s + 0.5 \times p \times (V_s)^2 ) \} \]

Where \( P_{\text{pump}} \) in Pascal and subscripts \((d)\) for discharge and \((s)\) for suction sides.

The power of the pump may be given by:

\[ W_{\text{pump}} = M \times g \times H_{\text{pump}} = Q \times P_{\text{pump}} \text{ in (Watt)} \]

The pump efficiency may be given by:

\[ \eta = \frac{W_{\text{pump}}}{W_{sh}} \]

Where: \( W_{sh} \) is the shaft power of the pump.
Example - 3

A pump is used in a closed system with flow rates of (7.6 l/s). The discharge pipe diameter is 68.7 mm and that for the suction side is (80.7 mm). The expansion tank is located at the suction side at a height of 15 m above the centerline of the pump suction pipe. There is a gauge pressure in the discharge side which reads (250 kPa) during the normal operation of the pump. Calculate the total pressure and the power of the pump.

Example - 4

A gauge pressure located at the inlet side of a cooling coil reads (100 kPa). Another gauge pressure is located at the exit side at a height of (1.0 m) above the location of the inlet side gauge. The exit side gauge pressure reads (50 kPa). Calculate the pressure drop for the cooling coil.

Example - 5

Determine the equivalent length of a gate valve (D = 50 mm), a union (D = 50 mm) and T-connection (D = 500 mm) with flow rate of 1.0 kg/s.

Example - 6

A piping system consists of a pump, a chiller, three cooling coils connected in series. The expansion tank is located at the suction side of the pump at a height of (10 m) above the centerline of the suction pipe of the pump. There is (10) gate valves, (20) elbow 90 in the circuits. The longest pipe run is 100 m length. Calculate the total pressure and pumping power for the system.
Fig. 1  Friction Loss for Water in Commercial Steel Pipe (Schedule 40)

Fig. 2  Friction Loss for Water in Copper Tubing (Types K, L, M)

Fig. 3  Friction Loss for Water in Plastic Pipe (Schedule 80)
**Table 6  Equivalent Length in Metres of Pipe for 90° Elbows**

<table>
<thead>
<tr>
<th>Velocity, m/s</th>
<th>15</th>
<th>20</th>
<th>25</th>
<th>32</th>
<th>40</th>
<th>50</th>
<th>65</th>
<th>90</th>
<th>100</th>
<th>125</th>
<th>150</th>
<th>200</th>
<th>250</th>
<th>300</th>
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<tr>
<td>0.33</td>
<td>0.4</td>
<td>0.5</td>
<td>0.7</td>
<td>0.9</td>
<td>1.1</td>
<td>1.4</td>
<td>1.6</td>
<td>2.0</td>
<td>2.6</td>
<td>3.2</td>
<td>3.7</td>
<td>4.7</td>
<td>5.7</td>
<td>6.8</td>
</tr>
<tr>
<td>0.67</td>
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<td>0.6</td>
<td>0.8</td>
<td>1.0</td>
<td>1.2</td>
<td>1.5</td>
<td>1.8</td>
<td>2.3</td>
<td>2.9</td>
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<td>4.2</td>
<td>5.3</td>
<td>6.3</td>
<td>7.6</td>
</tr>
<tr>
<td>1.00</td>
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<td>0.6</td>
<td>0.8</td>
<td>1.1</td>
<td>1.3</td>
<td>1.6</td>
<td>1.9</td>
<td>2.5</td>
<td>3.1</td>
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<td>4.5</td>
<td>5.5</td>
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<td>0.5</td>
<td>0.6</td>
<td>0.8</td>
<td>1.1</td>
<td>1.3</td>
<td>1.7</td>
<td>2.0</td>
<td>2.5</td>
<td>3.2</td>
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<td>5.8</td>
<td>7.1</td>
<td>8.4</td>
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<tr>
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<td>0.7</td>
<td>0.9</td>
<td>1.2</td>
<td>1.4</td>
<td>1.8</td>
<td>2.1</td>
<td>2.6</td>
<td>3.4</td>
<td>4.1</td>
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<tr>
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<td>0.5</td>
<td>0.7</td>
<td>0.9</td>
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<td>1.4</td>
<td>1.8</td>
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<td>1.5</td>
<td>1.9</td>
<td>2.2</td>
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<td>0.9</td>
<td>1.3</td>
<td>1.5</td>
<td>1.9</td>
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<td>2.8</td>
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<td>6.5</td>
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<tr>
<td>3.00</td>
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<td>0.7</td>
<td>0.9</td>
<td>1.3</td>
<td>1.5</td>
<td>1.9</td>
<td>2.3</td>
<td>2.9</td>
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<td>8.1</td>
<td>9.6</td>
</tr>
<tr>
<td>3.33</td>
<td>0.5</td>
<td>0.8</td>
<td>0.9</td>
<td>1.3</td>
<td>1.5</td>
<td>1.9</td>
<td>2.4</td>
<td>3.0</td>
<td>3.8</td>
<td>4.6</td>
<td>5.4</td>
<td>6.8</td>
<td>8.2</td>
<td>9.8</td>
</tr>
</tbody>
</table>

**Table 7  Iron and Copper Elbow Equivalents**

<table>
<thead>
<tr>
<th>Fitting</th>
<th>Iron Pipe</th>
<th>Copper Tubing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elbow, 90°</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Elbow, 45°</td>
<td>0.7</td>
<td>0.7</td>
</tr>
<tr>
<td>Elbow, 90° long turn</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Elbow, welded, 90°</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Reduced coupling</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>Open return bend</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Angle radiator valve</td>
<td>2.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Radiator or convector</td>
<td>3.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Boiler or heater</td>
<td>3.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Open gate valve</td>
<td>0.5</td>
<td>0.7</td>
</tr>
<tr>
<td>Open globe valve</td>
<td>12.0</td>
<td>17.0</td>
</tr>
</tbody>
</table>

*Source: Giesecke (1926) and Giesecke and Badgett (1931, 1932a).*

*aSee Table 6 for equivalent length of one elbow.*
Refrigeration : Is the process of removing heat from matter which may be solid, a liquid or a gas. Removing heat from the matter cools or lowers its temperature.

Refrigeration machine: The refrigeration machine is a reversible heat engine that runs in a reversed direction as shown in the figure below. The refrigerator absorbs heat $Q_c$ from the heat source at a temperature $T_C$ and rejects heat $Q_H$ to the heat sink at temperature $T_H$. Work must be done on the system to do such a process.

![Diagram of a refrigeration system]

Application of the second law gives:

$$Q_H - Q_c = W$$  \text{ or }  
$$Q_H = Q_c + W$$

This equation represents the fundamental balance of a refrigeration machine. The performance of a refrigeration machine is expressed as the ratio of useful heat (refrigeration effect) to the input work.

C.O.P. = Refrigeration effect $(Q_c)$ / Input work $(W)$
Carnot refrigeration cycle:

The Carnot cycle is a theoretical model that useful for understanding a refrigeration cycle. In some applications the Carnot refrigeration cycle is known as the reverse Carnot cycle. The following processes take place in the Carnot refrigeration cycle as shown in the figure below:

1-2 is the ideal compression at constant entropy.

2-3 Is the rejection of heat in the condenser at a constant condensation temperature.

3-4 Is the ideal expansion at constant entropy.

4-1 Is the absorption of heat in the evaporator at a constant evaporation temperature.

\[ Q_H = T_H (S_2 - S_3) \]

\[ Q_C = T_C (S_1 - S_4) \]

\[ S_2 - S_3 = S_1 - S_4 \]

\[ W = Q_H - Q_C = (T_H - T_C) (S_1 - S_4) \]

\[ \text{C. O. P}_{\text{Carnot}} = \frac{Q_C}{W} = \frac{T_C}{(T_H - T_C)} \]

Where temperatures in Kelvin (K)
Refrigerants:

Refrigerant is the fluid that circulate in the refrigeration machine and absorbing heat during evaporation. These refrigerants which provide a cooling effect during the phase change from liquid to vapor are commonly use in refrigeration, air conditioning and heat pump systems. In selection the appropriate refrigerant it expected to meet the following conditions:

1- Ozone and environment friendly
2- Low boiling point
3- Low volume flow rate per unit capacity
4- Vaporization pressure lower than atmospheric pressure
5- High latent heat of vaporization
6- Non-flamable and non toxic
7- Non-reactive with lubrication oils of compressor
8- High critical point
9- Low cost
10- Detectable in case of leakage.

There are several types of refrigerant that are:

1- Halocarbons such as Freon (R11) and (R12) and (R22)
2- Hydrocarbons such as methane (R50), Propane (R290) and Butane (R600)
3- Inorganic such Ammonia (R717), CO2 (R744) and Air (R729).

Saturation Vapor Compression Refrigeration Cycle:

The reversed Carnot cycle with vapor as refrigerant can be used as practical cycle with minor modifications that are:

1- The isothermal processes of heat rejection and absorption accompany condensation and evaporation are nearly perfect processes and easily achieved in practice.
2- The isentropic compression and expansion processes however have certain limitations which are:

a- Dry versus wet compression because wet compression may damage the compressor since liquid cannot be compressed easily.

b- Throttling versus isentropic expansion, because the expansion required a turbine and the work of the turbine is so small therefore throttling is preferable.

The vapor compression system consists of:

1- Compressor
2- Condenser
3- Expansion device
4- Evaporator

In plants with large amount of refrigeration charge (refrigerant) a reservoir is installed in the liquid line. A drier is also installed in the liquid line in Freon system.

The representation of the saturation vapor compression refrigeration cycle on the P-H and T-S diagram are as follow:
The thermodynamic processes are as follows:

1-2 Isentropic compression \( S_1 = S_2 \)

2-3 De super heating and condensation at \( P = \text{constant} \)

3-4 Throttling \( (h = \text{constant}) \)

4-1 Evaporation at \( P = \text{constant} \)

Further calculations:

\[
Q_{\text{condenser}} = Q_c = \frac{m}{1} (h_2 - h_3)
\]

\[
Q_{\text{evaporator}} = Q_e = \frac{m}{1} (h_1 - h_4)
\]

\[
W_{\text{compressor}} = m (h_2 - h_1)
\]

\( h_4 = h_3 \) Throttling processes

The mass flow rate \( m \ (\text{kg/s}) \) can be calculated as:

\[
m = \frac{\text{Refrigeration capacity (kW)}}{\text{Refrigeration effect (kJ/kg)}} = \frac{Q_e}{(h_1 - h_4)}
\]
C.O.P. = \frac{Q_e}{W} = \frac{(h_1 - h_4)}{(h_1 - h_2)}

Piston displacement of the compressor can be given by:

\[ V_p = \pi \left( \frac{D^2}{4} \right) L \frac{N}{60} = \frac{m \cdot v}{\eta_v} \]

Where \( \eta_v \) is the volumetric efficiency, \( v \) is the specific volume at point 1 (m\(^3\)/kg)

\( L \) and \( D \) is the stroke and diameter of the piston

\( N \) is the revolution per minute r.p.m.

The values of enthalpies can be obtained either from Charts or tables.

If tables are used then:

\( h_1 = h_g \) the evaporator temperature (the low temperature)

\( h_3 = h_f \) at the condenser temperature (the high temperature)

\( h_4 = h_3 \) Throttling process

\( h_2 = h_g \) at condenser temperature + \( c_p (T_2 - T_{\text{condenser}}) \)

\( T_2 \) can be found from:

\( S_1 = S_2 = S_g \) at condenser temperature + \( C_p \ln \left( \frac{T_2}{T_{\text{condenser}}} \right) \)

If a heat exchanger is employed to vapor saturated cycle the system will be as shown below with its representation on the T-S and P-H diagram:
Examples:

1-A reversed Carnot cycle required 14.0 kW for 10 TR refrigeration. The temperature of the low temperature source is (-20 c). Calculate:

- C.O.P. of the Carnot cycle
- Temperature of the high temperature source
- The heat rejection in kW
- If the device works as a heat pump what is its C.O.P. for heating
- Show that \( C.O.P_{\text{Heating}} = 1.0 + C.O.P_{\text{cooling}} \)

2-A refrigerator working on the saturated vapor compression refrigeration cycle. Its refrigeration capacity is (15 kW). It works with evaporator temperature of (-5 c) and condenser temperature of (35 c). The refrigerator use R12 as a refrigerant. Determine:

- The mass flow rates of the refrigerants R12 (m kg/s)
- The work of the compressor
- The heat rejected in the condenser
- C.O.P
- C.O.P Carnot

3-A vapor compression refrigeration cycle work with R12 as a refrigerant. The refrigeration capacity of this cycle is (15 kW). The evaporator temperature is (-5 c) and the condenser temperature is (35 c). The vapor enter the compressor as a super heated vapor at (5 c) above its evaporator temperature. The liquid refrigerant leave the condenser in sub cooled state with (4 c) lower than its condenser temperature. Calculate:

- The heat rejected at the condenser
- The work done by the compressor
- The piston displacement of the compressor \( V_p = m v_1 \)
- C.O.P of the cycle.

4-A vapor compression refrigeration system working with (R12) as a refrigerant. The condenser temperature is (35 c) while the evaporator temperature is (-15 c). A heat exchanger is used in this system where the vapor enter the compressor as a super heat vapor at a temperature of (15 c). Calculate the C.O.P. and the hours power of the system. Note that in heat exchanger, Heat gained = Heat rejected.

5-Ice store for fish work with Ammonia (R717) as a refrigerant. The temperature of freezing for fish is (-20 c). The condenser of the system is cooled by water and has a pressure of (1352 kPa). The system has a heat exchanger in which the liquid ammonia is sub cooled by (5 c). If the refrigeration capacity of the system is (20 kW) find C.O.P and \( m_{\text{water}} \) (kg/s) in the condenser if the water temperature difference is (5 c).
Solved example:

Consider a refrigerator which operates on the ideal refrigeration cycle. The evaporator temperature is \(-20^\circ\text{C}\) and the condenser temperature is \(40^\circ\text{C}\). The refrigerant is R-134a and its flow rate in the cycle is 0.2 kg/s. Calculate the following:

- compressor work rate \((W)\),
- condenser heat rate \((\dot{Q}_H)\),
- evaporator heat rate \((\dot{Q}_L)\),
- COP, and
- COP based on the Carnot cycle.

**Solution:**

Based on the input data given above, we take the thermodynamic data in terms of enthalpy, pressure and temperature from the thermodynamic tables of R-134a and list them in the following table, along with the cycle \(T-s\) diagram:

<table>
<thead>
<tr>
<th>No</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>(h) (kJ/kg)</td>
<td>386.08</td>
<td>431.24</td>
<td>256.54</td>
<td>256.54</td>
</tr>
<tr>
<td>(P) (kPa)</td>
<td>133.7</td>
<td>1017.0</td>
<td>1017.0</td>
<td>133.7</td>
</tr>
<tr>
<td>(T) (°C)</td>
<td>-20</td>
<td>50</td>
<td>40</td>
<td>-20</td>
</tr>
</tbody>
</table>

We now calculate the compressor work from Equation 3.5 as follows:

- \(W = \dot{m}(h_2 - h_1) = 0.2(431.24 - 386.08) = 9.0\ \text{kW}\)

and the condenser heat rate from Equation 3.6:

- \(\dot{Q}_H = \dot{m}(h_2 - h_3) = 0.2(431.24 - 256.54) = 34.9\ \text{kW}\)

and the evaporator heat rate (e.g. refrigeration load) from Equation 3.8:

- \(\dot{Q}_L = \dot{m}(h_1 - h_4) = 0.2(386.08 - 256.54) = 25.9\ \text{kW}\)

and the COP from Equation 3.10:

- \(\text{COP} = \dot{Q}_L / W = 25.9/9.0 = 2.87\)

and the COP based on the Carnot cycle from Equation 3.11:

- \(\text{COP}_{\text{Carnot}} = T_L / (T_H - T_L) = (273.15 - (-20))/(40 + 20) = 4.22\)

As calculated above, the COP which was found from energy balance equations is 32% less than the COP calculated based on the Carnot cycle which is theoretically the maximum COP that we can reach.
A actual Vapor Compression Refrigeration Cycle:

The actual vapor compression refrigeration cycle is shown in the following figure. In this actual system the pressures of the condenser and evaporator are no constant due to the presence of friction loss. The compression process in the compressor is accomplished with heat transfer loss and friction loss too, therefore it is not isentropic.
Tables and Charts:

![Graph showing pressure and enthalpy relationships for R-12](image-url)
<table>
<thead>
<tr>
<th>Property</th>
<th>Machine Oil</th>
<th>Vacation Oil</th>
<th>Methyl Oleate</th>
<th>Xylene</th>
<th>Naphtha</th>
<th>Light Fuel Oil</th>
<th>Heavy Fuel Oil</th>
<th>Kerosene</th>
<th>Diesel</th>
<th>Jet</th>
<th>Kerosene</th>
<th>Naphtha</th>
<th>Paraffin</th>
<th>No. 2 Fuel Oil</th>
<th>No. 6 Fuel Oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass, g/cm³</td>
<td>0.825</td>
<td>0.825</td>
<td>0.825</td>
<td>0.825</td>
<td>0.825</td>
<td>0.825</td>
<td>0.825</td>
<td>0.825</td>
<td>0.825</td>
<td>0.825</td>
<td>0.825</td>
<td>0.825</td>
<td>0.825</td>
<td>0.825</td>
<td>0.825</td>
</tr>
<tr>
<td>Density, kg/m³</td>
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<td>888</td>
<td>888</td>
<td>888</td>
<td>888</td>
<td>888</td>
<td>888</td>
<td>888</td>
<td>888</td>
<td>888</td>
<td>888</td>
<td>888</td>
<td>888</td>
<td>888</td>
<td>888</td>
</tr>
<tr>
<td>Viscosity, mPa·s</td>
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<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
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<td>1.5</td>
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<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Surface tension, mN/m</td>
<td>48</td>
<td>48</td>
<td>48</td>
<td>48</td>
<td>48</td>
<td>48</td>
<td>48</td>
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</tbody>
</table>

*Data are the values at 25°C.*

1st annual boiling point
2nd annual boiling point

---

Refrigerant 11 (Dichlorodifluoromethane) Properties of Saturated Liquid and Saturated Vapor

<table>
<thead>
<tr>
<th>Property</th>
<th>Temperature, °C</th>
<th>Pressure, bar</th>
<th>Saturated liquid density, kg/m³</th>
<th>Saturated liquid specific volume, m³/kg</th>
<th>Saturated vapor density, kg/m³</th>
<th>Saturated vapor specific volume, m³/kg</th>
<th>Latent heat of vaporization, kJ/kg</th>
<th>Efficiency, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Machine Oil</td>
<td>30.0</td>
<td>0.0023</td>
<td>1.1272</td>
<td>0.0997</td>
<td>2.803</td>
<td>0.957</td>
<td>22.80</td>
<td>0.00</td>
</tr>
<tr>
<td>Vacation Oil</td>
<td>30.0</td>
<td>0.0028</td>
<td>1.1272</td>
<td>0.0997</td>
<td>2.803</td>
<td>0.957</td>
<td>22.80</td>
<td>0.00</td>
</tr>
<tr>
<td>Methyl Oleate</td>
<td>30.0</td>
<td>0.0028</td>
<td>1.1272</td>
<td>0.0997</td>
<td>2.803</td>
<td>0.957</td>
<td>22.80</td>
<td>0.00</td>
</tr>
<tr>
<td>Xylene</td>
<td>30.0</td>
<td>0.0028</td>
<td>1.1272</td>
<td>0.0997</td>
<td>2.803</td>
<td>0.957</td>
<td>22.80</td>
<td>0.00</td>
</tr>
<tr>
<td>Naphtha</td>
<td>30.0</td>
<td>0.0028</td>
<td>1.1272</td>
<td>0.0997</td>
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<td>0.957</td>
<td>22.80</td>
<td>0.00</td>
</tr>
<tr>
<td>Paraffin</td>
<td>30.0</td>
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<td>0.0997</td>
<td>2.803</td>
<td>0.957</td>
<td>22.80</td>
<td>0.00</td>
</tr>
<tr>
<td>No. 2 Fuel Oil</td>
<td>30.0</td>
<td>0.0028</td>
<td>1.1272</td>
<td>0.0997</td>
<td>2.803</td>
<td>0.957</td>
<td>22.80</td>
<td>0.00</td>
</tr>
<tr>
<td>No. 6 Fuel Oil</td>
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<td>0.0997</td>
<td>2.803</td>
<td>0.957</td>
<td>22.80</td>
<td>0.00</td>
</tr>
</tbody>
</table>

---

*The values are for the 25°C base.*

---

Notes:

*1st annual boiling point

2nd annual boiling point

---

The table above provides properties of saturated liquid and saturated vapor for various substances at a temperature of 30°C, including machine oil, vacation oil, methyl oleate, xylene, naphtha, paraffin, and fuel oils. The properties include density, specific volume, latent heat of vaporization, and efficiency. The data are presented in a structured format, allowing for easy comparison and analysis.
<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Density (kg/m³)</th>
<th>Vapour Pressure (kPa)</th>
<th>Liquid Density (kg/m³)</th>
<th>Liquid Viscosity (cSt)</th>
<th>Liquid Latent Heat of Vapourization (kJ/kg)</th>
<th>Specific Heat Capacity (J/kg·K)</th>
<th>Vapour Density (kg/m³)</th>
<th>Vapour Viscosity (cSt)</th>
<th>Specific Heat Capacity (J/kg·K)</th>
<th>Vapour Latent Heat of Condensation (kJ/kg)</th>
<th>Liquid Condensation Enthalpy (kJ/kg)</th>
<th>Vapour Heat Capacity (J/kg·K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-130.0</td>
<td>542.9</td>
<td>0.29</td>
<td>0.81</td>
<td>2.43</td>
<td>126</td>
<td>219.2</td>
<td>0.84</td>
<td>0.41</td>
<td>15.7</td>
<td>2.08</td>
<td>91.6</td>
<td>180.4</td>
</tr>
<tr>
<td>-120.0</td>
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<td>0.81</td>
<td>2.43</td>
<td>126</td>
<td>219.2</td>
<td>0.84</td>
<td>0.41</td>
<td>15.7</td>
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<td>91.6</td>
<td>180.4</td>
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<tr>
<td>-110.0</td>
<td>542.9</td>
<td>0.29</td>
<td>0.81</td>
<td>2.43</td>
<td>126</td>
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<td>0.84</td>
<td>0.41</td>
<td>15.7</td>
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<td>91.6</td>
<td>180.4</td>
</tr>
<tr>
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<td>0.81</td>
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<td>180.4</td>
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<td>0.81</td>
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<td>219.2</td>
<td>0.84</td>
<td>0.41</td>
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<td>180.4</td>
</tr>
<tr>
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<td>0.81</td>
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<td>126</td>
<td>219.2</td>
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<td>0.41</td>
<td>15.7</td>
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<td>180.4</td>
</tr>
<tr>
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<td>0.29</td>
<td>0.81</td>
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<td>219.2</td>
<td>0.84</td>
<td>0.41</td>
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<td>219.2</td>
<td>0.84</td>
<td>0.41</td>
<td>15.7</td>
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<td>180.4</td>
</tr>
<tr>
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<td>0.81</td>
<td>2.43</td>
<td>126</td>
<td>219.2</td>
<td>0.84</td>
<td>0.41</td>
<td>15.7</td>
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<td>180.4</td>
</tr>
<tr>
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<td>0.81</td>
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<td>126</td>
<td>219.2</td>
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<td>0.41</td>
<td>15.7</td>
<td>2.08</td>
<td>91.6</td>
<td>180.4</td>
</tr>
<tr>
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<td>0.81</td>
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<td>126</td>
<td>219.2</td>
<td>0.84</td>
<td>0.41</td>
<td>15.7</td>
<td>2.08</td>
<td>91.6</td>
<td>180.4</td>
</tr>
</tbody>
</table>

*Note: The table above represents properties of Refrigerant 22 (Chlorodifluoromethane) at various temperatures.*
<table>
<thead>
<tr>
<th>Temperature, °C</th>
<th>Mass Density, kg/m³</th>
<th>Viscosity, mPa·s</th>
<th>Laminar Flow, m/s</th>
<th>Turbulent Flow, m/s</th>
<th>Specific Heat, J/kg·K</th>
<th>Latent Heat, J/kg</th>
<th>Surface Tension, mN/m</th>
</tr>
</thead>
<tbody>
<tr>
<td>-78.0</td>
<td>1.200</td>
<td>0.019</td>
<td>1.190</td>
<td>0.120</td>
<td>135</td>
<td>25.5</td>
<td>3.25</td>
</tr>
<tr>
<td>-61.0</td>
<td>1.150</td>
<td>0.019</td>
<td>1.130</td>
<td>0.120</td>
<td>135</td>
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<td>3.25</td>
</tr>
<tr>
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<td>3.25</td>
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<td>3.25</td>
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<td>3.25</td>
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<td>0.543</td>
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<td>135</td>
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<td>3.25</td>
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<td>3.25</td>
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<tr>
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<td>0.439</td>
<td>0.120</td>
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<td>3.25</td>
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<td>3.25</td>
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<td>3.25</td>
</tr>
<tr>
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<td>0.150</td>
<td>0.019</td>
<td>0.135</td>
<td>0.120</td>
<td>135</td>
<td>25.5</td>
<td>3.25</td>
</tr>
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<td>0.085</td>
<td>0.120</td>
<td>135</td>
<td>25.5</td>
<td>3.25</td>
</tr>
</tbody>
</table>

**Note:** Temperatures have been converted from the USP-45 scale of the original formulation to the USP-40 scale.

- °C: °Celsius
- °F: °Fahrenheit
- psi: Pounds per square inch
- m: Meter
- cm: Centimeter
- m/s: Meter per second
- mPa·s: Millipascal-seconds
- W/m·K: W per meter Kelvin
- g/cm³: Grams per cubic centimeter
- atm: Atmospheres
- psi: Pounds per square inch
- °C: Degrees Celsius
- °F: Degrees Fahrenheit
Refrigeration Equipments

The refrigeration equipments consists of the following components with some other aided and complementary parts:

1-Compressors:

It is the heart of the refrigeration system which circulate the refrigerant through the system parts to do the required refrigeration effects. There are several types of compressor that are:

a- Reciprocating compressors

b- Scroll compressors

c- Rotary compressors

d- Screw compressors

e- Centrifugal compressors

Type (a) is the most common one in small to moderate capacities systems. For large refrigeration capacities the centrifugal compressor is most appropriate compressor, however it required a great amount of electricity to work.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>rotary</th>
<th>scroll</th>
<th>reciprocating</th>
<th>screw</th>
<th>centrifugal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical capacity</td>
<td>&lt; 5 TR</td>
<td>5-10 TR</td>
<td>1-150 TR</td>
<td>100-750 TR</td>
<td>100-10000 TR</td>
</tr>
<tr>
<td>Max. capacity</td>
<td>5 TR</td>
<td>10 TR</td>
<td>400 TR</td>
<td>2000 TR</td>
<td>20000 TR</td>
</tr>
<tr>
<td>Displacement</td>
<td>positive</td>
<td>positive</td>
<td>positive</td>
<td>positive</td>
<td>not positive</td>
</tr>
</tbody>
</table>
Various types of refrigeration compressors  
a) reciprocating  
b) scroll  
c) rotary  
d) screw  
e) centrifugal
2- Condensers :

The second component in the refrigeration system is the condenser. It is a device where the vapor refrigerant that coming from the compressor at high pressure and temperature is to be condensed and become in a liquid state with lower temperature and approximately the same high pressure of the compressor except the pressure losses due to friction in condenser pipes and fittings. The condenser is cooled by air in small capacities systems while the water is used for large ones. There are several types of condensers in use in the refrigeration systems that are:

a- Air cooled condenser.

b- Shell and tube water cooled condensers.

c- Evaporative condenser.

In air cooled condensers air is used to absorb the latent heat of condensation released during de-superheating, condensation and sub-cooling.

In water cooled condensers, latent heat of condensation released from the refrigerant during condensation is extracted by water. This cooling water often called condenser water is taken directly from river, lake, sea, underground well or a cooling tower to cool the hot water that come out of the condenser to use it again in the system.

In an evaporative condenser uses the evaporation of water on the outer surface of the condensing tubes to remove the latent heat of condensation of the refrigerant during condensation.

An evaporative condenser is actually a combination of water-cooled condenser and a cooling tower. It is usually located on the rooftop and should be near the compressor as possible.
Various types of refrigeration condensers: 

- a- air cooled
- b- shell and tube water cooled
- c- evaporative cooled
3- Expansion devices:

These are devices used to lower the pressure from the high pressure value at the compressor, condenser side to the lower value at the evaporator side to help the refrigerant to evaporate and absorb the required heat at the evaporator. There are two types of expansion devices that are:

a- Constant restriction devices: this type is used for small capacity and domestic equipments. It is a capillary tube with constant diameter and appropriate length.

b- Variable restriction expansion devices: These are of two types, the first one is called constant pressure expansion valve and the second is a thermostatic expansion valve. The second type is useful for varying load conditions.

There exist other types such as orifice plate valves and float valves for other certain uses.

![Diagram of expansion device](a) Thermostatic expansion valve
4- Evaporators:

This is the component of the VCRC in which the refrigeration effect takes place i.e. the place where the heat is absorbed and the temperature is reduced due to the process of evaporation of the liquid refrigerant. There are several types of evaporators that are:

a- Plate evaporators: It is used in domestic and small refrigerator and deep freezer.

b- Natural convection coil: It is replaced now a day

c- Liquid chiller: It is the most common type that in use for air conditioning applications

d- Direct expansion DX-coil: It is used in freezing or cooling duty for air or other gases.

\[\begin{array}{c}
\text{Suction} \\
\text{Refrigerant in} \\
\text{Water in} \\
\text{Water out} \\
\text{DX-coil} \\
\end{array}\]

\[\begin{array}{c}
\text{Condensing unit} \\
\text{Evaporative Condenser} \\
\text{Unhoused fan} \\
\text{Filters} \\
\end{array}\]

a) Liquid chiller b) DX evaporator located in an air handling unit.
5- Cooling towers:

This is an equipment that be used to cool the water of the VCRS condensers or any other heat exchange process. The tower cooled the water by spraying it in an air stream across several layers of backing. These layers are used to increase the surface area of heat transfer and to break the water jets into small droplets for more contact. The evaporation of the droplet surface leads to cool the rest of water and increases the DBT and humidity of the outgoing air. There are several types of towers that are:

a- Natural cooling tower: The air is crossing the tower naturally by wind speed.

b- Forced draft tower: The air is forced to the tower by fans.

c- Induced draft tower: The air is induced from the tower by fans.