A Theoretical Comparative Study of Heat Load Distribution Model of a Cold Storage

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ABSTRACT - In this study a mathematical model of cold storage (with the help of computer programming ; and other mathematical tools) has been proposed which can be used for further developments in the field of refrigeration – science and technology ; the proposed model aims for the development of cold storage in the upcoming future. In this paper we have proposed a theoretical comparative study of heat load distribution model of a cold storage. Velocity of air (v) temperature difference (dt), Relative humidity (Rh) are the basic variable and three range are taken each of them in the model development.

Keywords - cold storage refrigeration plant, Heat load, Convective heat transfer model.

INTRODUCTION

A major use of refrigeration is in the preservation, storage and distribution of perishable foods. Although the use of low temperatures for this purpose has been known and practiced for many thousands of years, it was not until the last century that Pasteur and others determined the bacteriological nature of food spoilage and the beneficial effect of cooling. An immediate advantage was to make it possible to provide the extra food required by the growing urban populations. A large international trade has built up on this, starting with the transport of frozen meats to Europe in 1873 and 1876.

Cold Storage is a special kind of a room, the temperature of which is kept sufficiently low with the help of machines and precision instruments. Cold storage plays an important role in the preservation of perishables especially fruits and vegetables. It helps in scientific preservation of perishables, stabilizes prices by regulating marketing period and supplies. It also helps the primary producer from distress sale and encourages farmers to produce more. In view of the fall in prices of fruits and vegetables immediately after harvest and to avoid spoilage of fruits and vegetables worth cores of rupees, it has become necessary to create cold storage facility in the producing as well as consuming centres to take care of the existing and projected production of fruits and vegetables.

Energy crisis is one of the most important problems the world is facing nowadays. With the increase of cost of electrical energy operating cost of cold storage storing is increasing which forces the increased cost price of the commodities that are kept. So it is very important to make cold storage energy efficient or in the other words reduce its energy consumption. Thus the storage cost will eventually comes down. In case of conduction we have to minimize the leakage of heat through wall but in convection maximum heat should be absorbed by refrigerant to create cooling uniformity thought out the evaporator space. If the desirable heat is not absorbed by tube or pipe refrigerant then temp of the refrigerated space will be increased, which not only hamper the quality of the product which has been stored there but reduces the overall performance of the plant. That's why a mathematical modeling is absolutely necessary to predict the performance.

In this paper we have proposed a theoretical comparative study of heat load distribution model of a cold storage using computer programming. Velocity of air (V), Temperature difference (dT), Relative Humidity (RH) are the basic variables and three ranges are taken each of them in the model development. Graphical interpretations from the model justifies the reality.

MODEL DEVELOPMENT

Practical heat load calculation:

In this study, analysis of heat load calculation has been done using a designed sample data of a cold storage , Jalpaiguri, West Bengal, India. Using the technique of heat

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load calculation we can calculate the total heat of the designed cold store. With the help of the obtained data machineries are being installed for running the store. The process of heat load calculation is the summation of different heat loads which are being calculated on different factors considered in the running, designing and fabrication of the cold store. Managerial aspects are also taken in consideration of heat load calculation.

Total heat load = Transmission load + Product cooling load + Product respiration load + Ventilation load + Infiltration load + Air handling unit load + Lighting load

i. Transmission load – It is the kilowatt amount of heat to be extracted from the chamber that gets transmitted from the ambient to inside of the chamber due to conduction. Design factors includes the surface of the chamber (including all the four walls, floor, ceiling), temperature difference between the surrounding and inside of the chamber, thermal coefficient of the material used for the purpose of insulation, number of hours required to pull down the heat content inside the chamber, number of hours of working of compressor required to pull down the heat load. Transmission load is given by the equation:

{Area*thermal coefficient of insulation(U)*temperature difference*hours*3.51}/(12660*working hours of compressor)

ii. Product cooling load- It is the kilowatt amount of heat to be extracted from the chamber that gets inside the chamber when the product is first entered into the chamber from the field. This heat load include the own heat content of the product and mainly the field heat from the ambient. Design factor is based on the daily loading factor into the chamber, temperature difference between the pre-cooled chamber and the temperature to be attained of the product in a certain period of time, working hours required by the compressor to reach the desired temperature. Product cooling load is given by:

(5%of total capacity of the chamber *0.86*4.186*temperature difference*3.51)/(12660*working hours of compressor)

iii. Product respiration load–It is the kilowatt amount of heat to be extracted from the chamber that gets generated inside the chamber from the product itself due to its respiration process. This heat load plays a very important role among all the other different heat loads calculated for the design purpose. Design factor includes the loading rate as per the chamber capacity, respiration rate of the product at the desired temperature, working hours of the compressor required to extract the heat generated. Production respiration load is given by:

(5%of the loading rate*respiration rate of the product*3.51)/(12660*working hours of the compressor)

iv. Ventilation load–It is the kilowatt amount of heat that gets inside the chamber from the ambient due to air exchange. Fresh air is the most important and only food for the products kept inside the chamber for long duration. During air exchange process great amount of heat transfer takes place, as a result inside temperature get increases to some extent. Air exchange is also required so as to exhaust the carbon di-oxide which gets accumulated due to respiration of the product. Design factor includes volume of the air or the chamber, number of air changes, working hours of compressor so as to pull down the temperature. Ventilation load is given by:

(volume inside of chamber *74.5* number of air changes*0.3*3.51)/(12660*working hours of compressor)

v. Infiltration load–It is the kilowatt amount of heat that gets infiltrated mainly due to human practices for regular work done for the cold store. Loading, un-loading, routine checks of the products and temperature etc., maintenance purpose inside the chamber. This also includes very few percentages of the openings and closing of the door due to the above causes. Design factor includes number of person or workers, average heat load of human body, number of working hours inside the chamber in a certain period of time. Infiltration load is given by:

(Number of workers * average heat load of a human body *working hours*3.51)/12660

vi. Equipment load, air handling unit – It is the minimum kilowatt amount of heat that is generated inside the chamber from the running of motor of air handling units. This load is constant almost constant all over the period of time for which the product has to be kept inside the chamber. Design factor includes number of motor of fans inside, kilowatt of each motor. Equipment load is given by:

(Number of rows or column *number of fans *kilowatt of each motor*3.51)/12660

vii. Equipment load, lighting – It is the minimum kilowatt amount of heat that is generated due to the lighting inside the chamber for different purposes. These days technologies have been improved, power saver lamps are used up with part lighting procedure. Design factor includes kilowatt of each bulb / light, number of lights, lighting hours. Equipment load lighting is given by:

kilowatt of each light*number of lights*hours of lighting

Heat load calculations: A CASE STUDY

CONDITIONS	DATA
Storage size – chamber 1 & 2	87.478m*34.138m*16.764m
Outside surface area (including floor) –Ch. 1 & 2	10050.19m²
Volume of chamber 1& 2	50062.74m³
Insulation	EPS (expanded polystyrene)
Ambient condition	25ºC and 70%RH
Temperature difference at storage	3 ºC
Humidity range at storage	(85-95) %
Storage capacity	14600MT
Loading weight per day	5% of chamber capacity per day
Air change per day during loading	2 air changes per day
Air change per day during pull-down	2 air changes per day
Air change per day during holding	1 air changes per day

1. Transmission load

[{Area (10050.19 m²)*U (1.1)*TD (33-15)*hours (24)*3.51}/(12660*24hr)] = 55.17KW

2. Product cooling load

[{5%of the total capacity (14600000kg)*0.86*4.186*TD (25-10)*3.51}/ (12660*24hr)] = 303.59KW

3. Product respiration load

[{5%of the loading rate (14600mt)*respiration rate(12206)*3.51}/(12660*24hr)] = 102.94KW

(As at temp. 25°C respiration rate for potato is 12206kj/tons/day and at temp. 3°C respiration rate for potato is 812kj/tons/day)

4. Ventilation load (with 70% Recovery)

[{volume (500620.74 m²)*74.5*2 air changes*0.3*3.51}/(12660*24hr)] = 258.5KW

5. Infiltration load

{(28 workers*1000kj/hr*8hours*3.51)/12660} = 62.1KW

6. Equipment load

Air handling unit = {14nos*12nos of fans*0.5hp*(3112kj/hp)*3.51}/12660 =72.47KW

Internal lights = 0.018(kw)*400*18hrs=129.6KW

Total heat load = 55.17KW+303.59KW+102.94KW+258.5KW+62.1KW+72.47KW+129.6KW =984.37KW/day

So practical heat load per month = 984.37 x 30 = 29531.1 KW/Month

Theoretical heat load calculation:

In this study heat transfer from evaporating space to refrigerant (which are in tube or pipe) only being considered. The transfer heat evaporating space to refrigerant are calculated in terms of velocity of air (**V**), temp. Difference (**dT**) & relative humidity (RH). The three values of air velocity (**V**) of evaporator space are 0.74m/s, 1.25m/s and 1.76m/s respectively. The three values of temperature difference (**dT**) of evaporator space are 2, 5 & 8 centigrade respectively. The three values of relative humidity (**RH**) of evaporative space are 0.85, 0.90 & 0.95 respectively are taken measured values.

Basic equation for heat transfer:

$Q_T = Q_{conv} + Q_{condensation}$.

$Q_{conv} = A h_c dT$ & $Q_{condensation} = A h_m (RH) h_{fg}$.

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Here Q_{conv}=heat transfer due to convection & $Q_{condensation}$=heat transfer due to condensation & Q_T=Total heat transfer or absorb heat into refrigerant.

And $h_c/h_m=c_p\,(Le)^{2/3}$ & $h_cL/K=Nu=0.026(Re)^{0.8}(Pr)^{0.3}$

The final heat transfer equation due to velocity of air (**V**), temp. difference (**dT**) & relative humidity RH) is **$Q_T=7.905V^{0.8}(dT + 2490\,RH)$.**

Hera **A**=surface area of tubes in evaporator space 1872 m^2.**h_c**=convective heat transfer co-efficient. **h_m**=convective mass transfer co-efficient.**h_{fg}**=latent heat of condensation of moisture.

Output of the equation using C programming:

First, the values of V and T remain constant
Enter the value for RH within the range of 0.85 to 0.95
RH=.85
Keeping V=1.25 and T=5 and incrementing the value of RH by 0.01,the corresponding values of Q are:

RH	Q
0.85	19940.047
0.86	20174.084
0.87	20408.119
0.88	20642.154
0.89	20876.189
0.90	21110.226
0.91	21344.263
0.92	21578.298
0.93	21812.333
0.94	22046.371
0.95	22280.406

Now, the values of V and RH remain constant
Enter the value for T within the range of 2 to 5
T=2
Keeping V=1.25 and RH=0.90 and incrementing the value of T by 0.5,the corresponding values of Q are:

T	Q
2.0	21082.029
2.5	21086.730
3.0	21096.128
3.5	21091.429
4.0	21100.828
4.5	21105.527
5.0	21110.226
5.5	21114.925
6.0	21119.626
6.5	21124.326
7.0	21129.025
7.5	21133.724
8.0	21138.423

Last, the values of T and RH remain constant
Enter the value for V within the range of 0.74 to 1.76
V=0.74
Keeping T=5 and RH=0.90 and incrementing the value of V by 0.1,the corresponding values of Q are:

V	Q
0.74	13878.746
0.84	15359.896
0.94	16806.109
1.04	18221.810
1.14	19610.501
1.24	20975.011
1.34	22317.662
1.44	23640.404
1.54	24944.880
1.64	26232.515
1.76	27757.158

So theoretical maximum heat (Q) = 27,757.158 KW

RESULTS AND DISCUSSIONS

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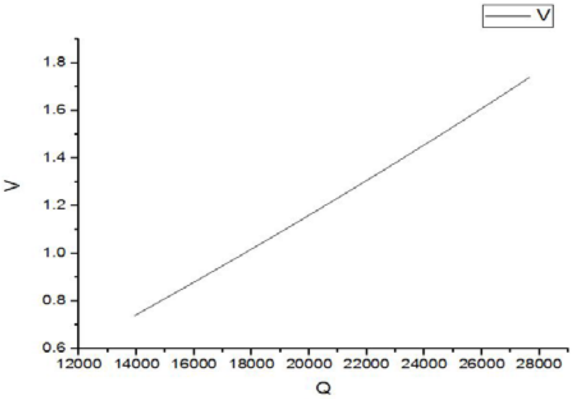

Figure: variation of heat transfer v/s air velocity

The graph indicates heat absorption increase with velocity of air increases.

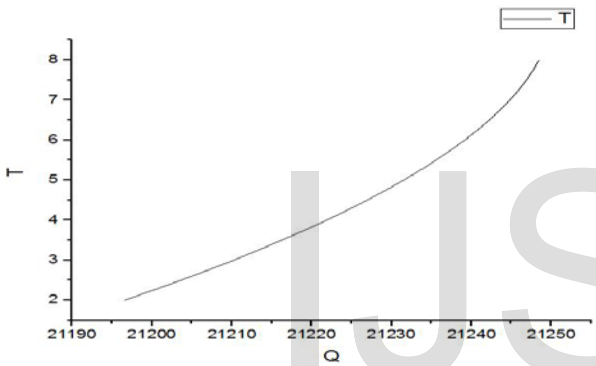

Figure: variation of heat transfer v/s temperature difference.

The graph indicates that heat absorption increase with temperature difference increase and at lower temperature difference it is more affected than the higher temperature difference.

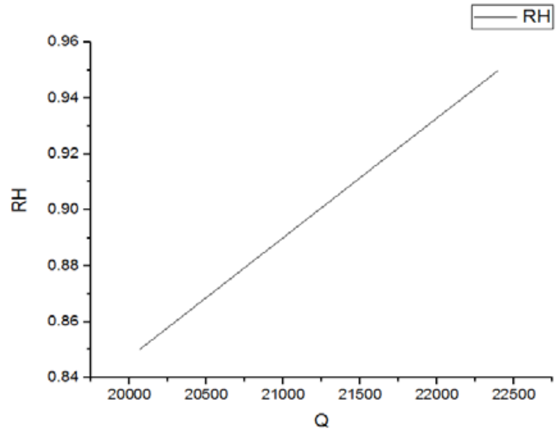

Figure: variation of heat transfer v/s relative humidity.

The graph indicates that heat absorption increase with increase in relative humidity.

CONCLUSION

Here the work is concerned with the theoretical comparative study of heat load of a cold storage and we have seen that practical heat load more than theoretical heat load, but the difference is minor. So we can consider this model. Analysis of the heat load calculation has been done using real time sample data; programming has been done on C, while the graphs have been plotted using origin. With increasing the velocity of air, temperature difference and relative humidity heat absorb by the refrigerant is increased.

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