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Research Article

Design and Adaptation of Chilling Plant for Evaporative Cooling of Cold Room

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Abstract

A major use of refrigeration is in the preservation, storage and distribution of perishable foods. Cold room is refrigerated space where low temperatures maintain for preservation of Food. The demand of cold room is going to increases due to adverse climatic conditions over worldwide so it needs to develop a cold chain which includes harvest cooling (pre-cooling) cold room transport to market. This design of cold storage is adaptive design which is operated on evaporative cooling suitable for preservation of the vegetables and fruit. The cold room is designed with refrigeration capacity 1.15 TR. During design these system various design parameter like cooling load calculation, selection of compressor, thermostatic expansion valve, condenser capacity and piping design are considered.

Keywords: *Evaporative cooling, Cooling load calculation, Latent heat and sensible heat.*

1. Introduction

Cold chain is now recognized as a sunrise sector in India because India has first rank in milk production in word and second number in Fruit and vegetables production. It was absorbed that force evaporation system is used in cold room which is force convection type so achieve the desire temperature into cold room. Improper system design and selection of unsuitable equipment or component leads to high energy consumption, high cooling time and variable temperature in cold room. Evaporative cooling is process to achieve low temperature with the help of evaporation of water. This system is based on the principle that when moist but unsaturated air comes in contact with a wetted surface whose temperature is higher than the dew point temperature of air, some water from the wetted surface evaporates into air. The latent heat of evaporation is taken from water, air or both of them. In this process, the air loses sensible heat but gains latent heat due to transfer of water vapor. Thus the air gets cooled and humidified. The cooled and humidified air can be used for providing storage for agricultural products. In this system water used as secondary refrigerant because water is easily available, cheap, non- inflammable, non hazardous refrigerant and high specific heat.

2. System Setup

This system is divided into two parts in which first part is refrigeration systems which chill water as secondary refrigerant and second part is water circulated in evaporator pipes in cold room. System is operating with ambient temperature 35^0c and storage temperature 10^0c. In practice, the cold room will operate for 24 hours daily and which provide storage for agricultural product. In this article evaporative cooling is examined for cold room purpose which is an innovating one and not used in any type of cold room. So it will be economical and energy efficient than other types forced circulation cold room. This will help to suggest alternative method of preservation of fruit and vegetable over the regular system and help to reduce initial cost and operating cost. The salient components of vapor compression refrigeration system used in cold storage system are Evaporator, compressor, condenser and expansion valve for the vapor compression cycle and another is centrifugal water pump and Evaporative coil in cold room. A typical schematic diagram fig.1 of the refrigeration system is shown below.

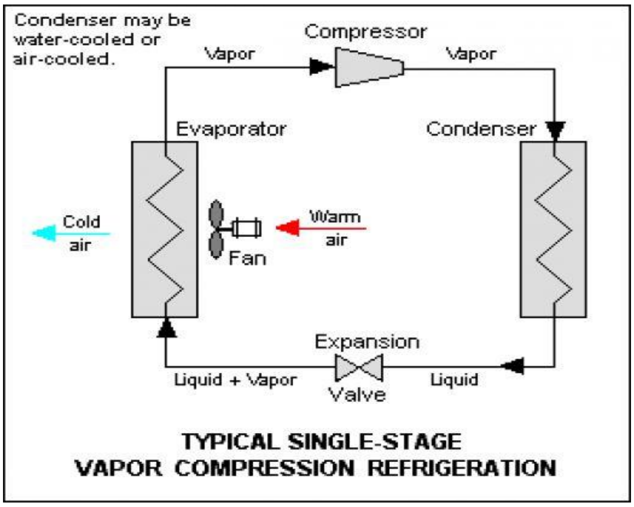

Fig.1 Typical vapor compression cycle

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Compressor raises the pressure and temperature of the refrigerant Condenser is rejected heat gained by compressor. Thermostatic expansion valve is use as throttling device which expands the liquid refrigerant and Evaporator is used to absorb heat from the refrigerated space. Then chilled water is circulated in evaporative coil of cold room with the help of centrifugal pump to achieve desire temperature.

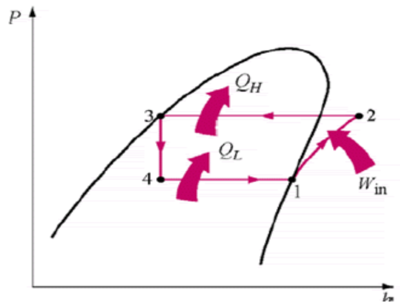

Fig.2 P-h diagram for Vapour compression cycle

Table 1 Specification of experimental setup

S. No	Parameters	Description
1	Type	Water Chiller
2	Refrigerant	R22
3	Capacity	1.5 TR
4	Compressor	Hermetically sealed, Reciprocating, two cylinders.
5	Condenser	Finned coils, Air cooled
6	Expansion device	Thermostatic expansion valve
7	Evaporator	Bare tube type

3. Cooling load source for cold room

3.1 Assumption for load calculation

Some main factors considered during cooling load calculation Design ambient temperatures, Storage area temperature and humidity requirements, Storage area dimensions and type of construction, insulation, exposure, type and amount of stored product, Electrical service requirements any miscellaneous loads including people, lights appliances etc. Some main factors considered during cooling load calculation.

3.2 Sources of sensible heat

Sensible heat: Sensible heat is energy that is 'sensible', which is to say related to a change in temperature.
1. Heat transmitted thru floors, ceilings, walls
2. Occupant's body heat
3. Appliance & Light heat
4. Solar Heat gain thru glass

Latent heat: Latent the heat required to convert a solid into a liquid or vapor, or a liquid into a vapor, without change of temperature

1) Moisture-laden outside air form Infiltration & Ventilation
2) Moisture from Equipment & Appliances

3.3 Heat leak through wall & insulation

The amount of heat enters or leak due to temperature difference present between the refrigerated space and atmospheric condition is given by the following formula -

$$Q = \frac{T1-T2}{\frac{L\,wall}{K\,wall \times A\,wall} + \frac{L\,insulation}{K\,insulation \times A\,insulation}} \text{ (W)} \qquad (1)$$

Where, T_1=Refrigerated space temperature (°C).
T_2 =Atmospheric Temperature (°C).
K=Thermal conductivity (w/m^2k).
A=Area (m^2).

3.4 Product load

The amount of the heat released by the food Stuff, vegetables and fruit is considered as product load. Agriculture product contains two types of heat one is sensible heat and another is latent heat. The specific heat will vary with the type of product and is different above and below 0°C, Product load can be calculated by

$$Q=m \times C_p \times \Delta T(W) \qquad (2)$$

Where, m= mass of the product (Kg).
C_p=specific heat of the product (kJ/kg K).
ΔT= temperature difference between inlet and product temperature. (°C)

3.5 Heat of respiration

Heat of respiration is the amount of heat respires by product. Certain food products experience chemical changes after storage. This is true of most fruits and vegetables, and some dairy products. This chemical change results in heat production which must be considered in the load calculation which is calculated by simple formula as below.

Q= mass of product × Heat of respiration per day (W) (3)

Where, Mass of product in kg
Heat of respiration/24 hrs in kJ/kg

3.6 Air infiltration load

Each time a door is opened outside warmer air come inside the room and add heat load to refrigeration system. This heat is containing sensible heat and latent heat can calculate by following formula.

Q=0.33×volume of cold room ×air flow rate × ΔT (W) (4)
Where, ΔT= temperature difference between inlet and outlet temperature (°C)

3.7 Working person load

During handling the storage product entry of human being also add heat load in it.

Q=No. of person × heat released by person/hr W (5)

3.8 Miscellaneous loads

All electrical energy used by lights, motors, heaters, etc., located in the refrigerated area, and must be included in the heat load. To calculate these loads it need to calculate amount of heat energy released by equipment. The amount of heat released by electrical equipment is directly obtained from its wattage capacity. These all load together give total amount of heat load on refrigeration system. Following table shows the amount of cooling load for the evaporative cold room on experimental purpose with product load 40 kg of potato.

Table2. Cooling load calculation

Sr.No	Cooling load parameters	Value(TR)
1	Cold room at empty condition	0.05
2	Heat leak through Wall	0.071
3	Product load	0.34
4	Heat of Respiration	0.080
5	Person load	0.02
6	Light load	0.01
7	Air infiltration Load	0.04
8	Miscellaneous Load	0.05

4 Component selection criteria

4.1 Compressor

Compressor selection of compressor totally depend on the calculated heat load of the system, Evaporating temperature and suction temperature because evaporating temperature of compressor affects the volumetric efficiency of compressor. Evaporating temperature decreases the volumetric efficiency of compressor decreases. It is also depend on types of refrigerant used into the system. For above system as per cooling load 1.5 TR hermetically sealed compressor selected. The specification of compressor is given into the table.

Table3 Compressor specifications

No.	Parameter	Unit	Value
1	Capacity	TR	1.528
2	Evaporating Temperature	^{0}c	7.2
3	Condensing Temperature	^{0}c	55
4	Suction Pressure	bar	5.23
5	Discharge Pressure	bar	21

4.2 Condenser

Selection of condenser totally depend on its heat rejection factor, cooling capacity, Temperature difference between refrigerant and atmospheric.

The condenser load is given by formula,

Condenser load = Compressor capacity × heat rejection factor (6)

Heat rejection factor obtained by condensing and evaporating temperature of system. The condenser capacity is determine using following formula

$$Q = U_o \times A_o \times \Delta T \quad (W) \qquad (7)$$

Where, U_o = Overall heat transfer coefficient based on outside area (W/m^2 ˚C).
A_o = Outside area of tube (m^2).
ΔT = L.M.T.D for condenser (°C).

4.3 Thermostatic expansion valve

Selection of thermostatic expansion valve and its orifice is completely depends on the pressure drop down. It is also depend on refrigerant type, evaporating temperature, liquid temperature entering the valve, and pressure drop across the valve.

4.4 Evaporator design

During the designing, Evaporator temperature and Condensing temperature is important which give the cooling capacity of the evaporator, the value of evaporator cooling capacity obtained from standard data sheet of compressor. Materials of evaporator, velocity of refrigerant, thickness of wall and contact surface area are some parameters which affect the cooling capacity of evaporator. Evaporator capacity can be calculated as following formula.

$$Q = U_o A (T_2 - T_1) \text{ (W)} \qquad (8)$$

Where,
U_o = Overall heat transfer coefficient (W/m$_2$)
A = Area of evaporator surface in (m$_2$),
T_2 = outside the evaporator Temperature (°C),
T_1= inside the evaporator Saturation temperature (°C)
Following table give the various values for evaporator coil designed for experimental purpose.

Table4 Evaporator coil calculation.

Sr.No	Parameter	Unit	Value
1	Mass Flow Rate of refrigerant	kg/min	1.75
2	Velocity of refrigerant	m/sec	0.1586
3	Reynolds Number		12291.7
4	Heat transfer coefficient at refrigerant side	w/m^{2}k	430.86
5	Overall Heat transfer coefficient	w/m^{2}k	261.5
6	LMTD for Evaporator	˚C	10.34
7	Length of evaporator coil	meter	31.04

4.5 Results and discussions

A simple vapor compressor system is designed for chilled water which further circulated into the cold room for achieving evaporative cooling. According to the observation and readings obtained from experimental setup gives Carnot cop of the system is 5.2.its theoretical cop is 3.8 as per calculation. Actual performance of the evaporative cooling is calculated by keeping product load inside the cold room. Actual cop of system is 1.42.Design and adaptation of vapor compressor cycle able to chill 320 liter water in 180 minutes. As mass flow rate of water is increased evaporative cooling time is decreased. Some readings and observation is given below table

Table 5 Experimental observations for system

Sr.No.	Parameters	Unit	Readings
1	Condenser Pressure	bar	200
2	Evaporator Pressure	Bar	38
3	Condenser Inlet Temp.	^{0}C	62
4	Condenser Outlet Temp	^{0}C	35
5	Evaporator Inlet Temp	^{0}C	7
6	Evaporator Outlet Temp	^{0}C	18
7	Mass Flow Rate Of Refrigerant	lph	40
8	Water Temperature	^{0}C	9

4.6 Graph

Figure 3 shows time versus temperature drop graph on which y-axis has temperature drop and x-axis with time. It shows as time is increases temperature drop is goes on increasing. Temperature drop is also depends on mass flow rate of secondary refrigerant that is the water used into system.

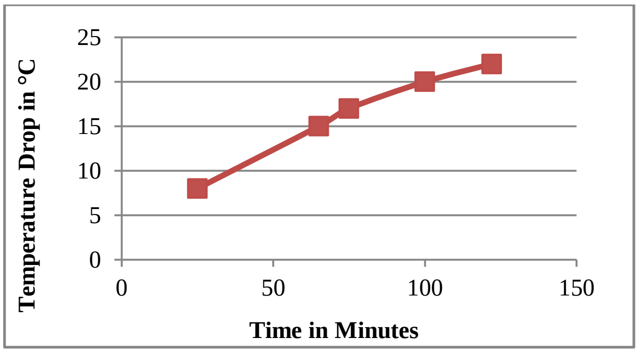

Fig.3 Temperature drop Vs Time graph

Conclusions

1) Design vapor compressor chilling plant able to chill water 250litres in 120 minutes with temperature difference 25^{0}C
2) It is found that according to designing the capacity of the chilling plant is 1.15 TR at condensing temperature 62 ˚C and evaporative temperature -2˚C.
3) Compressor energy efficient ratio (EER) is 2.74 kcal/W-h and its efficiency is 81%.
4) When centrifugal pump start to deliver water inside the cold room with initial water temperature 5˚C it drop down temperature of cold room up to 20˚C within 30 minutes.
5) With the help of evaporative cooling the load on refrigeration get reduced which is helpful to save power consumption and economical running of the plant.

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