Simple Vapour Compression Refrigeration System

A vapour compression refrigeration system is an improved type of air refrigeration system in which a suitable working substance, termed as refrigerant is used. It condensed and evaporates at temperatures and pressures close to the atmospheric conditions. The refrigerants usually used for this purpose are ammonia, carbon dioxide and sulphur dioxide.

Advantage and disadvantages of vapour compression and air refrigeration system:

- **Advantage:**
  1. It has smaller size for given capacity of refrigeration.
  2. It has less running cost.
  3. It can be employed over a large range of temperatures
  4. The coefficient of performance is quite high.
Disadvantages:

1. The initial cost is high
2. The prevention of leakage of refrigerant is the major problem in vapour compression system.

Comparison between gas cycles and vapor cycles

Thermodynamic cycles can be categorized into gas cycles and vapour cycles. In a typical gas cycle, the working fluid (a gas) does not undergo phase change, consequently the operating cycle will be away from the vapour dome. In gas cycles, heat rejection and refrigeration take place as the gas undergoes sensible cooling and heating. In a vapour cycle the working fluid undergoes phase change and refrigeration effect is due to the vaporization of refrigerant liquid. If the refrigerant is a pure substance then its temperature remains constant during the phase change processes. Hence, the required mass flow rates for a given refrigeration capacity will be much smaller compared to a gas cycle. Vapour cycles can be subdivided into vapour compression systems, vapour absorption systems, vapour jet systems etc. Among these the vapour compression refrigeration systems are predominant.

Mechanism of simple vapour compression refrigeration system:

Compression refrigeration cycles take advantage of the fact that highly compressed fluids at a certain temperature tend to get colder when they are allowed to expand. If the pressure change is high enough, then the compressed gas will be hotter than our source of cooling (outside air, for instance) and the expanded gas will be cooler than our desired cold temperature. In this case, fluid is used to cool a low temperature environment and reject the heat to a high temperature environment.

Vapour compression refrigeration cycles have two advantages. First, a large amount of thermal energy is required to change a liquid to a vapor, and therefore a lot of heat can be removed from the air-conditioned space. Second, the isothermal nature of the vaporization allows extraction of heat without raising the
temperature of the working fluid to the temperature of whatever is being cooled. This means that the heat transfer rate remains high, because the closer the working fluid temperature approaches that of the surroundings, the lower the rate of heat transfer.

The refrigeration cycle is shown in Figure below and can be broken down into the following stages:

1 – 2 Low-pressure liquid refrigerant

In the evaporator absorbs heat from its surroundings, usually air, water or some other process liquid. During this process it changes its state from a liquid to a gas, and at the evaporator exit is slightly superheated.

2 – 3 The superheated vapour

Enters the compressor where its pressure is raised. The temperature will also increase, because a proportion of the energy put into the compression process is transferred to the refrigerant.

3 – 4 The high pressure superheated gas

Passes from the compressor into the condenser. The initial part of the cooling process (3-3a) superheats the gas before it is then turned back into liquid (3a-3b). The cooling for this process is usually achieved by using air or water. A further reduction in temperature happens in the pipe work and liquid receiver (3b - 4), so that the refrigerant liquid is sub-cooled as it enters the expansion device.

4 - 1 The high-pressure sub-cooled liquid

Passes through the expansion device, which both reduces its pressure and controls the flow into the evaporator.
Figure 1. Schematic representation of the vapour compression refrigeration cycle

Figure 2. Schematic representation of the refrigeration cycle including pressure changes
Figure 3. Layout of simple vapor compression refrigeration machine
Simple Vapor Compression Refrigeration Cycle

It is shown on T-S below at point 1, let $T_1$, $P_1$, and $s_1$ be the properties of vapour refrigerant. The four processes of the cycle are as follows:

Figure 5: T-s diagram of simple vapor compression refrigeration cycle

Figure 6: P-h diagram for simple vapor compression refrigeration cycle
1. Compression process:

The vapour refrigerant at low pressure \( p_1 \) and temperature \( T_1 \) is compressed isentropically to dry saturated vapour as shown by the vertical line 1-2 on T-s diagram and by the curve 1-2 on p-h diagram. The pressure and temperature rises from 1 to 2.

The work done during isentropic compression is given by:

\[ W = h_2 - h_1 \]  \hspace{1cm} \text{1}

2. Condensing process

The high pressure and temperature vapour refrigerant from the compressor is passed through the condenser where it is completely condensed at constant pressure \( p_2 \) and temperature \( T_2 \). The vapour refrigerant is changed into liquid refrigerant. The refrigerant while passing through the condenser, gives its latent heat to the surrounding condensing medium.

3. Expansion process:

The liquid refrigerant at pressure \( p_3 = p_2 \) expanded by throttling process through the expansion valve to a low pressure \( p_4 = p_1 \) and temperature \( T_4 = T_1 \). Some of the liquid refrigerant evaporates as it passes through expansion valve, but the greater portion is vaporized in the evaporator. During the throttling process no heat is absorbed or rejected by the liquid refrigerant.

4. Vaporizing process:

The liquid vapour mixture of the refrigerant at pressure \( p_4 = p_1 \) and temperature \( T_4 = T_1 \) is evaporated and changed into vapour refrigerant at constant pressure and temperature. During evaporation, the liquid vapour refrigerant absorbs its latent heat of vaporization from medium (air, water or brine) which is to be cooled.
The heat absorbed or extracted by the liquid vapour refrigerant during evaporation is given by:

\[ R_E = h_1 - h_4 = h_1 - h_{f3} \]

Where \( h_{f3} \) is sensible heat at \( T_3 \) (enthalpy of liquid refrigerant leaving the condenser). The coefficient of performance is

\[
\text{C.O.P} = \frac{\text{refrigerating effect}}{\text{work done}} = \frac{h_1 - h_4}{h_2 - h_1} = \frac{h_1 - h_{f3}}{h_2 - h_1}
\]

Types of refrigerant used in vapour compression systems

A variety of refrigerants are used in vapor compression systems. The required cooling temperature largely determines the choice of fluid. Commonly used refrigerants are in the family of chlorinated fluorocarbons (CFCs, also called Freons): R-11, R-12, R-21, R-22 and R-502. The properties of these refrigerants are summarized in Table 1 and the performance of these refrigerants is given in Table 2 below.

**Table 1. Properties of commonly used refrigerants**

<table>
<thead>
<tr>
<th>Refrigerant</th>
<th>Boiling Point **(^\circ)C)</th>
<th>Freezing Point (^\circ)C</th>
<th>Vapor Pressure (^)kPa</th>
<th>Vapor Volume (^)m(^3)/kg</th>
<th>Enthalpy (^)kJ/kg</th>
<th>Vapor (^)kJ/kg</th>
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</thead>
<tbody>
<tr>
<td>R-11</td>
<td>-23.82</td>
<td>-111.0</td>
<td>25.73</td>
<td>0.61170</td>
<td>191.40</td>
<td>385.43</td>
</tr>
<tr>
<td>R-12</td>
<td>-29.79</td>
<td>-158.0</td>
<td>219.28</td>
<td>0.07702</td>
<td>190.72</td>
<td>347.96</td>
</tr>
<tr>
<td>R-21</td>
<td>-40.76</td>
<td>-160.0</td>
<td>354.74</td>
<td>0.06513</td>
<td>188.55</td>
<td>400.83</td>
</tr>
<tr>
<td>R-22</td>
<td>-45.40</td>
<td>---</td>
<td>414.30</td>
<td>0.04234</td>
<td>188.87</td>
<td>342.31</td>
</tr>
<tr>
<td>R-502</td>
<td>-45.40</td>
<td>-77.7</td>
<td>289.93</td>
<td>0.41949</td>
<td>808.71</td>
<td>487.76</td>
</tr>
<tr>
<td>R-7 (Ammonia)</td>
<td>-33.30</td>
<td>-77.7</td>
<td>289.93</td>
<td>0.41949</td>
<td>808.71</td>
<td>487.76</td>
</tr>
</tbody>
</table>
**At Standard Atmospheric Pressure (101.325 kPa)**

Table 2. Performance of commonly used refrigerants

<table>
<thead>
<tr>
<th>Refrigerant</th>
<th>Evaporating Press (kPa)</th>
<th>Condensing Press (kPa)</th>
<th>Pressure Ratio</th>
<th>Vapor Enthalpy (kJ / kg)</th>
<th>COP*** carnot</th>
</tr>
</thead>
<tbody>
<tr>
<td>R – 11</td>
<td>20.4</td>
<td>125.5</td>
<td>6.15</td>
<td>155.4</td>
<td>5.03</td>
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<tr>
<td>R – 12</td>
<td>182.7</td>
<td>744.6</td>
<td>4.08</td>
<td>116.3</td>
<td>4.70</td>
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<tr>
<td>R – 22</td>
<td>295.8</td>
<td>1192.1</td>
<td>4.03</td>
<td>162.8</td>
<td>4.66</td>
</tr>
<tr>
<td>R - 502</td>
<td>349.6</td>
<td>1308.6</td>
<td>3.74</td>
<td>106.2</td>
<td>4.37</td>
</tr>
<tr>
<td>R - 717</td>
<td>236.5</td>
<td>1166.5</td>
<td>4.93</td>
<td>103.4</td>
<td>4.78</td>
</tr>
</tbody>
</table>

*At -10 °C

** At -15 °C Evaporator Temperature, and 30 °C Condenser Temperature