Applying CFD for the Optimization of the Drying Chamber of an Indirect Solar Dryer

Dounia Chaatouf, Mourad Salhi, Benyounes Raillani, Samir Amraqui, and Ahmed Mezrhab

Abstract The importance of renewable energy technologies is illustrated by their dependence on inexhaustible sources, and it has a friendly relationship with the environment, because of its several advantages. This type of systems are more attractive to investors as well for researchers in terms of development, In this paper, we are particularly interested in the modern system used for drying products, more precisely the one based on solar energy, like the indirect solar dryer, It generally consists of a solar air collector that generates a flow of air that passes through it and goes up to the drying chamber. In order to make the performance of the chamber more efficient, we try in this work to improve the efficiency of the solar dryer by improving the geometry, with the aim of reducing the drying time while guaranteeing the high quality of the dried product. The geometry of the chamber is divided into two sections: the first where the trays are located and the second one is a side-mounted plenum chamber. The width of this latter as well the distance between the first tray and the rooftop of the drying chamber where studied using ANSYS FLUENT software, under the climate of the oriental region of Morocco. And the results showed that the most suitable width for the side-mounted plenum chamber is 0.4 m with an optimal distance between the first tray (the upper tray) and the top of the chamber of 0.06 m.

Keywords ANSYS FLUENT · Indirect solar dryer · Side plenum chamber

1   Introduction

The indirect solar dryer is one of the best solar dryers in terms of conserving the quality of products from the shape, color, and vitamins. Besides this, its simple structure doesn't require electricity or too much equipment, which makes it low cost [1] and the best choice for farmers. However, this type of solar dryer was not of interest to some producers due to its inherent flaw, which is the non-uniform moisture content of the end product caused by the non-uniformity of air distribution inside the

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solar dryer. And that was one of the topics that interested the researches that try to improve the air distribution inside the indirect solar dryer.

In general, the indirect solar dryer consists of a solar air heater and a drying cham-ber that contains the trays filled with the product. The hot air enters from the bottom of the chamber which makes the lower tray receive a lot of heat compared to the upper trays where the heat won't reach it because the air gets cold and moisty when it will arrive at it. To overcome this disadvantages, Kabeel and Abdelgaied [2] divided the drying chamber into two stages with reheating systems that composed with two double pass solar air heaters in a way that the outlet of the first stage is the inlet of the second solar air heater that is going to reheat the air and send it to the second stage, this method makes sure that the hot air is going to reach all the trays in the chamber non just the lower ones. In another way, a lot of researches choose to use air duct to guide the air directly to the corresponding tray, like Abubakar et al. [3] and Darabi et al. [4] who studied a drying chamber containing three independent trays and each one is connected to a pipe which makes the air distributed uniformly along the trays.

The computational fluid dynamics is a powerful tool that has been widely used to solve many problems related to fluid dynamics and it has been proved that it's an effective and efficient design and analysis tool for the food industry [5].

The aim of this study is the improvement of the air distribution inside the drying chamber of an indirect natural convection solar dryer using the ANSYS FLUENT software under the climate of the oriental region in Morocco to make the study more realistic. The studied geometry characterizes by a side plenum chamber mounted on the side of the drying chamber, in order to improve the air distribution by passing it horizontally through the trays, while the study is based on the improvement of the side-mounted plenum chamber by finding the optimal dimensions corresponding to a uniform air distribution along the trays.

2   Methodology

2.1   Solar Dryer Description

The solar dryer studied is an indirect type working under natural convection, composed of a 1.5 m^2 simple solar air heater, that generates the hot air and guides it to the drying chamber, which composed of 2 sections a drying chamber that contains the three trays filled with the product which is figs in our case, and a side-mounted plenum chamber as shown in Fig. 1.
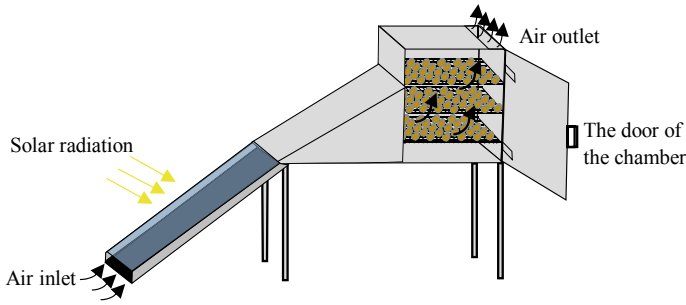
Fig. 1 Schematic diagram of the solar dryer studied

2.2 Boundary Conditions and Climate Data

To make the study more realistic, we studied the solar dryer under the climate of the oriental region in Morocco, specifically, the Oujda city. The meteorological data were collected from the meteorological station installed in the Mohammed first university in Oujda city, the data provided for our study where the ambient temperature and the solar irradiations of a sunny summer day. An Excel treatment is made to present the data in form ofapproximated Eqs. (1) and (2).

$$T_{amb}(t) = 25 + 6\cos\left(\frac{\pi}{12}(t - 14)\right) \tag{1}$$

$$G_{sun}(t) = 965 \sin\left(\frac{t - 6}{14}\pi\right), \quad 6 < t < 20 \tag{2}$$

The inlet and the outlet of the solar dryer are a pressure type and the walls of the chamber are made of wood in which we have convective losses where the heat transfer coefficient is defined in (3), for the glass cover of the solar air heater we have a combination of external convection and radiation boundaryconditions.

$$h_0 = 2.8 + 3V_w \tag{3}$$

where $V_w = 3$ m s^{-1} is the wind velocity.

To simulate the resistance to the airflow by the trays that are filled with the fruit of the fig, we modeled them as a porous medium with 50% porosity using the power-law model [6].
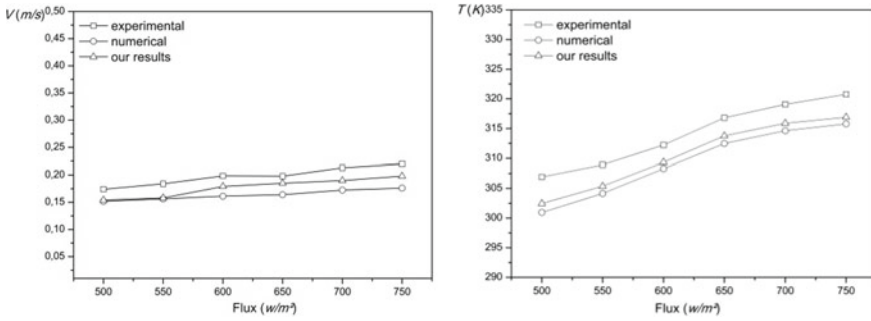
Fig. 2 Comparison of the average outlet temperature and velocity with those of [7]

3 Results

3.1 Validation of the Results

In order to validate the obtained results, we compare our results with the ones studied by Jyotirmay et al. [7] that studied experimentally and numerically a cubical wooden chamber, similar to a cabinet dryer equipped with an inclined solar chimney for natural ventilation. The results are presented in Fig. 2. In terms of average outlet velocity and temperature. The results found by ANSYS FLUENT showed a good correlation to the experimental ones, it's even better than the numerical results found by the authors.

3.2 The Optimal Size of the Plenum Chamber

In this section, we are going to study the side-mounted plenum chamber, specifically its optimum deflection angle, and to do so, there are two ways, either to change the width of the plenum chamber or the distance between the upper tray and the rooftop of the chamber. And that is exactly what we are going to do.

Before every simulation, we must first make an independency mesh test, and for that, four different grids 5532, 12,130, 16,606, and 23,820 triangular cells were studied, and the results show that a mesh grid with 12,130 cells is quite enough to study the geometry.

In order to obtain the optimal width of the plenum chamber in the studied case, we analyze nine different widths that range from 0.25 to 0.65 m. The results are presented in the Fig. 3 in terms of the average velocity of each tray in the sunshine hours of the chosen day. We can see that the velocity increase with the increase in width. However, when the width arrives at 0.4 m, the velocity starts to decrease even if the width increases. But the distribution form of the air along the trays stayed the same even if we increase in the width of the plenum chamber.
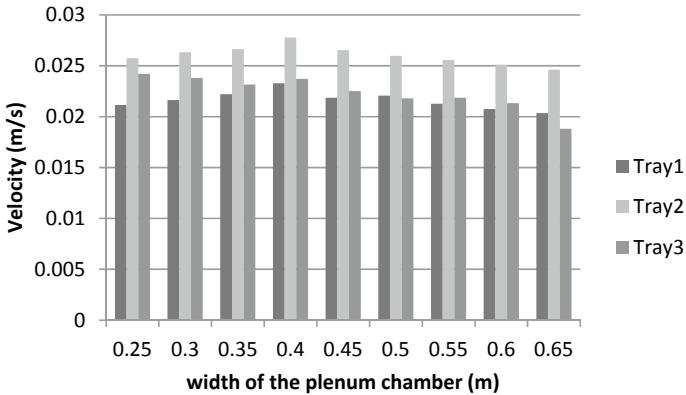
Fig. 3 The average velocity of the three trays in the sunshine hours of the chosen day for different widths at 1:00 pm

Regarding the distance between the first tray (the upper tray) and the rooftop, we analyzed six different distances and the results are presented in the Fig. 4, in terms of the average velocity of each tray in the sunshine hours of the chosen day. The results show that as the distance between the upper tray and the rooftop increase, the velocity decreases. As well the air distribution becomes more uniformed along the trays as long as we decrease that distance.

The optimal geometry is simulated and presented in four different hours along the chosen day in the Fig. 5. The side-mounted plenum chamber allows the air to crosses horizontally in the trays, and that prevents the reduction in temperature as well as the velocity of air after crossing the lower tray. The optimal geometry shows a good uniformity of air along the trays.
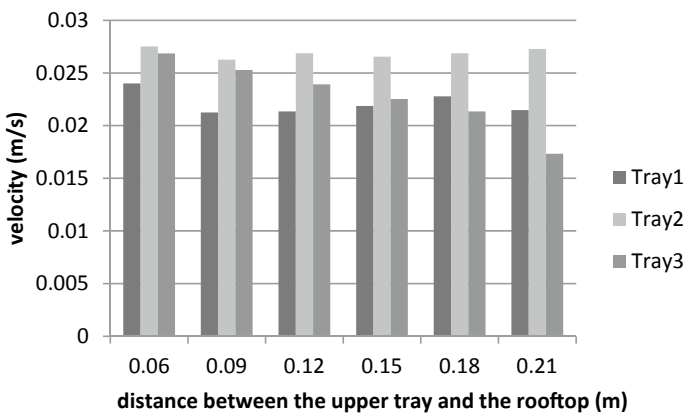

Fig. 4 The average velocity of thethree trays in the sunshine hours of the chosen day for different distances between the upper tray and the rooftop at 1:00 pm
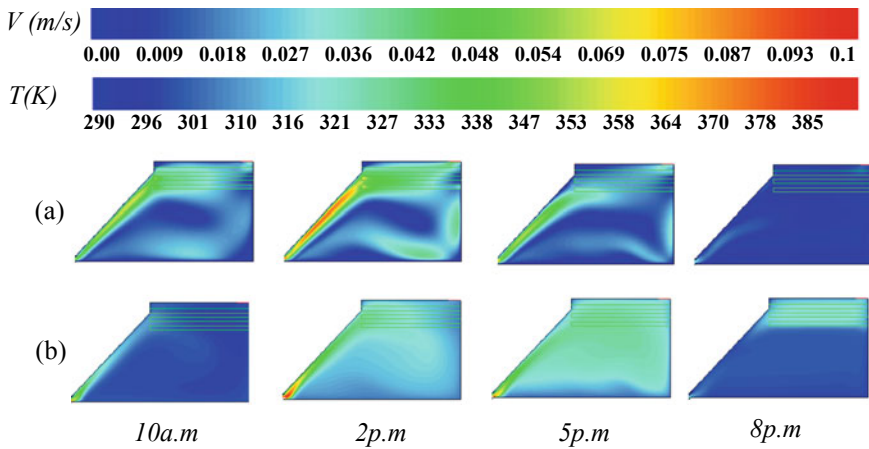
Fig. 5 Distribution of velocity (**a**) and temperature (**b**) inside the chamber at 4 different hours in the chosen day

4 Conclusion

The new technologies dedicated to the drying process are diverse, and each of them has a specific operating principle and its own source of energy to carry out this operation. In this study, we have focused mainly on indirect solar drying systems due to their importance in terms of quality and environmental cleanliness. The whole system, consisting of a solar air heater, a drying chamber equipped with a side-mounted plenum chamber. The width of this latter as well the distance between the first tray and the rooftop where studied using ANSYS FLUENT software, and the results showed that the most suitable width for the side-mounted plenum chamber is 0.4 m and the optimal distance between the first tray (the upper tray) and the top of the chamber is 0.06 m.

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