REFRIGERATION

Vapor Compression Refrigeration Systems

Instructional Objective:

- To learn the basic concepts of a vapor compression refrigeration system
REFRIGERATION

• Provides cool storage of foods
• T \( \rightarrow \) 60°F (16°C) to 28°F (-2°C)
• Water in the food is not frozen
  • the shelf life of perishable products is extended only for days or a few weeks
• Growth of nearly all pathogenic m.o. is prevented
  • some spoilage microorganisms (psychrophiles) may thrive

EFFECTS OF REFRIGERATION ON FOODS

DESIRABLE EFFECTS
a. Microbial growth rates decrease
b. Chemical and biochemical reaction rates decrease
c. Shelf life increases (2-5 fold for every 10°C decrease in temperature)

UNDESIRABLE EFFECTS
a. Textural deterioration
b. Chilling injury
ENERGY REMOVAL DURING REFRIGERATION

Removal of heat (Q):

\[ Q = mC_p\Delta T \]

- \( m \) = mass/weight of food
- \( C_p \) = specific heat of food above freezing
- \( \Delta T \) = temperature difference

VAPOR COMPRESSION REFRIGERATION SYSTEMS

- A refrigeration system allows transfer of heat from a cooling chamber to a location where the heat can be easily discarded.
- The transfer of heat is accomplished by using a refrigerant, which can change its state from liquid to gas.
- However, unlike water the refrigerant has a much lower boiling point.
REFRIGERANT

• A fluid which, through phase changes from liquid to gas and back to liquid, facilitates heat transfer in a refrigeration system.

• Refrigerants have much lower boiling points than water and their boiling points can be varied by changing the pressure of the system.

• A good example of a common refrigerant is ammonia (NH₃).

VAPOR COMPRESSION REFRIGERATION SYSTEMS

• Ammonia boils at -33.3°C, compared to 100°C for water at atmospheric pressure.

• Similar to water, ammonia needs latent heat of vaporization to change from liquid to vapor, and it discharges latent heat of condensation to change from vapor to liquid.

• The boiling point of a refrigerant can be varied by changing the pressure.

• Thus, to increase boiling point of ammonia to 0°C, its pressure must be raised to 428.5 kPa (62.1 psia)
SELECTION OF A REFRIGERANT

The following characteristics are important in the selection of a refrigerant:

1. A high latent heat of vaporization is preferred.
2. Excessively high condensing pressures should be avoided.
3. The freezing temperature of the refrigerant should be below the evaporating temperature.
4. The refrigerant should have a sufficiently high critical temperature.
5. The refrigerant must be non-toxic, non-corrosive, and chemically stable.
6. It should be easy to detect leaks.
7. Low cost refrigerant is preferred in industrial applications.

Ammonia offers exceptionally high latent heat of vaporization among all other refrigerants.

Other commonly used refrigerants include Freon 12 and Freon 22.

Due to the adverse effects of Freon 12 on the ozone layer, the use of this refrigerant is now being seriously curtailed.
Table. Properties of refrigerants used in warehouse refrigeration at -15°C evaporator temperature and 30°C condenser pressure

<table>
<thead>
<tr>
<th>Refrigerant</th>
<th>Ammonia</th>
<th>Freon 12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaporator pressure, kPa</td>
<td>236.5</td>
<td>182.7</td>
</tr>
<tr>
<td>Condenser pressure, kPa</td>
<td>1166.5</td>
<td>744.6</td>
</tr>
<tr>
<td>Latent heat of vaporization @ -15°C, kJ/kg</td>
<td>1314.2</td>
<td>161.7</td>
</tr>
<tr>
<td>Liquid refrigeration circulated per ton of refrigeration, kg/s</td>
<td>31 x 10⁻²</td>
<td>2.8 x 10⁻²</td>
</tr>
<tr>
<td>Stability (Toxic products)</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Flammability</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Odor</td>
<td>acrid</td>
<td>ethereal</td>
</tr>
<tr>
<td>Evaporator temperature range</td>
<td>-68 to -7</td>
<td>-73 to 10</td>
</tr>
</tbody>
</table>

COMPONENT OF A REFRIGERATION SYSTEM

Major component of a vapor-compression refrigeration system are shown in the following diagram

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Purwiyatno Hariyadi/ITP/Fateta/IPB
Function as heat pumps and contain four essential mechanical components

A. Evaporator
   (1) Where the liquid refrigerant vaporizes into a gas
   (2) When this happens, heat from the stored food is "extracted"
COMPONENT OF A REFRIGERATION SYSTEM

C. Condenser
(1) Where the heat is transferred from the refrigerant to another medium (air or water)
(2) When this happens, the refrigerant decreases in T and condenses

D. Expansion valve
(1) Where the flow of liquid refrigerant is controlled
(2) When this happens, the evaporator receives a constant supply of refrigerant
MECHANISM

Location a: - refrigerant gas enters compressor and compressed to a high pressure
Location b: - superheated compressed gas exits the compressor

Location c:
- compressed gas enters the condenser
- the condensing temperature must be higher than that of an easily available heat sink, e.g., ambient air, water, etc.
- the refrigerant gas discharges latent heat of condensation the heat sink and changes phase to liquid
Location d:
- refrigerant in a saturated liquid state
- expansion valve separates high as refrigerant passes through the expansion valve the sudden decrease in pressure causes some of the refrigerant to change into gas.

Location e:
- the refrigerant absorbs heat, equivalent to its latent heat of vaporization, and completely converts into gas.
MATHEMATICAL EXPRESSIONS USEFUL IN THE ANALYSIS OF VAPOR-COMPRESSION REFRIGERATION

COOLING LOAD:
- The cooling load is total heat energy that must be removed from a given space in order to lower the temperature to a desired level.
- A common unit of cooling load is “ton of refrigeration”

1 ton of refrigeration = 288,000 Btu/24 hr
= 303,852 kJ/24 hr

MATHEMATICAL EXPRESSIONS USEFUL IN THE ANALYSIS OF VAPOR-COMPRESSION REFRIGERATION

REFRIGERANT FLOW RATE
- The refrigerant flow rate depends upon the total cooling load on the system and the amount of heat that refrigerant can absorb

Refrigerant flow rate
\[ = \frac{\text{Cooling Load}}{H_2 - H_1} \]
MATHEMATICAL EXPRESSIONS USEFUL IN THE ANALYSIS OF VAPOR-COMPRESSION REFRIGERATION

COMPRESSOR

- The work done on the refrigerant during the compression step is the product on the enthalpy increase of the refrigerant inside the compressor and the refrigerant flow rate

rate of work done on the compressor

\[ = (\text{refrigerant flow rate}) (H_3 - H_2) \]

MATHEMATICAL EXPRESSIONS USEFUL IN THE ANALYSIS OF VAPOR-COMPRESSION REFRIGERATION

CONDENSER

- The heat rejected to the environment in the condenser depends upon the refrigerant flow rate and the latent heat of condensation of the refrigerant

heat rejected in the condenser

\[ = (\text{refrigerant flow rate}) (H_3 - H_1) \]
MATHEMATICAL EXPRESSIONS USEFUL IN THE ANALYSIS OF VAPOR-COMPRESSION REFRIGERATION

EVAPORATOR

• The heat absorbed by the evaporator depends upon the refrigerant flow rate and the latent heat of evaporation of the refrigerant.

heat absorbed by the evaporator

\[ = (\text{refrigerant flow rate}) \times (H_2 - H_1) \]

MATHEMATICAL EXPRESSIONS USEFUL IN THE ANALYSIS OF VAPOR-COMPRESSION REFRIGERATION

COEFFICIENT PERFORMANCE

• The coefficient performance is a ratio between the heat absorbed by the refrigerant as it flows through the evaporator to the heat equivalent of the energy supplied to the compressor.

\[ \text{COP} = \frac{(H_2 - H_1)}{(H_3 - H_2)} \]
Power requirement in horsepower/ton refrigerant (for F12)

\[
\text{HP/(ton)r} = \frac{12,000 \text{ BTU}}{\gamma(\text{COP}) h \text{ (ton)}} \left( \frac{1 \text{ HP}}{2545 \text{ BTU/h}} \right) \\
= \frac{4.715}{\gamma(\text{COP})}
\]

Example

- A refrigeration system is to be operated at an evaporator coil temperature of -30°F (-34°C) and a condenser temperature of 100°F (37.8°C) for the liquid refrigerant. For Freon 12, determine: (a) the high-side pressure; (b) the low-side pressure; (c) the refrigeration capacity per unit weight of refrigerant; (d) COP; (e) HP of compressor per ton of refrigerant; (f) quantity of refrigerant circulated through the system per ton of refrigeration.
PRESSURE ENTHALPY (P-H) DIAGRAMS

- P-H diagrams are useful in designing and analyzing vapor compression refrigeration systems.
- These diagrams are available for all types of refrigerants.

`Saturated liquid line`
`Saturated vapor line`
`Constant temperature line`
`Constant entropy line`

Enthalpy (H; kJ/kg)
Fig. 10.5. Pressure-enthalpy diagram for Freon 12 (CCl₂F₂). (Courtesy of E. I. Du Pont de Nem-

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Fig. 10.5. Pressure-enthalpy diagram for Freon 12 (CCl₂F₂). (Courtesy of E. I. Du Pont de Nem-
Lihat Gambar 10.5, p. 406

For Freon 12

Lihat Gambar 10.1, p. 400

T = -30°F (-34°C) → P= 12.3 psia (85 kPa)
T = 100°F (37.8°C) → P=133 psia (910 kPa)

H1 → P= 12.3 psia → 74 btu/lb (17.2 kJ/kg)
H2 → P= 85 psia → 32 btu/lb (7.4 kJ/kg)
H3 → pada P 910, Tp2 → 94 btu/lb (21.8 kJ/kg)

Refrigerant capacity (heat/kg refrigerant):

H1 – H2 = (17.2 – 7.4)x 10^4 = 98,000 J/kg
COP = \frac{(H_2 - H_1)}{(H_3 - H_2)}
= \frac{(17.2 - 7.4)}{(21.8 - 17.2)}
= 2.1

For Freon 12
P (psia) P (psia)

133 12.3

32 74 94

Enthalpy (H; btu/lb)

HP per ton refrigerant:
Lihat Gambar 10.1, p 400:
Cp/cv F-12 = 1.14

HP/(ton) = \frac{4.715}{\gamma(COP)}
= \frac{4.715}{(1.14)(2.1)} = 1.97

One ton refrigerant for F12 = 12,000 BTU/h or 3517 W

Weight = \frac{\text{Cooling capacity/ton refrigerant}}{\text{Cooling capacity/unit weight of refrigerant}}
= \frac{12,000 \text{ BTU/h}}{42 \text{ BTU/lb}}
= 286 \text{ lb refrigerant/h}
= 0.0359 \text{ kg refrigerant/s}
Selesai .............
Sekarang ke.......  
Pembekuan