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Design and Cost Estimation of an Economic Air Blast Freezer

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ABSTRACT
Air blast freezer is the technology of rapidly freezing food to its desired storage temperature. This quick-freezing form very small crystals of ice which do not rupture the preserved food's cells when melts and thus ensures the taste and texture of food being unaffected. This paper presents economic design of an air blast freezer considering preservation of 1000 kg poultry meat from 25^{o}C to -18^{o}C within 4 hours, selection of necessary equipment, cooling load calculation and finally a calculation of BOQ (Bill of Quantity). A very simple design was selected that could be made by locally available low-cost material and could be fabricated and installed by local technicians. The proposed design minimizes the complication in structure and best equipment for best performance is tried to select. The estimated cost for the proposed design and equipment is found lower than the existing system of same capacity.

Keywords: Quick freezing, Poultry meat, Cooling load, Cost

1. Introduction

The design, calculation and analysis are done considering the preservation of poultry meat. The present meat and egg production can meet only 68 and 64% of the national demand. Poultry contributes about 22-27% of the total animal protein supply in the country [1]. Due to wrong preservation method, the poultry meat loses its quality. A proper preservation system is necessary to ensure food security and supply of quality protein to people. Quick freezing is a reliable method for food preservation maintaining the food quality. There are several processes of quick freezing such as- Multi-Station Plate Forster, Air-Blast Freezing Tunnels, Fluidized Bed Freezers, Immersion Freezing, Freeze Flo Process etc. The most commonly used method of freezing food is air, as it is cost-effective, sanitized and relatively non-corrosive to equipment. Air blast freezing is the method of taking a product at a temperature and freezing it quickly to its target storage temperature, which varies from product to product, between 12 and 48 h (e.g. Fish -20 °C, beef - 18 °C) [2]. In a blast freezer refrigeration device, the evaporator temperature normally varies between -35 °C and -52 °C [3]. For food products with unusual shapes, air blast freezers are more suitable. In these situations, the product package represents the barrier between product and refrigeration. Short freezing times are possible by maintaining high air velocities within the freezer compartment, low air temperature, and good contact between package and product surface. W. Boonsupthip and D. R. Heldman got freezing time 2.7 hours for freezing of fish (thickness of 0.11m) at a temperature - 20°C. W. Boonsupthip and D. R. Heldman also reported that a range of 3 to 4 meters per second air velocity is most suitable for economically freezing of foods [4].

2. Design consideration

The optimum design and operation of the blast freezers involve consideration of a large number of factors including:

1. Selection of freezer type
2. The air blast freezer should be suitable for operating by a person.
3. The freezer should be simple in construction so that local manufacturers can easily fabricate it.
4. The freezing chamber should have multi tray facilities.
5. Product quality
6. Specification of product size, packaging, shape, production rate and final storage temperature
7. Evaporative weight loss
8. Rate of freezing
9. Freezing time
10. Thermal properties of product
11. Surface heat transfer coefficients
12. Air temperature
13. Air velocity
14. The tray spacing and air velocity of the freezer should be adjustable.
15. Air infiltration
16. Refrigeration system and efficiency
17. Fan and air-cooling performance
18. The cost of the freezer must be within the reach of small medium buyer.
19. It should be easy to repair and maintain.
20. The freezer should be made with locally available materials.
21. The freezer should have simple and easy adjustment and
22. Energy use should be as low as possible.

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2.1 Body of the freezer

The body was made of 256.54 cm × 259.08 cm rectangular shape and 190.5 cm long. It consists of cooling chamber, fan, thermostat, valve and freezing chamber.

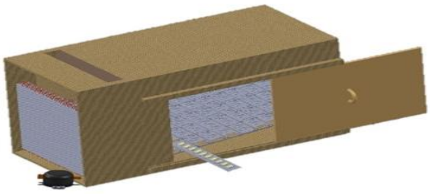

Fig.1 The body of the freezer

2.2 Cooling chamber

The refrigeration cycle was made by connecting compressor, evaporator, condenser, expansion valve, capillary tube etc. Then the refrigeration cycle is connected with the cooling chamber.

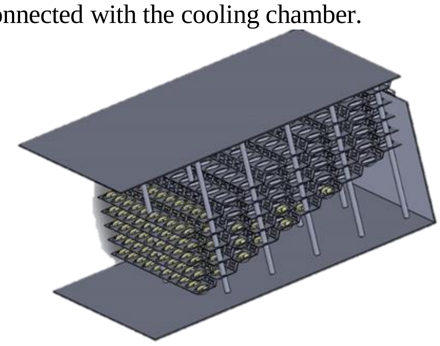

Fig.2 Cooling chamber

2.3 Freezing chamber

The freezing chamber was made of MS sheet with a dimension of 39 cm×34 cm×26 cm. The insulation was made of glass wool of thickness 7.62 cm. Plastic cover was used to cover the insulating material.

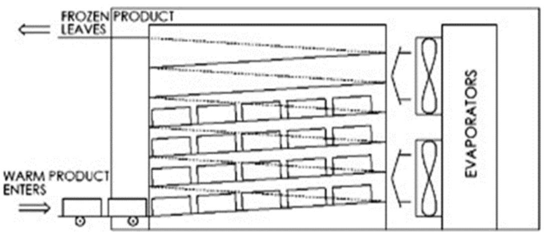

Fig.3 Freezing chamber

2.4 Cooling fan

The centrifugal fan was connected with motor and set up at the intersection of freezing chamber and cooling chamber. The fan forced air in the freezing chamber from cooling chamber. The revolution per minute of the fan is 7200. A regulator was connected with the fan to control the speed of the fan.

Fig.4 Cooling fan

Table 1 Properties of poultry and design consideration

Mass Per poultry	2.5 kg
Total Mass (m)	1000kg
No. of Poultry	400
Initial Temperature(T_1)	25 ° C
Freezing Temperature (T_{freeze})	-3 ° C
Final Temperature(T_2)	-18ºC
Specific Heat Above Freezing ($C_{p, fresh}$)	4.34 KJ/kg.k[5]
Specific Heat Below Freezing ($C_{p, frozen}$)	3.32 KJ/kg.k[5]
Latent Heat of Fusion (L_{latent})	220 KJ/kg[5]
Safety Factor	15%
Storage Period	12 Months at -18°C

3. Load calculation

The total heat required to be removed from the space in order to bring it at the desired temperature by the air conditioning and refrigeration equipment is known as cooling load. To design a system and to select size of equipment, cooling load calculation is required. Cooling load depends on product load, infiltration, lighting, solar heat gain etc. We have considered only product load and infiltration load for designing the project. Because other load is very negligible for sealed room.

So, Total cooling load will be sum of product load and infiltration load.

i.e. Total cooling load=Product load + Infiltration load

3.1 Product load calculation

Cooling to the freezing point (removing the sensible heat), freezing (removing the latent heat), and further cooling to the desired subfreezing temperature (removing the sensible heat of frozen food) are involved in the freezing of poultry. The three components of the product load can be determined from following equations,

$$Q_{cooling,fresh} = mc_p(T_1 - T_{freeze}) \quad ....(1)$$

$$Q_{freezing} = mh_{latent} \quad ....(2)$$

$$Q_{cooling} = mc_{p,frozen}(T_{froze} - T_2) \quad ....(3)$$

Table 2 Product Load Calculation in kj [5]

Load above freezing(By Using Equation-1)				
Mass, m(kg)	Sp. Heat above Freezing, Cp(KJ/kg^{0}k)	Initial Temp.T_1 (^{0}C)	Freezing Point,T_{freeze} (°C)	Heat, $Q_{cooling\ fresh}$ (KJ)
1000	4.34	25	-3	121520

Load for freezing(By Using Equation-2)		
Mass, m(kg)	Latent Heat h_{latent} ,(KJ/kg)	Heat, Q $_{freezing}$ (KJ)
1000	220	220000

Load below freezing(By Using Equation-3)				
Mass, m(kg)	Sp. Heat Below Freezing, Cp (KJ/kg^{0}k)	Freezing Point,T_{freeze} (^{0}C)	Final Temp,T_2 (^{0}C)	Heat Q $_{cooling}$ (KJ)
1000	3.32	-3	-18	49800

Table 3 Total Product Load in kw

Heat $Q_{cooling}$(KJ)	121520
Latent Heat $Q_{freezing}$(KJ)	220000
Heat $Q_{cooling}$(KJ)	49800
Heat Q_{Total} (KJ)	391320
Time (Sec)	4×60×60
Load (KW)	27.175
TR(3.5KW=1TR)	7.764

3.2 Infiltration load

Due to the surrounding warm air entering the refrigerated space through gaps and open doors, the heat gains occur and refrigeration system's infiltration load also increases. Over time, the infiltration load changes. To scale the refrigeration device properly, we should consider the maximum value and to properly estimate the average energy consumption, we should consider the average value. The infiltration load can amount to more than half of the total cooling load in installations that require the doors to remain open for long periods of time.

Here we use the crack length method for calculating the infiltration load.

The equation is,

$$V1 = \frac{(L \times W \times H \times Ac)}{60} \frac{m3}{min} \quad ....(4)$$

$$SHGIA = 0.02044V_1(T_1 - T_2) \quad ....(5)$$

$$LHGIA = 50V_1(W_1 - W_2) \quad ....(6)$$

Where, T_1: Outside température, ^oC

T_2: Inside température, ^oC

Table 4 Infiltration Air Velocity

Length, L(m)	2.92
Width (m)	2.57
Height, H(m)	2.6
Air change /hr (A_c)	1
Velocity, V_1 (m^3/min)	0.324

Table 5 Sensible Heat Gain due to Infiltration Air

Infiltration air Velocity V_1 (m^3/min)	0.324
Ambient Temp. (T_1 ^{0}C)	27
Inside Temp. (T_2^{0}C)	25
Sensible Heat (KW)	0.01324

Table 6 Latent Heat Gain due to Infiltration Air

Infiltration air Velocity V_1 (m^3/min)	0.324
W_1 (kg/kg of dry air)	0.022802
W_2 (kg/kg of dry air)	0.020173
Latent Heat gain (KW)	0.04258

3.3 Total cooling load

Total cooling load will be the sum of total product load and infiltration load.

Safety factor is also considered to determine the total cooling load.

Table 7 Total Cooling Load

Types of load	Load (KW)	Safety factor (15%)	Total Load
Product Load	27.175	4.076	31.25
LHGIA	0.01324	0.004686	0.01792
SHGIA	0.04258	0.006387	0.048967
			Total=31.32 KW

4. Equipment selection

The equipment selection process is considered in the early stage of the design process since the equipment selection process decides the quality, cost, and reliability, which are important for customer satisfaction. Equipment selection of freezer means proper selection of compressor, evaporator, condenser, expansion valve, cooling fan etc. based on cooling load. By analyzing from different websites and software, TGE 40-42 model expansion vale, 6HE-25Y-40P model compressor, R-134a refrigerant were selected.

5. Bill of Quantities (BOQ)

Table 8 Bill of quantities (BOQ)[6]

Name of component	Model	Qty.	Rate (Taka)	Amount (Taka)
Compressor	6HE-25Y-40P	1	40,000	40,000
Expansion valve	TGE 40-42	1	2000	2000
Condenser	Tube type	1	50,000	50,000
Evaporator	Tube Type	1	60,000	60,000
Cooling Fan	IWD 1004 ET	1×3	5600	16800

Refrigerant	R-134	1 barrel	3600	3600
Foam				8000
MS Sheet		3000in^3	5/in^2	15000
MS plate	95 inch (0.2 in Th.)	40	500	20,000
MS Flat Bar	95 inch (0.2 in Th.)	40	350	14,000
MS Nut Bolt				2000
MS Rod	105 inch (2 in dia.)	6	300	1800
Glass Wool	12 in^2	1	3500	3500
Aluminum Plate	102 in^2	1	5000	5000
Adequate safety Device		4	1600	6400
Copper Tube		15 m	200/m	3000
Carrying Cost				5000
Setup Cost				15,000
		Total Cost (Taka)		2,71,100

6. Result and Discussion

In this project an air blast freezer is designed for 1000kg poultry meat. The materials and equipment were selected from website and using some software. Some data have been assumed. That's why the selected equipment size and model may be varied. Best equipment for best performance was tried to select.

Cooling load has been calculated assuming two parameters such as product load and infiltration. But in actual case it is necessary to consider all other factors to have better performance.

The cost to develop this project has been shown which is much lower than the existing system of same capacity. That is why the project is feasible.

7. Conclusion

Preservation of poultry products is costly in Bangladesh due to having low design quality. Since the production of poultry meat is increasing in the country, it is needed to preserve this in freezer for business purpose. The system exists in the country has high cost compared with performance. So design has been proposed in this project, which has high performance and low cost. If this system could be installed, power and money would be saved.

8. References

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NOMENCLATURE

m: Mass of the food product, kg

$c_{p,fresh}$: Specific heat of the food before freezing, KJ/kg^{0}k

$c_{p,frozen}$: Specific heat of the food after freezing, KJ /kg^{0}k

h_{latent} : Latent heat of fusion of the food, KJ /kg

T_{freeze}: Freezing temperature of the food, ^{o}C

T_1: Initial temperature of the poultry (before refrigeration), ^{o}C

T_2: Final temperature of the poultry meat (after freezing), ^{o}C

L: Room length, m

W: Room width, m

H: Room Height, m

A_c: Air changes per hour

SHGIA: Sensible Heat Gain due to Infiltration Air, KW

LHGIA: Latent Heat Gain due to Infiltration Air, KW