Numerical Analysis of Solar Air Heater using CFD

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Abstract-In rural sector, non-renewable energy sources are very costly or expensive for drying agricultural products. Using solar energy for drying of agricultural products is more efficient and effective and solar energy is easily available energy source. As it seems number of researchers have done the improvements in the air heater using different technologies therefore this was an attempt to develop an effective technology for drying of agricultural product and evaluated its performance for drying grapes to produce raisins. Using convection forced technique, solar dryer is going design and develop. In this paper convection forced technique air heater is designed and its performance is tested using ANSYS FLUENT R17.1 Academic.

***Keywords*- Solar air heater; Turbulence; baffle plates; CFD; Solar drying**

I.Introduction

In India though solar energy is abundantly available, there is less attention towards its effective utilization. Over an average 3000-3200 hr./ year sun shines in India which was delivering 2000 kWh/m^2-year of solar radiation on the horizontal suraface of earth[4].Though the technology is present which depends on it, the efficiency of such systems is very less. There should be some improvements in available techniques and there should be research to develop the new technology. 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[2].

The common method is used to drying was sun drying in various countries all over the world for agricultural and aligned products. In a rural sector, various agricultural products were dried with open sun drying method which affects the quality of the pruduct due to climatic conditions and attack of dust, rain, dirt, animals,insects and other micro organisms. Use of solar energy for drying agricultural products will reduse the use of various fossile fules,which helps to reduse pollution[2]. Drying under the required climate condition helps to save the critical losses in quality and quantity of the product. Solar dryers were used over a large renge for superior energy efficient choice in the developing countries. Solar drying is an alternative method used for drying which gives various benifits over open sun drying and it has been developed for various agricultural crops for drying process.

Grapes are one of the popular and tasty fruits in the world. In various parts of the world, preservation of grapes by drying is an imerging industry, where grapes are cultivated. The grapes werre dried to produce raisin by using open sun drying, shade drying or mechanical drying. The production of raisins is a very important export business in many countries[3]. In India raisin having increasing demand because of its sweet teste, nutritional values and healthy effect on human body. Various variety of grapes are produced in India according to geographical conditions and varirty of grapes. 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. For raisin production in India, Thompson Seedless and its sub variation (Sonaka, Tas-A-Ganesh, Manik Chaman) are mainly used for raisin production.

II.Design of Solar Dryer:

Solar dryer having solar flat plate collector, centrifugal air blower, connecting pipes, drying chamber and stands for support. The absorber plate was made from an aluminum sheet (2 mm thick and 2m × 1.4m × 0.15m in size) which was fixed in the air heater which was made up of plywood through which air is passed. Glass plate (5 mm thick, 2 m ×1.40 m in size) was fixed on the frame of the absorber surface. Galvanized iron angles and screws are used to fit the glass sheet on the frame. For connecting the collector outlet to the inlet of dryer chamber, a connector made from plastic pipe (stable up to 200°C) was provided. Centrifugal blower was used to force the air through solar air heater, orifice meter is fitted with manometer at the outlet section of blower to measure the air flow rate through the blower outlet and flat plate solar air heater inlet.

The reducer was used to connect the outlet of the blower to inlet of solar air heater with plastic pipe and collector outlet to inlet of drying chamber by plastic pipe. The cross section of the reducer was increased gradually from inlet to outlet, which helps in maintaining the uniform distribution of air in the drying chamber. In the dryer cabinet, arrangement was made to keep two number of trays on which small grapes bunches were placed on the tray to produce raisin. Analysis of air heater was done by using baffle plates and without baffle plates. Results were compared with plate and without plate.

A) Design of drying chamber:

The amount of moisture removed from the grapes, Mw (kg) was calculated by using the following equation.

$$m_w = m_p \frac{m_i - m_f}{(100 - m_f)} \qquad (2.1)$$

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.

$$Q = m_w \times h_{fg} \quad (2.2)$$

$$h_{fg} = 4186\,[597 - (0.56 * T_{pr})]$$

Q = 9243.9136 KJ.
We are giving this "Q" amount of heat to the water content in grapes with the help of the collector.
Mass of Air Required:-

$$m_a = \frac{m_w}{(w_o - w_i) * t} \quad (2.3)$$

Where $m_w =$ amount of moisture to be removed in Kg.
w_o = outlet humidity of air from heater.
w_i= humidity of air inlet to heater.
t = time in hours/day.
m_a =47.43 Kg/hr or 0.01378 Kg/s.

B) Solar air heater design :
Total heat energy required (KJ.)

$$E = m_a(h_f - h_i)t_d \quad (2.4)$$

Where m_a = mass flow of air in Kg/ hr.
h_f= final enthalpy of air.
h_i= initial enthalpy of air.
t_d= drying time for one day in hours.
E = 14039.28 KJ
For solar collector area,

$$E = A_c \times I \times \eta \quad (2.5)$$

Where A_c = solar collector area in m^2
$I =$ Total global radiation = 20000 KJ/ m^2/ day (taken the average values)
η = collector efficiency = 25 % (assumption)
14039.28 = A_c ×20000 ×0.25
A_c = 2.80 m^2.

Using this collector area, mass of air, diameter of inlet and outlet pipe is calculated as follows,

$$m_a = \rho A v \quad (2.6)$$

Therefore, diameter of pipe, **d= 0.06757m 67.57 mm.** standard size of pipe available in market **3 inch (76mm or 0.076 m)** is selected for inlet and outlet of heater.

Baffle plates are used to create turbulence in the air heater for increase the efficiency of collector. Three suitable baffles are made up of aluminum material used for turbulence which are equally spaced in the air heater. Dimensions of baffle plate is 1m*0.15m*2mm (length*height*thick)

Table 2.1 Dimensions of Air heater.

Length(m)	Width (m)	Height (m)	Diameter of inlet and outlet pipe(m)
2	1.40	0.15	0.076

C) Blower Selection:

Blower is used for forced convection. Specification of blower is as follows,
CFM- 500, RPM- 1440, Motar Rating – 0.5 Hp.

III. NUMERICAL ANALYSIS OF SOLAR AIR HEATER

This chapter deals with the design and numerical analysis of solar air heater to predict the thermal performance of collector. ANSYS Fluent 17.1 Academic was used as CFD solver in present study. To different collector models that are with baffle plate and without baffle plates are tested for this work.
Governing equations are given as follows:
Continuity equation:

$\rho\partial u\partial x + \rho\partial v\partial y + \rho\partial w\partial z = 0$ (3.1)

Momentum equation:

$\partial\partial x\,(\rho U) + \nabla\cdot(\rho UU) = -\nabla P + \nabla\tau + B$ (3.2)

Energy Equation:

$\rho Cp\,(V.\nabla)\,T = k\nabla^2 T$ (3.3)

3.1 CAD modeling of solar air heater

The preliminary design of the solar air heater is done in Solidworks by considering all the dimensions listed in Table 2.1.Geometry was constructed in SolidWorks and was meshed using ANSYS Meshing modular. Baffle plates are used to create turbulence on the air heater to increase the efficiency of collector. Baffle plates are placed in the air heater to create turbulence.

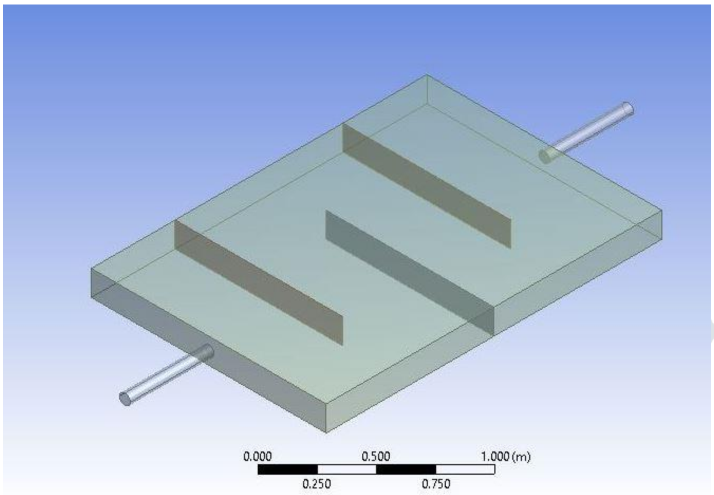

Fig. 3.1 Geomerty of solar air Heater

3.2 Meshing 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. Following Fig. 3.2 shows the meshing of the air heater.

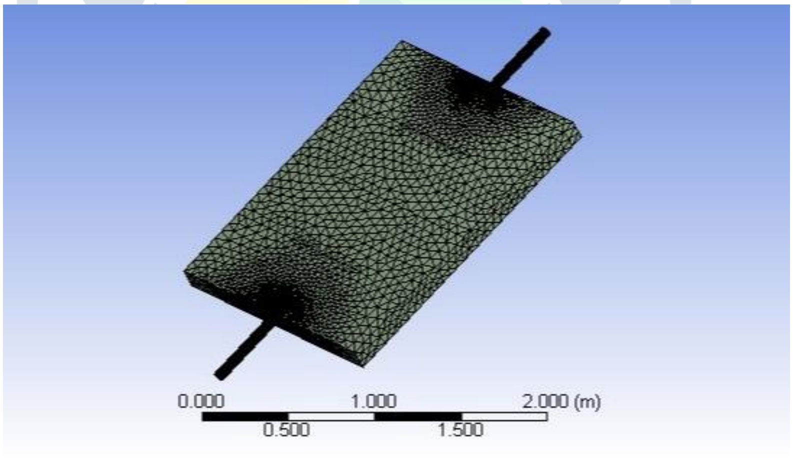

Fig.3.2 Meshing Domain of air heater

Table 3.1 Mesh Count

Nodes	Element
34497	176882

3.3. Boundary conditions:-

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

Table 3.2 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	303
2	Outlet	Outflow	-	-
5	Wall	-	No slip condition	-

3.4 Solver settings

The solver used for the analysis is 3D- Pressure based solver with standard K-ω model and energy equation was also activated. In the radiation setting, Rosseland model is activated. For solar load, solar ray tracing model is used in which solar calculator setting is done for this work. In the solar calculator global position was set at Islampur, District-Sangli (Maharashtra) 74.26º longitude and 17.05º latitude at time zone +5.30GMT. The fluid properties and boundary conditions are specified. The SIMPLE algorithm for pressure-Velocity coupling was used. The second order upwind scheme was used for pressure, momentum, turbulent kinetic energy, Specific dissipation rate and energy.

IV.RESULT AND DISCUSSION

4.1 Temperature profile:

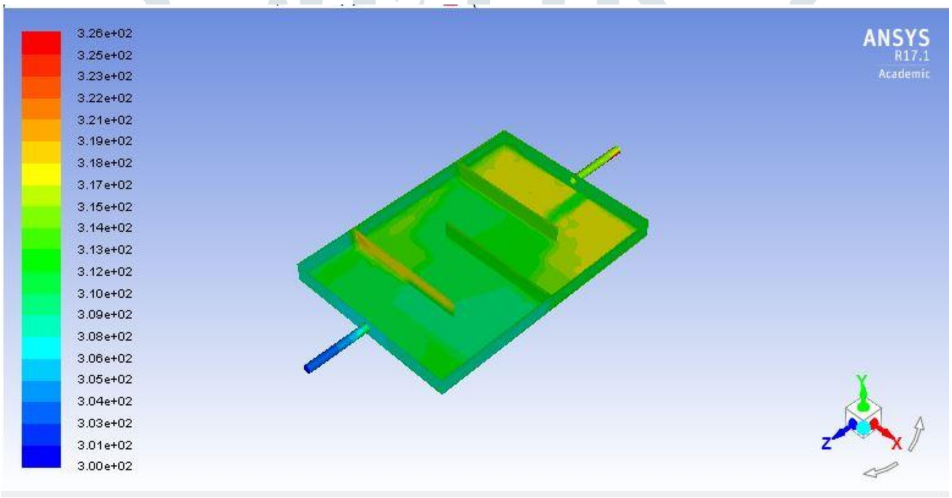

Fig.4.1 Temperature distribution of solar air heater

Fig. 4.1 shows Temperature distribution in solar air heater with baffle plates. This shows that uniformity of temperature has been achieved in solar air heater. Temperature in the air heater is gradually increasing as compared to without baffle plate air heater.

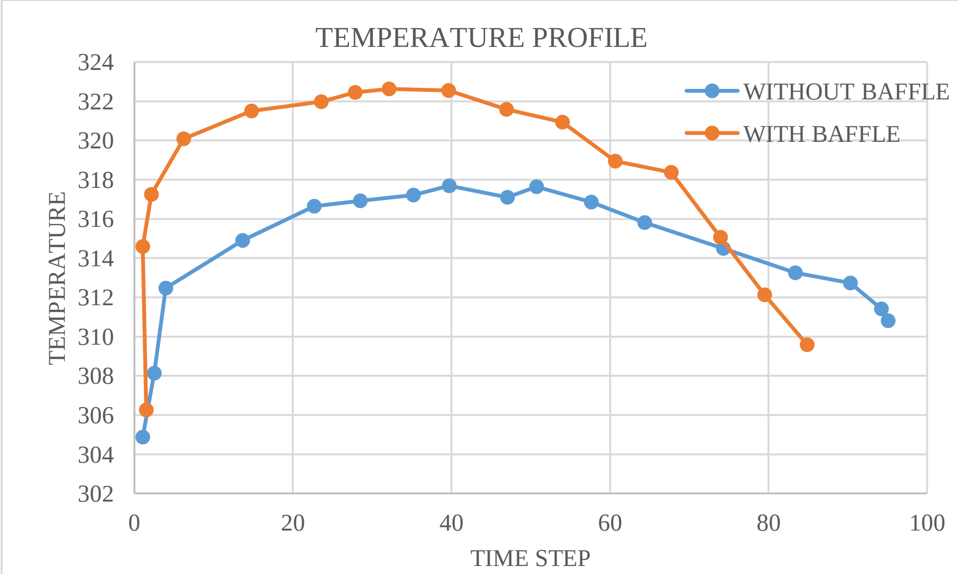

Fig 4.2 Air outlet Temperature

During the analysis of air heater with and without baffle plate, variation of outlet air temperature were plotted in Fig 4.2. From this figure, it is observed that air temperature rise due to turbulence in the air heater. Temperature profile shows that, with baffle plate heater air outlet temperature is greater than without baffle plate. It shows that this solar air heater is suitable for drying of agricultural products.

4.2 Effect of turbulence:-

If the turbulence was created in the solar air heater then because of turbulence effect, temperature of outlet is increased as compare to without turbulance air heater. Difference between the outlet temperatures of both air heater is observed in the renge of 5 to 8º C.

V. Conclusions

In this forced convectional solar air heater which is designed is capable to create high temperature difference of 18 to 20º C which is validated by using CFD tool. This system is capable to producing highly dried raisins from grapes with low cost and high effectiveness. As the result shown, time requirement for producing raisin by using this forced convective solar air heater is less as compare to previous research available.

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