Energy and Performance Analysis of a new Solar Dryer

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Abstract. The discrepancies of using open-air sun drying method for drying agricultural produce and to preserve other variety of food items still exists. In the present time, to get rid of all the disadvantages associated with it, many comprehensive design structures of solar food dryer and their modification has been presented and investigated. This research paper highlights the energy analysis performed on a latest design of a solar food dryer in which impinging jet mechanism and fins are clubbed together. The enhancement in heat transfer under preferred range of important parameters investigated namely mass flow rate ($\dot{m}$), Reynolds’s number, Flow-wise pitch ratio, Fin-spacing ratio etc. It has been observed that this new design of solar food dryer is more efficient and user friendly. The result has been plotted for Reynolds’s number (Re), mass flow rate ($\dot{m}$). The findings for this new design of solar food dryer reflect that temperature range of air coming out from outlet section is in the range of (45°C-55°C) which is undoubtedly good.

Keywords: Flow-wise pitch ratio; jet hole-diameter ratio; fin-spacing ratio; impinging jet fins.

1. Introduction
In recent times, energy conservation is the most important and concerned factor. It is off course the base of the development of our nation and a green future for our planet. Among the other available finite amount of resources on our planet, we need to find the best alternate options to meet the raising demands of human beings for their survival. Enormous amount of clean, vital and utilisable energy generated by sun is known as non-conventional energy that is one of the most popular options and the attractive area of research since from past decades. As this form of energy is available in every part of globe, it becomes very easy to tap this energy and re-use it in other convincible types. Solar energy operated devices such as solar food dryers are one of the important apparatus. The best feature among all the qualities is pollution free mode of operation, hassle free maintenance, and low budget. The main motive of a solar food dryer is to supply sufficient amount of heat i.e. more than the surrounding heat that can be used in crop drying application. The designs of a simple food dryer consist of a solar collector and food cabinet. In the last decades, many significant efforts were made to get better performance of collectors. Plenty of innovative techniques have been presented by many researches, ample of analysis has been discussed which leads to establish the truth that jet impingement technique is one of the amazing methods to improve the performance of solar air heater. This method is becoming more attractive by using various techniques along with it and insertion of fins is one fabulous option in this sequence. Relevant literature in the form of numerous research papers,
technical reports etc. is available which focuses on the innovative design of solar food dryer and their modification to improve the thermal efficiency and reduce the demerits of direct crop drying system. Satcunanathan and Deonarine [1], Kuzay, Malik, and Boer [2], Wijeysundera, Lee, and Tjoe [3] investigated innovative designs of solar collectors. The application of impinging jet mechanism is a new advancement in this direction. Kercher and Tabakoff [4] used this concept and studied the square array and influence of spent air on the heat transfer. Chaudhary and Garg [5] investigated an impinging jet solar air heater and noticed beneficial aspects. Brevet et al. [6] formulated a relation of $Nu$ and studied its trend with respect to impingement distance, $(Re)$ and span-wise hole spacing. Chauhan and Thakur [7] experimentally investigated thermo-hydraulic performance using the same technique, in their work the authors studied the effect of inline & staggered fashion of holes. Sontakke and Salve [8] analysed that force circulation drying gives better result than natural circulation solar dryer. Tiwari [9] presented a review on box dryer, tend dryer solar cabinet dryer and green house dryer. They found that there is no standard solar dryer or air heating system in India. Fudholi et al. [10] presented a techno-economic analysing on solar drying system and found that a 2 pass solar collector is best suited for marine products. Hu and Herold [11], Dejong et al. [12] presented their work on a off-strip type exchangers and discussed the performance of the system. Recently Goel and Singh [13, 14, 15] presented their work on performance studies of a jet solar air heater with longitudinal fins in which an enhancement of 3-14.7% in thermal efficiency was observed for the Reynolds number range (3000-15000). In these works the authors has described the utility of using fins in the existing designs of solar air heaters, the results were examined as a function of the geometrical parameters. The comprehensive study of published research and relevant literature survey confirms that many design of solar food dryer has been discovered in past studies. However, solar food dryer based on the mechanism of implementing longitudinal fins underneath the absorber plate along with the jet impingement technique is untouched. Hence, because of the research gap identified there is a need to investigate a new design of solar food dryer that could be of great benefit to the society and especially small-scale farmers who could not afford a high expenditure for arranging some device for crop drying purpose. In the present work a new design of solar food dryer in which jet impingement technique is implemented along with longitudinal fins have been investigated. The essential performance characteristics such as heat transfer, collector efficiency factor, and effective heat transfer coefficient has been evaluated through experiments using a prototype model under specific assumptions. These important parameters are the crucial indices that will outline the viability of this prototype.

2. Materials and Methodology

In this paper to perform the experimentation of this prototype, the analysis carries standard assumptions. This prototype consists of a glass sheet at the top, an absorber-plate with fins attached, jet plate with array of holes. The complete assembly of the model along with two flow channels is shown in Fig.1. In this, the air from the blower came directly into the duct, from their air passes through the jet plate then they passes through the fins attached to the absorbing plate which is been heated by the solar energy and the heat is been convected and carried by the flowing air towards the drying chamber.

2.1 Experimentation and procedure

In the present prototype model, different plates are embedded with the thermo couple (K-type) with ± 1.5% accuracy, the different temperatures are recorded with the help of a temperature display units, digital hot wire anemometer with a precision of ± 1% is used to record inlet air velocity ($v_1$), and outlet air velocity ($v_2$) which finally enhances the temperature of the air at outlet section. A digitalsolar intensity recorder is used to measure the intensity of solar flux on the model. The complete set up is
mounted on a wooden frame in which wheels are attached so that model could be easily operated in the outdoor conditions. The main components of the solar food drying system are drying chamber, solar collector and a blower. The size of the drying chamber is (0.050× 0.06 × 0.9). The solar collector is a single pass with jet impingement technique along with the longitudinal fins. The size of solar collector is (1.15 × 0.6 × 0.25). The bottom and sidewalls are been insulated with a 5mm thick sheet of asbestos, same as in the drying chamber to avoid heat loss to the surrounding. The experiment begins with the entry of surrounding air through blower inside the duct. The apparatus is started and remains in standby mode to get into steady state, once the steady state is attained the test runs are conducted and the different experimental data related to inlet and outlet air velocity and different temperatures are recorded. The experiments are conducted for a week at different intensity of solar radiation, varying air mass flow rate, varying geometrical parameters and finally at different Reynolds number values. With the help of the same prototype model, the analysis of the smooth (conventional) type duct is conducted so that the superiority of the proposed configuration could be established properly. The details and the model of prototype are shown in Fig.1 (a-d) respectively.

Fig 1: Experimental Setup
3. Results and Discussion

In the results section the observations pertaining to the heat transfer coefficient for different configuration of duct such as smooth and jet with fins have been presented. For the sake of comparison, the obtained experimental results are compared with Garg et al. [15]. In Fig. 2 the distribution of $Nu$ while considering smooth duct has been presented. It is clear from the plot that with an increase in the values of ($Re$) the ($Nu$) also increases. The maximum value of ($Nu$) is found at higher value of ($Re = 16000$) respectively. Fig. 3 represents the variations of ($F''$) with respect to $Re$. The value of ($F''$) of Solar Food Dryer is found to be higher in comparison to that of smooth one. At the maximum value of ($Re=16000$) it is maximum ($F''=0.47677$). While referring Fig. 4 the variations of ($F'$) with respect to ($Re$) can be easily interpret. The value of ($F'$) of solar food dryer is found to be higher in comparison to that of smooth one the trend is identical to that of ($F''$) for the maximum value of ($Re=16000$) it is maximum ($F'=0.47677$). Fig. 5 has been drawn to show the variation of effective heat transfer coefficient. Effective heat transfer coefficient is deduced while considering the combined effects of jet and fins. It is clear from the distribution of the values that for all complete range of $Re$ considered in the present analysis the value of effective heat transfer coefficient is always higher than heat transfer coefficient of smooth duct. In general, the value of effective heat transfer coefficient increases with an increase in the $Re$ and attains a maximum value at the highest value of ($Re=16000$) respectively. A maximum percentage enhancement observed is 67% in the heat transfer.

![Fig. 2. Variation of ($Nu$) as function of ($Re$)](image1)

![Fig. 3 Variation of Collector heat removal factor ($F''$) as function of ($Re$)](image2)

![Fig. 4 Variation of Collector efficiency factor ($F'$) as function of ($Re$)](image3)

![Fig. 5 Variation of Effective heat transfer coefficient as function of ($Re$)](image4)
4. Conclusions
The initial theoretical analysis with reference to this model suggests the energy efficient characteristics and its advantages over the previously created prototypes. It is also highlighted that the shorter duct length and moderate range of air mass flow rate are the two major constraints in designing of prototype.

1. It is seen that with the increase in the Reynolds Number(Re) the Nusselt Number increases and with increase in Nusselt Number we get more convected heat which is our most important target.
2. It is seen that for solar collector with the applications of fins and jet plate the collector efficiency factor (F") increases with the increase in the value of Reynolds Number(Re).
3. It is seen that Effective heat transfer coefficient under the effects of jet and fins is more with respect to the increase in the value of Reynolds Number(Re). According to the previously designed prototypes the value of Effective heat transfer coefficient for this prototype are quite higher.

5. Policy implication and Future scope
It is well known that the devices using the renewable energy as the input source is been increasing, to minimize the use of natural resources and exploiting them. So this technology is operated on solar energy and is more advantageous to small scale farmers in drying their crops at a very nominal cost. This systems are based on conventional technique so it is easy to understand and easy to operate. This device does not use any kind of natural non-renewable resources like petrol, diesel, coal and natural gas. If we use this device the pollution level also get reduced. Solar energy have their own characteristics such as it is available in adequate amount, it is hygienic, it is a cost effective system. However solar energy is the cleanest source of energy available right now. As it is clear that with the use of fossil fuels leads to the emission of sulphur dioxide, nitrogen oxide and other harmful gases and fumes which leads to the air pollution, water pollution and land pollution.

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