MULTIDISCIPLINARY INNOVATIONS IN TECHNOLOGY AND SCIENCE JOURNAL
Vol. No. 01, Issue No. 01, April 2024, pp. 35-40

MITS JOURNAL
Multidisciplinary Innovations in Technology and Science Journal

A Study on Analysis of Solar Dryer using Computational Fluid Dynamics (CFD)

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Abstract: Solar dryer emerges as best eco-friendly method for drying or space heating purpose. Various researches had undergone in past to make the dryer more efficient in terms of drying time and less heat loss to the ambient. But still the researches are carried out to make it more efficient and compact. The application of software makes this easier. CFD is used to study the fluid flow inside the dryer so that the fluid dynamics inside the dryer can be better understood. The temperature variation and variation in flow velocity can be easily analyzed using CFD. The software (CFD) easily simulates the free stream flow of fluid and the interaction of fluid with other surfaces within the defined boundary conditions. The paper presents the previous studies on CFD analysis of solar dryer and also the procedure that can be adopted to carry out the CFD analysis of any system. This helps the readers in easily implementing the CFD for analysis of their developed systems.

Keywords: CFD, solar dryer, greenhouse, simulation, software

1 Introduction

The world population rises from 6 billion to 7.7 billion in last 20 years [1] and expected to reach 9.7 billion in 2050 [2]. With increase in population the quantity of food required to feed the people also increases. To produce the required quantity of food is not possible as agricultural land will also decreases with increasing population. So drying is the only method is to conserve the food materials [3]. Solar dryers are developed to dry the products especially the agricultural produce so that it can be stored for long duration.

Solar dryers are basically of three types namely direct, indirect and mixed mode on the basis of the way the dryer receives the solar radiation [4]. All the dryers operate on two modes only that are either on active or passive mode [5]. Hybrid dryers are developed to operate the dryer in off sunshine period as they uses some thermal energy storage material if operating on single source or operates using more than one sources like solar with biomass, LPG etc. [6].

The performance of dryers are still tried to improve by various researchers. Various modifications have been applied to the solar dryer like making north wall opaque for reducing heat loss [7], attaching flat plate collector to preheat the air before supplying to greenhouse chamber [8], using thermal storage materials to store the excess heat that can be utilized during nocturnal or off sunshine period [9], application of various software like CFD, ANSYS, TRNSYS, MATLAB, FORTRAN etc. to simulate the behavior of drying, using soft computing techniques like fuzzy logic, neural network and others to optimize the required variable affecting the drying etc. [10]. Fig. 1 shows the some modifications carried out by researchers.

The paper presents the application of computational fluid dynamics on solar dryers so as to simulate the drying parameters basically the air flow rate and the temperature at several points. This helps in detecting the points where the losses are occurring and helps in improving the performance of dryer.

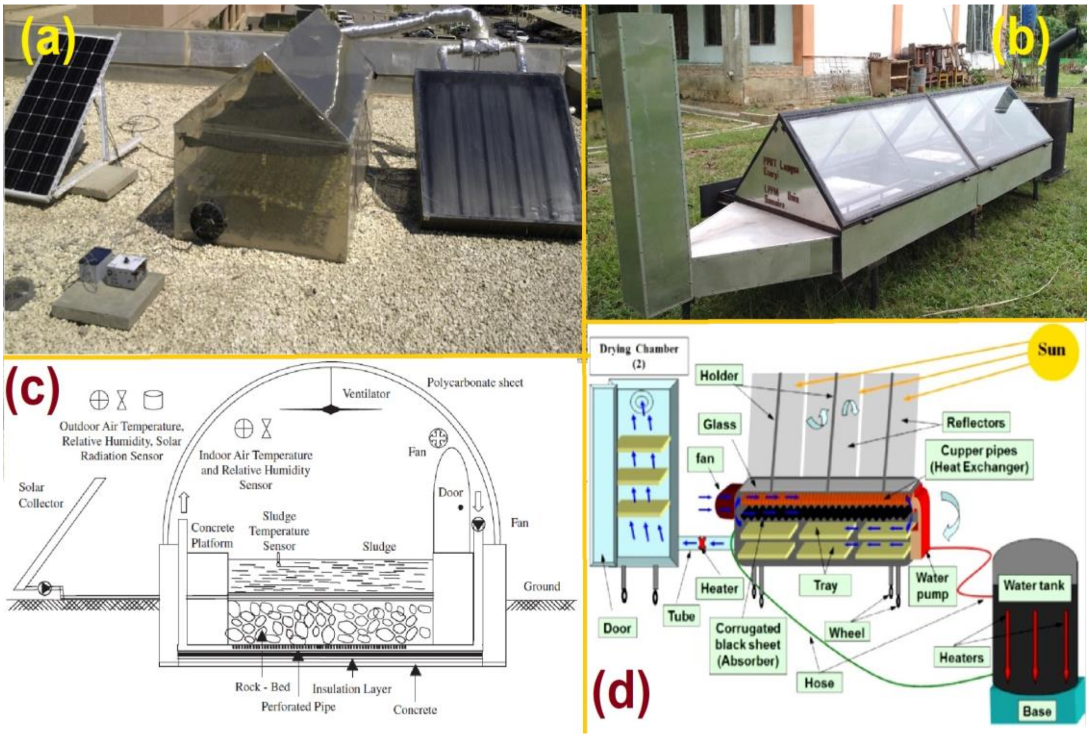

Figure 1 Modification on Greenhouse to improve its performance [11]–[14]

2 CFD Analysis of Solar Dryer

CFD is the tool to carry out the analysis of fluid flowing inside the solar dryers. The pattern in which the temperature of fluid is varying inside the dryer can be determined and also the variation in air flow rate and velocity can be simulated [15]. The CFD analysis helps in predicting the variations in temperature and air flow rate of fluid in advance without performing the experiment. The results obtained from simulation can be used to minimize the heat loss occurring from the dryer by detecting the points where the temperature and air flow rate is not as per the requirement. The steps involved in carrying out the CFD analysis of any system are shown in Fig. 2 by means of flow chart. The simulation is carried out by using equations of energy, momentum and heat and mass transfer [16].

In solar dryers, CFD simulation of heat and mass transfer taking place inside drying chamber can be carried out by solving three dimensional mass momentum and energy equations. The solution of these governing equations are obtained by applying the boundary conditions and selecting the kind of flow taking place whether it is transient, laminar or turbulent flow. For incompressible flow, the partial differential equations of the governing equations are given by Eq. 1 to Eq.3. [17], [18]

Continuity Equation

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \bar{u}) = 0 \tag{1}$$

Energy Equation

$$\frac{\partial (\rho E)}{\partial t} + \nabla \cdot \left(\bar{u}(\rho E + P)\right) = \nabla \cdot \left[\lambda_{eff} \nabla T - \sum_j H_j J_j + \left(\bar{\tau}_{eff} \bar{u}\right)\right] \tag{2}$$

Momentum Equation

$$\frac{\partial(\rho\bar{u})}{\partial t} + \nabla\cdot(\rho\bar{u}\bar{u}) = -\nabla P + \nabla(\bar{\tau}_{eff}) + \rho g\beta(\bar{T}_0 - \bar{T}) \quad (3)$$

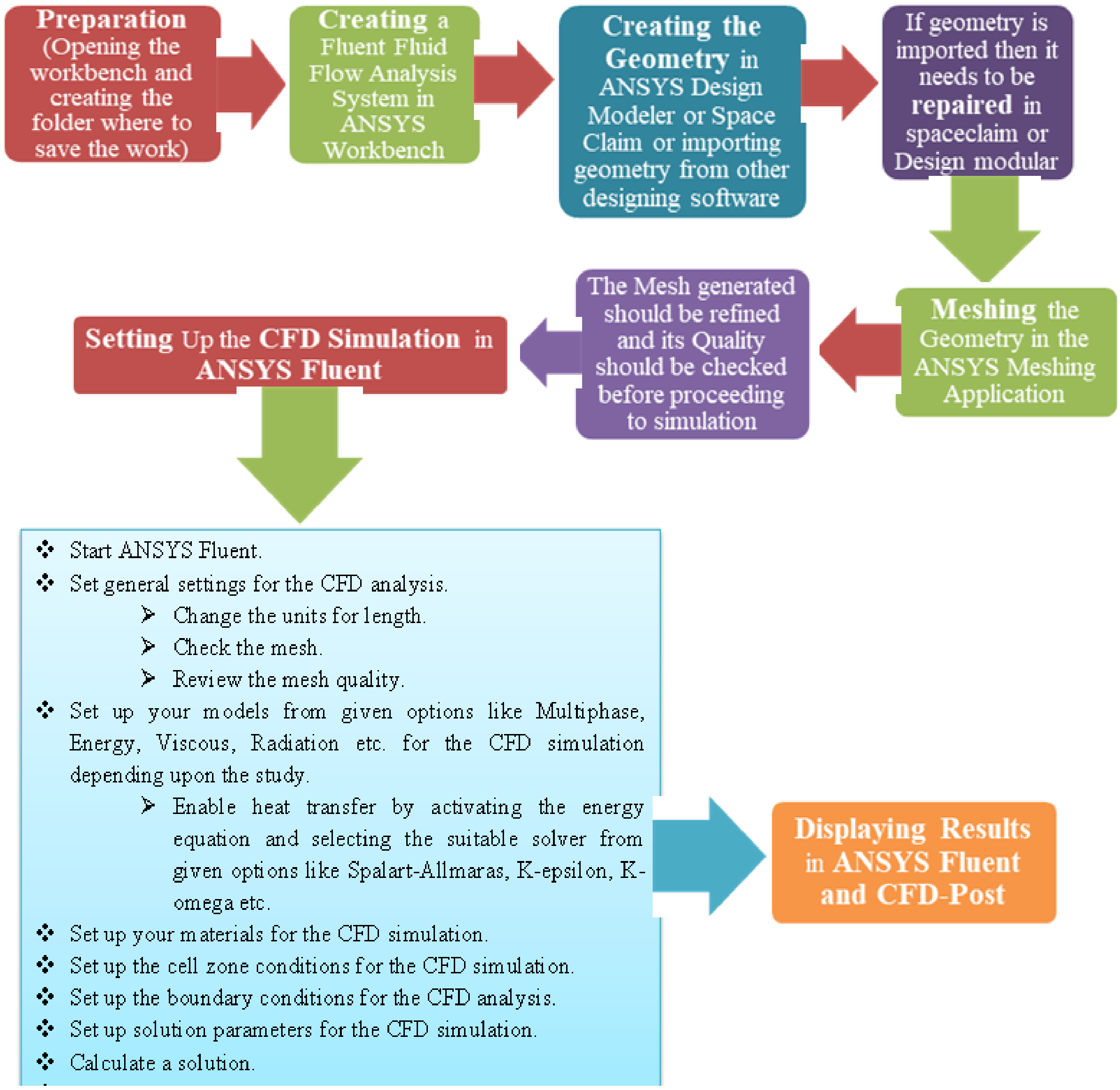

Figure 2 Steps involved in CFD simulation of any system

Mathioulakis et al. carried out the simulation of industrial tray dryer for drying fruits. Simulation was carried out by considering three boundary conditions namely no-resistance, assuming wall shear stress and fixed mass inflow. CFD Fluent was used to optimize the drying process in each tray. The result obtained from CFD and experimentation showed the good correlation [19].

Bartzanas et al. studied the effect of vent provided for air circulation in a tunnel type greenhouse dryer. CFD Fluent V.5.3.18 software was used to determine the effect of ventilation through airflow and temperature distribution pattern. 3-D sonic anemometer was used to record the airflow variation and tracer gas method was used to record the ventilation flow rate. The average air velocity varies from 0.2 to 0.7 m/s inside the drying chamber. The CFD analysis helps in placing the ventilation holes for proper circulation of air [20].

Sonthikun et al. carried out the CFD analysis of biomass integrated hybrid dryer constructed for drying natural rubber sheets. CFD analysis gives slightly more value of temperature than experimental values due to non-consideration of moisture transport occurring inside dryer. The k-ϵ turbulent model was used to simulate the flow of air. The value of R2 was 0.98 which shows the closeness in experimental and predicted values. The path lines of air flow obtained through CFD analysis is shown by Fig. 3.

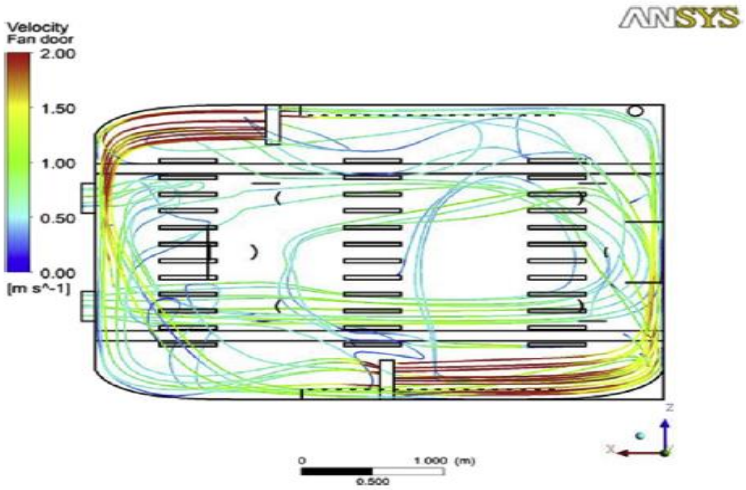

Figure 3 Air flow rate distribution inside dryer [17]

Chen et al. used the CFD software for analyzing the photo-catalytic solar dryer. For analysis of fluid flowing inside the dryer, Reynolds-averaged equation of continuity and momentum was used. Turbulence intensity was considered 10% for inlet stream and at walls; no-slip boundary conditions were used. To achieve better result, the meshing of geometry was done using hexahedral shaped 600,000 cells. SIMPLE algorithm was used to solve the difference equation of pressure-velocity coupling of N-S equation [16].

Krawczyk and Badyda applied CFD analysis in greenhouse active dryer constructed for drying sludge. Unsteady state condition was used due to thermodynamic characteristic of sludge and conditions affecting the drying. As the CFD package is not able to give the good result with its predefined control parameters so the user defined functions (UDF) were developed using C language to adopt variable material properties, boundary conditions and initialization parameters. To get better result, the fine grid is suggested to use at the boundary[21].

Amjad et al. developed the batch type dryer for drying potatoes slices. The ANSYS-Fluent analysis was carried out to simulate air flow inside the dryer. The k-ϵ turbulence model was used along with steady state condition and considering air inlet velocity as 5m/s. The correlation coefficient between experimental and simulated result was 87.09%, which can be considered as good correlation [22].

Demissie P. et al. carried out the CFD analysis of indirect rack type solar dryer. ANSYS Fluent 18.1 was used to predict the variation in temperature and air flow rate. The mean value of air flow rate was predicted 0.14 m/s for the lower shelve while for other three selves it was 0.12 m/s and the maximum temperature inside the drying chamber was predicted as 320K. The maximum difference between the experimental and simulated temperature value was 4.3°C [23]. The temperature distribution inside the dryer using CFD analysis is shown by Fig. 4.

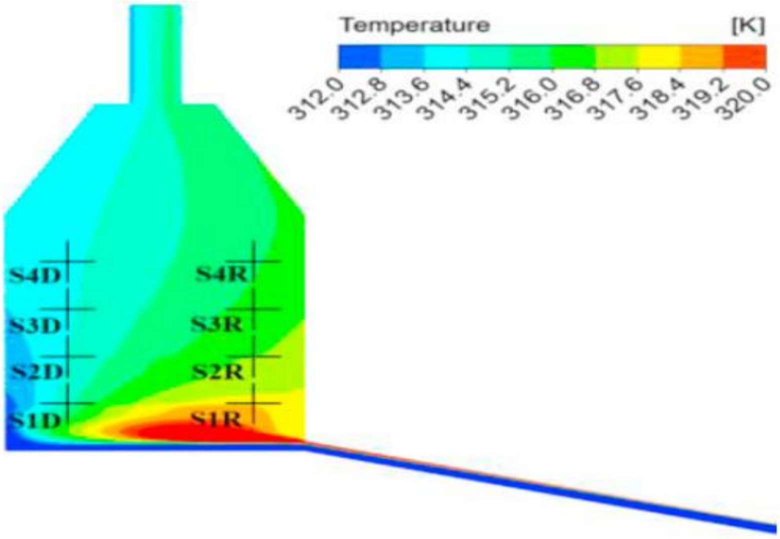

Figure 4 Temperature distribution inside dryer [23]

3 Conclusions

The solar drying technique is the very oldest technique of drying crops. Due to certain limitations of drying in open sun, solar dryers were developed. Various modifications have been done till now to improve the efficiency of dryer so as to reduce the heat losses and reducing the drying time keeping the nutritious value unaffected. CFD analysis helps in predicting the points from where the heat losses are taking place. The CFD analysis also helps in locating the position of chimney or ventilation holes by air flow variation analysis. The important things that are necessary to be considered for getting good result are:

Generating mesh as fine as possible, keeping hardware limitation and analysis time in mind.

Finer mesh at boundaries gives better result at surface.

Mostly k-ϵ turbulent model is used by the researchers but other models are also available.

Developing UDF gives the more realistic result as it can consider the entire possible phenomenon occurring inside the dryer which is usually not provided in ANSYS Fluent package.

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