Temperature and Velocity Distribution in Apple cold storage by CFD simulation.

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***Abstract*:- performance of cold storage depends on the cooling capacity of the refrigeration unit are installed in cold storage plant, but the air flow and velocity distribution is highly effected on the harvesting product, the purpose of this study is to perform simulation of airflow model develop in Apple cold storage using Computational Fluid Dynamics (CFD) technique.The air distribution parameters addressed in this study are air velocity and air temperature. The best results from a proper preservation are obtain when the temperature of each vegetables is maintained with fewer fluctuations in storage chamber, as well as the appropriate distribution of cooling air. Temperature variation is minimized with adequate air circulation. Air velocity is important to protect agricultural product in the cold storage.**

Keywords:- load calculation, CFD model of cold storage, design of cold storage

I. INTRODUCTION

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 crores of rupees, it has become necessary to create cold storage facility in the producing as well as consuming centers to take care of the existing and projected production of fruits and vegetables.

India is the largest producer of fruits and second largest producer of vegetables in the world. In spite of that per capita availability of fruits and vegetables is quite low because of post-harvest losses which account for about 25% to 30% of production. Besides, quality of a sizable quantity of produce also deteriorates by the time it reaches the consumer. This is mainly because of perishable nature of the produce which requires a cold chain arrangement to maintain the quality and extend the shelf-life if consumption is not meant immediately after harvest. In the absence of a cold storage and related cold chain facilities, the farmers are being forced to sell their produce immediately after harvest which results in glut situations and low price realization. Sometime farmers do not even get their harvesting and transportation costs what to talk of the cost of production or profit. As a result, our production is not getting stabilized and the farmers after burning fingers in one crop switch over to another crop in the subsequent year and the vicious cycle continues. Our farmers continue to remain poor even though they take risk of cultivating high value fruits and vegetable crops year after year. A cold storage facility accessible to them will go a long way in removing the risk of distress sale to ensure better returns. This document endeavors to provide information on various broad technical and financial aspects of a cold storage unit to enable the financing banks and entrepreneurs in formulation and implementation such projects.

A uniform cooling and cold storage of fresh produce are difficult to obtain in industrial cooling rooms because of an uneven distribution of the airflow, Computational fluid dynamics (CFD) is a simulation tool, which uses powerful computer and applied mathematics to model fluid flow situations for the prediction of heat, mass and momentum transfer and optimal design in industrial processes. Recent years that CFD has been applied in the food processing industry. The application of CFD in food processing industries including drying, sterilization, refrigeration and mixing. In the past few years' great development has taken place in these areas. [1]

The annual production of fruits and vegetables in the country accounts for 18 to 20% of our agriculture output. Apple cold storage is mainly used to extend the processing of fresh Apple, the inside temperature should be controlled at 02 °C to 05 °C , relative humidity of 75 % to 95%.

II. COLD STORAGE ACQUIRE DATA

India is the largest producer of fruits and vegetables in the world but the availability of fruits and vegetables is significantly low because of Post-Harvest loses which account for about 25% to 30% of productionOur farmers continue to remain poor even though they take risk to cultivate high value fruits and vegetables year after year. Introduction of Cold storage/Cold room facilitywill help them in removing the risk of distress sale.The annual production of fruits and vegetables in the country accounts for 18-20% of our agriculture output. Apple cold storage is mainlyused to extend the processing of fresh Apple, the inside temperature should be controlled at 02 °C to 05 °C , relative humidity of 75 % to 95%.

- **Chamber Size**

Table-1 show the actual cold storage data

For project purpose H.R. & SONS **(COLD. STORAGE & PRESERVERS)** was selected, situated in Hapa, Jamnagar, Gujarat. There are two no of cold chambers.

Total Storage size = 39.37 (feet) x 39.37(feet) x 20.67 (feet)

Volume = 32037.2724 $(feet)^3$

- **Insulation**

100 mm thick PUF sandwich panels are provided for insulating the cold room walls and ceiling. 6-inch concrete with rigid insulation is provided for floor insulation.

Sr. No.	Description	Specifications
1.	Room dimension	12 (L) x 12 (B) x 6.3 (H)
2.	Room temperature	2 ^{0}C to 5 ^{0}C (± 2 ^{0}C)
3.	Humidity	75 - 95% RH
4.	Ambience Temperature	30 ^{0}C (max.)
5.	Material to be stored	Apple
6.	Product quantity	300 MT
8.	Product entry Temperature	21-23 ^{0}C
9.	Pull down time	48 hrs / Batch
10.	Insulation	100 mm PUF Sandwich pannel
12.	Hinge door	3.5 (feet) x 7.5 (feet) – 2No.
13.	No of units	150 x 2 - 2 nos
14.	Refrigerant	NH_3

- **Cooling unit**

NH_3 refrigerant is used for the cooling unit. Room temperature is between 02 ^{0}C to 05 ^{0}C maintained inside the chamber. Outside daytime and night-time temperatures can vary greatly, especially during the summer months. In temperature difference calculations, it is customary to use an average outside summer temperature for a specific geographical location. **[2]** The average outside temperature is 30 ^{0}C

- **Electrical Work**

Electrical work shall include main power distribution switch board, feeder switches for cooling units, capacitors, power distribution cables, electric lighting, and earthling of equipment.

- **Stand by generator**

Provision has to be made for stand by Generator set to meet the power requirement during load-shedding/power cuts. The generator shall have out starting device to start it in case of failure of electric supply.

- **Method of Storage for fruits & vegetables**

Refrigeration (cold store) – The ideal environmental condition for storage of fresh fruits and vegetables is the lowest temperature which does not cause chilling injury to the product. Hence, temperature control in cold storage is very important. In mechanical refrigeration, the refrigerated Gas (e.g. Ammonia, Freon etc.) takes out the heat from the chamber/store as it expands. The expanded gas is then compressed and the heat removed from the compressed gas by means of running water or circulation air over the tubes containing the hot gas. The gas is liquefied and the cycle is repeated. With such system accurate temperature control is maintained.

- **Design parameters**

Basic design 300MT cold room

Sr. No.	Particulars	Specifications
1	Capacity	300 MT
2	Cold room temperature	02 °C (± 2 °C)
3	Maximum field temperature	30 ^{0}C
4	Optimum storage temperature	02 ^{0}C
5	Temperature differential between field	28 ^{0}C
6	Outside moisture	50 %
7	Type	Pre-fabricated room with floor
8	External Room Dimension	12 m (L) x 12 m (B) x 6.3 m (H)
9	Insulation	Poly-urethane foam panel (PUF)
10	Insulating outrace	100 mm thick
11	Turn over	Long storage
12	Man powers	4 nos.
13	Lighting	200 watt
14	Motor power	0.37 KW
15	Motor running period	6 – 8 hrs
16	Duration	6 – 8 hrs (Lighting)
17	Product	Apple
18	Process	Fresh product storage
19	Product enter tem	21 °C - 23°C
20	Product leaving temperature	02 °C (± 2 °C)
21	Daily turnover	33 % (During available)
22	Processed period	48 hrs
23	Product quantity	300,000 kg
24	Running compressor	6-8 hrs

Table 2Calculation of the refrigerating power

- **Apple Properties**

Sr No	Particulars	Specifications
1	Water content (%)	84
2	Freezing Point ^{0}C	- 2
3	Specific Heat (KJ/kg. ^{0}C) ▪ Above Freezing ▪ Below Freezing	 3.81 1.98

4	Latent Heat of Fusion (KJ/kg)	280
5	Density, ϱ (kg/m^3) unfrozen	845
6	Thermal Conductivity k (W/m^{20}C)	0.427
7	Specific heat(KJ/Kg ^{0}C)	3.64

Table 3: Details of Apple Properties

- **Heat Load Calculation**

Refrigerated spaces are maintained belowthe temperature of their surroundings, and thus there is always a driving force for heat flow toward the refrigerated space from the surroundings.

As a result of this heat flow, the temperature of the refrigerated space will rise to the surrounding temperature unless the heat gained is promptly removed from the refrigerated space. Refrigeration system should obviously be large enough to remove the entire heat gain in order to maintain the refrigerated space at the desired low temperature.

Therefore, the size of a refrigeration system for a specified refrigerated space is determined on the basis of the rate of heat gain of the refrigerated space The total rate of heat gain of a refrigerated space through all mechanisms is called the refrigeration load, and it consists of

1) Transmission load,
2) Infiltration load
3) Product load
4) Internal load

In this paper we have calculated all load can be conducted in the cold chamber the total load of cold chamber is following this load is actual cold chamber load of site.

$$Q_{total}(KW) = Q_{transmission} + Q_{infiltration} + Q_{product} + Q_{internal}$$

= 2.4246 + 0.8376 + 353.888 + 2

= 359.1502 KW

= 102.122612 Ton (refrigeration)

This load can be apply in the CFD model and calculate a various types of evaporator arrangement afffeted to cold chamber performance and maintain the temperature.

III. RESULT AND DISSECTION

During the course of this study, to simplify the model, a number of assumptions were made;

(i) There was no heat flow through the walls of the test room.
(ii) The simplification of outside room conditions had no effect.
(iii) The air-conditioning systems studied are all in good and stable operations.
(iv) The measurements and simulation are done in a completely confined room space, with all the doors and windows closed.
(v) The anemometer used is well calibrated and in good conditions during measurement.
(vi) The airflow produced in the room studied is steady during measurements, where steady state conditions are assumed for simulation.
(vii) Internal heat sources in the ripening room such as fluorescent lights are considered to have small effects and thus neglected in study.
(viii) The outside temperature is constant at 30 °C during measurements.

- **Geometry**

Preprocessing is nothing but the process to define the geometry and boundary condition.An Apple Chamber is modelled. The loaded room contains Apple box inside. The cold store that is modelled has the dimensions 6.3m high, 12m wide and 12m deep and includes evaporator on the wall (Fig. 1).

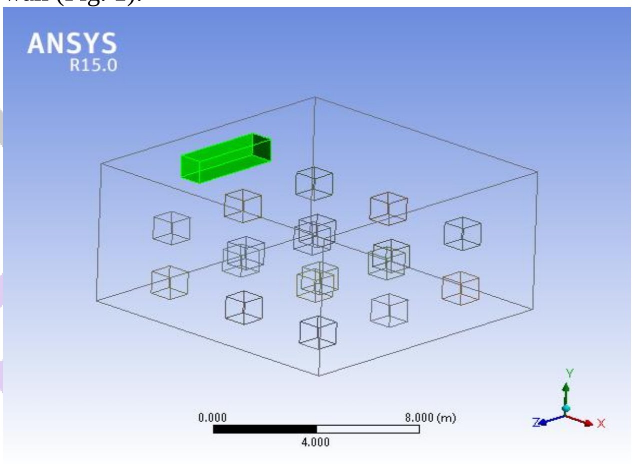


Fig. 1 Model 1 evaporator located on back wall

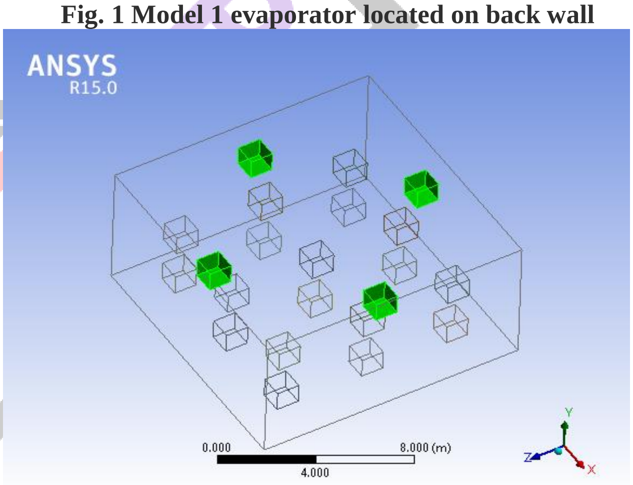


Fig. 2 Model 2 evaporator located on all wall (Straight)

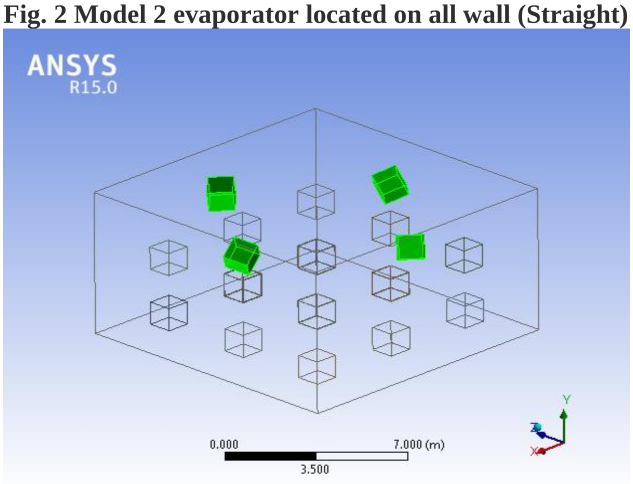


Fig. 3 Model 3 evaporator located on all wall (40° lower, 25° left or right)

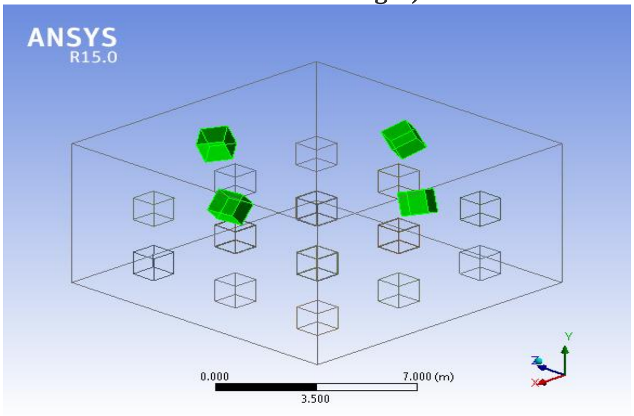


Fig. 4 Model 4 evaporator located on all wall (25° lower, 25° left or right)

- **Model Meshing**

For simulation a mesh of about 386738 hexahedral elements was generated. The resulting numerical solution gives two components of velocity, pressure, and temperature at every nodal point over the entire computational domain.

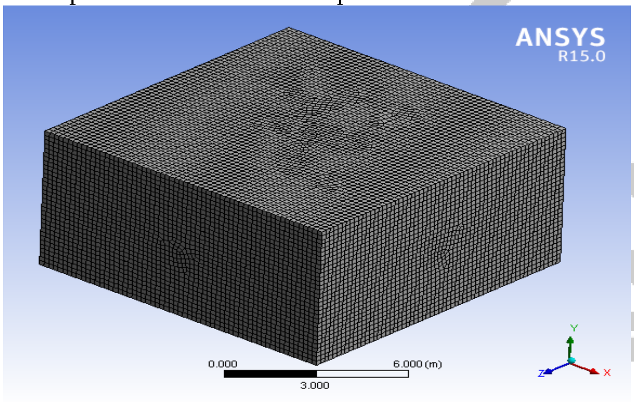


Fig. 5 Hexahedral-element meshes for 3-D model of cold storage

Figure 6, 7, 8&9 presents the solution of air velocity and temperature. For the Model 1, 2, 3 & 4

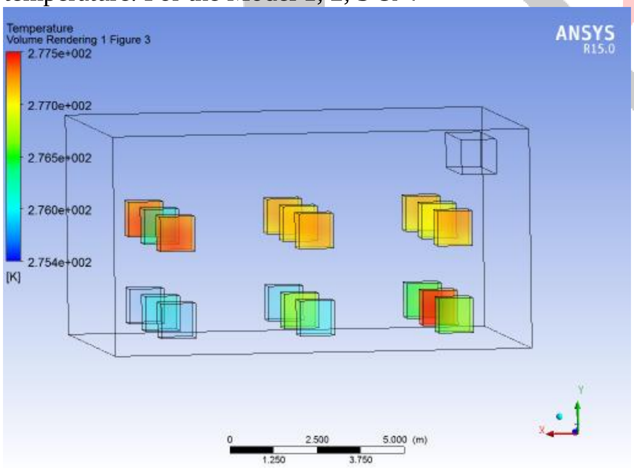


Fig. 6 Solution of air flow with Apple rack temperature. (Model-1)

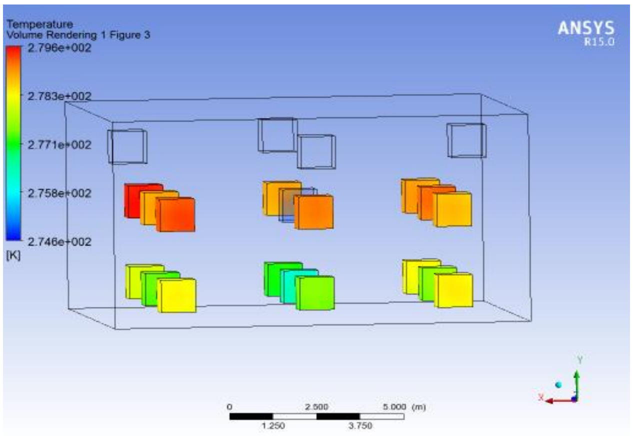


Fig. 7 Solution of air flow with Apple rack temperature. (Model-2)

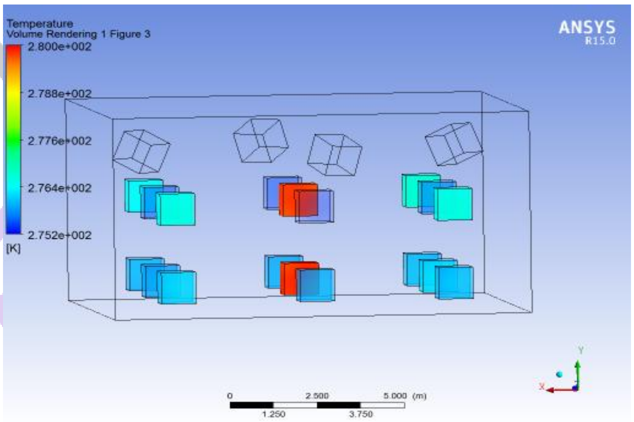


Fig. 8 Solution of air flow with Apple rack temperature. (Model-3)

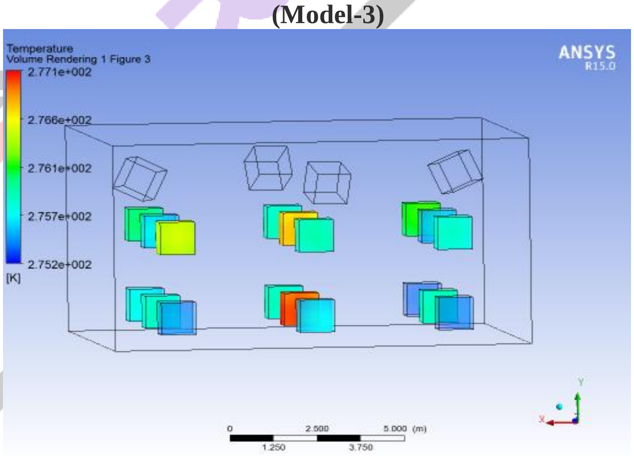


Fig. 9 Solution of air flow with Apple rack temperature. (Model-4)

The applicable thermal properties for air are taken from Kays et al. (2005) at a reference temperature of *T*ref= 0°C and listed as follows:

- Specific heat = 1006.43 J/KgK
- Gravitational acceleration g = 9.8 m/s^2
- Density of incoming air ϱ = 1.225 Kg/m^3
- Incoming mass flow rate of air = 54.4432 Kg/s
- Velocity of incoming air = 10.5 m/s

The thermal properties for the Apple is taken and calculated from Handbook of Refrigeration ASHRAE (2002)

- Specific heat = 3810 J/KgK
- Thermal conductivity = 0.427 W/m ^{0}K
- Density ϱ = 845 kg/m^3

The scope of this study includes pilot and actual measurements of the important air distribution parameters and the simulation performed by using a CFD software. The main procedures of this study are as follows:
(a) Selection of suitable Cold Chamber
(b) Performing actual measurement on important air distribution parameters and boundary parameters
(c) Performing CFD analysis on room air flow through computer simulation

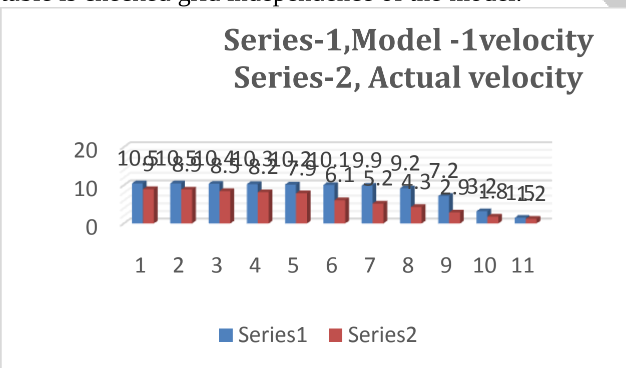
It may be noted that moisture content (humidity ratio) of the air in a refrigerated space is expected to be fairly low and therefore, the water vapour in the air has not been included as a part of the simulation model. In addition, the model considered only the steady-state operation of the warehouse and thus did not include periodic maintenance operations such as defrosting of the cooling coil.
In Figure 6,7,8&9 the temperature distribution inside the cold storage space is represented by a filled colour plot that shows different level of temperature in different regions of the domain for Model 1, Model 2, Model 3, & Model 4 The circulation formed by the combined effects of forced convection (due to the forced flow at the outlet and negative pressure at the inlet) and natural convection (due to buoyant force because of temperature-dependent variable density of air) creates a well-mixed region under the cooling unit with uniform low temperature as the result.

- **Grid Independence Table**

Element Size	Nodes	Elements	2m	4m	6m	8m	10m
0.1	172501	193364	10.5	10.3	10.1	8.8	7.1
0.09	191271	210565	10.3	10.3	10.1	8.7	6.9
0.08	224704	244097	10.2	10.2	10.1	8.9	6.8
0.07	271466	294213	10.3	10.2	10.1	9.1	6.4
0.06	357701	386738	10.3	10.2	10.1	9.2	6.5
0.05	465481	490685	10.5	10.1	10	9.2	6.4

Table.4Grid Independence Table

Here selected mesh size is 0.06m, their result are near about the further all mesh size result. Further selected of mesh size 0.05 & 0.04 and bellow there are minor change in result so selected mesh size in this case is 0.06m. Show the above table is checked grid independence of the model.



Comparison of Actual & Model -1 Velocity

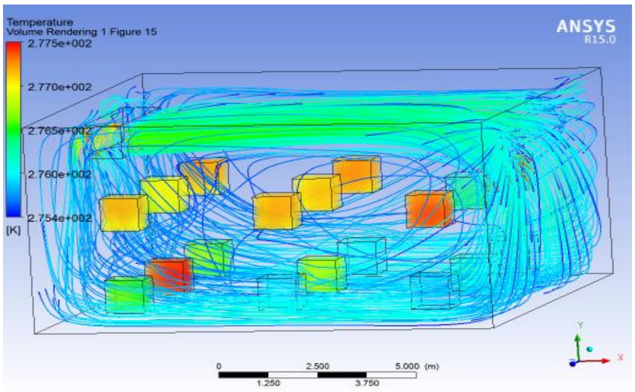


Fig. 10 Apple room Velocity Streamline. (Model 1)

The Figure 10 represent the air flow from duct to cold room they shoe that the mass flow rate of air is not circulated in the middle of cold storage i.e. the upper rack apple box is not cooled compare to below rack.

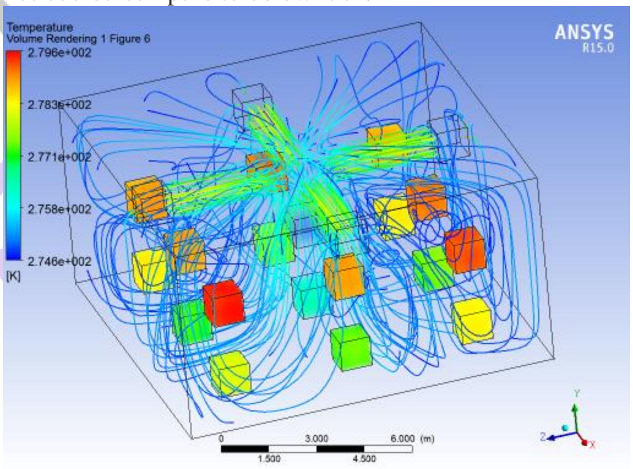


Fig. 11 Apple room Velocity Streamline. (Model 2)

Figure 11 is represented the mass flow rate of air from the duct to cold storage chamber in this case the mass flow rate of air is not properly distributed the cold storage they show in figure the upper rack apple box is warm compare to the below rack, the comparison of model-1 & model-2 than higher coldest rate of model-1. Than model-2 is not efficient compare to the model-1.

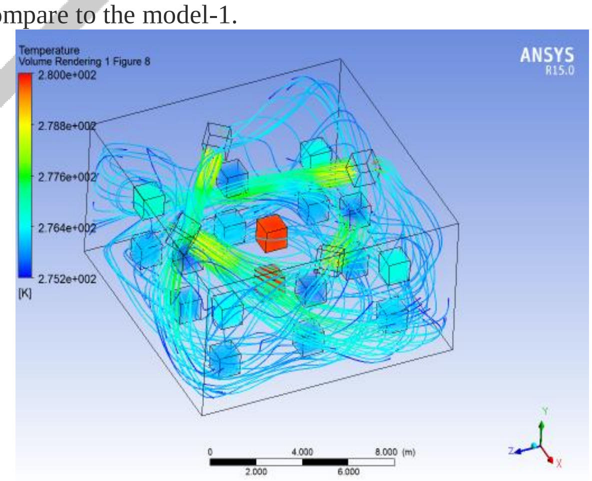


Fig. 12 Apple room Velocity Streamline. (Model 3)

The figure 12 is represented the mass flow rate of air velocity in cold store in model-3, this model the duct geometry is 45° lower side inclined and 25° left or right inclined in this case the compare all over temperature of cold store model-1 is less than the model-3 but in model-3 the temperature is higher only middle portion the overall efficiency of the model-3 is better compare to the model-1 because the another apple box temperature is coolest than model-1.In the model upper rack apple box and lower rack apple box is temperature lower compare to the model-1 & model-2.

The figure 11&12 is show the higher temperature upper rack compare to the model -3 is show in figure-12. in this case the model -3 is high temperature performance is given compare to the model-1 & model-2,but the middle portion of the cold store is less mass flow rate compare to both model 1 & 2.

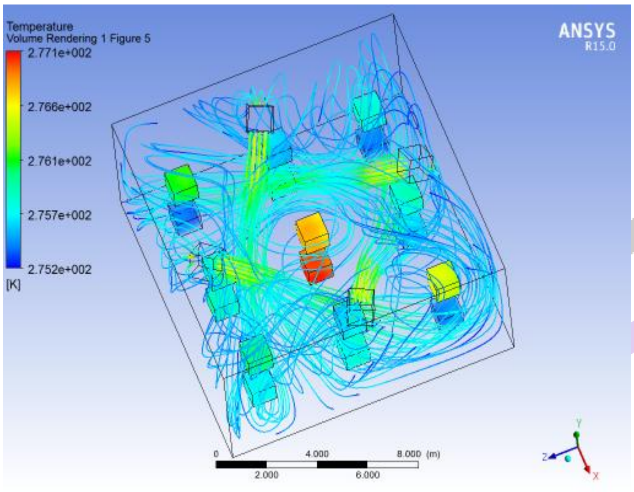


Fig.13 Apple room Velocity Streamline. (Model 4)

Figure 13 represent the mass flow rate of air distribution in cold chamber (model-4) this model geometry is 25° lower side inclined and 25° left or right side inclined. The comparison of the model-1, 2 & 3 for the model-4 then higher temperature distribution achieve in the another model. This model-4 mass flow rate of air is flow all over the cold chamber and the temperature distribution is better than the model-1, 2, &3.

In all the cases is show the mass flow rate of air distribution is highly effective performance in the model-4, because overall the upper rack and lower rack temperature distribution is more compare to the another model-1, 2 &3, in case of the model-4 the middle portion of the cold store temperature is lower than compare to another model that resion we can say that the temperature distribution is better than the other model.

In all the case of model-1, 2, 3 & 4 the temperature difference only 2°C to 4°C they have minor difference but the all over temperature distribution is better the model-4. In this model-4 result can say the temperature distribution is depends on the mass flow rate of air distribution and velocity of air.

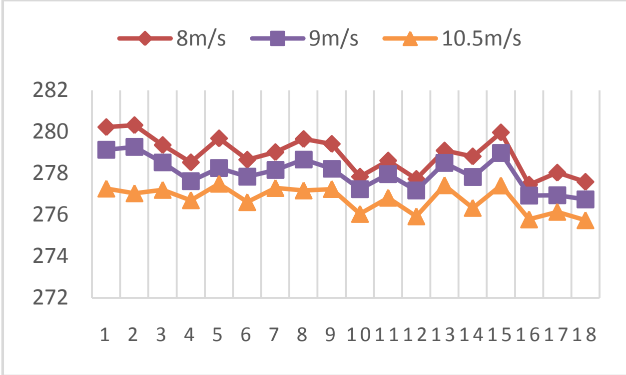


Fig. 14 Temperature Comparison of apple box at different velocity. (Model 1)

The figure 14 is present the comparison of different velocity to apple box temperature above graph show the apple box temperature is depends on the mass flow rate of air, the higher mass flow rate is give the better temperature distribution of the cold chamber here by the actual cold storage velocity is 9m/s and the model velocity is 10.5 m/s selected because they have better cooling rate compare to the lower rate of velocity.

IV. CONCLUSION

In this experiment, we have been emphasized over the four different arrangements of the evaporator location with first located in the back wall of cold storage second located in the all wall middle in straight position third is located in all wall in 40° lower inclination & 25° left or right inclined angle and fort is located to all wall middle position to 25° lower inclined and 25° left or right inclined in fore types of arrangement, the forth arrangement with 25° lower inclined and 25° left or right inclined is most preferable. Because the average temperature of the cold chamber is better compare to other arrangements of the evaporator location and they give the more temperature distribution of the cold chamber.

The average temperature difference between this four models is 2°C to 4°C is not much more. But the temperature distribution is not perfectly another three models compare the model-4. It means that the temperature distribution is depends on the evaporator location in cold storage and mass flow rate.

In this all four model the optimal solution is performance of temperature distribution is depends on the mass flow rate of air and evaporator location. In this presentation are show the model-4 is better temperature distribution performance compare to another three models.

The temperature distribution becomes better on increasing the mass flow rate of air & arrangement of the evaporator in cold storage.

V. REFERENCES

[1] Bin Xia, Da-WenSun,"Application of computational fluid dynamics(CFD) in the food dustry"Computer and Electronics in Agriculture. Vol 34, pp-5-24, 2002.

[2] DR.ChourasiaManoj Kumar, PROF. GoswamiTridibKumar,"Efficient Design Operation, Maintanance and management of cold storage" e-

Journal of biological science. Vol-1, ISSN: 2076-9946, EISSN: 2076-9954, 2009.

[3] Bjorn margeirsson, SigurjonArason. "Temperature monitoring and CFD modelling of a cold storage" International journal of physical Distribution & Logistics management, Vol-42, pp -355-371, 2012.

[4] Johnson Lim Soon Chong, Adnan Husain & Tee Boon Tuan, The AEESAP International conference 2005, "Simulation of Airflow in Lecture Rooms", 7-8 June 2005.

[5] A.Ambaw, M.A.Delete, T.Defraeye, Q.T.Ho, L.U.Opara, B.M.Nicolai, P.Verboven, "The use of CFD to characterize and design post-harvest storage facilities: Past, present and future" Computer and Electronics in agriculture, Vol-93, pp-184-194, 2013.

[6] M.A.Delele, A.Schenk, H.Ramon, B.M.Nicolai, P.Verboven, "Evaluation of a chicory root cold store humidification system using computational fluid dynamics" Journal of food engineering, Vol-94, pp-110-121,2009.

[7] H.B.Nahor, M.L.Honge, P.Verboven, M.Baelmans, B.M. Nicolai, "CFD model of the air flow, heat and mass transfer in cool stores" International journalof refrigeration, Volume-28, pp-368-380,2005.

[8] Da-Wen sun, Zehua Hu, "CFD predicting the effects of various parameters on core temperature and weight loss profiles of cooked meat during vacuum cooling" Computer and electronics in Agriculture. Vol-34, pp-111-127, 2002.

[9] M.L.Hoang, P.Verboven, J.DeBaerdemaeker, B.M.Nicolai, "Analysis of the air flow in a cold store by means of computational fluid dynamics" International journal of refrigeration, Vol-23, pp-127-140,2002.

[10] J.A.EvansaA.M.FosteraJ. M.uetb, Lreinholdt, K.Fikiinc,C. Ziliod. "Specific energy consumption values for various refrigerated food cold stores" Energy and Building, Vol-74, pp-141-151, 2014.

[11] SereapAkdemir, SerhatOzturk, firatOquzEdis, Erdinicbal, "CFD modeling of two different cold stores ambient factor" International conferenceon agricultural and natural resources Engineering.IERIProcedia 5, pp-28-40,2013.

[12] ASHRAE. 1981. American Society of Heating, Refrigerating and Air Conditioning Engineers Handbook 1982 Applications. ASHRAE, Atlanta GA