JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

Experimental and Numerical Studies of Forced Convection Solar Dryer with Turbulence and optimization for Agricultural Product (Raisin)

Suraj S. Gavade[1], Chinmay Patil[2], Suraj Rishwadkar[3],Prajwal Satao[4], Basveashwar Patil[5]

[1]*Asst. Professor, Mechanical Department, SKNCOE,Pune, Maharashtra, India*

[2,3,4,5]*UG Students, Mechanical Department, SKNCOE,Pune, Maharashtra, India*

ABSTRACT:

Drying of an agricultural product using conventional methods is energy and time consuming process. Solar energy is viable alternative for drying applications to overcome the losses and shortage of fossil fuels. In the present work, forced convection solar dryer has been designed, analyzed and developed for certain key experiments. Dryer consists of flat plate air collector with baffle plates, drying chamber with chimney arrangement and air blower. Air collector consists of 2.80 m^2 total area. Numerical analysis of solar air collector is executed for fluid flow analysis of air and mass flow rate. From the result of numerical analysis, four baffles are used for creating turbulence in air heater and 0.013775 kg/s mass flow rate provided higher temperature. Using these results, solar dryer has been developed for drying the grapes (Super Sonaka) to produce raisin. Experimental result shows that dryer with turbulence having 7 to 8ºC temperature rise shown increase in the performance in the context of drying than without turbulence. Drying rate for grapes with turbulence was 48 sunshine hours whereas 56 hours for dryer without turbulence.

Keywords: *Solar Dryer, Turbulence, baffle plates, Optimized Experiments, Numerical Analysis, CFD, Raisin.*

Introduction-

In India though solar energy is abundantly available, there is less attention towards its effective utilization. Though the technology is present which depends on it, the efficiency of such systems is less one. D. R. Pangavhane and R. L. Sawhney [2] have studied natural convection solar drying method for grapes to producing raisins. There should be improvements in available techniques and there should be research to develop the new technology. Solar drying is old and ancient technique in which up-gradation is always going on. Solar drying is cost effective and represents an effective alternative to traditional and mechanical drying systems, especially in locations with good sunshine during the harvest season. The increased consumption of energy, resulting in soaring prices of fossil fuels and ecological imbalance, has increased the interest in utilization of solar dryers. Experiments performed in many countries have clearly shown that solar dryers can be effectively used for drying agricultural crops. It is a matter of adopting it and designing the right type of solar dryer. Sun is an important source of renewable energy. Solar power is the energy conversion from sun radiations which are easily available everywhere in the world. In India, solar energy is available in large amount but there is less attention towards the utilization of available energy. Sun shines in India near about 3000 to 3200 hr. /year delivering solar radiations on the surface of the earth over an average 2000 W/m^2-year.

Drying is one of the oldest method where the products such as vegetables, fruits, fish, and meat, etc. to be dried exposed directly to the sun. There are various methods used for drying such as 1) Open sun drying, 2) Shade drying, 3) Mechanical Drying and 4) Solar Drying. Open sun drying method has many disadvantages such as spoilt products due to rain, wind, dust, insect infestation and animal attack. The speed of drying was very high especially in open sun drying which was directly exposed in the solar radiation and it will causes the product's surface and becomes hard. Abhay Lingayat et. al. [4] has designed indirect type of solar dryer for banana. Dryer consist at plate collector with absorption plate, insulated drying cabinet and chimney for exhaust air. The moisture inside the product has a chance to evaporate and over drying affect the quality of dried product. Open sun drying also suffers from a high labor requirement and excessive crop handling particularly in periods of changing weather which can result in high costs, crop damage and a loss in quality. In this study the renewable solar dryer was designed to solve this problem and produce a better quality product and reduce the time required for the product. Grapes are one of the popular and tasty fruits in the world. The grapes were dried to produce raisin by using open sun drying, shade drying or mechanical drying.

Pangavhane et al. [3] have reviewed various drying methods and new trends in solar drying for grapes. Grapes are a member of the most popular and palatable fruits in the world. Preservation of grapes by drying is a major industry in many parts of the world, where grapes are grown. Drying the grapes, either by open sun drying, shade drying or mechanical drying, produces raisins. The production of raisins is a very important export business in many countries. There is always increase in demand of raisins in India due to more consumption of raisins because of its nutritional values and its healthy effects on human body. Drying practices for grapes are largely traditional and vary with geographical locality and with the variety of grapes. The bunches of grapes were spread over the ground or on a platform in a thin layer exposed directly to the sun, which is traditional method that is open sun drying.In the grape cultivating countries this method is partially used for drying purpose and this is very cheapest method which was successfully applied for drying the grapes. Capital cost for investment of equipment was very less or low but more labours were considered which was very costly. The drying time required for this method was nearly 15-20 days. In open sun drying, thereis a possibility of degeneration due to dust and microorganisms infection. Due to weather changes, it also affect the product.Direct sun radiation on the product will also results in the colour change. It was very di_cult to remove raisins, small stones, leaves, dust etc. while collecting prepared raisins. Sometimes to reduce the weather risk grapes were covered with transparent sheet. In this case, drying time also gets reduced as compared to without transparent by a day. The quality of the raisins will be also good in comparison to that when dried without a transparent cover.

Major production of raisins in India is from Thompson Seedless. The Thompson Seedless is a white, thin skinned grape, which produces the best raisins available today. Its small berries are oval and elongated. It does not contain seeds and has high sugar content. Besides the other varieties viz. Muscat of Alexandria, Waltham Cross and other white and colored seeded varieties are also used for raisins production. In India, Thompson Seedless and its mutants (Sonaka, Tas-A- Ganesh, Manik Chaman) are mainly used for raisin production. However there are gaps in the experiments and understanding of solar drying of grapes. Hence on of the objective of present work is to establish an effective test set-up and conducting the experiments on drying of grapes. The solar energy absorbed the fruit in the morning and evening is subsequently utilized for water vaporization during the shaded mid-day period, as well as after sunset. The drying time in this method is usually high. The above methods were found to be unsatisfactory because of mass losses and low quality of the raisins produced due to their exposure to rain, dust and insects. Further, direct exposure to solar radiation results in undesirable colour changes. Uncontrolled conditions may also result in microbial attack, spoiling the entire stock inthe process. Because of the ever present possibility of rainfall occurring during the drying period of the grapes, the artificial (mechanical) drying process, which is rapid and controlled, is attractive to grape growers, but a large number of small farmers engaged in growing grapes have not been able to use this because of the large initial investment and additional running energy cost. The energy cost was comparatively high for this application, even prior to the energy crisis. Moreover, the increasing rate of fuel consumption in agriculture has made it necessary, not only to save energy by intensifying the drying process, improving designs etc., but also by using renewable energy sources for the drying process. [2], [5], [6]

Methods and Protocols:

Section to details numerical protocols followed to come up with optimized results and configuration. Proposed configuration has been developed in the form of establishment (set-up) which is presented in section three. This is followed with results and discussion in section four with conclusions to end the manuscript.

1] Numerical Configuration:-

Theoretical design of a solar dryer was designed with the help of literature where various calculations were conducted. CAD model was constructed using solid works with design calculations. Numerical analysis of solar air collector was performed using ANSYS FLUENT R 17.1 Academic. Using result from numerical analysis, solar dryer was manufactured for experimental analysis. Forced convective solar dryer consists solar flat plate air collector, drying chamber, trays, centrifugal blower, connecting pipe with control valve and flexible pipe, supporting stand. Solar air heater (12 mm thick, 2m×1.40m×0.15m) made from plywood consist an absorber plate (0.9mm thick, 2m×1.40m) in size, made from aluminum coated with black paint. Four baffle plates are made for creating turbulence in the air heater. Baffle plate was made up from plywood on which aluminum sheet fitted on both side of baffle. Glass plate (6mm thick) was fitted on the frame of solar air heater. Drying chamber (0.32m×0.32m×0.65m) made from plywood with tray arrangement inside the chamber. From the bottom to top side of the chamber, five trays were placed at distance 100mm apart from each other. These trays are manufactured from Nylon mesh fixed with screws on iron rod. At the bottom side inlet for air is constructed with pipe arrangement. Ceiling of drying chamber having chimney arrangement for exhaust of air. Inlet and outlet pipe diameter for air heater and drying chamber was 76 mm (3 inch).

Design Calculation:

The amount of moisture removed from the grapes, m_w (Kg) was calculated using the following equation.[8]

$$m_w = m_p \frac{m_i - m_f}{(100 - m_f)} \quad (1)$$

Where m_w = amount of moisture to be removed, m_p = total quantity of grapes in Kg.

m_i = initial quantity of moisture in grapes in percent.

m_f = final quantity of moisture in raisins in percent.

m_w =3.7951 Kg

This quantity of moisture needs to be removed from grapes for raisin making.

$$Q = m_w \times h_{fg} \quad (2)$$

Where, h_{fg} – latent heat of evaporation. Equation for latent heat (h_{fg}) was as follow,

$$h_{fg} = 4186\left[597 - \left(0.56 \times T_{pr}\right)\right] \quad (3)$$

T_{pr} -Temperature of Product

Q = 9243.9136 KJ.

Mass of Air Required:-

$$m_a = \frac{m_w}{(w_o - w_i) \times t} \quad (4)$$

Where m_w = amount of moisture to be removed in kg.

w_o = outlet humidity of air from heater (kg/kg dry air).

w_i= humidity of air inlet to heater (kg/kg dry air).

t = time in hours per day.

m_a =47.43 kg/hrs. Or 0.01378 kg/s.

Solar air heater design:

Total heat energy required (kJ.), [4]

$$E = m_a(h_f - h_i) \times t_d \quad (5)$$

Where m_a = mass flow of air in kg/ sec.

h_f= final enthalpy of air (kJ/kg).

h_i= initial enthalpy of air (kJ/kg).

t_d= drying time for one day in hours.

E = 14039.28 KJ

For solar collector area, [16]

$$E = A_c \times I \times \eta \quad (6)$$

Where A_c = solar collector area in m^2

I = Total global radiation = 20000 kJ/ m^2/ day (taken the average values), [23]

η = collector efficiency = 25 % (Normally efficiency of flat plate collector lies between 24 to 28%)

14039.28 = A_c ×20000 ×0.25

A_c = 2.80 m^2.

Four suitable baffle plates are made up of aluminum and plywood material used for turbulence which is equally spaced. A dimension of baffle plate is 1m×0.15m×5mm (length×height×width).[19]

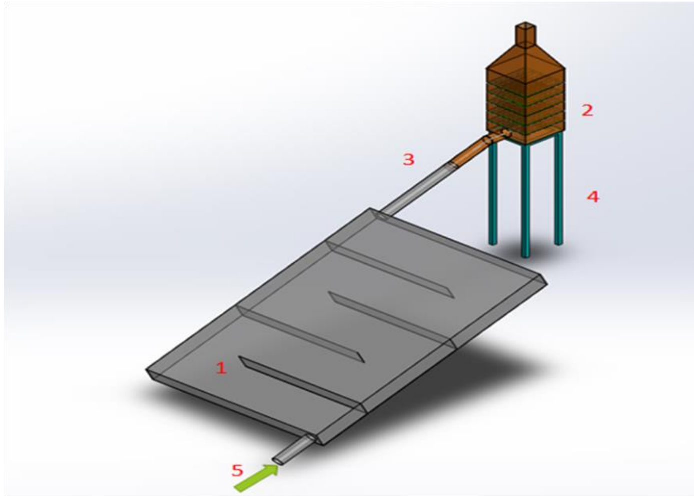

Figure 1. Schematic Layout of Solar Dryer

1- Solar Air Collector with Baffle plates

2- Drying chamber with Tray

3- Connecting Pipe

4- Supporting Stand

5- Air Inlet from Blower

Blower specification:

Blower was used for forced convection to enhance the air flow rate. Specifications of blower are as follows, CFM- 500, RPM- 1440 and Motor Rating – 0.5 Hp.

Instrumentation:

Solar dryer consists thermocouple sensors were attached at the various positions to detect the temperatures of air. Four thermocouples were attached to inlet and outlet of air collector and drying chamber. Fifth thermocouple sense ambient air temperature. Solar irradiance on a plane surface was measured with Pyranometer. It is designed to measure the solar radiation flux density (W/m^2) from the hemisphere above within a wavelength range 0.3 µm to 3 µm. Air flow rate was calculated by measuring air velocity with Anemometer (accuracy ±0.01 m/s) at the inlet of air collector. Electronic weighing machine was used to measure weight of sample.

2) Numerical Analysis of Air Heater using CFD

CAD modeling of solar air heater

The primary design of the solar air heater was drawn in solid works with considering designed calculations. Geometry constructed in solid works and was meshed using ANSYS Meshing modular. Four CAD models were designed for numerical analysis which contents without baffle plate and with baffles numbers 3, 4 and 5 baffles.[20]

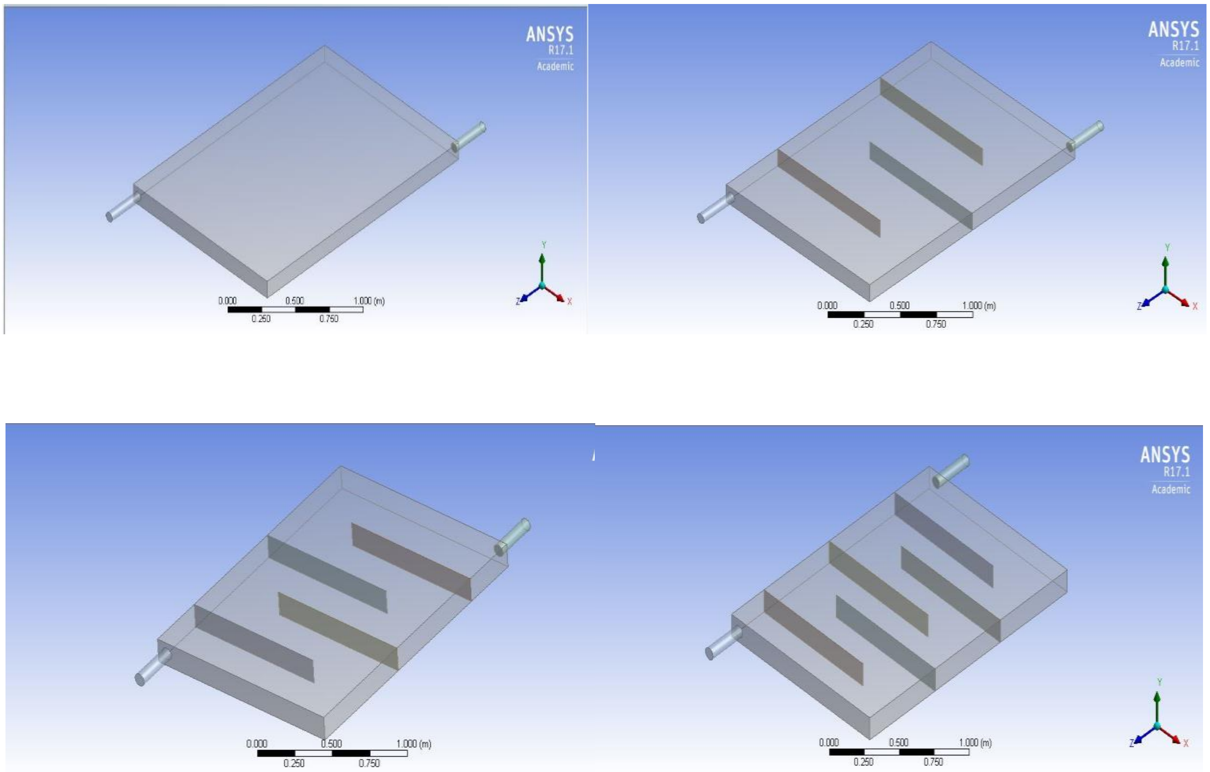

Figure 2.CAD Models of Solar air heater

Meshing Details of solar air Heater

The meshing of the solar air heater is carried out in ANSYS meshing modular. Unstructured tetrahedral mesh is used to discretize the air heater domain. Figure 3 shows the meshing of the air heater without baffle plates and with 3, 4 and 5 baffle plates, respectively.

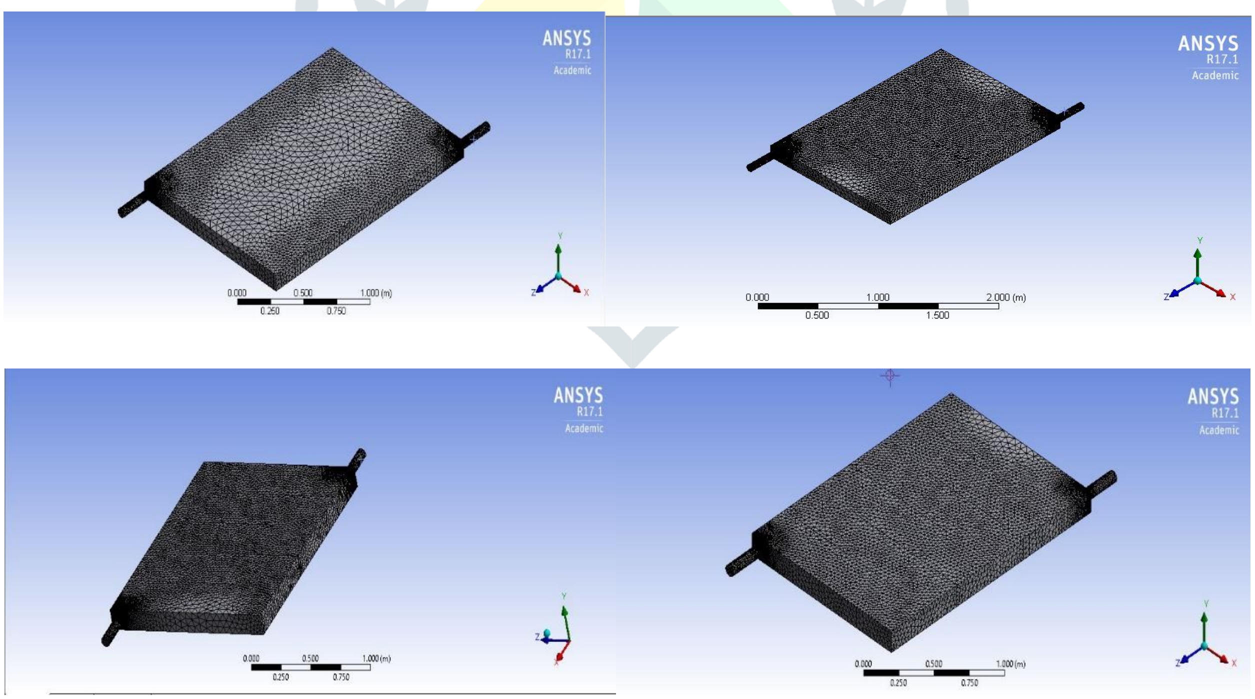

Figure 3. Meshing domain of Air heater

Meshing Details:-

Sr. No.	Air Heater Configuration	Nodes	Elements
1	Without baffle plate	32745	164248
2	3 baffles	34497	176882
3	4 baffles	34705	178255
4	5 baffles	35250	173117

Boundary conditions:-

This work deals with heat and fluid flow analysis through solar air heater. The boundary conditions are shown as follows,

Table-1 Boundary conditions

Sr. No.	Face	Type of boundary condition	Velocity/Pressure magnitude	Temperature (k)
1	Inlet	Mass flow inlet	Mass flow rate= 0.013 Kg/s (This is calculated in analytical framework)	303
2	Outlet	Outflow	-	-
3	Wall	-	No slip condition	-

For analysis, 3-D pressure based solver with K-ε model was used as a solver with activated energy equation. Solar ray tracing was used to calculate solar load. For solar load calculations, global position was set at Vadgaon Bk. Pune (Maharashtra) 73.85º longitude and 18.51º latitude at time zone +5.30GMT. The second order upwind scheme was used for pressure, momentum, turbulent kinetic energy, Specific dissipation rate and energy.

Numerical Analysis Result:

Temperature Profile:

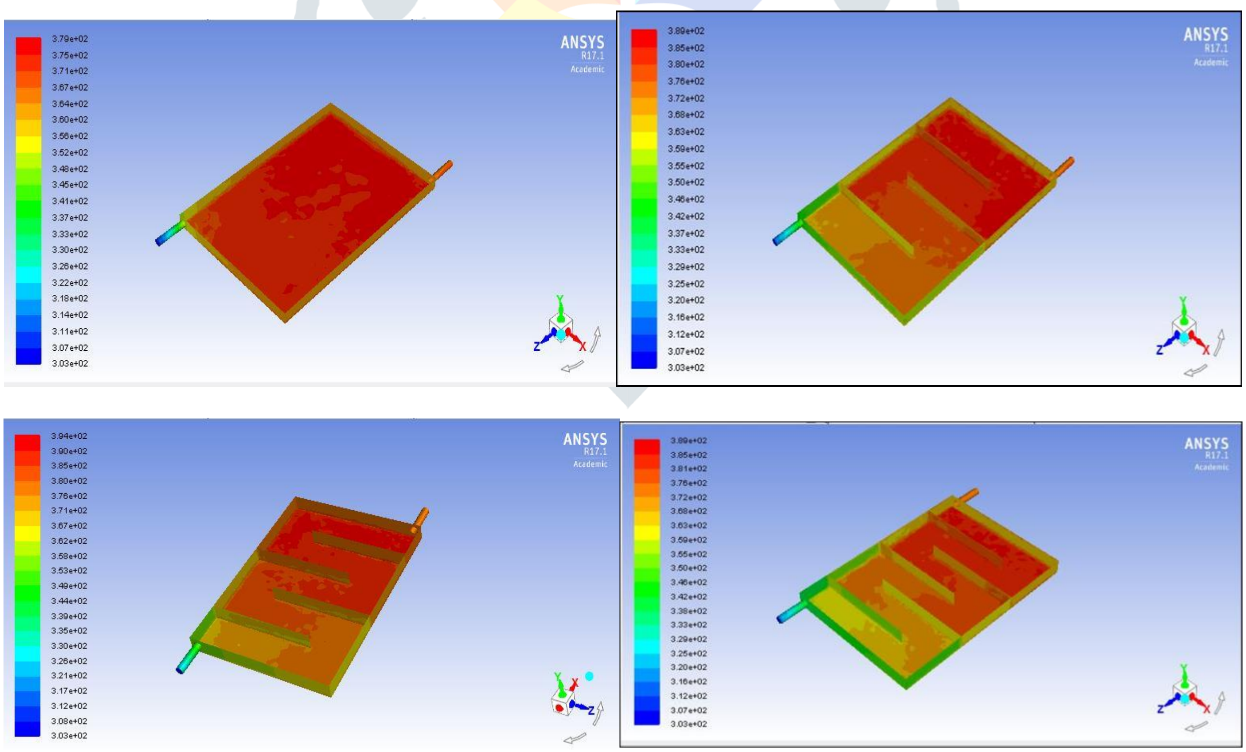

Figure 5. Temperature distribution profiles of solar air heater with and without turbulence

Figure 5 shows the temperature distribution of air heater using CFD. It seems that air heater with baffle plate's gives higher temperature of air at outlet than that of without baffle plate.

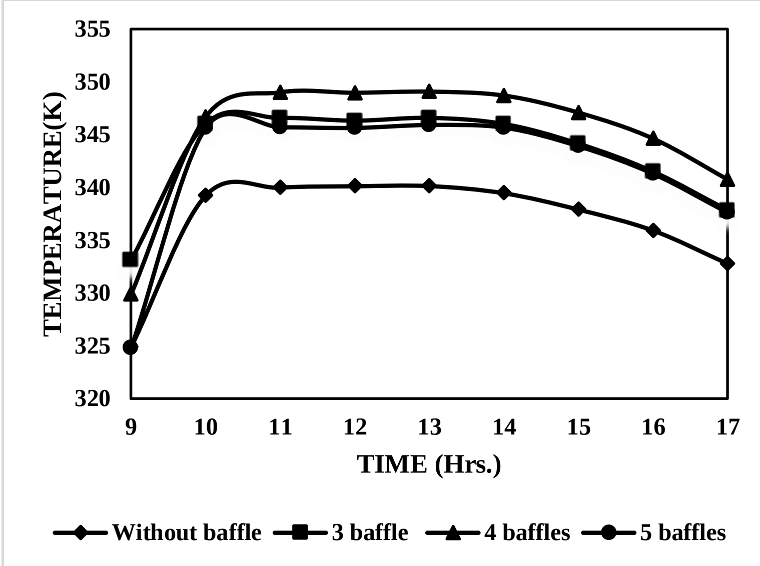

Figure 6. Temperature comparisons

Graphical representation of temperature distribution in solar air heater with and without baffle plates was shown in Figure 6. The temperature at the outlet of air heater with 4 baffle plates was 7 to 8ºC greater than without baffle plates. This temperature difference was due to increase in turbulence with addition of baffle plates. The solar air heater with four baffle plates was manufactured for experimentation.

Air Flow Domain:

Figure 7 defines the velocity streamline of air flow through solar air heater with and without turbulence respectively. From figure it seems that, because of baffle plate's air flows in turbulent manner with gives higher air temperature than without baffle plate.

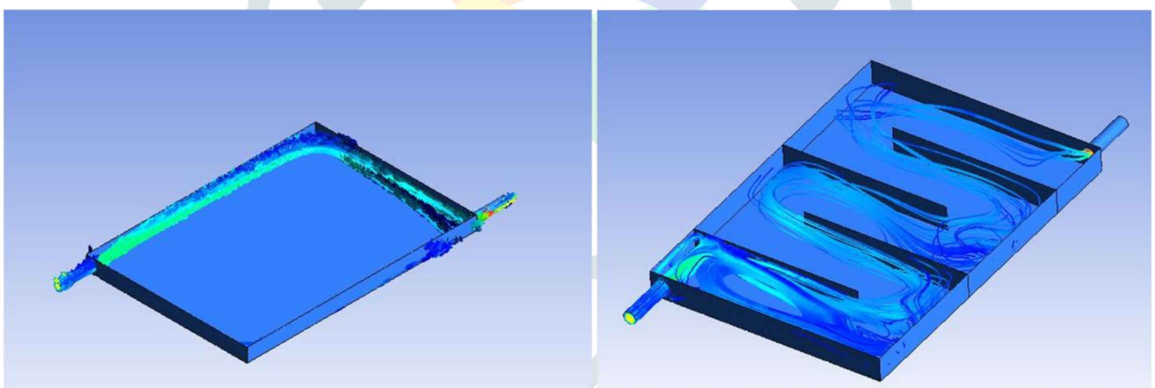

Figure 7. Air Flow Domain of Solar Air Heater

Effect of mass flow rate:

From above figure 6, it was finalized that 4 baffles were used for turbulence, so all the simulations performed for 4 baffles. Simulations were carried out at various mass flow rates as 0.013775, 0.021, 0.025, 0.0325 Kg/s. Figure 8 shows that graph of temperature v/s mass flow rate, it seems that as mass flow rate increases then outlet temperature will decreases. As the mass flow rate is increases then it will gives the cooling effect in the solar air heater as compared to low mass flow rate. Temperature at the outlet will gradually decreases with increase in mass flow rate. Decreasing temperature affect the efficiency of air heater.

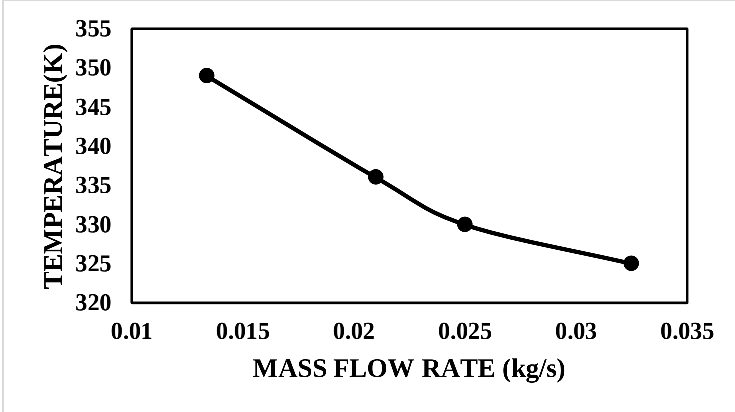

Figure 8. Temperature v/s Mass flow rate comparison at air heater outlet

3) EXPERIMENTATION OF SOLAR DRYER:

In the experimentation of solar dryer, super sonaka grapes were used in the dryer as test sample. Two experiments were performed in the month of April 2019 for with and without turbulence provided in the air heater. Before experimentation, pretreatment is required for reducing drying time of grapes. Bunches of grapes were dipped into solution 2.0% dipping oil and 2.5% K_2CO_3 at ambient temperature for 5 min. After pretreatment process, bunches were cut into small bunches and equally spread on the five trays. Temperature at various locations such as air collector inlet and outlet, drying chamber inlet and outlet, ambient air temperature were noted after every one hour from 9 am to 5 pm of each and every day during experimentation. Weight loss of the sample was measured at the end of every day. As per the result of CFD simulations, mass flow rate 0.013775 Kg/s (velocity 2m/s) was set for experimentation.

Figure 9. Experimental Set-up

4) RESULT AND DISCUSSION:

Experiment was performed according above mentioned method for drying of grapes to produce raisin. Considering eight sunshine hours per day (9 am to 5 pm), seven days required for without turbulence and six days required for turbulence with four baffle plates in solar air heater. Graphs were plotted for variation in solar intensity, reduction in weight of grapes against drying time. These samples were tested in the laboratory for their nutritional quality, chemical properties (moisture) and sensory qualities (colour).

Figure 10. Result of First trial without baffle Plates

Figure 11. Result of First trial with 4 baffle Plates

Weight Reduction:

During the experimentation, weight reduction of grapes was measured against time with constant air flow rate 0.0137 kg/s (2 m/s velocity). Variation in the weight reduction with and without turbulence was recorded during experimentation. . Graphical representation of reduction in the weight of grapes with and without turbulence shown in figure 9. Hot air removes the moisture content from the grape berries which affect to reduce the weight of grapes for producing raisins. Trial No. 1 requires 56 hours and reduced moisture content 80% to 20% whereas Trial No. 2 reduces moisture content 80% to 16% within 48 hours.

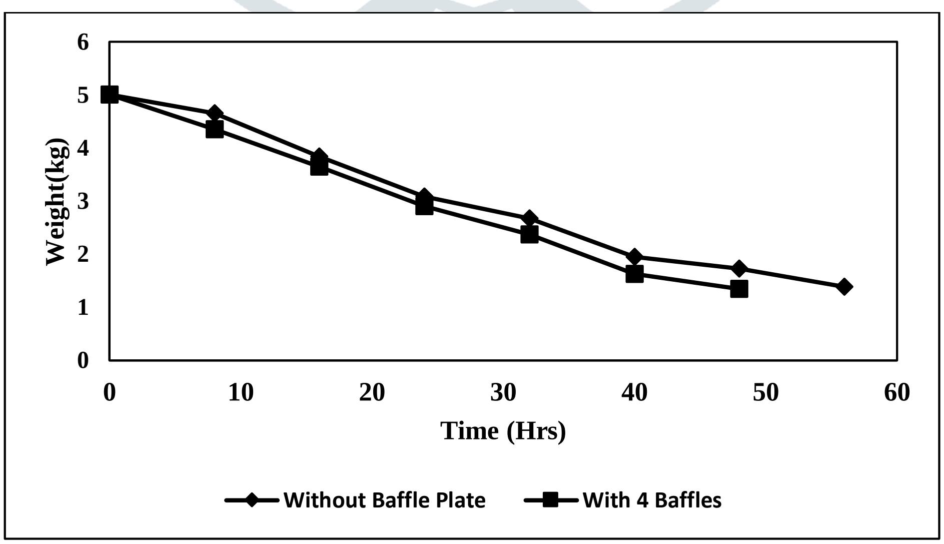

Figure 12. Weight reduction of grapes

Experiment was performed seven numbers of days for without turbulence and six days with turbulence. During the experimentation, weight was measured at the end of day, and temperatures were recorded every hour. Solar intensity was measured with the help of pyranometer from 9 am to 5 pm and recorded in the data logger. This data was potted against hours of per day. Maximum solar irradiance measured by pyranometer was at the peak hours of the day (11.30 am to 3 pm) which was varies from 850 to 1021 w/m^2.

Validation:

Experimental and numerical analysis results of temperature variation with and without turbulence were compared and validated with research article of Pardhi and Bhagoria [12] as mentioned in figure 10. There is good agreement between the both results with an average 9.47% deviation between numerical and experimental results.

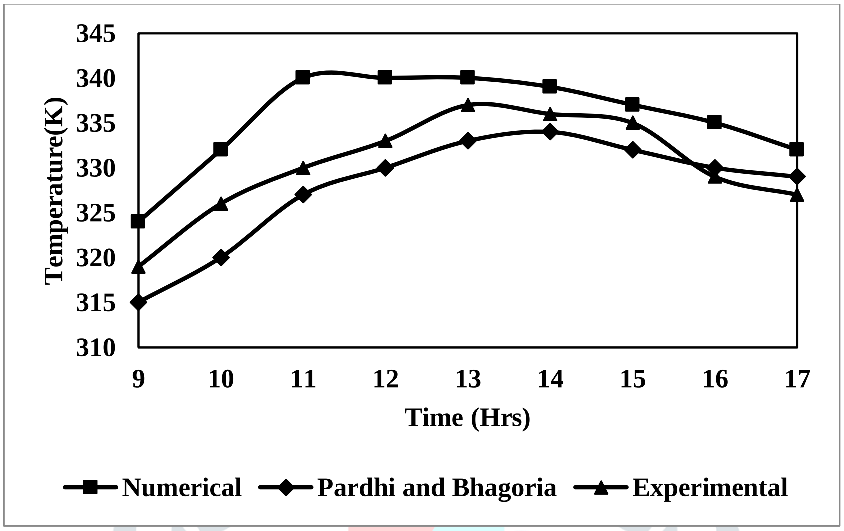

Figure 13. Validation for without turbulence

CONCLUSION:

Designed and developed forced convectional solar dryer was performed successfully with numerically as well as experimentally. In this solar dryer pretreated grapes were dried and produced raisins from them. Various effects such as solar intensity, mass flow rate, temperature of air collector, turbulence effect has calculated.

From this present work following conclusions have been arrived from numerical and experimental investigation of solar dryer.

- Numerical analysis states that solar air heater with turbulence gives 7 to 8ºC higher temperature than without turbulence which was validated with experimental performance.
- Designed Solar dryer with turbulence requires 48 sunshine hours for final product which was less than traditional methods and having good quality.
- Turbulence induced in terms of baffle plates in the air collector gives better results in form of increased air temperature and high drying rate as compared to without turbulence.
- Designed solar air heater with turbulence having 5.75% increased efficiency than without turbulence. Similarly drying chamber has 1.49% increased efficiency.

REFERENCES

1. J. Ehiem, S. Irtwange, S. Obetta, et al., Design and development of an industrial fruit and vegetable dryer, Research Journal of Applied Sciences, Engineering and Technology, vol. 1, no. 2, pp. 44{53, 2009.
2. D. R. Pangavhane, R. Sawhney, and P. Sarsavadia, Design, development and performance testing of a new natural convection solar dryer, Energy, vol. 27, no.6, pp. 579-590, 2002.
3. D. Pangavhane and R. Sawhney, Review of research and development work on solar dryers for grape drying, Energy conversion and management, vol. 43, no.1, pp. 45-61, 2002.
4. A. Lingayat, V. Chandramohan, and V. Raju, Design, development and performance of indirect type solar dryer for banana drying, Energy Procedia, vol. 109, pp. 409-416, 2017.
5. J. Singh, Review paper of study on solar dryer, Journal of Mechanical and Mechanics Engineering, vol. 1, pp. 14-24, 2015.

6. O. Prakash and A. Kumar, Historical review and recent trends in solar drying systems, International journal of green energy, vol. 10, no. 7, pp. 690-738, 2013.
7. A. El-Sebaii and S. Shalaby, Solar drying of agricultural products: A review, Renewable and Sustainable Energy Reviews, vol. 16, no. 1, pp. 37-43, 2012.
8. A. ELkhadraoui, S. Kooli, I. Hamdi, and A. Farhat, Experimental investigation and economic evaluation of a new mixed-mode solar greenhouse dryer for drying of red pepper and grape, Renewable energy, vol. 77, pp. 1-8, 2015.
9. S. Chaudhari, M. Makwana, R. Choksi, and G. Patel, Cfd analysis of solar air heater, International Journal of Engineering Research and Applications, vol. 4, pp. 2248-2247, 07 2014.
10. M. Hossain and B. Bala, Drying of hot chilli using solar tunnel drier,Solar Energy, vol. 81, no. 1, pp. 85-92, 2007.
11. M. S. D. Shaikh, R. Yadav, S. Sheikh, M. S. D. Shaikh, R. Yadav, and S. Sheikh, Study on performance evaluation of forced convection solar dryer for turmeric (curcuma longa l.), International Journal, vol. 4, pp. 30-39, 2017.
12. R. Gopi, Experimental investigation of at plate collector with cylindrical in a solar air heater,J Indus Pollut Control, vol. 33, no. 2, pp. 1128-1131, 2017.
13. A. Benhamou, F. Fazouane, and B. Benyoucef, Simulation of solar dryer performances with forced convection experimentally proved, Physics Procedia, vol. 55, pp. 96-105, 2014.
14. C. B. Pardhi and J. L. Bhagoria, Development and performance evaluation of mixed-mode solar dryer with forced convection, International journal of energy and environmental engineering, vol. 4, no. 1, pp. 23, 2013.
15. G. Singh Bagga and S. Kumar, Analysis of at plate solar air collector in different convection mode with induced turbulence, International Journal of Engineering Research and, vol. V5, pp. 488-494, 07 2016.
16. M. N. Musembi, K. S. Kiptoo, and N. Yuichi, Design and analysis of solar dryer for mid-latitude region, Energy procedia, vol. 100, pp. 98-110, 2016.
17. A. Vyas and D. Shringi, Cfd based thermal efficiency analysis of solar air heater with smooth plate and perforated plate, Imp. J. Interdisc. Res, vol. 3, pp. 415-422, 2017.
18. C. Zidani, Cfd simulation of thermo-aeraulic _elds in a channel with multiple baffle plates, Journal of Thermal Engineering, vol. 4, no. 6, pp. 2481-2495, 2018.
19. J. Lopez, N. Anand, and L. Fletcher, Heat transfer in a three-dimensional channel with baffles, Numerical Heat Transfer, Part A Applications, vol. 30, no.2, pp. 189-205, 1996.
20. P. Ingle, A. Pawar, B. Deshmukh, and K. Bhosale, Cfd analysis of solar at Plate collector, International Journal of Emerging Technology and Advanced Engineering, vol. 3, no. 4, pp. 337-342, 2013.
21. A. S. Husainy and P. Kulkarni, \Performance analysis of a solar grape dryer with thermal energy storage by pcm, Int. Res. J. Eng. Technol, vol. 2, pp. 54-60, 2015.
22. N. Ramesh, M. Paschapure, N. Nippanikar, S. Karigoudar, J. Nataraj, and K. Badarinarayana, Performance studies of sustainable solar dryer for drying agricultural products, Indian Journal of Science and Technology, vol. 9,pp. 45, 2016.
23. A. Mani, Handbook of solar radiation data for India," Resonance, pp.1082-1086, 2008.