CFD Analysis of Air Flow Modeling in Apple Cold Storage

Jaydeep Bhanderi[1]
[1,2]Department of Mechanical Engineering
[1,2]Gujarat Technological University Rajkot, Gujarat, India

Abstract— When fruits and vegetables are harvested, they are cutoff from their source of water and soon start to deteriorate, the purpose of this study is to perform simulation of airflow 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, 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.

Key words: Cold storage load, CFD analysis 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. CFD METHODOLOGY

A. *Creation of Mathematical Model*

The starting point of any numerical method is to convert the physical problem into the mathematical model, i.e. the set of partial differential or integro differential equations and specify the boundary conditions. One chooses an appropriate model for the target application (incompressible, inviscid, turbulent; two- or three-dimensional, etc.). As already mentioned, this model may include simplifications of the exact conservation laws. A solution method is usually designed for a particular set of equations. Trying to produce a general purpose solution method, i.e. one which is applicable to all flows, is impractical, if not impossible and, as with most general purpose tools, they are usually not optimum for any one application.

B. *Choose a Discretization Method*

After selecting the mathematical model, one has to Choose a suitable discretization method i.e. a method of approximating the differential/integral equations by a system of algebraic equations for the variables at some set of discrete locations in space and time. There are many methods, but the most important ones are:

1) Finite Difference Method (FDM)
2) Finite Volume Method (FVM) and
3) Finite Element Method (FEM)

Other methods, like spectral schemes, boundary element methods, and cellular automata are used in CFD but their use is limited to special classes of problems. Each type of method yields the same solution if the grid is very fine. However, some methods are more suitable to some classes of problems than others. The preference is often determined by the attitude of the developer.

1) *Numerical Grid Generation*

The discrete locations at which the variables are to be calculated are defined by the numerical grid which is essentially a discrete representation of the geometric domain on which the problem is to be solved. It divides the solution

All rights reserved by *www.ijsrd.com*

domain into a finite number of subdomains (elements, control volumes etc.) and gives the set of discrete points for the discretization scheme.Some of the options available are the following:

a) Structured (regular) grid

Regular or structured grids consist of families of grid lines with the property that members of a single family do not cross each other and cross each member of the other families only once. An example of a structured 2D grid is shown in Fig.2.1

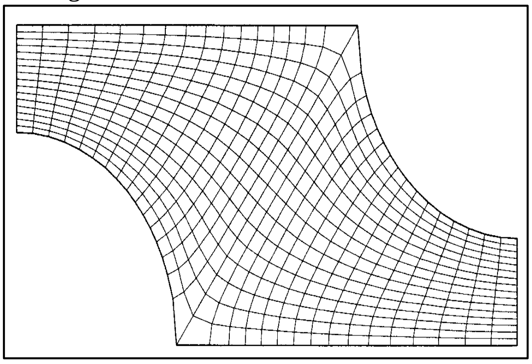

Fig. 1: Example of a 2D, structured, non-orthogonal grid

b) Unstructured grids

For very complex geometries, the most flexible type of grid is one which can fit an arbitrary solution domain boundary. In principle, such grids could be used with any discretization scheme, but they are best adapted to the finite volume and finite element approaches. In practice, grids made of triangles or quadrilaterals in 2D, and tetrahedral or hexahedral in 3D are most often used. An example of an unstructured grid is shown in Fig.2.2

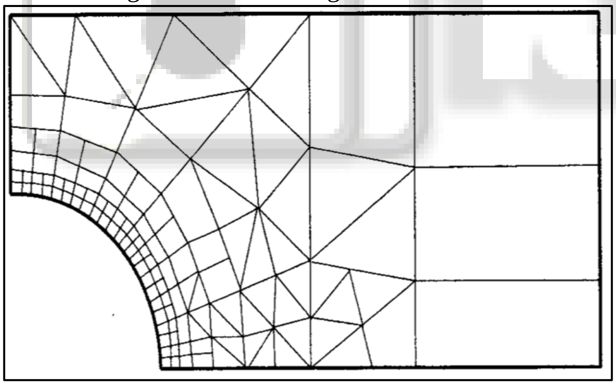

Fig.2.2 Example of a 2D unstructured grid

2) Finite Approximation

After selecting the type of grid, the next step is the finite approximations to be used in the discretization process. In a finite difference method, approximations for the derivatives at the grid points have to be selected. In a finite volume method, one has to select the methods of approximating surface and volume integrals. In a finite element method, one has to choose the shape functions (elements) and weighting functions.

3) Solution of Algebraic Equations

Discretization yields a large system of algebraic equations. The method of solution of these algebraic equations depends on the type of the problem i.e. steady or unsteady. For unsteady flows, methods based on those used for initial value problems for ordinary differential equations (marching in time) are used. Steady flow problems are usually solved by pseudo-time marching or an equivalent iteration scheme. The choice of solver depends on the grid type and the number of nodes involved in each algebraic equation.

4) Convergence Criteria

Finally, one needs to set the convergence criteria for the iterative method. Usually, there are two levels of iterations: inner iterations, within which the linear equation are solved, and outer iterations, that deal with the non-linearity and coupling of the equations. Deciding when to stop the iterative process on each level is important, from both the accuracy and efficiency points of view.

III. MATHEMATICAL MODEL

CFD is a numerical technique to obtain an approximate solution numerically. We have to use a discretization method, which approximate the differential equations by a system of algebraic equations, which can then be solved on a computer. The approximations are applied to small domain in space and/or time so that the numerical solution provides results at discrete locations in space and/or time.

The physical aspect of any fluid flow is governed by the following three fundamental principles:

1) Conservation of Mass
2) Conservation of Momentum
3) Conservation of Energy

These fundamental principles can be expressed in terms of partial differential equations. CFD is a numerical technique to replace these partial differential equations of fluid flow into the algebraic equations by numbers and discretizing them in space and/or time domain. With the advent of high speed digital computers, CFD has become a powerful tool to predict flow characteristics in various problems in an economical way.

A. Conservation Equations

1) Mass conservation equation

The equation for conservation of mass, or continuity equation, can be written as follows:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{v}) = S_m \quad (3.1)$$

This equation is the general form of the mass conservation equation and is valid for incompressible as well as compressible flows. The source S_m is the mass added to the continuous phase from the dispersed second phase (e.g., due to vaporization of liquid droplets) and any user-defined sources.

B. Momentum conservation equation

Conservation of momentum in an inertial (non-accelerating) reference frame is described by

$$\frac{\partial}{\partial t}(\rho \vec{v}) + \nabla \cdot (\rho \vec{v} \vec{v}) = -\nabla p + \nabla \cdot (\bar{\bar{\tau}}) + \rho \vec{g} + \vec{F} \quad (3.2)$$

where,

p is the static pressure

τ is the stress tensor (described below), and ρg and F are the gravitational body force and external body forces (e.g., that arise from interaction with the dispersed phase), respectively.

F also contains other model-dependent source terms such as porous-media and user-defined sources. The

All rights reserved by *www.ijsrd.com*

stress tensor τ is given by.

$$\overline{\overline{\tau}} = \mu \left[(\nabla \vec{v} + \nabla \vec{v}^{\,\mathrm{T}}) - \frac{2}{3} \nabla \cdot \vec{v} I \right] \quad (3.3)$$

Where

μ is the molecular viscosity

I is the unit tensor, and

The second term on the right hand side is the effect of volume dilation.

C. Choosing a turbulence model

It is an unfortunate fact that no single turbulence model is universally accepted as being superior for all classes of problems. The choice of turbulence model will depend on considerations such as the physics encompassed in the flow, the established practice for a specific class of problem, the level of accuracy required, the available computational resources, and the amount of time available for the simulation. To make the most appropriate choice of model for particular application, one needs to understand the capabilities and limitations of the various options. While it is impossible to state categorically which model is best for a specific application?

1) *The RNG k-ε model*

The RNG-based k- **ε** turbulence model is derived from the instantaneous Navier-Stokes equations, using a mathematical technique called “renormalization group" (RNG) methods. The analytical derivation results in a model with constants different from those in the standard k- **ε** model, and additional terms and functions in the transport equations for k and **ε.**

The RNG k- ε model has a similar form to the standard k- ε model:

Transport Equations for the RNG k-ε Model

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_i}(\rho k u_i) = \frac{\partial}{\partial x_j}\left(\alpha_k \mu_{eff} \frac{\partial k}{\partial x_j}\right) + G_k + G_b - \rho\epsilon - Y_M + S_k \quad (3.4)$$

And

$$\frac{\partial}{\partial t}(\rho\epsilon) + \frac{\partial}{\partial x_i}(\rho\epsilon u_i) = \frac{\partial}{\partial x_j}\left(\alpha_\epsilon \mu_{eff} \frac{\partial \epsilon}{\partial x_j}\right) + C_{1\epsilon}\frac{\epsilon}{k}(G_k + C_{3\epsilon}G_b) - C_{2\epsilon}\rho\frac{\epsilon^2}{k} - R_\epsilon + S_\epsilon \quad (3.5)$$

Where,

α_k and α_ε are inverse effective Prandtl numbers for k and ε respectively Other variables are same as in Standard k-ε model.

The values of model constants are:

$C_{1\varepsilon}$ = 1.42, $C_{2\varepsilon}$ = 1.68, C_μ = 0.0845

2) *Thermal properties for air,*

- 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 = 24.43 Kg/s
- Velocity of Air = 10.5 m/s

D. Thermal properties for the Apple

- Specific heat = 3810 J/KgK
- Thermal conductivity =0.427 W/m K
- Density ϱ ^{0}C = 845 kg/m3

IV. Result and Discussion

Here comparisons of actual cold storage result and model result and check grid independence and check temperature distribution of cold chamber, check dependency of temperature and thermal performance is depend upon the air velocity of col chamber.

The below cold storage model is actual model of cold storage model.

The size of actual cold storage model is.

Hight of chamber = 6.3 Meter.

Width of chamber = 12 Meter.

Length of chamber = 12 Meter.

In the cold storage total Load capacity is 300MT and the temperature is maintain 2 to 5 °C

The figure.1. is represent the actual cold storage room dimension and this actual model is check performance in CFD.

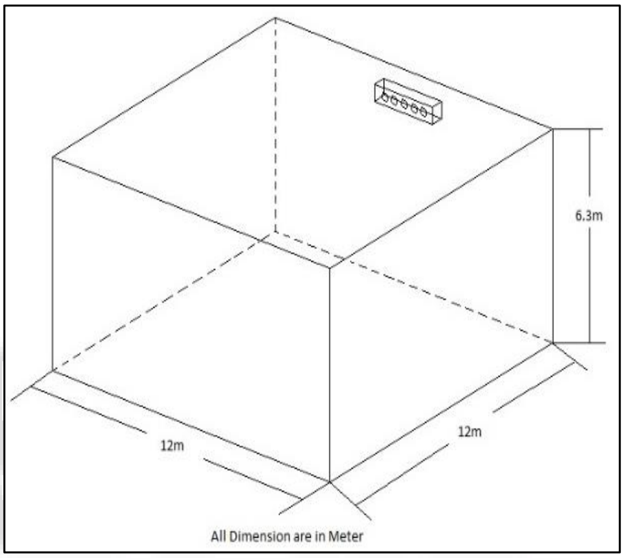

Fig. 1: Schematic view of experimental Apple storage Chamber

A. Meshing:

Ease of numerical solution of define model divided into the small elements which are called as grids or meshing. In present study meshing has been done with the help of ANSYS CFD meshing tool

- No. of Nodes: - 357701
- No. of Elements: - 386738
- Meshing Type: - 3D
- Type of Element: - hex dominant

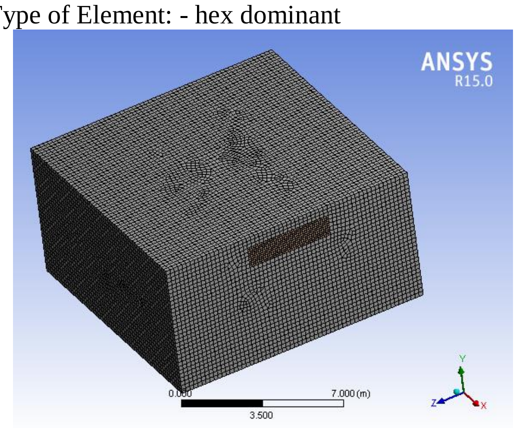

Fig. 2: Meshing of Model

All rights reserved by www.ijsrd.com

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
.05	465481	490685	10.5	10.1	10	8	6.1

Fig. 3: Grid independence chart

The fig.3 checked grid independence table of the model they have knowing about the which type of grid is perfect for analysis of cold storage, hear checked a various types of element size and check distance of variation of velocity here consider the standard model is 0.06mm element size they element size after small variation is given because in this article select model is 0.06mm element size.

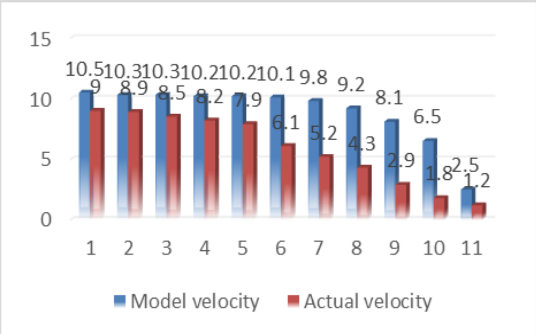

Fig. 4: Velocity V/S Distance Chart

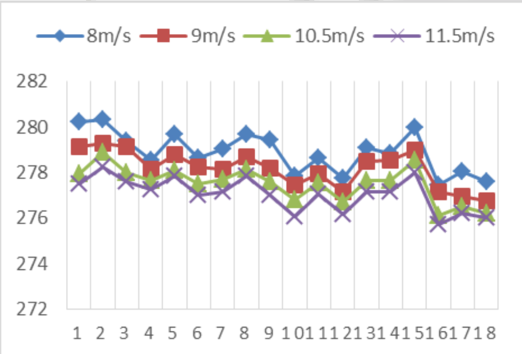

Fig. 5: Temperature comparison at different velocity

In the figure.5 consider velocity is 10.5 because after then consider the higher value of air velocity the cold storage temperature is not more variation. Above figure.5 consider the four difference velocity 8m/s, 9m/s, 10.5m/s & 11.5m/s.

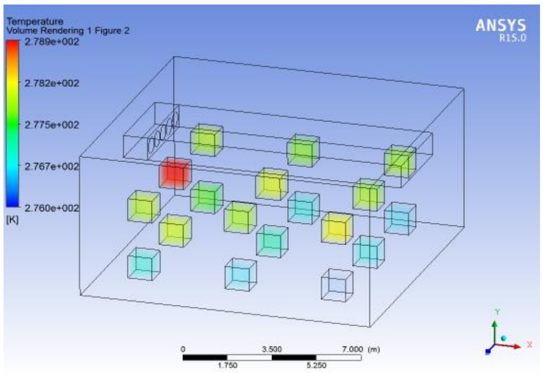

Fig. 6: Apple Rack Temperature (k)

The figure. 6. Hear 18Nos apple box is consider. Here the apple box size consider 1m square and applied load is 395.643 w/m2. Hear the total cold storage load is 300MT this 300MT load is total area of cold storage load is converted to 18m square area than start analysis.

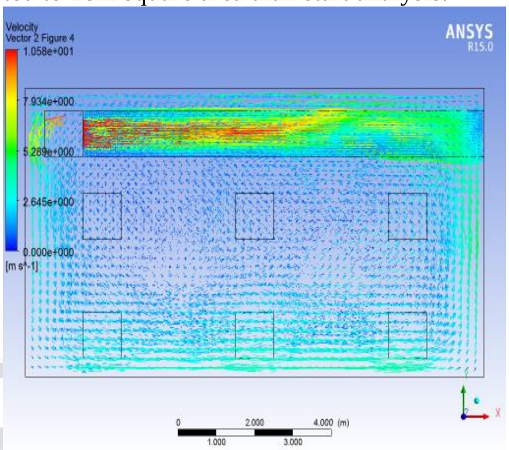

Fig. 7: Velocity Vector Chart

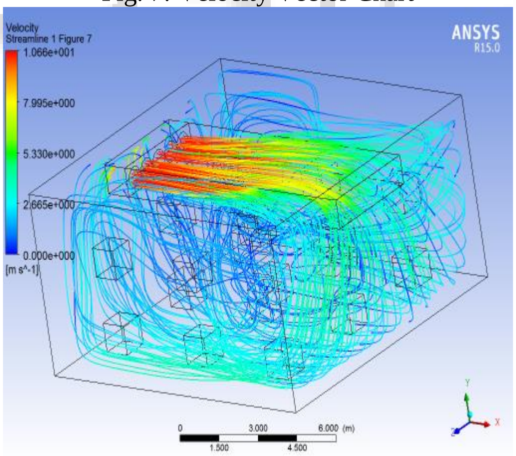

Fig. 8: Velocity Streamline Chart

All rights reserved by *www.ijsrd.com*

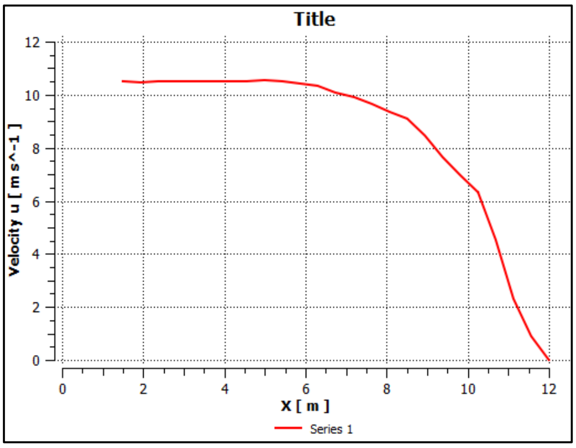

Fig. 9: Velocity v/s Distance chart (10.5m/s Vs 12 meter)

V. Conclusion

In this paper main objective is check performance of cold storage temperature is depends on the air flow velocity of the diffuser of cold storage. In this model consider the 8m/s, 9m/s, 10.5m/s and 11.5m/s velocity and check performance. This paper the given result is show the temperature variation is depends on the air velocity of diffuser of cold storage and their mass flow rate of air. However, Cold storage rooms are occupied post-harvest fruits and foods so it dependable on the thermal environment created in the cold storage room the study of the airflow modelling is crucial towards achieving desirable thermal environment in the cold storage.

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.Chourasia Manoj Kumar, PROF. Goswami Tridib Kumar,“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, Sigurjon Arason. “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.De Baerdemaeker, 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.Evansa A.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] Sereap Akdemir, Serhat Ozturk, firat Oquz Edis, Erdinic bal, “CFD modeling of two different cold stores ambient factor” International conference on agricultural and natural resources Engineering.IERI Procedia 5, pp-28-40,2013.
[12] ASHRAE. 1981. American Society of Heating, Refrigerating and Air Conditioning Engineers Handbook 1982 Applications. ASHRAE, Atlanta GA

All rights reserved by www.ijsrd.com