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Simulation of solar biomass hybrid dryer for drying cashew kernel

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ABSTRACT

Cashew processing industries are mostly located in rural areas. Especially in and around cuddalore district, Tamilnadu, India, there are many industries using conventional methods for drying of cashew kernels without knowing the advance method of solar drying techniques. The solar dryer performance is mainly depending on the uniform distribution of temperature flow field inside the dryer. In this study a solar biomass hybrid dryer was constructed and experimentally tested without any trays and any load. The temperature distribution of air flow inside the dryer was performed with Solidworks 2014 SP4.0 .The experimental data's was used for the boundary conditions. The simulation results show that the results might be acceptable when compared with the experimental value.

Key words: Cashew kernel, Hybrid dryer, Solidworks 2014 SP4.0, Simulation, temperature distribution.

INTRODUCTION

India is the largest producers and processor of cashews in the world. The total area in India under cashew cultivation is about 868000 ha with annual production of 665000 tonnes giving an average productivity of 860 kg/ha [1].In Tamilnadu state has a total of 417 cashew processing units which produces an average of 41225 metric tonnes of raw cashew nut per annum. [2] Processing of cashew involves drying of raw nuts, steaming, shelling, drying of the kernels, peeling and grading out of which drying of the kernels is the energy intensive process. This process needs a temperature 65-70°C around 4-6 hours to reduce moisture content from 9-3% [3].

Simulation modeling studies are needed for the efficient design and operation of dryer. The predictions of airflow, temperature use and humidity inside the dryer helps to design most suitable geometric configuration of the dryer. Nowdays given the increase in computing power, the application of simulation tools can be valuable for engineering design and analysis of complex system

Dhanushkodi.S et al., studied thermal performance of solar biomass hybrid dryer for cashew drying they are concluded that the dryer can be operated in any climatic conditions; as a solar dryer during normal sunny days, as a biomass dryer during night time and as a hybrid dryer during cloudy days and it is suitable for small scale cashew nut farmers in rural areas of developing countries. [4]

The performance of solar batch drying is affected by temperature of heated air and the collector surface area of the dryer whereas the dimension of the dryer and quantity of the dried product are less important. By using solar batch dryer of 3m² collector surface area and temperature at 50°C can dry 250kg of product per day [5]

Yunus et al. simulated a hybrid solar dryer by CFD tools under different operational modes. The velocity and temperature distribution inside the dryer is simulated using FLUENT software .The simulation results were validated by comparing with the experimental measurement. The results indicate that the solar with biomass backup heating gives the good results when compared to other operational modes [6]

Solar dryer box with ray tracing CFD Technique was analyzed by Akinola et al.in Nigeria. During the experiment it was found that the average collector temperature reaches over 67°C and drying chamber rack temperature shows 42°C. The simulation results showed that, the required temperature is achieved within very short exposure to sunrays. This showed that it can be used for regions where fewer hours of sunshine is available.[7]

Cristiana et al. have used CFD method to analyze the airflow inside a hybrid solar-electrical dryer. The dryer was tested experimentally without the trays and with no load. The simulation result showed that the velocity and temperature distribution is uniform in the solar collector and drying chamber. Also, the numerical results were good agreement with experimental results. [8]

Manoj et al. [9] simulated solar dryer utilizing green house effect for cocoa bean drying. In this study MATLAB based modeling was carried out to predict the velocity distribution of the dryer. The product obtained from the dryer would give good grades and meet international standards.

Suhaimi et al. [10] carried out a study to predict the drying uniformly in tray dryer system using CFD simulation. In this study the velocity of tray number 1,7,8 and 15 are having more velocity than other trays. The result showed that the average air velocity in the drying chamber is about 0.38m/s and the temperature is uniform for all the trays. Finally it was concluded that, this dryer is suitable for drying agricultural products.

Ratti et al. [11] designed a batch type-solar drying system. Its drying performance is predicted using drying rate, drying temperature, and moisture content, which are time dependent. This system allows for the shrinkage of particles. Air temperature is necessary to complete the drying process, and all its existing parameters are independent.

There are no precise references to the literature concerning numerical simulation of air flow and heat transfer in the intensity of dryer. The main objective of the present study is to investigate the temperature profile in experimental solar biomass hybrid dryer using Solidworks 2014 SP4.0 software.

- ✓ To optimise the design of drying chamber to achieve higher heat/mass transfer rate and uniform drying by avoiding an unfavorable aero dynamic phenomenon in the chamber
- ✓ To improve the design of existing drying system.
- ✓ To predict the drying time if connected to the thin film equation

MATERIALS AND METHODS

Mathematical model and governing equations.
Analytical solutions are only available for simple problems. They make many assumptions and fail to solve most practical problems. Finite Volume Method (FVM) is a general approach for both simple and complex problems. This method is among preferred methods for fluid phenomena modeling. SolidWorks Flow Simulation solves time-dependent Navier-Stokes equations with the Finite Volume Method (FVM) on a rectangular (parallelepiped) computational mesh. Computational domain is a rectangular prism where the calculation is performed. Computational domain's boundary planes are orthogonal to the Cartesian coordinate system's axes and envelopes the fluid volume inside a model.

The mass, momentum and energy conservation equations are given in a general form by equation (1)-(6)

Mass: $\frac{\partial \rho}{\partial t} + \mathrm{div}(\rho \mathbf{u}) = 0$ (1.1)

Energy: $\rho \frac{DE}{Dt} = -\mathrm{div}\,(pu) + \left[\frac{\partial(u\tau_{xx})}{\partial x} + \frac{\partial(u\tau_{yy})}{\partial y} + \frac{\partial(u\tau_{zx})}{\partial z} + \frac{\partial(v\tau_{xy})}{\partial x} + \frac{\partial(v\tau_{yy})}{\partial y} + \frac{\partial(v\tau_{zy})}{\partial z} + \frac{\partial(w\tau_{xz})}{\partial x} + \frac{\partial(w\tau_{yz})}{\partial y} + \frac{\partial(u\tau_{zz})}{\partial z}\right] + \mathrm{div}\,(k\ \mathrm{grad}\ T) + S_E$ (1.2)

x-momentum: $\frac{\partial(\rho u)}{\partial t} + \mathrm{div}(\rho u \mathbf{u}) = -\frac{\partial p}{\partial x} + \mathrm{div}\,(\mu\ \mathrm{grad}\ u) + S_{Mx}$ (1.3)

y-momentum: $\frac{\partial(\rho v)}{\partial t} + \mathrm{div}(\rho v \mathbf{u}) = -\frac{\partial p}{\partial x} + \mathrm{div}\,(\mu\ \mathrm{grad}\ v) + S_{My}$ (1.4)

z-momentum: $\frac{\partial(\rho w)}{\partial t} + \mathrm{div}(\rho w \mathbf{u}) = -\frac{\partial p}{\partial x} + \mathrm{div}\,(\mu\ \mathrm{grad}\ w) + S_{Mz}$ (1.5)

Convective heat and mass transfer modeling in the k – ε model is given by the following equation:

$$\frac{\partial}{\partial T}(\rho E) + \frac{\partial}{\partial x_i}\left[u_i(\rho E + p)\right] = \frac{\partial}{\partial x_i}\left[\left(k + \frac{C_p \mu_t}{Pr_t}\right)\frac{\partial T}{\partial x_i} + u_i(\tau_{ij})_{eff}\right] + S_h \tag{1.6}$$

The design model is 3-D, flow is compressible and steady in x and y direction. The body forces are neglected as the working fluid is gas

Simulation procedure.
A 3-D model of solar dryer geometry was created using solid woks version 2014 SP with a Pentium IV system, speed 2.0 GHz, 2GB ram and 520MB hard disk. Solidworks 2014 SP4.0 flow Simulation results provides sufficient practical information to identifying the low temperature spot of the system and consequently this will be useful for improvement of the dryer designs. Solidworks FloXpress does not consider heat transfer effects in solids. Solidworks FloXpress computes the correct temperature distribution in the fluid, but there is no option to view the result. Velocity, mass flow rate, volume flow rate, or pressure (static and total) boundary conditions are specified at models' inlets and outlets. Time-dependent Reynolds-averaged 3D Navier-Stokes equations using the k -ε turbulence model. Flow Simulation using Solidworks involves the following procedure. 3D model of the dryer is shown in Fig 1.1 .The following simulation procedures is used in this study.

- Creation of the solid work part model for the flow simulation
- Setting up the flow simulation project for internal flow analysis
- Setting up a 3D flow condition
- Initializing the mesh
- Applying boundary conditions
- Meshing the model. This is a series of automatic steps in which the code subdivides the model and computational domain into computational cells.
- Running the flow simulation and check for convergence.
- Visualize the temperature flow field.

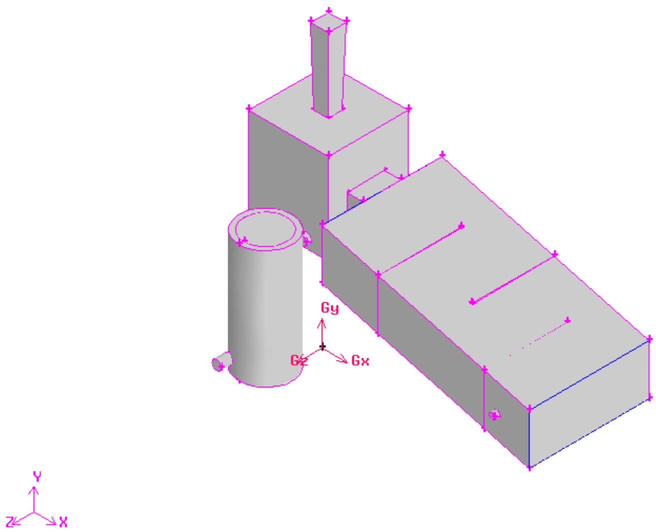

Fig. 1. 3D model of solar biomass hybrid dryer

RESULTS AND DISCUSSION

The experiments were performed on a prototype solar biomass hybrid dryer at PRIST University (India). The simulation was performed on empty chamber without the cashew kernel in both forced and natural convection mode. Temperature profile was presented according to the mode of drying from the unloading experimental results. The validation of the result was done by simulating the initial operating conditions of experimental measurement

Simulation for natural solar dryer
The simulation was carried out and the temperature distribution obtained for natural convection mode solar dryer is presented in Fig. 2. It can be seen that air enters into solar collector at an ambient temperature and being heated by solar collector. The temperature at the start of drying is equal to that of the ambient and increases towards the top of the collector. Since this temperature is higher than that in the ambient, it increases the thermal buoyancy. It could be seen that the highest temperature is concentrated at the top of the solar collector which is around 340 K to 348 K

.The heat was transferred from solar collector to the drying chamber by natural convection. The temperatures inside the drying chamber are in the range of 65-45°C, except for the top portion of the drying chamber. The bottom and middle portion of the drying chamber recorded the highest temperature around 338K since it is exposed to the high temperature air flow. However, as the location of the tray become farther, the temperature decreases due to the heat losses to the surroundings and to heat up the lower trays. The lowest temperature was spotted just above the top tray and it represents the exhaust air temperature which flow out of the dryer.

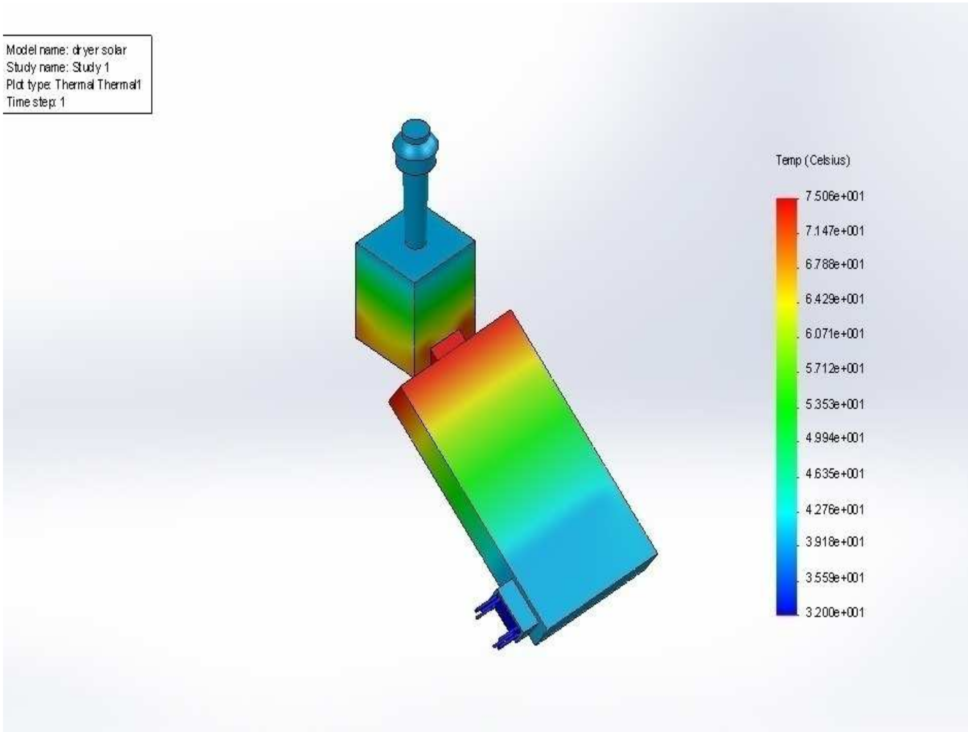

Fig. 2. Distribution of air temperature in natural convection solar dryer

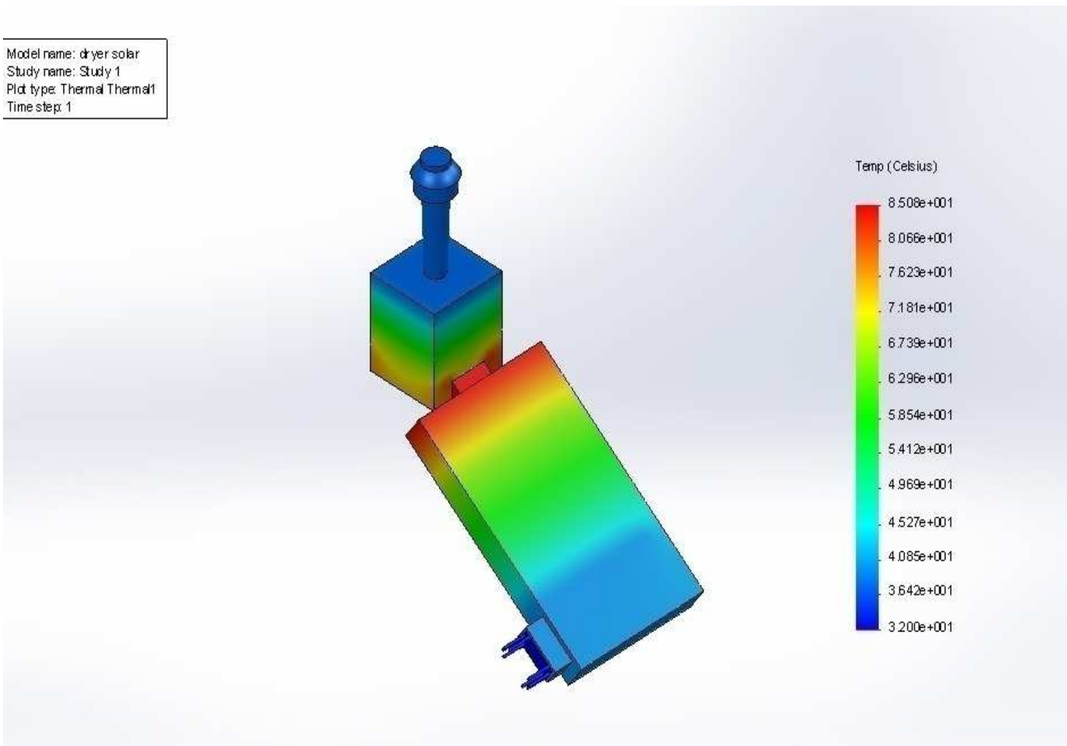

Fig. 3.Distribution of air temperature in forced solar dryer

Simulation of forced solar dryer

The temperature distribution inside the solar collector and the drying chamber in forced convection solar dryer is shown in Fig 3. The forced air from the blower enters into the inlet of the solar collector and it is distributed from the bottom to top of the collector and then to the drying chamber through a rectangular opening provided in between solar collector and drying chamber. The simulation result shows that temperature rises from 35-85°C across the solar collector. The higher temperature is observed at bottom of the drying chamber because in these regions the high temperature air is coming from the solar collector. In general the temperature changes more along and across the solar collector, than along and across the drying chamber. The hot air temperature in the drying chamber was in the range of 63-70°C.Temperature inside the drying chamber has an important role in the drying kinetics of the cashew. The difference of temperature among the portion of drying chamber is considered small and it can be assumed that the present design successfully achieved the reasonable uniform air temperature. Also it was observed that the temperature profile of exit air was well developed to affect drying; this indicates that the drying chamber length is capable of accommodating more trays without any significant drop in the temperature.

Simulation of forced solar biomass hybrid dryer

The temperature distribution of the solar biomass hybrid dryer is shown in Fig 4. It can be seen that, the required drying temperature 60-70°C was obtained in the drying chamber. It can be seen that the distribution of temperatures inside the drying chamber is almost homogeneous, excepting at the exit of the drying chamber, where lower temperatures of about 303 K, is obtained. The uniform temperature profile in the drying chamber could be as a result of additional controlled air heating through biomass backup heater. This temperature distribution is benefic, because it is expected to provide uniform drying and thereby avoiding different final moisture content of the products. The drying temperature obtained in this mode of operation is very much desirable for drying cashew kernel since it guarantees a high-quality and homogeneous drying process. The relative humidity of the drying air is also an important factor affecting the drying rate. With the increase in the drying temperature, relative humidity takes lower values. This enhances drying rate and therefore drying occurs in a short span of time with the increase of the drying temperature

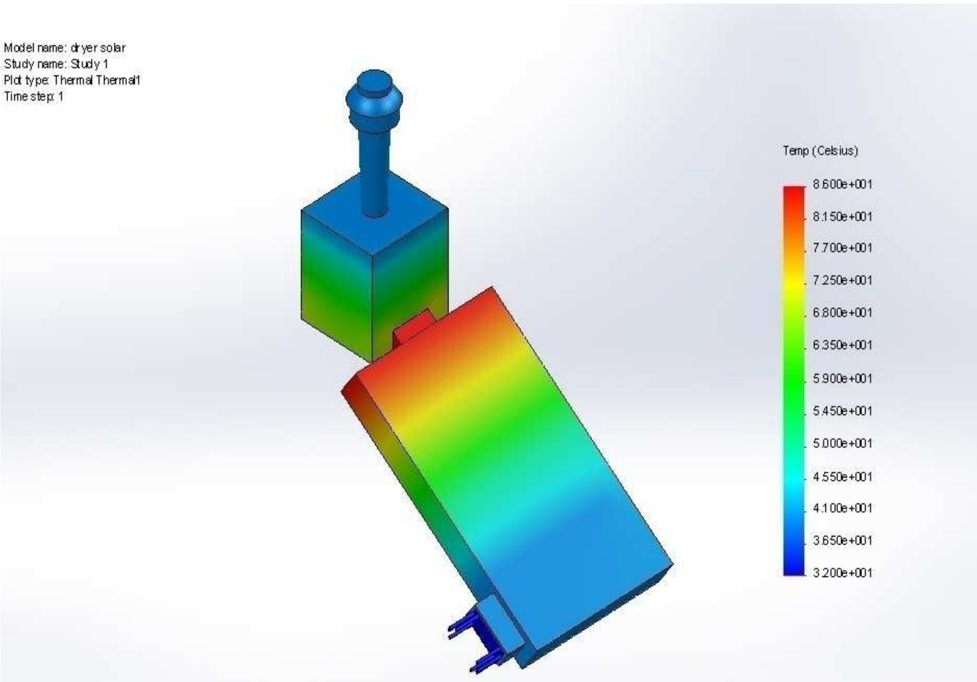

Fig. 4. Distribution of air temperature in forced solar biomass hybrid dryer

Comparison of experimental and simulation results

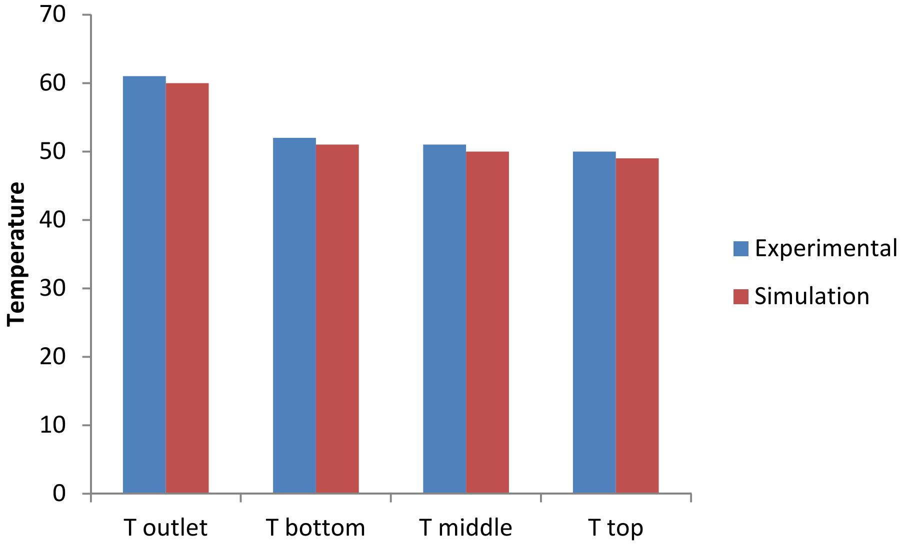

Fig. 5. Comparison of experimental and simulation results under Natural Solar mode

The comparison of experimental and simulation results in natural convection solar dryer are listed in Fig 5. The results indicate that the average temperature of drying air is in good agreement for the top, middle and bottom portion of the drying chamber, since the variation in average temperature is around 2%.

The percentage difference between the experimental and simulation results under forced solar dryer is shown in Fig 6. In this mode the numerically estimated mean temperatures results are slightly lower than the experimental results. The temperature obtained in simulation results vary from 4.1 % to 5.7%

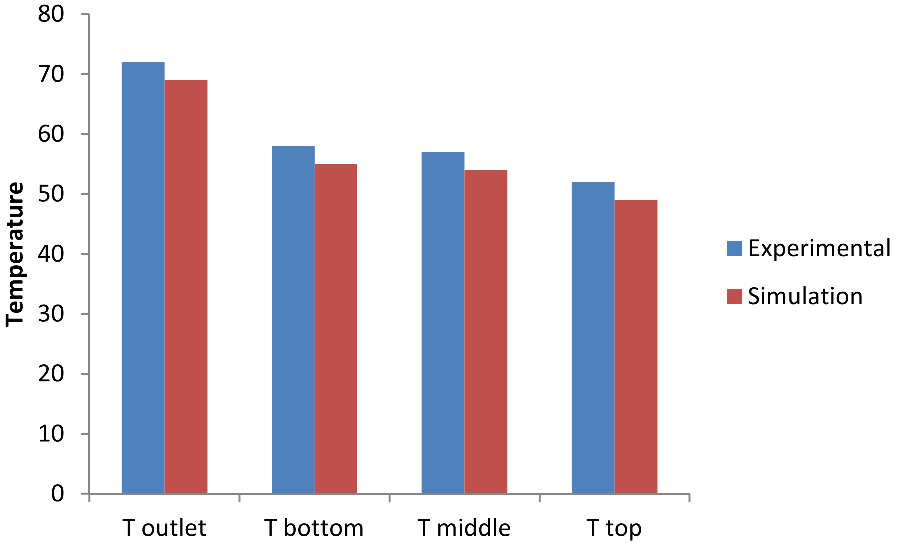

Fig. 6. Comparison of experimental and simulation results under Forced solar mode

The simulation and experimental results of solar biomass hybrid mode is shown in Fig 7. It indicates the temperature is more or less uniform in the drying chamber. In this mode the average temperature in the drying chamber is highest when compared to natural and forced solar dryer. The temperature variation in the simulation results is around 3 % . Hybrid mode is the most appropriate mode for drying application since it provides the highest temperature and falls within the required drying temperature range.

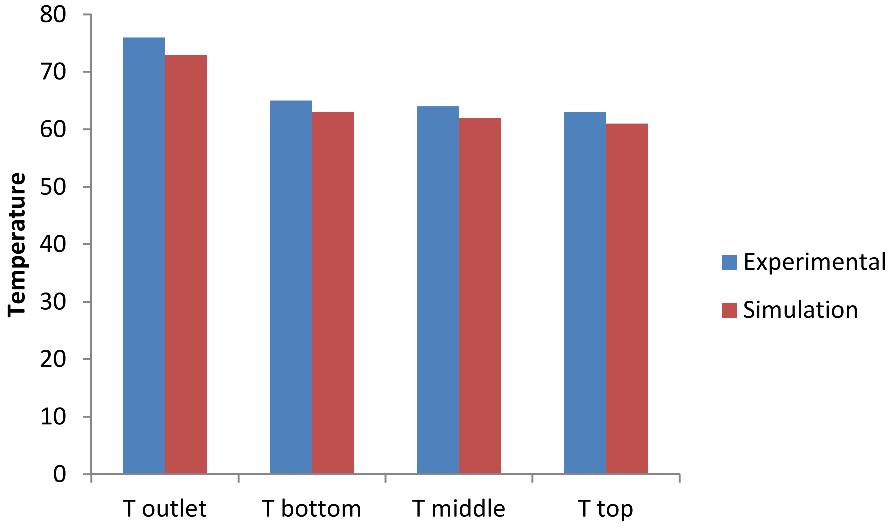

Fig. 7. Comparison of experimental and simulation results under Forced Hybrid mode

CONCLUSION

The objective of the simulation of the dryer is to find the most efficient design and operation mode for optimum temperature distribution. The numerical simulation of the temperature inside the solar biomass hybrid was performed with Solid works. Experimental data was used for the boundary conditions and numerical validation. The following key conclusions are made from the analysis.

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