ABSTRACT

One of the most important applications of refrigeration and air conditioning is to produce ice for commercial applications with minimum energy consumption. The methodology of the project work is divided into a few distinct stages. Firstly, the cooling load required for producing definite quantity of ice is estimated using heat transfer relations and empirical relations from ASHRAE handbook. For the design considerations, the time required for producing definite quantity of ice is decided. The selection of primary and secondary refrigerant is done based on the cooling load, suitability for particular application and its physical and thermodynamic properties. Then the components for the system are designed. Accordingly, the scaled down test rig is fabricated and its performance is checked.

The project is the dissertation work. The duration of the project is one year. The project aims at designing experimental test set up for commercial applications. For this purpose, a case study is done in one of the laboratories for designing and fabricating the proposed system in Nagpur, a major city in central part of India. Considering the geographical location, the cooling load is estimated and the system is designed. Then the economic feasibility and pay back period of the system is calculated. From commercial point of view, the energy consumption for the proposed system is substantially less than that for the conventional systems. The system is designed and fabricated for checking its performance and suitability. The project work can be extended to make the system more sophisticated.

Ethylene glycol is better suited as secondary refrigerant for the requirements of the system due to its excellent thermodynamic and physical properties over the conventionally used brine solution. The mini ice plant designed for this project gives satisfactory performance over a wide range of physical and atmospheric conditions. It produces desired quantity and quality of ice in the desired time of operation. It is successfully scaled down working model of the actual industrial ice plant and has low maintenance. The mini ice plant designed for this project serves its purpose as a testing kit for the study of operational intricacies of industrial ice plants.

Working Principle of Proposed System (Figure 3)

The liquid refrigerant absorbs heat from the secondary refrigerant, which is circulated around the refrigerated space in the evaporator. The secondary refrigerant absorbs heat directly from the refrigerated space and transfers this heat to the primary refrigerant, which circulates in the evaporator coil. The primary refrigerant absorbs heat in the form of sensible heat & latent heat of vaporization and undergoes a change in phase. The low-temperature & low-pressure vapour refrigerant so obtained is sent to the hermetically sealed reciprocating compressor where it is compressed to high-temperature & high-pressure vapour refrigerant.

This high-temperature & high-pressure vapour refrigerant from the compressor is passed to the cross flow evaporative condenser where it loses its latent heat of condensation to the cooling medium to undergo change in phase and gets condensed to high-pressure liquid refrigerant. The high-pressure liquid refrigerant from the condenser is throttled to low-pressure liquid refrigerant by the expansion valve without change in phase. It is then filtered to remove any impurities that it may have acquired in the system and finally sent again to the evaporator.

Design Calculations for proposed system

1. Amount of Ice to be produced = $m_i = 4 \text{ kg}$.
2. Time of heat removal = $t = 20 \text{ min}$.
3. Heat to be removed ($Q$) = Refrigeration Effect (R.E.)
A. Heat to be removed from Water (Q):

\[ Q = m_w [C_{pw} (T_1 - T_2) + h_f + C_{poe} (T_2 - T_3)] = 2052.4 \text{ KJ} / 20 \text{ min} \]

\[ Q = 1.71 \text{ KW} = 0.486 \text{ TR} \]

B. Refrigeration Effect produced in the system (R.E.):

The power rating of the Compressor is 0.675 KW and the refrigerant used is R-12 i.e. Dichlorodifluoromethane.

C. Mass flow rate of Refrigerant (m_r):

\[ m_r = \frac{(V_1 \times N)}{(\nu_1 \times 60)} = 0.018 \text{ kg} / \text{s}. \]

D. Refrigeration Effect produced in the system (R.E.):

\[ R.E. = m_r (h_1 - h_4) = 1.75 \text{ KW} \]

\[ R.E. = 0.498 \text{ TR} \]

\[ Q \approx R.E. \]

Therefore, the selection of the compressor and refrigerant stated above is correct.

Selection of components for experimental set up

1. Selection of Compressor

The power of the compressor to pump refrigerant in the system determines the overall capability of achieving the desired refrigeration effect. Hermetically Sealed Compressor is the most commonly used compressor in small capacity refrigeration systems. This compressor eliminates the use of a crankshaft seal, which is used in ordinary compressors for preventing leakage of the refrigerant. This compressor operates on either reciprocating or rotary principle and has its shaft mounted in horizontal or vertical position. In this compressor, the motor and reciprocating compressor are mounted on a common shaft and enclosed in a common casing eliminating the possibility of leakage of refrigerant. The casing provides protection of the elements against atmospheric or mechanical damage.

The prime mover is an electric motor, which converts the input electrical energy to useful mechanical work. This work is transmitted as torque to the compressor through common shaft and coupling. The compressor uses this mechanical work to actuate the piston cylinder arrangement. The refrigerant in the cylinder is compressed to the required high pressure and exhausted to the condenser for cooling. A lubrication system is inbuilt into the casing, which provides the necessary lubrication and prevents wear and tear of the mechanical elements.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Description</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Name of Manufacturer</td>
<td>Kirloskar Copeland Pvt. Ltd.</td>
</tr>
<tr>
<td>2</td>
<td>Model Number</td>
<td>CAJ2612M-DE1.</td>
</tr>
<tr>
<td>3</td>
<td>Suction Pressure (P_1)</td>
<td>1.83 bar</td>
</tr>
<tr>
<td>4</td>
<td>Discharge Pressure (P_2)</td>
<td>12.19 bar</td>
</tr>
<tr>
<td>5</td>
<td>R.P.M (N)</td>
<td>3000</td>
</tr>
<tr>
<td>6</td>
<td>Ambient Temperature (°C)</td>
<td>35</td>
</tr>
</tbody>
</table>
2. Selection of Condenser (Figure 1)

Cross flow evaporative condenser used in the setup has a shell and coil construction consisting of copper coils through which the refrigerant flows. The entire system of coils is enclosed in a tank, which contains the cooling water. The water contained in the tank is pumped to the top of the coil using a small pump from where it is allowed to fall on to the copper coils in the form of a shower. Hot vapour refrigerant enters from the top portion of the copper coil and flows downwards after cooling due to gravity. Thus the hot vapour refrigerant rejects its sensible heat and latent heat of condensation to the cooling water. A small portion of the cooling water gets evaporated by losing heat to the atmospheric air. The copper coils are exposed to the atmosphere and some heat is rejected to the atmospheric air by convection. Thus, the total cooling is the effective sum of the heat rejected from the refrigerant to the cooling water and to the atmosphere, the reason for calling this condenser as evaporative condenser. As the cooling water and atmospheric air flow in a direction normal to the flow of refrigerant, this condenser is known as a cross flow condenser.

Table 2: Condenser specifications

<table>
<thead>
<tr>
<th>Sr. No</th>
<th>Description</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Material of coil</td>
<td>Copper</td>
</tr>
<tr>
<td>2</td>
<td>Material of tank</td>
<td>G.I. sheet (24 gauge)</td>
</tr>
<tr>
<td>3</td>
<td>Internal diameter of coil (mm)</td>
<td>3.75</td>
</tr>
<tr>
<td>4</td>
<td>External diameter of coil (mm)</td>
<td>5.75</td>
</tr>
<tr>
<td>5</td>
<td>Thickness of tank material (mm)</td>
<td>0.7</td>
</tr>
<tr>
<td>6</td>
<td>Mass flow rate of water (kg/s)</td>
<td>0.009</td>
</tr>
<tr>
<td>7</td>
<td>Power rating of pump (HP)</td>
<td>0.25</td>
</tr>
<tr>
<td>8</td>
<td>Number of turns of coil</td>
<td>26</td>
</tr>
<tr>
<td>9</td>
<td>Total length of tube</td>
<td>15240</td>
</tr>
</tbody>
</table>

3. Selection of Evaporator (Figure 2)

The evaporator is the component closest to the space to be refrigerated and is used in the low-pressure side of the refrigeration system. The primary refrigerant flows through the evaporator coil made of copper. The water to be converted to ice is stored in the refrigerated space. The secondary refrigerant is circulated around the refrigerated space using a small pump. The secondary refrigerant absorbs heat from the refrigerated space and transfers it to the primary refrigerant circulating in the coil. The temperature of the refrigerant in the evaporator is maintained less than that of surrounding medium to allow heat transfer to the refrigerant.

The high-pressure liquid refrigerant in the condenser is throttled to low pressure by the expansion valve. This low-pressure liquid refrigerant is circulated through evaporator coil where it absorbs latent heat of vaporization from the secondary refrigerant. The secondary refrigerant circulated in the evaporator absorbs heat from the space to be refrigerated. Due to continuous absorption of heat from the refrigerated space via the secondary refrigerant, the temperature of primary refrigerant rises beyond its saturation temperature and the sensible absorption of heat makes the refrigerant superheated.
Table 3: Evaporator specifications

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Description</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Material of tank</td>
<td>G.I. sheet (24 gauge)</td>
</tr>
<tr>
<td>2</td>
<td>Material of cooling box</td>
<td>G.I. sheet (24 gauge)</td>
</tr>
<tr>
<td>3</td>
<td>Thickness of tank material (mm)</td>
<td>0.7</td>
</tr>
<tr>
<td>4</td>
<td>Thickness of cooling box material</td>
<td>0.7</td>
</tr>
</tbody>
</table>

4. Selection of Expansion Valve

The capillary tube is commonly used as an expansion device in small capacity refrigeration units due to its cheap availability and ease of operation. It is a long copper tube of very small internal diameter of about 0.5 mm to 2.25 mm and the length of about 0.5m to 5m depending upon the specific application. A fine filtering mesh screen provided before the expansion tube protects the valve from choking and contamination. A small dehydrating filter provides additional freezing-up of the refrigerant in the capillary tube.

Table 4: Capillary tube specifications

<table>
<thead>
<tr>
<th>Sr.No.</th>
<th>Description</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Material of tube</td>
<td>Copper</td>
</tr>
<tr>
<td>2</td>
<td>Internal diameter of tube (mm)</td>
<td>0.36</td>
</tr>
<tr>
<td>3</td>
<td>External diameter of tube (mm)</td>
<td>0.8</td>
</tr>
<tr>
<td>4</td>
<td>Length of tube (mm)</td>
<td>300</td>
</tr>
</tbody>
</table>

Selection of Refrigerant

Refrigerant is a heat-carrying medium, which absorbs heat at a low temperature and discards it at a higher level. The refrigerant alternately vaporizes from liquid state to absorb heat in the evaporator and condenses in the condenser by rejecting heat to the cooling medium without any chemical change.

1. Selection of Primary Refrigerant

These refrigerants directly take part in the refrigeration system and undergo alternate vaporization and condensation in the system. As they are in direct contact with or flow through the major components of the vapour compression refrigeration system, they are called primary refrigerants. The primary refrigerant selected is R-12.

Reasons for using R-12 over Ammonia as Primary Refrigerant

1. It is non-toxic, non-corrosive and non-explosive as compared to ammonia.
2. It is fully miscible in oil simplifying the problem of oil return, which is not possible in ammonia.
3. It has latent heat of vaporization of 159 kJ/kg as compared to 1316.5 kJ/kg for ammonia at -15°C.
4. It retains its stability even under extreme operating conditions.
5. It condenses easily at moderate pressure under atmospheric conditions.
6. It has excellent electrical insulation properties making it suitable for semi and fully hermetically sealed compressors.
7. Ammonia causes corrosion of copper, brass and copper alloys. Thus, it requires the use of steel for the entire piping.
2. Selection of Secondary Refrigerant

Refrigerants, which are first cooled by primary refrigerants and then used for cooling purposes, are secondary refrigerants. The secondary refrigerants do not come into direct contact with all the components of vapour compression refrigeration system and are usually restricted to the evaporator. In the evaporator, the secondary refrigerants absorb sensible heat from the space to be refrigerated and reject heat in the form of sensible heat and latent heat of vaporization to the primary refrigerant circulating in the evaporator coil. The secondary refrigerant selected is Ethylene Glycol.

Reasons for using Ethylene Glycol over Brine as Secondary Refrigerant

1. Brines are corrosive to copper & steel under atmospheric conditions which may lead to excessive leakage.
2. Brines are not suitable for temperatures below -20 °C.
3. Ethylene glycol is non-corrosive to copper & steel.
4. Ethylene glycol is suitable even below -20 °C.

Future scope of the project

1. There is provision for different accessories to measure various system parameters so as to make system more sophisticated.
2. The system can be made suitable to check performance of alternative refrigerants so that it can be used as research attachment module.
3. There is provision of better insulation to achieve a higher heat transfer rate & reduce losses so as to improve performance of the system.

Maintenance Checklist for the set up

1. Amount of refrigerant should be maintained at proper level.
2. Leakage of refrigerant must be checked after a period of 6 months.
3. Amount of lubricating oil must be checked after a period of 1 year.
4. Level of water in condenser should be maintained at 250 mm.
5. Cooling water must be completely drained after a period of 1 month.
6. Fresh water must be properly purified before use in the condenser.
7. Electrical connections must be checked for any damage after a period of 1 month.
8. Scaling on condenser and evaporator coils must be periodically removed by mechanical and chemical treatment.
9. Level of secondary refrigerant in the evaporator must be maintained at proper level.
10. Any leakage should be rectified immediately for better performance of the system.

CONCLUSION

The project is the dissertation work. The duration of the project is one year. The project aims at designing a experimental test set up for commercial applications. For this purpose, a case study is done in one of the laboratories for designing and fabricating the proposed system in Nagpur, a major city in central part of India. Considering the geographical location, the cooling load is estimated and the system is designed. Then, the economic feasibility and pay back period of the system is calculated. From commercial point of view, the energy consumption for the proposed system is substantially less than that for the conventional systems. The system is designed and fabricated for checking its performance and suitability. The project work can be extended to make the system more sophisticated.
REFERENCES

1. ASHRAE Handbook of Fundamentals, 1997, American Society of Heating Refrigeration and Air Conditioning Engineers, 1791 Tullie Circle, Atlanta, GA 30329
Figure 1: Schematic of Cross flow evaporative condenser used in fabricated set up
Figure 2: Schematic of Evaporator for fabricated set up
Figure 3: Schematic of complete experimental set up for scaled down ice plant