Numerical Simulation of Solar Greenhouse Dryer Using Computational Fluid Dynamics

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Abstract:- **Moisture removal from crops and other food items is one of the ways to preserve them for longer duration. Previously, drying openly in sun was used to reduce moisture content. But it had some disadvantages like contamination due to dirt and other unwanted elements as well as attack by rodents and birds. Drying in covered close space with vents would be helpful in overcoming these problems. Solar greenhouse dryers are the close conduits in which crops can be dried without negatively affecting the nutrition value. The factors affecting the crop drying are solar radiation, climatic conditions, material of which the dryer is made of and shape of the dryer. A lot of experimental investigations have been done to improve the drying rate. With the advances in computational power and numerical techniques, Computational Fluid Dynamics (CFD) has emerged as a powerful tool to optimize any design. In the present study, simulations have been done on greenhouse dryer with modifications to identify the temperature distribution with variation in wind velocity. Different radiation levels have also been found out at different locations in the dryer. The model of the dryer has been created in CREO 5.0 and analysis has been performed using ANSYS 14.0. The simulation has been done for both forced and natural convection. Obtained results have been validated with the experimental work done by previous works. Better drying rate has been obtained for forced circulation as compared to natural convection which is in agreement with the available experimental results.**

Keywords **– Greenhouse dryer, solar radiation, temperature distribution, Relative humidity, CFD**

I. INTRODUCTION

Solar energy, one of the renewable energy sources has a great potential to be used in various systems [1]. Sun generates the energy by nuclear fusion of hydrogen nuclei into helium. Solar energy can be utilized broadly in two ways: directly and indirectly. Solar energy that includes thermal and photovoltaic conversion can be termed as and is direct source. Wind, biomass, wave energy, temperature difference in the ocean and marine current are indirect source of solar energy [2].

II. LITERATURE REVIEW

Sahu et al. [3] conducted experiment on simple and modified green house dryer with inclined roof to analyze the increase in drying rate of potato flakes. The weight of potato flakes was found to be reduced by 80.1% in modified greenhouse dryer in just 5 hours.

Manoj and Manivannan [4] developed a MATLAB-based modeling and simulation system to predict the air flow properties, equilibrium moisture content of the solar dryer technology. A greenhouse solar dryer is considered for analysis. Moisture removal process was analyzed for seven days and 7% of weight reduction was observed. The performed on mat lab program and the 3-D model has been developed on process. The Crank-Nicholson equation has been applied to heat and finite difference method has been used to develop for drying cocoa bean. This results show a time of drying reduces the moisture contains for 50% to 7% and 60% to 8% of moisture removal of dried bean.

Aravindha and Sreekumar [5] conducted experiment to find the effect for solar drying which was applied for two types of dryer i.e. open sun dryer and greenhouse solar dryer. The sample consists of bitter gourd and drying rate of both dryers was compared. From this study it was observed that 96% to 6% drying was achieved within less than 3 hours in open sun drying.

Sontakka and Salve [6] conducted experiments to investigate the performance of a new design of a solar dryer for drying chilies. The dryer consisted of drying cabinet, heat exchanger, parabolic solar collector, of dish types and water type heat storage unit. Three batches of chilies were dried in the dryer. 1 kg of chilies were dried for each batch. It was observed that in drying concentric collector gave better result than flat plate collector. The moisture reduction of chilies obtained with developed dryer was from 78% to 24% in 20 sunshine hours. The efficiencies of the solar collector were found out to be 40%-60%.

Barnwal and Tiwari [7] Experimentation was done using Thompson seedless grapes; DC fan was used for forced convection mode. For comparison, grapes were also dried in open as well as shade. The performance of green house drier was compared with natural drying and shade drying. It was found that convective mass transfer coefficient for greenhouse dryer was lower as compared to open sun drying and the product dried inside the greenhouse dryer had superior quality and colour as compared to that in naturally dried products.

III. MODELLING AND ANALYSIS

Geometry was modeled in CREO 5.0 and then imported to ANSYS workbench 14.0 where meshing was done, then the mesh was exported to FLUENT. The boundary conditions, material properties and encompassing properties were set through parameterized case files. FLUENT solves the problem until either the convergence limit is met or the amounts of iterations specified by the user are complete.

Preparation of the CAD model

The dimensions of the computational domain which consist of greenhouse dryer were based on the experimental work.Table1 shows the parameters of solar dryer.

Table 1: Geometric Dimensions of solar green house dryer

Length (cm)	Wide (cm)	Height (cm)	Angle (Deg)	Dia. of inlet holes (cm)
91	63	86	23^0	10

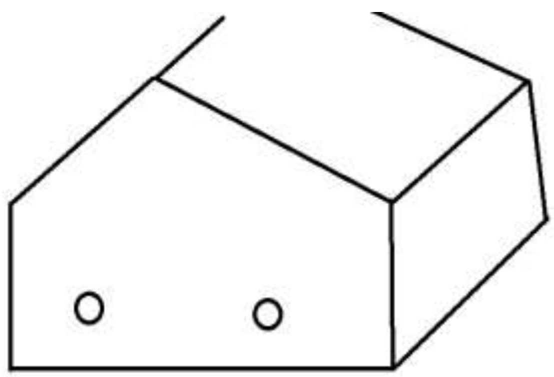

Fig. 1 Simple Green House Dryer

A simple green house dryer has its own significance on drying of potato flakes and tomato flakes but it has demerit of lack of perpendicular solar radiation on the dried items. Thus in present work, the top inclined roof and drying tray in solar greenhouse dryer has been inclined to the latitude of Bhopal city.

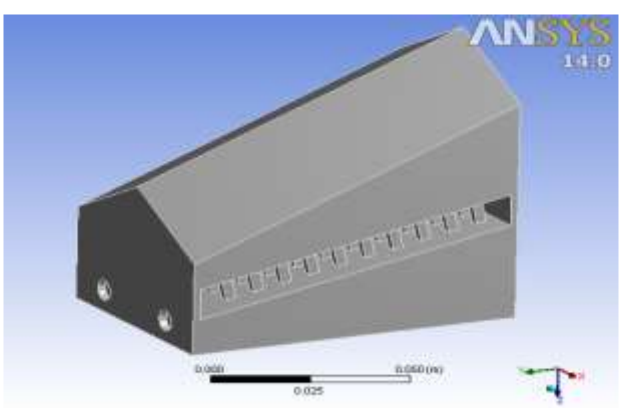

Figure 2. 3D Model of Modified Green House Solar Dryer.

Meshing of the Domain –

After modeling the geometry in CREO, it was imported to ANSYS workbench Design modular for its discretization. Meshing is dividing the complete geometry of interest into small parts. Mesh density varies based upon the assigned Refinement factor. Mesh is the key part of a high quality convergence.

For present case, hexahedral unstructured mesh has been used. Total number of nodes is 27271 and elements are 5805 which have been employed for the analysis of modified solar greenhouse dryer.

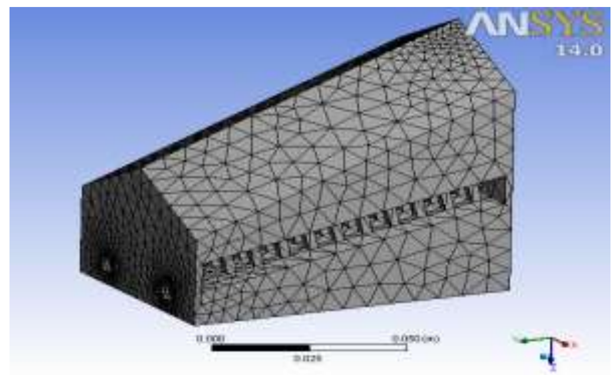

Figure 3. Mesh domain of the solar dryer.

Material Properties

Table 2: Materials Properties

Properties	Air	Glass
Density, ρ	1.225 Kg/m^3	2321 Kg/m^3
Thermal Conductivity, K	0.0242 W/m-K	571 W/m-K
Specific Heat, C_p	1006.43 J/Kg-K	1.15 J/Kg-K
Viscosity, μ	$1.7894x10^{-5}$	-----------------

Boundary conditions

Boundary conditions need to be defined for getting the output result. The computational domain employed is shown in table 3. The material of the solar dryer tray is glass. Beneath the computational domain is specified as heated discrete heat transfer radiation method at constant velocity of (3.5,3.6, 3.2, 3.6, 3.4, 2.7, 3.5m/s). The flow is assumed to be three-dimensional, incompressible, steady, turbulent and since the heating is low, constant air properties. Radiation effect is considered.

Table 3: Boundary conditions

Boundary Conditions	Governing Equations
Inlet	Air with varying velocity for different cases
Outlet	Pressure with value 1 atm
Absorber Glass	Solid with
Turbulence Model	K-ε Model
Number of Iteration	500
Convergence Criteria	Semi-Implicit Pressure Linked Equation

IV. RESULT ANALYSIS AND DISCUSSION

Introduction –

A three-dimensional model has been developed to investigate heat transfer and relative humidity in the solar greenhouse dryer for drying and moisture removing process. A series of numerical calculations have been conducted using commercial CFD code FLUENT. The results are presented in order to show the effects of temperature distribution and relative humidity with respect to time in the solar dryer.

Validation of the numerical Result

The validation of the numerical results has been done using the experimental results of Sahu et al. [3].

Result for Forced Convection

Variation in temperature

Table 4. shows experimental and simulation results of temperature for the solar green house dryer with variation in time.

Table 4: Experimental and simulation results of variation in temperature for the solar greenhouse dryer with time

Time	Experimental Result	Simulation Results
10:00 AM	40	47
11:00 AM	39	46
12:00 PM	47	57
1:00 PM	49	56
2:00 PM	48	50
3:00 PM	54	58
4:00 PM	56	59

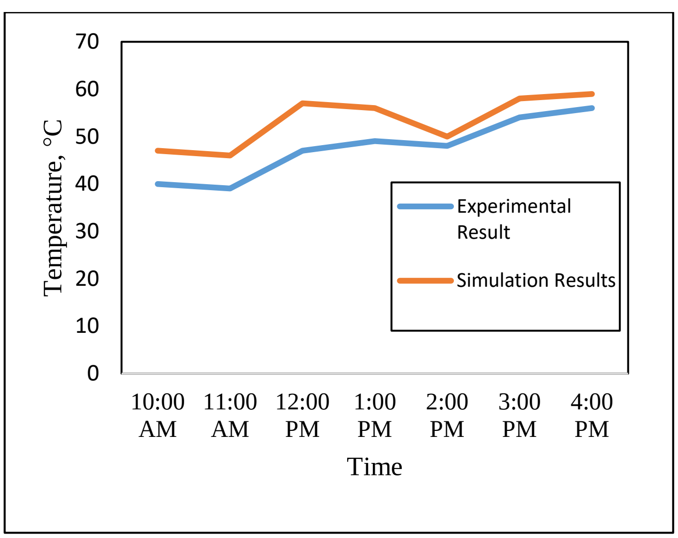

Figure 4. Results of variation in temperature for the solar green house dryer with variation in time

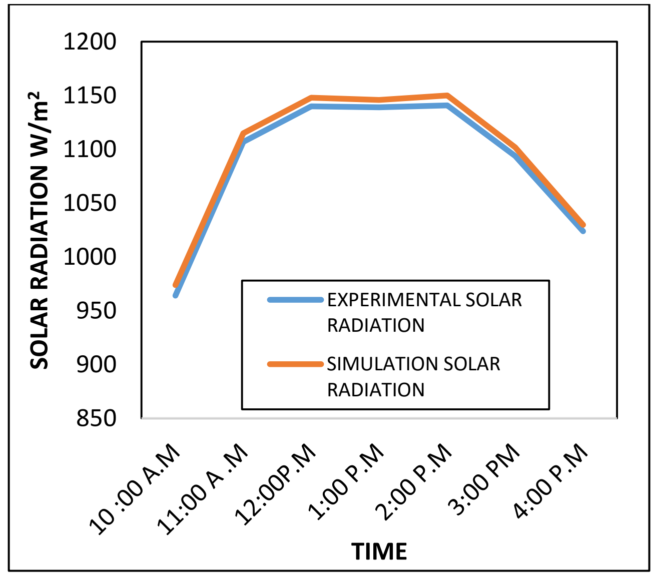

Figure 5. Results of solar radiation for the solar green house dryer in time

Figure 5. shows the experimental and simulation results of variation in solar radiation on greenhouse dryer. The simulated results have slightly higher than experimental values .The deviation is almost constant. These errors may be due to round off and discretization.

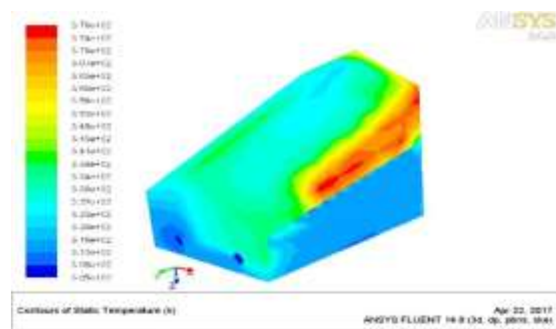

Figure 6. Temperature variations in solar green house dryer at 10 am under forced convection

Figure 6. shows the temperature distribution on solar dryer at 10:00 am with wind velocity 3.5 m/s. From the above contour plot, it is observed that, 47°C temperature is observed on tray of potato flakes

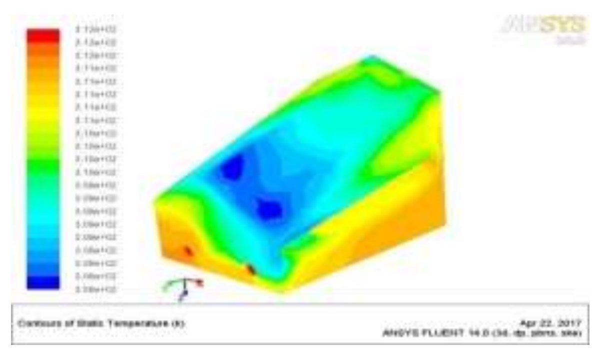

Figure 7. Temperature variations on solar green house dryer at 12:00 pm

Figure 7. shows the temperature variation on solar dryer at 12:00 noon. Sun rays are almost perpendicular over the green house dryer and tray. So, highest temperature is observed during this time period. It is observed that 57^0C temperature is found out to tray of potato flakes.

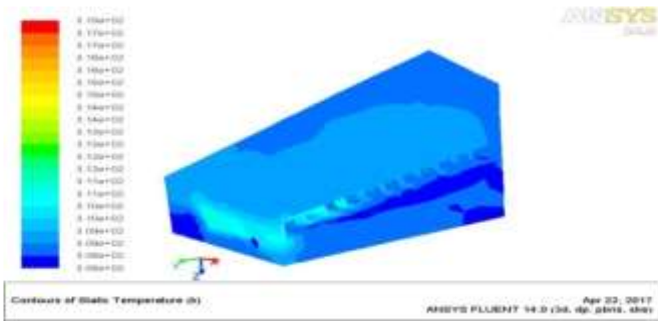

Figure 8. Temperature variations on solar green house dryer at 2:00 pm

Figure 8. shows the temperature variation on solar greenhouse dryer at 2:00 pm with wind velocity 3.4 m/s from the above contour plot, it is observed that at constant velocity of 3.4 m/s, 50°C of temperature was observed on tray of potato flakes.

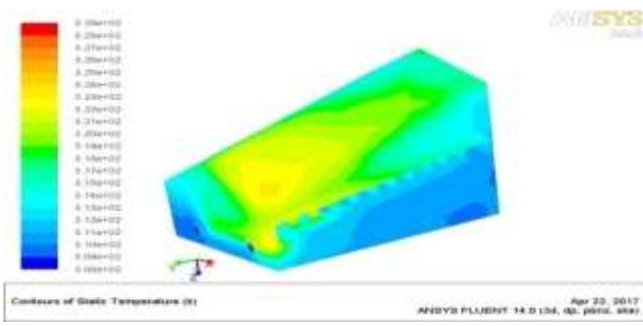

Figure 9. Temperature variations on solar greenhouse dryer at 4:00 pm

Figure 9.shows the temperature variation on solar greenhouse dryer at 4:00 pm with wind velocity 3.5 m/s From the above contour plot, it is observed that 59^0C of temperature is found out to be on tray of potato flakes .The reason for such high temperature is that nearly all the moisture from the potato flakes has been removed

Result for Natural Convection

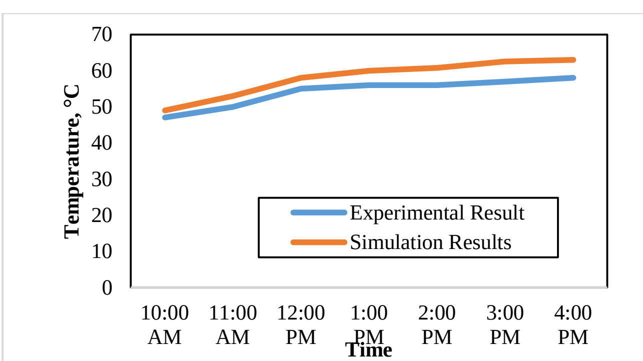

Figure 10. Result of temperature for the natural convection solar dryer with time (natural convection)

Figure 10. shows the experimental and simulation result of solar green house dryer to determine temperature. Numerical results are slightly above than experimental values, the deviation almost constant. This deviation can be due to that secondary losses cannot be exactly captured in CFD.

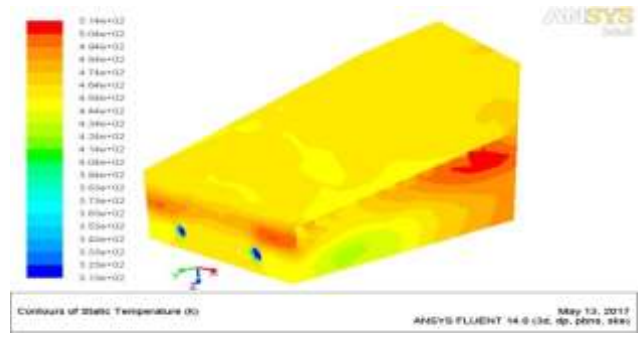

Figure 11. Temperature variations on solar green house dryer at 10 am

Figure 11.shows the temperature variation on solar greenhouse dryer at 10:00 am when wind velocity is 0.5 m/s It is observed that for wind velocity of 0.5 m/s, 49^o C of temperature is observed on tray of potato flakes which is higher than the temperature observed at same time for force convection. the reason for the air is at low velocity and so it is unable to take heat with it.

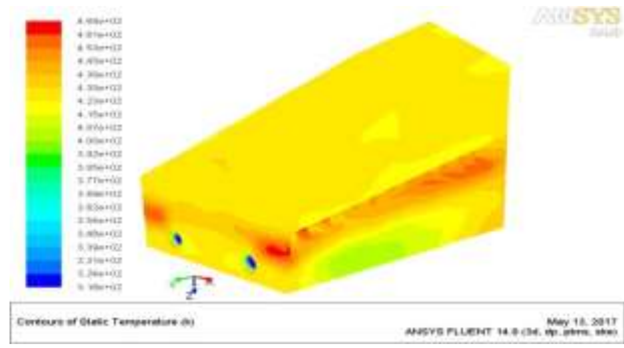

Figure 12. Temperature variations on solar green house dryer at 12:00 pm

Figure 12.shows the temperature variation on solar green house dryer at 12:00 pm with wind velocity 0.8 m/s from the above contour plot, it is observed that 58^0C temperature is observed on drying tray .Solar radiation is nearly perpendicular on the dryer. So temperature distribution is almost uniform.

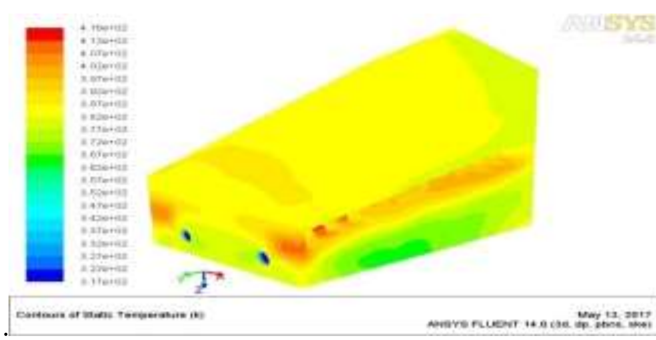

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Figure 13. Temperature variations on solar green house dryer at 2:00 pm

Figure 13. shows the temperature variation on solar green house dryer at 2:00 pm with wind velocity 0.6 m/s from the above contour plot, 60.8^0C of temperature is observed on tray of potato flakes.

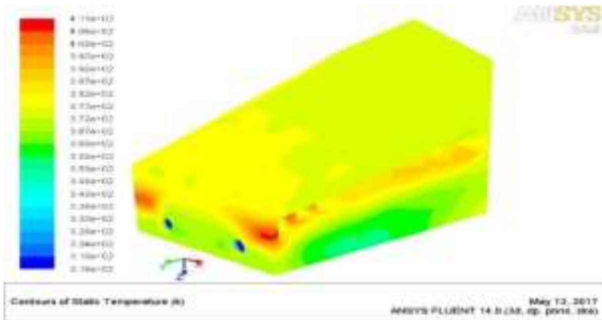

Figure 14. Temperature variations on solar green house dryer at 4:00 pm

Figure 14. shows the temperature variation on solar green house dryer at 4:00 pm with wind velocity 0.7 m/s From the above contour plot, 63^0C of temperature is observed on tray of potato flakes. higher temperature is observed at this time.

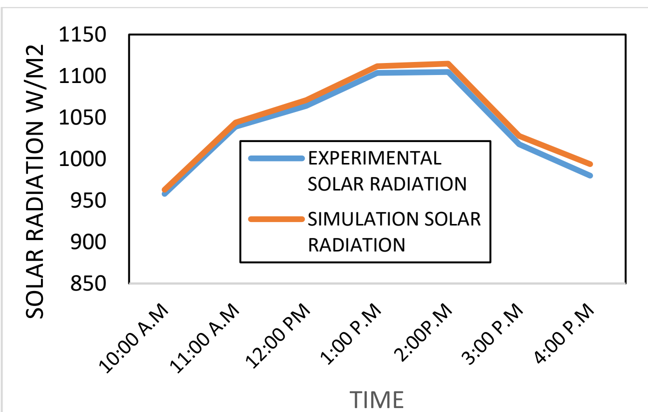

Figure 15. Variation of solar radiation with time (natural convection)

V. CONCLUSION

Computational model of solar greenhouse dryer has been modeled in CREO 5.0 and analysis has been done using Fluent 14.0. Solar greenhouse dryer at different wind velocity for both natural convection and forced convection dryer has been simulated. Numerically obtained results are in good agreement with experimental results. From the above results, less temperature is observed for forced convection as compared to natural convection. Forced convection for solar dryers have better heat transfer rate due to increase in fan velocity.

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