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Development of Air Blast Freezer for the Storage of Fruits and Vegetables

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ABSTRACT

The need for the conservation of agricultural produce is highly essential considering the global food crisis. Several methods of fruit and vegetable preservation do not normally conserve the nutritional values of the produce. This led to the development of the Air blast freezer which gives room for the conservation of nutritional and organoleptic values of compatible fruits and vegetables. The system was designed for a cooling capacity of 0.83116KW based on the average ambient temperature of 27^0*C, condensing and evaporating temperatures of 40*^{0}*C and -2*^{0}*C respectively. The system can handle 20 fresh fruits and vegetables or a combination of both. The system, when tested has a coefficient of performance (COP) of 3.55. It is capable of preserving fruit and vegetable samples for 14 days without significant change in the number of nutritional values and the organoleptic condition of the samples.*

Keywords: Air-Blast freezer, COP, Fruits, Organoleptic values, Preservation, Nutritional values, Vegetables.

1.0 INTRODUCTION

There is a need to preserve agricultural produce, in order to ameliorate the effects of food crisis around the world. Hence, the development of appropriate Air Blast Freezer for the storage of agricultural produce as presented in this work is most essential. The storage of food items and produce is an essential aspect of food preservation. Adequate storage increases the shelf life of the produce, preserves quality, makes produce available throughout the year, stabilizes price and prevents unnecessary field losses.

Refrigeration is essential to the prevention of losses and conservation of both quality and nutritional value of perishable food items. This has opened the possibility of a true world market of such commodities on a continuous year round basis. Fruits and vegetables are susceptible to spoilage very rapidly and become unsuitable for consumption when not properly conserved. It is difficult to give an estimate of losses in developing countries, but some organizations claim that for certain products, up to half the crop can be lost. Many authors have reported on the need to develop indigenous technology for engineering the various aspects of agricultural operations, this includes storage of fruits and vegetables [1-3]. The usefulness of Blast Freezer lies in its capacity to prolong the period during which perishable food items remain in an acceptable state. This is achieved by slowing down decay or physiological changes. Refrigeration makes it possible to market safe and high quality food items to non producing region. Chilling or freezing are particularly necessary when perishable food are to be transported to distant and better paying markets.

All types of food contain proteins, carbohydrates, fats (lipids) vitamins and minerals, such as iron, calcium and phosphorus which help in tissue building and body growth. The vitamins and minerals are essential to safeguard the body against diseases. The destruction of any one of the above mentioned components causes the spoilage of the food. The spoilage period depends upon the type of food. Perishable foods like meat, fish, milk and many fruits and vegetables begin to deteriorate immediately after harvesting unless properly preserved. The semi-perishables like eggs, onions and potatoes can be kept for several weeks in a cool dry place. The non-perishable food like cereals, pulses and nuts can be stored for a long period of time [4]. The spoilage of food comes in form of bad odours, unattractive colour and taste.

The advantage of food preservation, according to Ogunlowo *et. al.* [5], includes; preservation of quality, stabilization of market prices, steady and regular supply of food materials, increase in variety of food product and enhancing the potential of crop. The employment of Air blast freezer will be a good option for food preservation in the areas in which the greatest post-harvest losses of food items occur.

An Air blast freezer is a freezer in which air at a very low temperature is circulated by blowers or fans in order to cool and preserve fruits, vegetables and other food items. It is a thermally insulated compartment or cabinet in which air at subfreezing temperature is maintained for the rapid cooling and storing of perishable items. It employs the principle of vapour compression refrigerating system. Vapour compression refrigerating system presents some peculiarities with respect to other refrigerating systems because it is commonly used in a wide range of commercial and industrial application [6]. The advantage of Air blast freezer is its versatility: it can cope with a variety of irregular shaped products [7]. Blast freezers use air as the heat transfer medium and depend on contact between the product and the tray inside the cooling chamber. Complexity in airflow control and conveying techniques varies from crude blast freezing chambers to carefully control impingement freezer. The earliest blast freezers consisted of cold storage rooms with extra fans for air circulation. Improved airflow control and mechanization of conveying techniques have made heat transfer more efficient and product flow less labour intensive [8].

2.0 MATERIALS AND METHOD

The cooling load capacity of the blast freezer was determined by considering various sources of heat into the refrigerated space. The heat (or heat load) sources considered in this design are; Transmission Load (TL): heat transferred to the refrigerated space through the surfaces, Product Load (PL): consists of heat produced and removed from the produce placed in the refrigerated space, and Infiltration Load (IL) which is the heat gains associated with the air entering the refrigerated space.

Based on 12-hours of operation per day, the following parameters were assumed: an average ambient temperature of 27^0C; refrigerating chamber temperature of 0^0C; 20 kg of produce samples (vegetables or fruit); and cabinet thickness of 0.008 m. Other parameters such as surface area of the cabinet (0.6441 m^2); volume of the refrigerating chamber (0.2619 m^3) both evaporating and condensing temperature; compressor size and fan power were estimated.

2.1 Transmission Load (TL)

It is the measure of heat flow rate by conduction through walls of the refrigerated space from the outside in unit time. The amount of transmission load is calculated using equation (1) as given by Dossat [9], which was derived from Fourier's first law, mathematically written as

$$Q \propto A \frac{dt}{dx}$$

$$Q = AU \frac{dt}{dx} \qquad (1)$$

The U-values; overall heat transfer coefficient for the three layers of the cabinet comprising of mild steel plate, polystyrene insulator, and aluminum plate required in equation (1) is given in equation (2)

$$U = \frac{1}{1/f_o + x_1/k_1 + x_2/k_2 + x_3/k_3 + 1/f_1} \qquad (2)$$

where;

f_0= outside convection coefficient = 4.0, f_i = inside convection coefficient = 1.65

x_1= thickness of mild steel plate = 0.002 m, k_1= thermal conductivity of mild steel plate = 58 W/m.K, x_2= thickness of polyesthene = 0.004m, k_2 = thermal conductivity of polystyrene = 0.34 W/m.K, x_3= thickness of aluminum plate = 0.002m, k_3 = thermal conductivity of aluminum = 204.2 W/m.K ,Therefore U = 0.841, Q = the rate of heat transfer in (W), A = the outside surface area of the wall (m^2) = 0.6441 m^2 , U = overall co-efficient of heat transmission = 0.841(W/m^2K), ΔT = temperature differential across the wall = 27^0C, Therefore from equation 1, Q was estimated to be 0.014 kW

Infiltration load: This is the heat gains associated with the air entering the refrigerated space.

$$Q_f = \dot{m}(h_0 - h_1) \qquad (3)$$

Where;

$\dot{m}$= air infiltration rate into the refrigerated space, this is assumed to be 0.0036 L/s, h_0 = enthalpy of the outside air kJ/kg = 230.22 kJ/kg; h_1 = enthalpy of inside air kJ/kg = 200.00 kJ/kg. By applying equation (3) for the infiltration load, Q_f was estimated to be 0.0108 kW

2.2 Product Load

This is the heat produced and removed from the product brought into the refrigerated space this is expressed as in equation (4).

$$Q_p = \frac{mc(\Delta T)}{t} \qquad (4)$$

Where:

Q_p = the quantity of heat given by the product; m = mass of the product = 20 kg ;

c = specific heat capacity = 3.98 kJ/kg ; ΔT = change in product temperature = 27^0C

t = time (h). By applying equation (4) Q_p was estimated to be 0.1790 kW

The developed system was to accommodate at least 20 kg of produce, the highest specific heat capacity for fruits and vegetable was selected for the design. Addition to the product load is the heat of respiration which is the heat released by the produce as it respires. The maximum heat of respiration is given by Arora [7] was chosen which is 8.733 kJ/kg at storage temperature of 0^0C. Heat of respiration hr is given by equation (5) and was estimated to be 0.174 kW .

$$H_r = mch \qquad (5)$$

Where:

m = mass of the produce = 20 kg , H_r = heat of respiration = 8.733 kJ/kg

Therefore total refrigeration load = (0.1790 + 0.174) kW = 0.353 kW

Total cooling load (Q_H); this is summation of all the heats load, it was estimated to be 0.3778 kW . In order to provide for instrumentation and experimental errors, heat load of (1.1)(0.3778) was used. This is 10% above the calculated value which is 0.41558 kW .

2.3 Required Equipment Capacity (REC)

This is defined as the capacity at which equipment will perform more effectively and measured in kW and for 12 hours running time, this is given by equation (6).

$$REC = (Total\ cooling\ load).(24\frac{hours}{12}hours) \qquad (6)$$

From equation (6), REC was estimated to be = 0.83116 kW .

For REC over 12 hours operation, therefore a compressor of 1.0 Hp is required. The evaporator and condenser were selected based on this compressor capacity.

2.4 Determination of Refrigerating Effect

The refrigerating effect (Q_e) was calculated using equation (7) as given by Arora [10] using R134a as the working fluid. The enthalpy at various temperature levels was obtained from Arora [10]. The values

$$Q_e = (h_{ev} \dot{-} h_{ed}) \qquad (3)$$

where: (h_{ev} $-h_{ed}$) is the difference in the enthalpy of the refrigerant at evaporator and condenser temperatures. The design was based on 40^0C condensing temperature, -2^0C evaporating temperature, 5^0C superheating temperature and 27^0C average ambient temperature. The values for enthalpy were obtained from fundamental of thermofluid by Yunus *et al.* [11]. The T-s diagram is shown in Fig.1; hence Q_e was estimated to be 141.28 kJ/kg . Work done by compressor was estimated to be 39.69 kJ/kg using equation (8).

$$W = h_5 - h_3 \qquad (8)$$

2.5 Determination of Mass Flow Rate ($\dot{m}$)

The expected mass flow rate was estimated to be 0.593 *g/s* using equation (9) as given by Dossat [9]

$$\dot{m} = \frac{REC}{RE} \qquad (9)$$

Figs. 1a and 1b show the temperature-entropy diagram for the system and the pictorial drawing of the air-blast freezer respectively.

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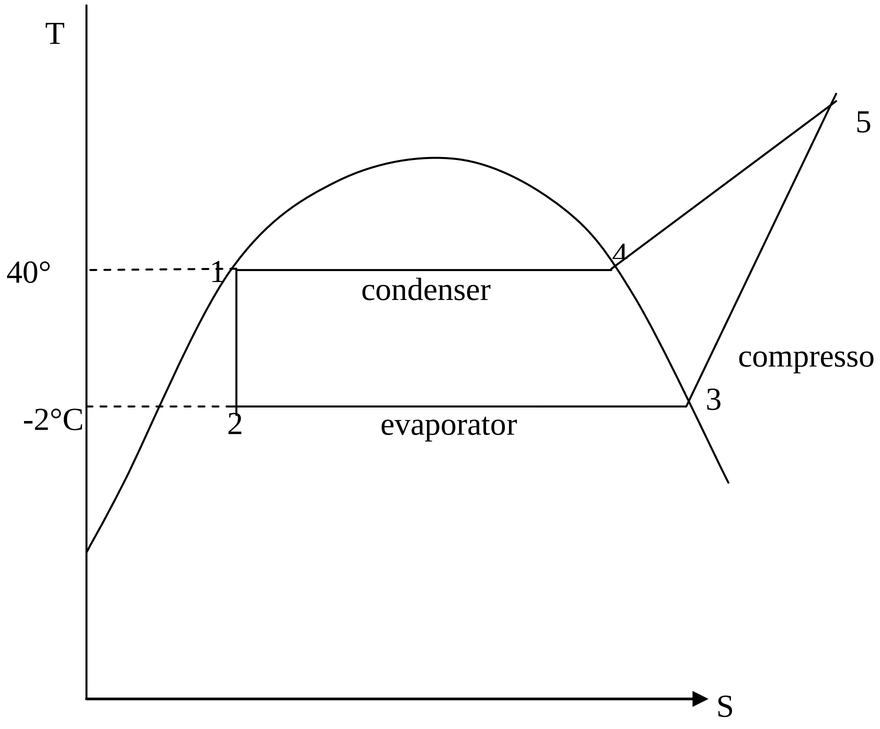

Fig. 1.a: Temperature – entropy diagram for the system

2.6 Determination of Coefficient of Performance (COP)

The performance of a refrigerating machine is expressed by the ratio of useful heat to work. This is presented mathematically as shown in equation (10)

$$C\dot{O}P = \frac{RE}{W} \tag{10}$$

Using the values obtained for refrigerating effect and work estimated by equations (7) and (9), the COP of the system was estimated to be 3.55 using equation (10)

Fig.1.b: Pictorial drawing of the Air-Blast Freezer

3. RESULTS AND DISCUSSION

The developed system was tested with samples of fruits and vegetable such as apple, orange, grape and carrot after construction. The cooling rate was determined both on no-load and loading conditions. Measured parameters include: ambient-, cabinet-, condenser-, and evaporator-temperature by using temperature measuring devices. These measured parameters were used to determine other parameters such as: refrigerating effect (Q_e), mass flow rate ($\dot{m}$), compression work (CW) and coefficient of performance (COP). Graphs were plotted relating the variations of these parameters with condenser and evaporator temperatures.

Fig.2 shows the variation of load temperatures with time. As it can be observed in the figure, as time increases the load temperatures decreases. Within the starting time (t=0) and when t=100 minutes, the rate at which the heat is being removed from the load is almost linear. After this period the temperature remains almost constant. The graph is steeper on no-load condition than loading condition. Fig.3 shows the Compression work (CW) and the refrigerating effect (Q_e) increase with the decrease in evaporator temperature. This shows that compressor compresses refrigerant at higher rate at low evaporator temperature and cooling effect is high at lower evaporator temperature. Fig. 4 shows that the coefficient of performance increases with decrease in evaporator temperature and the mass flow rate decreases with decrease in evaporator temperature. This shows that the system performs better at lower temperature and the rate of flow of refrigerant is slow at lower temperature. In Fig. 5, the Compression work and the Refrigerating effect increase with increase in condenser temperature. This shows that compression work and cooling effect are higher at high condenser temperature. Fig. 6 shows that the COP increases as mass flow rate decreases with increase in condenser temperature till the optimum temperature is reached. Fig. 7 shows that as mass flow rate increases, refrigerating effect decreases.

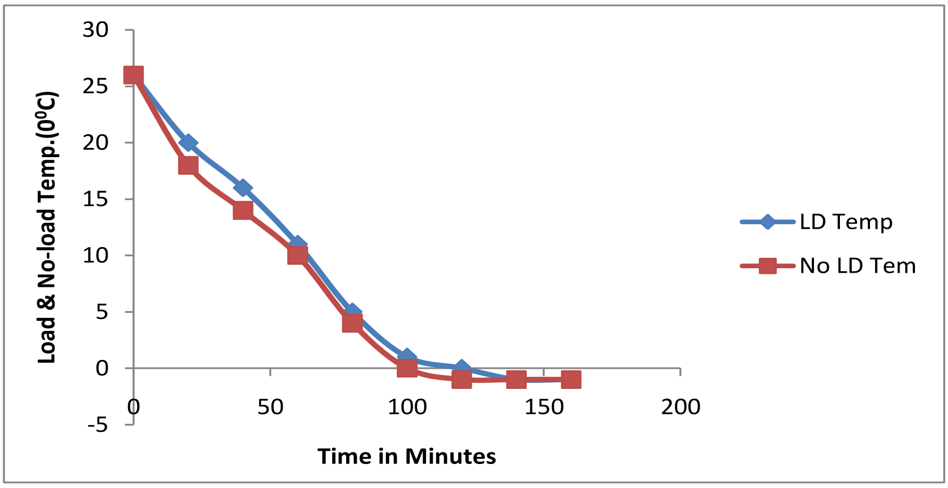

Fig. 2: Graph of Load and No-Load Temperature against Time.

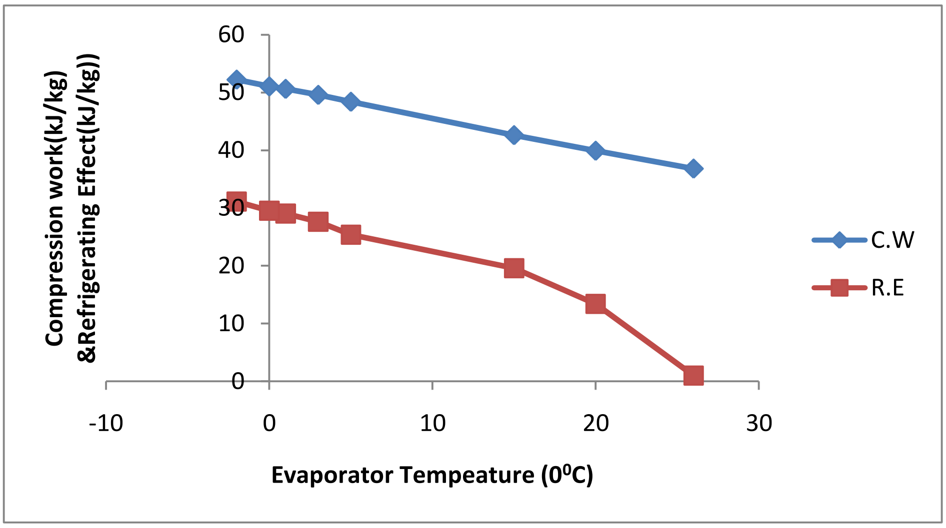

Fig. 3: Graph of Compression work and Refrigerating Effect against Evaporator Temperature.

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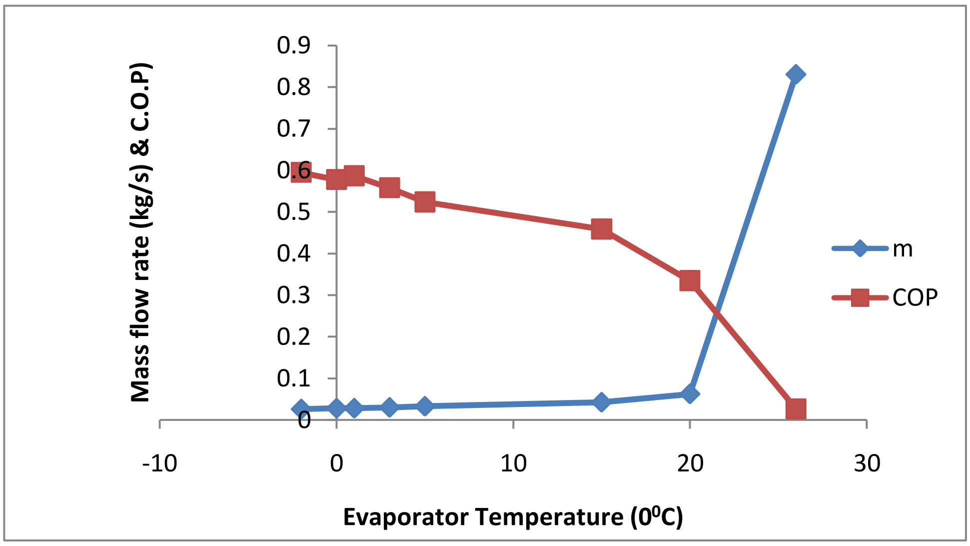

Fig 4: Graph of mass flow rate and Coefficient of Performance against Evaporator Temperature.

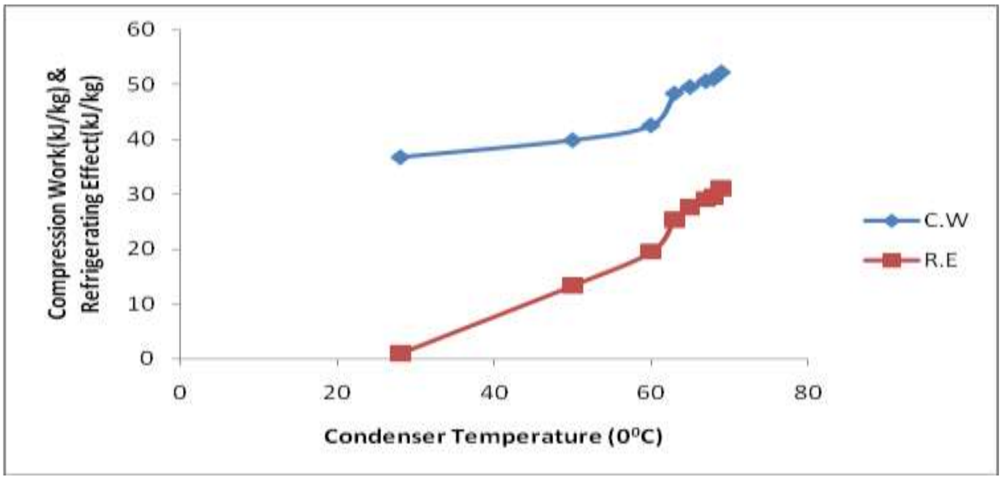

Fig. 5: Graph of compression work and Refrigerating Effect against Condenser Temperature.

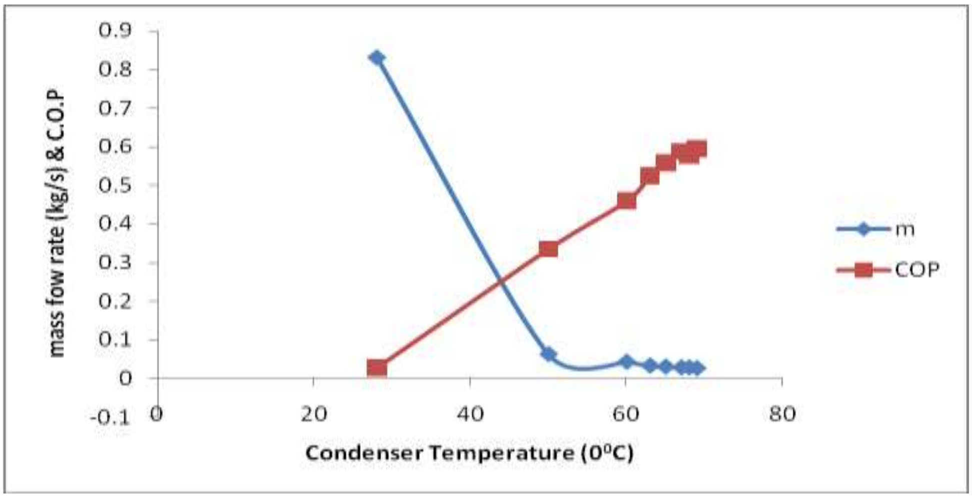

Fig. 6 Graph of mass flow rate and Coefficient of performance against Condenser Temperature.

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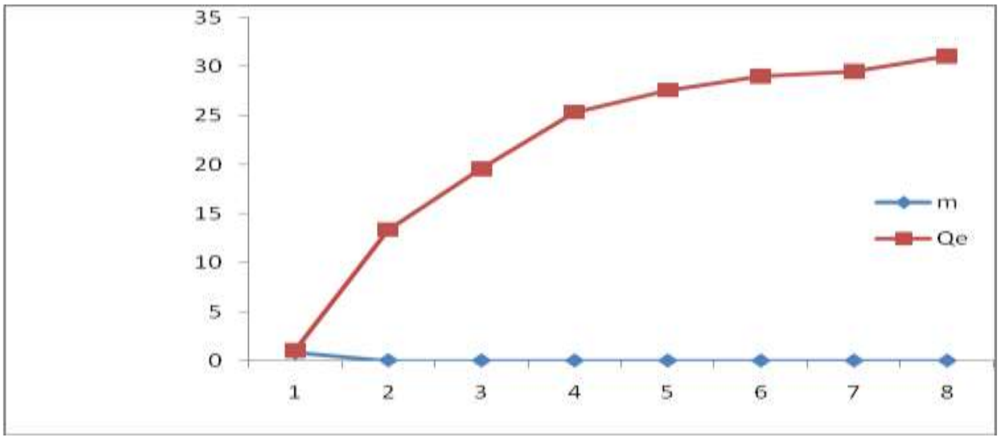

Fig 7 Graph of mass flow rate against refrigerating effect

4. CONCLUSION

In this work, an Air blast freezer of 0.83116 kW **c**apacity was designed and constructed. The Air blast freezer developed uses the vapour compression refrigerating system and a finned type evaporator, which has the distinct advantage of keeping the temperature of the stored item above the freezing point, was incorporated. The system having a cooling load of 0.353 kW was designed to accommodate 20 kg of fruits and vegetables or combination of both.

The system was tested on no – load condition and the parameters measured were the room temperature, condenser and evaporator temperatures using temperature measuring devices. Parameters such as Refrigerating effect (Q_e), mass flow rate (m), compression work (CW) and Coefficient of performance (COP) were calculated to be, 141.28 kJ/kg, 0.00593 kg/s, 39.69 kJ/kg and 3.55 respectively. The test result shows that compression work and the Refrigerating effect increase with decrease in evaporator temperature and that COP increase with decrease in evaporator temperature. This shows that the system performs better at lower temperature. Compression work and the refrigerating effect increase with condenser temperature. Also COP increases and mass flow rate decreases with increase in condenser temperature till the optimum is reached.

Afterwards the system was tested with 5 kg of fruits in order to study its effect on the stored produce. The observation of five observers' show that the system was able to retain the organoleptic and nutritional values of the stored produce for one week storage which proves the efficiency of the Blast freezer. Conclusively it can be inferred that the Blast freezer cooling rate is higher than that of domestic refrigerator of the same capacity, also the system has higher COP and hence refrigerating effect.

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