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Designing of Cold Stores and Choosing of Cooling System Elements

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Abstract: In this study, calculation of cooling load and choosing of the cooling system elements such as compressor, condenser and evaporator were explained for designing of the cold storage. Transmission heat (q_1), infiltration heat (q_2), product heat (q_3), heat of other sources (q_4) and unknown and unexpected heat (q_5) which is components of the cooling load were calculated. In addition, amount of the cooling fluid was calculated and choosing of the compressor, the condenser and the evaporator were explained.

Key words: Cold storage, cooling load, compressor, condenser, evaporator

INTRODUCTION

Cooling can be defined as the decrease of temperature of a substance or medium below temperature of its environment (Anonymous, 2001). Refrigeration is a process of lowering the temperature and maintaining it in a given space for the purpose of chilling foods, preserving certain substances, or providing an atmosphere conductive to bodily comfort. Storing perishable foods, pharmaceuticals, or other items under refrigeration is commonly known as cold storage. Such refrigeration checks both bacterial growth and adverse chemical reactions that occur in the normal atmosphere.

The most important factor in cold storage is ambient temperature. As a rule, the temperature in cold storage is higher than 1-2°C, which is the freezing point temperature of stored fruit and vegetable. Stored product must not be freezing in the cold storage (Cemeroglu and Acar, 1986). Ozkol (1999) reported that there is heat transfer in many places of cooling system and that the heat transfer widely takes place during the process. Tashtoush (2000) investigated process of heat and mass transfer during cold storage of fruits and vegetables and determined a mathematical model for presenting these processes. Equations are solved for different cold storage conditions.

The purpose of the calculation of cooling load is important choosing system components such as compressor, condenser etc. correctly and economically (Ozkol, 1999). Taner (1987) and Aybers (1992) stated that the choice of the ideal cooling system requires good calculation of the cooling load and all sources of cooling load must be take into consideration. According to Erol (1993), determination of all inputs of cooling load would not be possible, for this reason there may be some deviations in the cooling load and the focus point must be minimizing the deviation.

It is explained that the ambient temperature of cold storage, the situation of stored product before entering to the cold store, the daily working hours and the determination of which product will be stored are important for calculation of the cooling load (Anonymous, 1994).

The capacity of the compressor must be enough to suck and to pump the cooling gas to the compressor (Savas, 1987).

Preparing of an investment plan and feasibility analyses for the cold storage must be first to design a cold store. The location of the cold storage, the distance of the storage to the stored product, transportation, distance to market, the decision about products to be stored and aim of the cold storage must be determined. The objectives of constructing a cold storage must be to design it not only for a specific product but also for different kind of products. The design of some small cold rooms instead of a big cold storage a due to the impossibility of cold storage of more than one product minimizes the energy cost and unforeseen.

For the calculation of the cooling load of the environment, detailed construction design information used as cold store and meteorological conditions are required. The steps given below must be followed (Anonymous, 1998c).

Data collection: Building characteristics (construction materials, building size, colour of the outside of the building and shape), location of building (obtained from the construction plan), outside environment conditions, meteorological data, approved outside environment conditions for the project), interior environmental project conditions (dry and wet thermometer temperatures, amount of the ventilation), management strategy, operating date and time must be selected.

Data usage: After collecting the related data, the cooling load may be calculated according to the determined environmental conditions.

In this study, the way of calculation of the cooling load for the design of cold storage and the selection of the cooling system elements are tried to be explained. How to design a cold storage is explained by the use of different literatures.

CALCULATION OF COOLING LOAD

While determining the outside temperature for calculation of cooling load, the average temperature of the hottest month in the year is taken into account.

In order to calculate the heat load in cold storage, the heat amount of the produced heat by all sources should be determined and summed.

The load of the heat consists of the transmission heat(q_1), infiltration heat(q_2), products heat(q_3), other heat sources (q_4) and unknown and unexpected heat (q_5) for the calculation of the cooling load (Ozkol, 1999). Calculations were realized according to the above given explanations.

Transmission heat (q1): The calculation of the transmission heat created by walls, floor and ceiling requires information on thickness and type of isolation material used in construction of cold room, construction of building, physical specifications of the cold storage volume, inside and outside environment temperatures and the effect of sunshine. Following equations were used to calculate transmission heat (Taner, 2005; Anonymous, 1996b, 2001).

$$q_c = K.A. (T_{out}-T_i) \quad (1)$$

Where:

- q_c = Heat transmission at flat surface (W)
- K = Total heat transmission coefficient (W/m^2 K)
- A = Area of heat transmission (m^2)
- T_o = Temperature of outside or neighbour volume (K)
- T_i = Inside volume temperature (K)

$$\frac{1}{K} = \frac{1}{\alpha_i} + \sum_{i=1}^{n} \frac{x_i}{\lambda_i} + \frac{1}{\alpha_o} \quad (2)$$

Where:

- α_o = Coefficient of heat transmission of outside surface (W/m^2 K)
- α_i = Coefficient of heat transmission of inside surface (W/m^2 K)
- x_i = Material thickness (m)
- λ_i = Thermal conductivity (W/m^2 K)

Heat transmission coefficients can be selected from different literatures such as Ozkol (1999) and Anonymous (2001).

Following equation is used for practical calculations (Taner, 2005).

$$K = \frac{\lambda}{x} \quad (3)$$

Main effective factor on overall heat transmission coefficient (K) is thermal conductivity (λ) and material thickness. The effect of other factors can be generally neglected. Thicknesses of isolation materials determine due to investment and management costs. K overall heat transmission coefficient can be taken between 0.25 and 0.06 W/m^{2}K.

The calculation of T_{out} "outside temperature" is determined according to the hottest month of the year. However, a smaller value of the outside temperature may take into account because of economical reasons. Through benefiting from the information of long-term temperature data, calculated outside temperatures, wet and dry temperature data are also given by Ozkol (1999).

Infiltration heat (q_2): The infiltration heat load is defined as the value obtained through the entrance of the air with a higher enthalpy to the cold storage.

Some structural deformations such as windows, doors and walls, which cause to air leakage may occur. Air leakage create additional heat load during the cold storage. This heat load can be calculated by using following equation (Erol, 1993; Anonymous, 1998c).

$$q_2 = c_p.z.V.(T_{out} - T_i) \quad (4)$$

Where:

- q_2 = Heat produced by air changing and leakage air (kJ h^{-1})
- c_p = Specific heat of humid air (1300 J/m^3 K)(Erol, 1993)
- z = Daily number of air exchanging (Erol, 1993; Anonymous, 2001)
- V = Volume of cold storage (m^3)
- T_i = Storage temperature (K)

Product heat (q_3): The most important factor for the determination of the inside temperature is the purpose of the cold storage use. Inside temperature required for cooling is defined as storage temperature (Erol, 1993).

The fact that some stored products contain water in their structure, cause to some changes such as the decrease of the temperature during storage, the condensation of water vapour, water and liquid freezing, heat outcome if any chemical reaction takes place.

Stored product which contain water in their structure create heat load by losing their latent heat while condensation or freezing.

It is known that stored products especially fruits, vegetables continue their vitality after harvesting and they diffuse heat as a result of some chemical reactions to their environment during this period (Erol, 1993; Anonymous, 1998b; Cemeroglu *et al*., 2001).

If cold stored materials are placed into plastic or wooden boxes, heat load of these boxes must be taken into consideration.

Equation 5 calculates heat load created by cold stored product (Cemeroglu *et al*., 2001).

$$q3 = q3_1+q3_2 + q3_3+q3_4 \tag{5}$$

Where:
$q3_1$ = Heat produced by cooling above freezing points (W)
$q3_2$ = Heat must be taken during freezing (W)
$q3_3$ = Deep cooling after freezing of cold stored product (W)
$q3_4$ = Maturation heat (W)

Cooling may be classified as short-term cold storage and long-term cold storage

Calculation of heat load pre-cooling above freezing point ($q3_1$): Pre cooling lengthen storage time after making the product wait for 24 h in a cold room.

The amount of heat, which must be taken from stored product to decrease its temperature to cold room's temperature and heat used to decrease temperature of stored product from t1 to t2, can be calculated with the following equation.

$$q_{31} = \frac{G.c_1.(T_{out} - T_i)}{\Delta t_s/3600} xLF \tag{6}$$

Where:
$q3_1$ = Heat produced by cold stored product (W)
G = Amount of the stored product (kg)
C_1 = Specific heat up to product freezing (kJ kg^{-1} K) (Anonymous, 1998b, 2001)
T_{out} = Outside temperature (K)
T_i = Inside temperature (K)
Δt_s = Cooling time (h)
LF = Loading factor

Products may be placed into pre-cooling rooms before being placed into storages. The great differences between the temperature of the product and the storage cause to excessive work of evaporators. This is taken into consideration as loading factor during the calculation of cooling load. The loading Factor is only required for cold stores which has a pre-cooling room.

Weight of the daily boxes entered to cold store is calculated as follows:

$$Gk = n_b*W_b \tag{7}$$

Where:
n_b = Total number of boxes for a cold store
W_b = Weigh of a box (kg)

Heat produced while freezing ($q3_2$)

$$q3_2 = \frac{G.c_{dfreezing}}{\Delta t_{freezing}/3600} \tag{8}$$

Where:
$q3_2$ = Heat produced while freezing (W)
$c_{freezing}$ = Freezing heat of stored product (J kg^{-1})
$\Delta t_{freezing}$ = Freezing time (h) (Anonymous, 1998a)

Deep cooling after freezing ($q3_3$)

$$q3_3 = \frac{G.c_3.(T_0 - T_3)}{\Delta t_3/3600} \tag{9}$$

Where:
$q3_3$ = Deep freezing after cooling (W)
G = Amount of product (kg)
C_3 = Specific heat of the stored product after freezing (J kg^{-1} K)
T_0 = Freezing temperature of product (K)
T_3 = Temperature of the stored product at the end of the freezing (K)
Δt_3 = Cooling time for freezing period (h)

Maturation heat ($q3_4$): Heat produced during the storage called as maturity heat. The maturity heat ($q3_4$) calculates by using Eq. 10.

$$q3_4 = G.c_{maturity} \tag{10}$$

Where:
$q3_4$ = Maturity heat (W)
$c_{maturity}$ = Specific Maturity heat of the product during cold storage (W kg^{-1}) (Ozkol, 1999, Anonymous, 1998b)

Other heat loads (q_4): Other heat loads are composed of heat produced by people working in cold store, lighting devices, electrical engines and defrost processes. This heat load can be calculated as follows (Cemeroglu and Acar, 1986; Ozkol, 1999; Erol, 1993).

$$q_4 = q_{41}+q_{42}+q_{43}+q_{44} \quad (11)$$

Where:

q_4 = Other heat loads
q_{41} = Heat produced by humans working in cold store (J day)
q_{42} = Heat produced by lightening devices (J day^{-1})
q_{43} = Heat produce by ventilation (J day^{-1})
q_{44} = Heat produced by electrical defrost processes (J day^{-1})

$$q_{41} = n.c_i.t_1 \quad (12)$$

Where:

n = No. of workers
c_i = Heat load produced from a worker (W) (Ozkol, 1999; Anonymous, 2001; Erol, 1993)
t_1 = Average working time in cold store (h day^{-1}) (Approx. 1 h day^{-1})

$$q_{42} = N_{ay}.t_2 \quad (13)$$

Where:

N_{ay} = Total lightening power (W)
t_2 = Average daily working time of lightening in cold store (sec day^{-1})

$$q_{43} = N_{hava}.t_3 \quad (14)$$

Where:

N_{hava} = Power of the ventilation system (W)
t_3 = Daily working time of the ventilation system (sec day^{-1})

$$q_{44} = n.W.t_4.F \quad (15)$$

Where:

n = No. of electrical defrost heating (number)
W = Power of electrical heating (W)
t_4 = Time of the defrost for a day (sec day^{-1})
F = Defrost factor

Defrost factor is generally accepted 0.5 for the electrical defrost systems and 0.4 for the hot gas systems (Ozkol, 1999).

According to their working hours, power value of ventilator, electrical engines and forklift must be taken into account directly for the calculation of cooling load.

Effect of the unknown and unforeseen heat loads (q_5): After calculating all heat loads, 10% of the total heat load must be added as unknown and unforeseen heat and taking into consideration that the system will work for 20 h a day, 24/20 time factor must also be (Guzel *et al.*, 1996).

$$n_b = \frac{0.8.a.b}{k_e.k_b}.\frac{(h-(l_{tv}+l_{tb}))}{k_y} \quad (16)$$

Where:

n_b = Total number of the boxes (number)
a = Width of cold storage (m)
b = Length of the cold storage (m)
k_e = Width of the box (m)
k_b = Length of the box (m)
l_{tv} = Distances between ceiling of the cold store and boxes located at the top (m)
l_{tb} = Distances between floor of the cold store and bottom level of the boxes (m)
h = Total height of the cold store (m)

Amount of the total cold stored product;

$$M = n_b * M_b \quad (17)$$

Where:

M = Amount of the total stored product (kg)
M_k = Amount of product located in a box (kg/box)

CHOICE OF THE COMPRESSOR, CONDENSER AND EVAPORATOR

Temperature of condensation and evaporation for a cooling system with one compressor is generally taken as +30°C and -10°C for mild climatic conditions, respectively (Dagsoz, 1981, Anonymous, 1996a). Theoretical cooling cycle and pressure-enthalpy diagram is shown in Fig. 1.

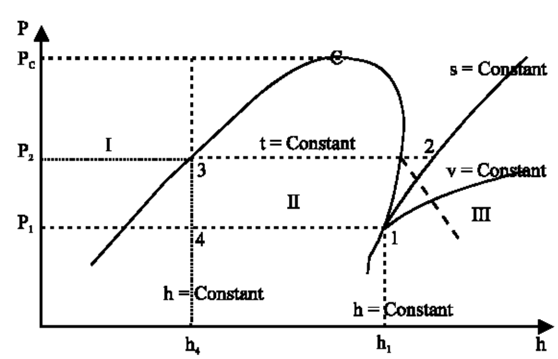

Fig. 1: Pressure-enthalpy for cooling circle

The specific heat load of the evaporator, evaporation capacity of the evaporator, amount of the cooling gas, specific heat load of condenser, evaporation capacity of condenser, pressure heat, power of the compressor, coefficient of management (ε) are calculated by using carts for cooling gases (Dagsoz, 1981; Savas, 1987; Bulgurcu *et al*., 1992).

Compressor capacity: The capacity of the compressor is equivalent to the amount of the heat, which must be taken from a cold storage. If a compressor is used in the cooling storage, the compressor capacity is determined according to the duration of repairing, maintenance and stopping and daily working time of the compressor. The daily working period depends on temperature of the storage, temperature of the evaporator and the daily defrost duration. The daily working hours generally change between 14 and 20 h (Ozkol, 1999).

Compressor capacity is considered equal to removing total heat load. Work of the compressor, theoretical compression heat and theoretical compression work can be calculated by the following equations;

$$L = (h_2 - h_1) \tag{18}$$

Where:
L = Compressor work (kJ h^{-1})
h_1 = Enthalpy at point 1 (Fig. 1) (kJ kg^{-1})
h_2 = Enthalpy at point 2 (Fig. 1) (kJ kg^{-1})

$$q_k = G.L \tag{19}$$

Where:
q_k = Theoretical compression heat (kJ h^{-1})
G = Amount of the cooling gas (kg h^{-1})

$$Wt = \frac{q_k}{860} \tag{20}$$

Where:
Wt = Theoretical compression work (kW)
860 = Heat equivalent of work

After calculating the theoretical power of the compressor, the effective compression power which is also called consumption power can be determined by the use of Eq. 21;

$$W_p = W_t.\frac{1}{\eta_i}.\frac{1}{\eta_m} \tag{21}$$

Where:
W_p = Practical compression power (kW)
η_i = Indicator efficiency (85%)
η_m = Mechanical efficiency (85%)

According to the effective compressor power, power of the driver engine is calculated from Eq. 22.

$$W_m = 1,35.\ W_p \tag{22}$$

Where:
Wm = Driver engine power for compressor (kW)

Amount of cooling gas: Amount of cooling gas is calculated by using the Eq. 23. (Erol, 1993).

$$G = \frac{Q}{h_1 - h_3} \tag{23}$$

Where:
G = Amount of cooling gas (kg h^{-1})
Q = Cooling load of the system (kJ h^{-1})
h_3 = Enthalpy at point 3 (KJ kg^{-1})

Capacity of evaporator: The specific heat load of the evaporator is calculated by using following equation after determining enthalpies for accepted evaporation and condensation temperatures from Mollier Diagram (Ersoydan, 1967; Dagsoz, 1981).

$$q_b = h_1 - h_3 \tag{24}$$

Where:
q_b = Specific heat load of the evaporator (kJ kg^{-1})

q_b will be positive because of $h_1 > h_3$. It means that the cooling system takes heat from Point 1 to Point 3.

The capacity of evaporator is equal to total removing heat load. This cooling load is received by the evaporator then passed to the cooling gas. The cooling gas is pressurized by the compressor. The temperature of the evaporation may be 10 and 15°C lower than the cold storage temperature. Evaporator capacity can be calculated by the use of the Eq. 25.

$$Q_b = Q = G.\ q_b \tag{25}$$

Where:
Q_b = Capacity of the evaporator (kJ h^{-1})

Capacity of condenser: According to the temperatures of the evaporation and the condensation, the specific heat load and the capacity of condenser can be calculated by the use of enthalpy values from Molliere Diagram (Anonymous, 1997).

$$Q_y = h_3 - h_2 \quad (26)$$

Where:
q_y = Specific heat of the condenser (kJ kg^{-1})

q_y is negative because of $i_2 > i_3$. It means that the system loses heat from point 2 to point 3 (Fig. 1).

$$Q_y = G.q_y \quad (27)$$

Where:
Q_y = Capacity of the condenser (kJ h^{-1})
G = Amount of the cooling gas (kg h^{-1})

In practice, the capacity of the condenser may be accepted 15% bigger than the total heat load. It can be calculated by the use of Eq. 28.

$$Q_y = 1.15.Q \quad (28)$$

Cooling effect (ε): Main objective of cooling systems is removing the heat from cold source at maximum level out of the storage. Consuming minimum work for this purpose depends on cooling efficiency. Cooling efficiency or cooling effect can be calculated by using Eq. 29 (Erol, 1993; Taner, 2005).

$$\varepsilon = \frac{h_1 - h_4}{h_2 - h_1} \quad (29)$$

The decrease of pressure at compressor suction, compressor working under lower efficiency and more working hours than normal cause increase cost of management. In contrary, the increase of suction pressure of compressor cause to be off the point of optimum working conditions and to the decrease life of the compressor.

CONCLUSIONS

Designing of a cold store and choosing suitable cooling system elements are important for effective cooling and creating suitable storage conditions for agricultural products. Objective of this article is to give a set of calculations for cooling system and to explain choosing process of the cooling system elements.

The load of the heat consists of the transmission heat (q_1), infiltration heat (q_2), products heat (q_3), other heat sources (q_4) and unknown and unexpected heat (q_5) for the calculation of the cooling load. The specific heat load and capacity of the evaporator, amount of the cooling gas, specific heat load of condenser and capacity of condenser, pressure heat, power of the compressor, cooling effect (ε) must be calculated for choosing cooling elements. Details of the all calculations of these factors were given in the article.

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