Thermal Studies on Effects of Use of Desiccant Cooling in Cold Storage by Using CFD Analysis

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ABSTRACT

Heat transfer within onions, stored in cold storage is highly dependent on the operating conditions. When the relative humidity increases, onions stored in the cold storage starts sprouting and rotting. This states the importance of reducing relative humidity under the recommended value i.e., within the range of 55-65%. The recommended temperature for a cold storage system is below 5°C. The study attempted to bring down the relative humidity as well as temperature within the best-required range to keep onions fresh for a longer period of time. This study is based on both experimental as well as Computational fluid dynamics software (CFD-ANSYS FLUENT 19). For maintaining relative humidity inside the cold storage, the desiccant cooling system was used. The duct has been added to the cold storage and desiccant material named blue silica gel is placed into the duct. Desiccant dehumidifies the air by absorbing the moisture of air of cold storage. In addition, a fan has been placed on the duct for proper circulation of air through the duct. The final obtained temperature was 4.6°C and relative humidity was recorded as 58.5%. The results obtained from CFD analysis have been validated with the experimental results. Based on this study, it can be stated that in onion storage into the cold storage system, desiccant material is evidently very effective and keeps the onion fresh for a longer period of time.

Keywords: Cold Storage, Desiccant cooling, Blue Silica gel, Humidity control, Computational fluid dynamics.

1. INTRODUCTION

The process of cooling the food is done for reducing the post-harvesting deteriorations [1]. Post harvesting, the worst occurring issue for vegetables as well as fruits is water loss. This accelerates the deterioration speed [2]. Several researches were made about this issue which exhibited that the storage's relative humidity significantly affects the products' quality [3]. The use of desiccant material is made as they are capable of absorbing the moisture content of the air and hence reducing the moisture content. The process of absorption is defined as the contact among the absorbent and absorber molecules through the process if intermolecular interactions [4]. The products of agriculture are precooled and are needed for preserving their qualities and also for extending their availability for fulfilling future demands. When the products are kept at a low temperature then their enzymatic activity will decrease along with microbial growths, reduces the loss of moisture content, and also decreases the production of ethylene [5].

The development of a transient 3-D CFD model was made by [6] for calculating the distribution of moisture, temperature, and velocity within a completely loaded and empty cold storage system.

When the plan for storing onions in the cold storage system under a lower temperature range was made, it was seen that there was a decrease in fresh onion temperature from 0-4°C. it was also seen that there was an increase in the relative humidity which exceeded the desired range of 55 to 65%. This causes rotting and sprouting of onions which results in reducing the life span of the onions along with increasing the several types of losses in the onions.

A very significant role is played by the relative humidity when the onions are placed in a cold storage system for a longer period of time. The factor of relative humidity has been considered and observed as a very crucial factor especially for air circulation and temperature. This research paper aimed for conducting an experimental analysis over temperature and relative humidity with varieties of flow rates. Blue silica gel is brought into use as desiccant material which will be used for absorbing the moisture content from the air. Various experimental conditions will be used for accomplishing the objective of this study.

2. MATERIALS AND METHODS

The onions are placed inside the crates and are placed above each other. The placement is made in 6 rows and 8 columns.

2.1 Physical Model

The cold storage system brought in use under this research has the capability of storing approximately 3 tons of onions at 5 degrees centigrade of storage temperature. As exhibited in Fig. 1, the rooms are 2.6678 × 2.5654× 2.8194 meters and other specifications are present in table 1. The room is availed with a circulation corridor near the walls in between rows. There is an addition of duct within the cold storage room and inside the duct, a desiccant material named blue silica gel is placed.

Table 1: Design parameters of cold storages

S. No	Particular	Specification
1.	Cold Storage Length	2.8194m
2.	Cold Storage Width	2.6678m
3.	Cold Storage Height	2.5654m
4.	Crates along the length	2
5.	Crates along the Width	4
6.	Crates along the height	6
7.	Dimensions of the crates	0.54m x 0.36m x 0.29m
8.	Capacity of crates	25 kg/crates
9.	Total capacity	1.2 MT
10.	Air flow velocity	1 m/s

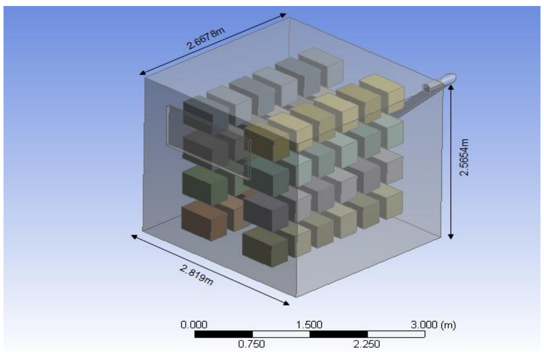

Figure 1: Major dimensions of cold storage

This study presents a cold storage system having a capacity of 3 TON and in accordance with the problem statement mentioned in the study, fans on the wall are implemented over the preexisting cold storage system as shown in figure 2, and table 2 shows the duct fan specification and a passageway of air flows is created on within which silica gel and air comes in contact with each other. In addition, a desiccant material made up of blue silica gel is added to the model which will absorb the moisture content of the air.

Table 2: Duct fan specification

S. No	Particular	Specification
1.	Power rating	48W
2.	Air flow rate	200 m^3/h
3.	Diameter	150mm

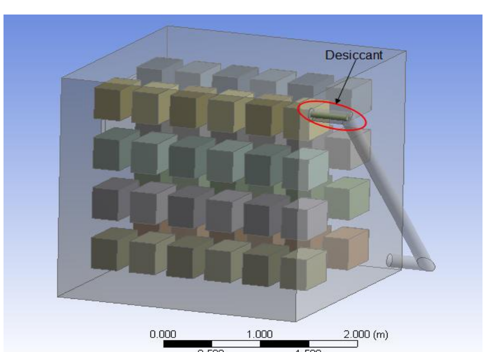

Figure 2: Placement of Desiccant (blue silica gel) into duct pipe attached with cold storage

2.2 Materials

Onions

The harvesting of fresh onions is made during August and after that, they are stored in a storage system for one complete year at a temperature of 4 degree centigrade. For experimentation, onion was kept in the modeled cold storage room. The dry matter content of onions stored for one year was 3% lower than that of freshly harvested [7].

Figure 3: Onion used in the experiment

Blue silica gel

In accordance of the results obtained from this study, 8 percent of its total weight was absorbed by silica gel. When placed in water, the color of the colored crystal will turn to pink from blue as shown in figure 4, (a) and (b). This is a simple indication that can be seen visually to indicate that now gel is completely saturated with the moisture contents of air and should be replaced now. The blue silica gel material property is exhibited in table 3.

Table 3: Technical specification of blue silica gel [8]

TECHNICAL SPECIFICATION As per IS-3401-1979/1992/2003	
Descriptions	Silica Gel Blue
Type	Indicating Type
ASSAY (as SiO_2)	97 – 99 %
pH	6-7
Bulk Density	0.600 - 0.700 gm/cc
Loss on Drying %	< 5-6 %
Loss on Attrition %	2.5%
Adsorption Capacity at 100% humidity	27 – 40 %
Friability	99.5
Chloride (as NaCl)	0.4 ppm
Sulphate (as Na_2SO_4)	0.5 ppm
Ammonium (NH_3)	NIL
Particle size (Mesh)	1-2,3-4, 3-8, 5-8, 9-16, 16-30
Chemical Formula	$SiO_2+H_2O+CoCl_2$

(a) (b)

Figure 4: Silica spherical ball a) before absorbing moisture b) after moisture absorbing

As exhibited in the above figures, the silica spherical balls were blue at the time when they were placed inside the duct pipe and they turned pink after absorbing the moisture content from the air.

2.3 CFD Model Formulation

Fluent Release 19.0 was used for running the CFD analysis for this study. The use of the averaged fluid equation of Reynolds is made for solving the continuous air flow issue. The establishment of this used model is made by utilizing a discretization scheme of 2nd order. Its use is also made for coupling of pressure and velocity. At the interface of air and onion, for determining the convective heat transfer coefficients and airflow fields, the use of transient simulation is made. By the indication made preciously, for refining the simulations and for obtaining better and satisfying outcomes, the definition of convergence criteria is made as for the movement and continuity equation, when there is enough reduction in residuals to make it below 10^{-3} then the convergence is said to be satisfied. For the energy equation, it is satisfied when the residuals reach a value below 10^{-6}.

The substitution of the product is made by porous mediums [9]. It was assumed the air present within the container was taken into consideration as incompressible and Newtonian fluid and at the same time, the Boussinesq was satisfied by it [2]

The division of the transport phenomenon into water vapors and absorption can be made in the absorber bed. The granules of the silica gel surfaces the flow rate equation of Navier-Stokes which are brought in use for solving the flow phases of water vapour [10].

Energy Equation

The principle of energy conversion is followed by the energy equation. Its derivation is made in accordance with the thermodynamics' 1st law which states that "a fluid's energy change rate is equivalent to the sum of rate at which the work is done and sum of rate at which the heat is supplied" [11]. The below-mentioned equation 1 provides the energy equation's conservative form.

$$\frac{\partial}{\partial t}\left[\rho\left(e + {v^2}/{2}\right)\right] + \nabla.\left[\rho\left(e + {v^2}/{2}\right)\right] = E_p + E_b + E_V + E_q + E \quad (1)$$

Where,

$$E_p = -\left[\frac{\partial}{\partial x}(pu) + \frac{\partial}{\partial y}(pv) + \frac{\partial}{\partial z}(p\omega)\right]$$

$$E_b = \rho(f_x u + f_y v + f_z \omega)$$

$$E_V = \frac{\partial}{\partial x}(\tau_{xx}u) + \frac{\partial}{\partial y}(\tau_{xy}u) + \frac{\partial}{\partial z}(\tau_{xz}u) + \frac{\partial}{\partial x}(\tau_{yx}v) + \frac{\partial}{\partial y}(\tau_{yy}v) + \frac{\partial}{\partial z}(\tau_{yz}v) + \frac{\partial}{\partial x}(\tau_{zx}\omega) + \frac{\partial}{\partial y}(\tau_{zy}\omega) + \frac{\partial}{\partial z}(\tau_{zz}\omega)$$

$$E_q = -\left[\frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right)\right]$$

$$E = \rho \dot{q}$$

Momentum Equation

The equation for calculating the momentum is dependent over the Newton's second law. The Newton's second law stated that "in a specific direction, the change in rate of momentum is equivalent to sum of all the forces acting on the fluid in the same direction" [2]. The surface forces comprise of viscous forces, normal forces, shear forces and pressure forces. The body forces comprise of centrifugal forces and gravity forces. The below mentioned equation 2 exhibits the mathematical expression of the momentum equation in an unsteady state:

Momentum equation in X-direction:

$$\frac{\partial}{\partial t}(\rho u) + \nabla.(\rho u V) = -\frac{\partial p}{\partial x} + \frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{zx}}{\partial z} + \rho f_x \quad (2)$$

Momentum equation in Y-direction:

$$\frac{\partial}{\partial t}(\rho v) + \nabla.(\rho v V) = -\frac{\partial p}{\partial y} + \frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{yy}}{\partial y} + \frac{\partial \tau_{zy}}{\partial z} + \rho f_y \quad (3)$$

Momentum equation in Z-direction:

$$\frac{\partial}{\partial t}(\rho \omega) + \nabla.(\rho \omega V) = -\frac{\partial p}{\partial z} + \frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial \tau_{zz}}{\partial z} + \rho f_z \quad (4)$$

Continuity Equation

The base of this equation is over the principle of mass conservation. This principle states that "the changing rate in the mass within the control volume is equivalent to mass flow rate". The mathematical expression of continuity equation is exhibited in equation 5:

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x}(\rho u) + \frac{\partial}{\partial y}(\rho v) + \frac{\partial}{\partial z}(\rho \omega) = 0 \quad (5)$$

2.4 Meshing

For all types of geometries, the creation of the mesh has different obstacles [10]. The mesh domain was split into 213735 elements71840 nodes as exhibited in figure 6. Tetrahedron type meshing is used in the cold storage area and on the onion, quadrilateral meshing is used. The overall element size taken is 5mm but 2mm of element size is used in the evaporating section.

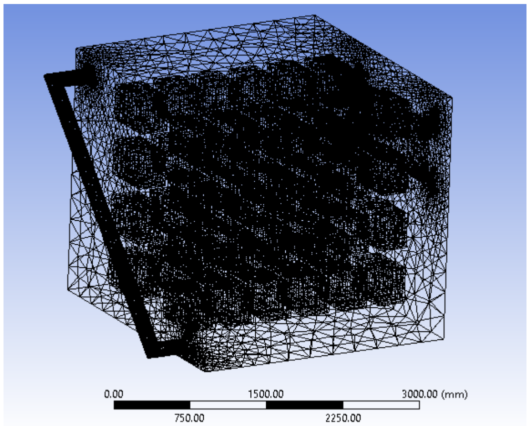

Figure 6: Wireframe meshing of cold storage

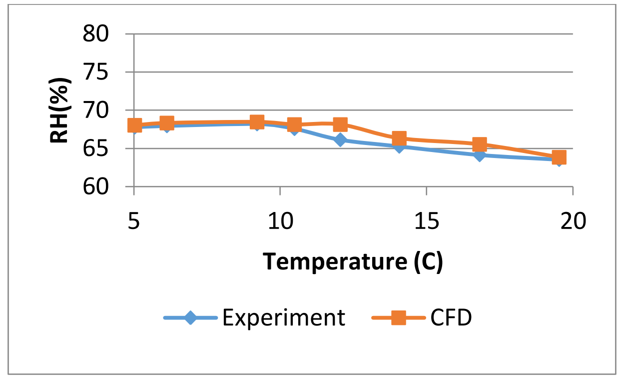

Figure 7: Validation graph of experimental and CFD study

2.5 Boundary Condition

For analyzing on CFD, the domain which was brought in use had the same size as that of the cold storage room. It also had a similar fan along with a similar heat exchange system. To solve the sets of governing equations, the relevant boundary condition is used. At the initial stage, the exit of the evaporator is brought into consideration as air velocity inlet for cold storage. The initial temperature at the inlet was 5^{o}C with 1m/s of velocity.

The implementation of the design conditions was made for the simulations. An assumption for the floor was made at a constant temperature of 300 Kelvin. The roof along with the side walls was assumed at a natural convection environment having a temperature of 300 Kelvin. A 1m/sec of inlet velocity was also considered. As this region constitutes of high air velocity and availability of large space is present, it is very much possible that turbulence occurs and the standard k- ϵ model might not be able to predict accurately.

3. RESULTS AND DISCUSSION

3.1 Result validation

The most important variable which affects the moisture components of the onion including moisture loss by fresh produce is relative humidity. The below graph represents comparison of experimental work and CFD work. The graph represents the relation of relative humidity and temperature. For both experimentally as well as CFD analysis 40 hours of work has been done. The results obtained for very similar and negligible differences can be reported. The maximum difference is when the temperature is 12^{o}C which showed the value from CFD analysis and experimentation as 68.1% and 66.1% respectively as exhibited in Figure 7. The experimental results were obtained from "Maulana Azad National Institute of Technology (MANIT), Bhopal, Madhya Pradesh".

3.2 Variation of Relative Humidity

The Figure 8 mentioned exhibits the results obtained before integrating the desiccant material in the cold storage system. The value of relative humidity was obtained as 69.04%. As discussed above, if the humidity is above 65% then the onions will start rotting and sprouting. The results were collected after 40 hours from placing the onions in the cold storage.

To remove the issues of rotting and sprouting of the onions, desiccant material made up of blue silica gel is added to remove the moisture content of the air. This reduced the humidity to 58.5% as shown in Figure 9. The results were collected after 40 hours from placing the onions in the cold storage.

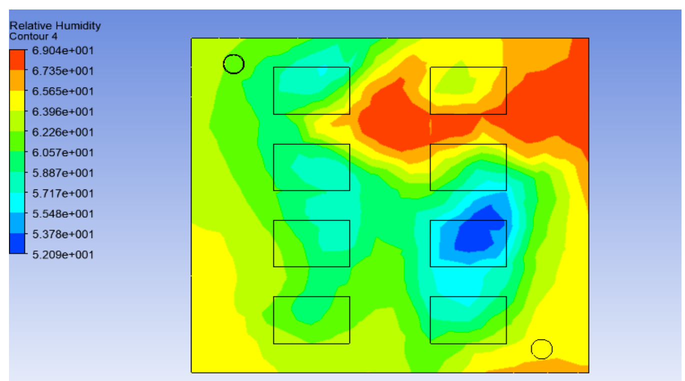

Figure 8: Relative Humidity of cold storage before using Desiccant

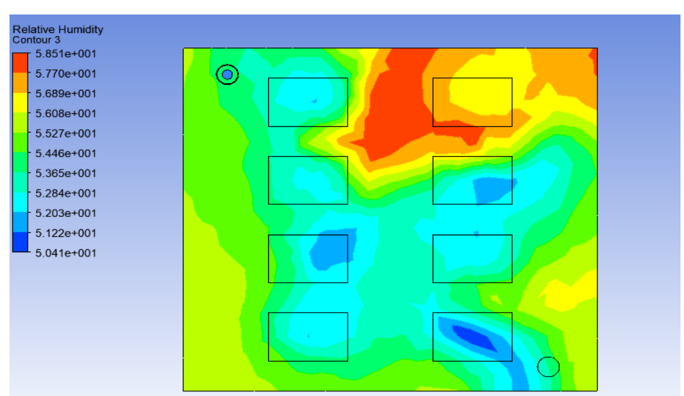

Figure 9: Relative Humidity of cold storage after using Desiccant

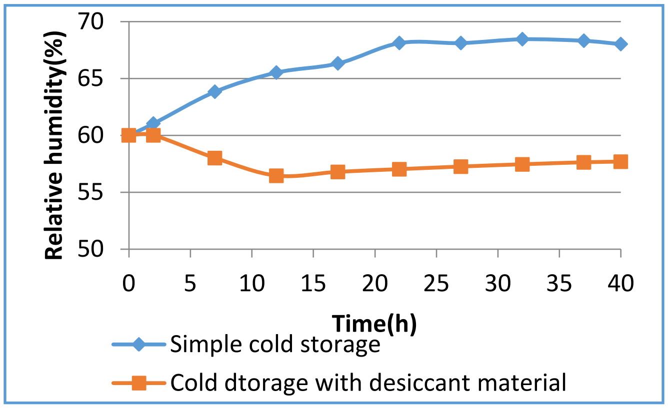

Figure 10: Comparison of Relative humidity of simple and modified cold storage from CFD analysis

The results were collected through cold storage without desiccant, after 1 hour, 20 hours and 40 hours as shown in figure 11. And then results were collected through cold storage with desiccant and After 1 hour, humidity content had minimum spread which increased after 20 hours and was at maximum after 40 hours (as shown in figure 12).

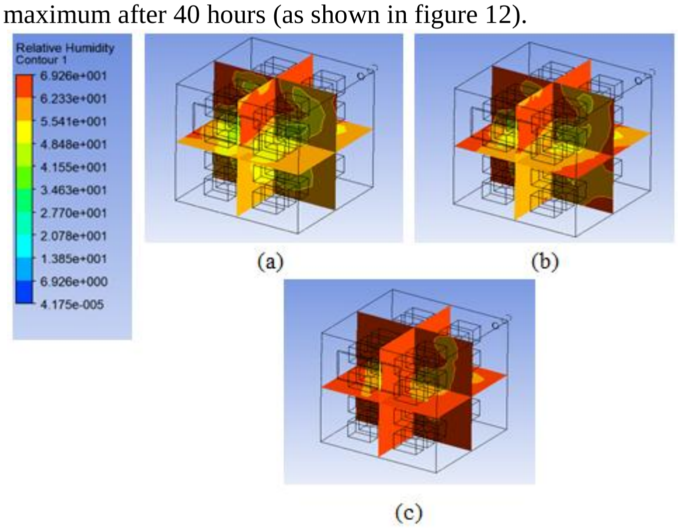

Figure 11: Relative humidity of Cold storage without desiccant (a) after 10 Hrs, (b) after 20 Hrs and (c) after 40 Hrs

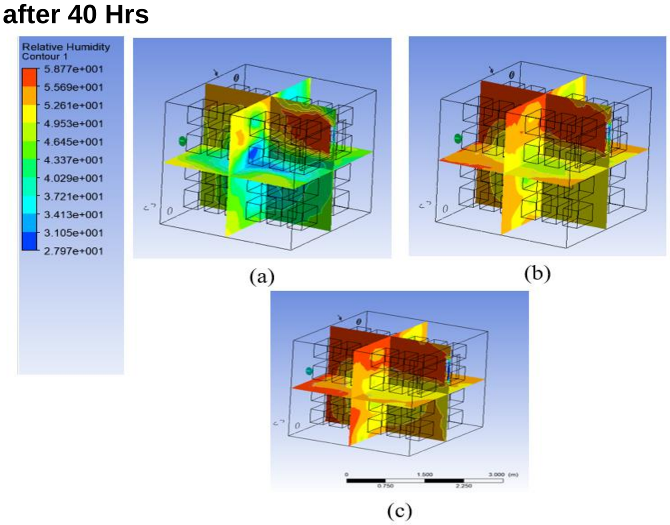

Figure 12: Relative Humidity of cold storage with the use of desiccant material (a) after 10 Hrs, (b) after 20 Hrs and (c) after 40 Hrs

3.3 Variation of Temperature

The below-mentioned figures exhibit the results obtained before integrating the desiccant material in the cold storage system. The temperature value recorded for onions before using desiccant material was around 25°C when measured after 10 hours and it drops down to around 19°C and 14°C when measured after 20 hours and 40 hours respectively as shown in Figure 13.

In the duct, a fan of 48W is mounted for experimental conditions which are helping in proper circulation of air through the duct so that the air of cold storage circulated through the duct and passes through desiccant placed into the duct, and because of this process and fan velocity temperature also reduces by some little value.

The results were collected after 1 hour, 20 hours, and 40 hours. After 1 hour, it was observed that temperature was at a maximum which decreased after 20 hours and was at minimum after 40 hours i.e. around 5°C, 3°C, and 2°C respectively.

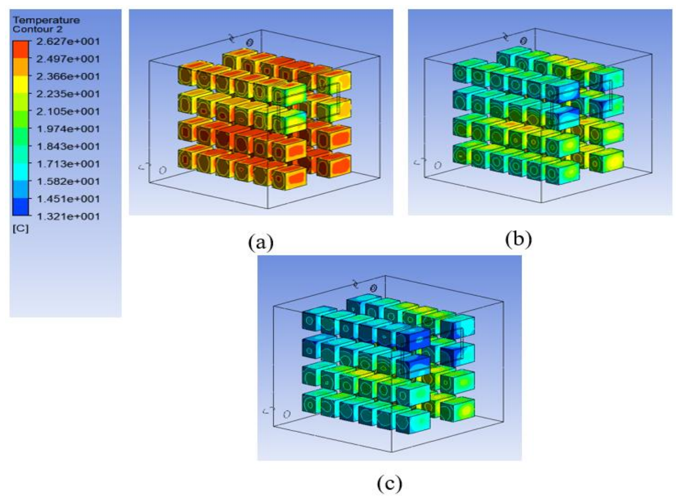

Figure 13: Onion temperature with the use of desiccant material (a) after 10 Hrs, (b) after 20 Hrs and (c) after 40 Hrs

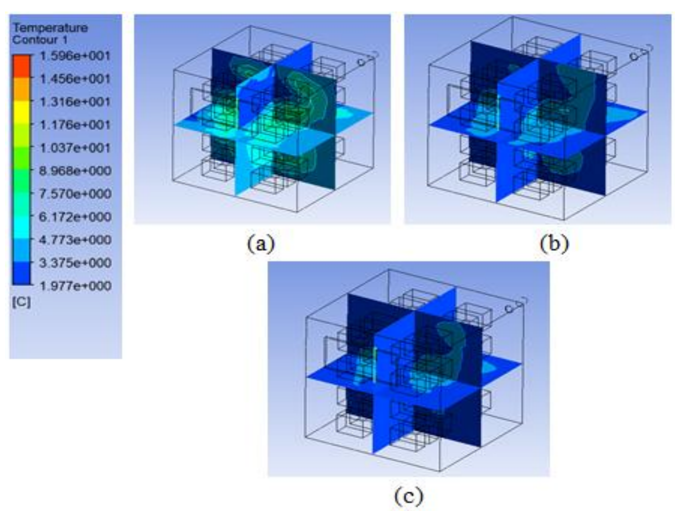

Figure 14: Cold storage temperature with the use of desiccant material(a) after 10 Hrs, (b) after 20 Hrs and (c) after 40 Hrs

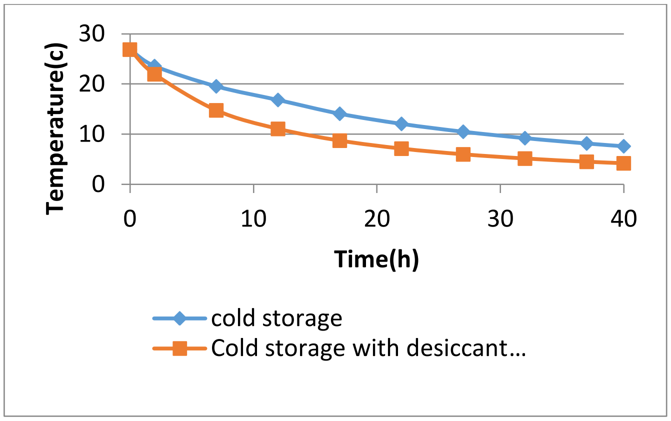

Figure 15: Comparison of Temperature of simple and modified cold storage from CFD analysis

The graphical representation of comparison of temperature inside the cold storage with desiccant material and cold storage without desiccant material is exhibited in Figure 15

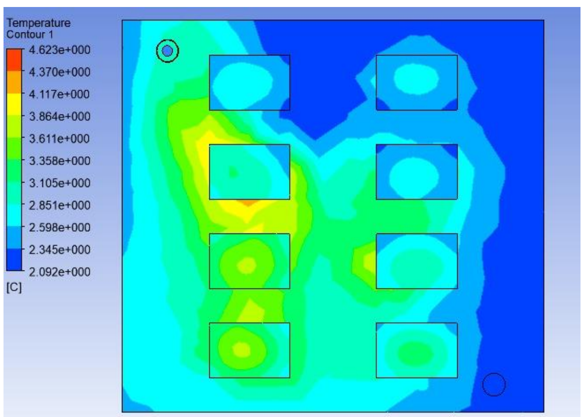

Figure 16: Final Temperature of cold storage with desiccant after 40 hour.

A total of 40 hours of study is presented above-mentioned graph in figure 15. There was a noticeable reduction in the temperature recorded at the initial stage of experimentation and the temperature recorded at the end of the experimentation. The temperature rapidly decreases during the initial 10 hours. After that, the decrease in the temperature slows down. The minimum required temperature for storing the onions in the cold storage is attained within 38 hours to 40 hours which is around in the range of 2^0C to 4.6^0C as shown in Figure 16.

4. CONCLUSIONS

This study was based on both experimental as well as CFD simulation. The used desiccant material brought down the humidity by a significant value. The maximum humidity required in cold storage for storing onions is within the range of 55-65%. The results in this study showed that after using the desiccant material, the obtained humidity was 58.5% in CFD analysis. This will help in storing the onions at a better-required humidity and will keep the onions fresh for a longer time. Since the humidity content affects the quality of the onions, therefore this desiccant material can now evidently be used on larger scales. It also reduced the temperature by a significant difference bringing down the temperature under the needed value i.e. 5^oC. The results showed a temperature of around 4.6^oC which was attained after using the fan in the duct.

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