Comparative Analysis of Forced Convection Direct Solar Dryer by varying the Dryer Load and Mass Flow Rate

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Abstract— A prototype direct solar dryer has been fabricated and tested in no load, partial load and full loading conditions under forced convection mode. Experiment has been conducted in different cases. Case -1 is when no load is used inside the dryer and air velocity is 2 - 10 m/s, case 2 is when partial load is used inside the dryer and air velocity 2 - 10 m/s. Case -3 when full load is used inside the dryer and air velocity is 2 - 10 m/s. Ambient temperature, solar radiation, solar dryer temperature and air velocity have been evaluated in thermal performance analysis and calculating the mass flow rate. The results also showing the effectiveness of moisture reduced and reduced weight per hour. In this paper, a direct solar dryer prototype is designed, constructed and performance tested for the analysis of the drying kinetics of these by products and their possible efficiency evaluation. The characteristics of the prototype are presented together with the variations of the properties of temperature, air velocity and mass flow rate for direct solar dryer. The analysis of the drying kinetics of the tomato or potato slices shows the performance of the direct solar dryer obtaining reductions of the drying time than the conventional drying.

Key words: Solar Dryer, Forced Convection, Mass Flow Rate, Dryer efficiency

I. Introduction

The production of fruits and vegetables in the world has been estimated around 392 million and 486 million tons, respectively in which 30%-40% is spoiled of total production due to lack of post harvest handling up to consumption in developed country [1]. India is a developing country and it is second the largest producer of fruits and vegetables [1, 2]. Nearly 35% losses are estimated during postharvest period of fruits and vegetables [1, 2, 3]. Food preservation is a process of moisture removal from agricultural produce up to a safe limit and this process is known as crop drying. Crop drying is a process of dehydration using the heat. The heat can be generated by burning of fossil fuels, through the electricity and by the solar radiation [3, 4, 5]. Renewable energy is not available in the form of heat but sun can generate enormous amount of heat energy through various available technologies like solar collectors, solar concentrator and solar dryers which had been developed in past. Solar energy is a rising and smart option for the rural occupiers and farmers [6, 7, 8, 9]. The sun has great potential to fulfill our energy needs. Solar drying is one of the traditional and general methods of conservation of food crops. Solar drying is a combined process of heat and mass transfer. In this first heat is supplied to the product from the sun and then mass transfer from crop surface to the surrounding in terms of moisture content. According to heat utilization technique, solar dryer can be classified as: direct, indirect and mixed mode [5, 10, 11]. Each dryer can be operated in either passive (natural convection) or active mode (forced convection). The passive mode of greenhouse dryer works on the principle of thermo-siphon effect. The humid gets ventilated through the ventilator provided at the roof or through the chimney of the dryer. Humid air is ventilated by the help of an exhaust fan provided at the ventilator. It is generally provided in the upper portion of the west wall [12-14]. The drying process is a basic operation that consists on reducing the moisture of a product so that the final product presents very different characteristics from the initial ones. The dehydration is one of the oldest techniques used for food or agricultural products storage as well as for the use of the by - products power [15-17]. Solar dryers can be proved to be a very useful device from the energy conversation point of view. It not only saves energy but also saves a lot of time, occupies less area and makes the process more efficient. Solar dryers avoid some of the major disadvantages of classical drying [18]. The traditional open- sun drying method of humid dates is controlled by a number of external factors (solar radiation, ambient temperature, wind velocity, and relative humidity) and internal factors (initial moisture content and the mass of product per unit exposed area). This method does not allow for obtaining a suitably high and reproducible product quality, mainly because of the inherent limitation in controlling the drying process [19]. Dates fruits quality is influenced by several factors, which could be linked to the climate, the soil and the applied cultural technique. This variety requires a post-harvest treatment to minimize losses and avoid accidents of preservation and storage according to the climatology of the year. Although a considerable amount of data has been reported in the literature about the design and evaluation of solar dryers for agricultural products, there are just a few studies regarding solar drying processes of agro industrial waste of high moisture for energy applications and similarly happens with the studies on hybrid solar dryer [21,22]. A direct solar was introduced. In this dryer, solar radiation impacts on glass firstly after then reach the drying material due to use of transparent glass. We use the blower also for enhancing the thermal performance of the direct solar drying system and it in this present experimental work, direct solar dryer without solar collector is introduced. We have taken direct solar dryer. There are 24 holes in front side of the direct solar dryer for supplying the air and there are 24 holes back side also of the direct solar dryer for rejecting the air. The diameter of these holes is 8mm. The objectives of this investigation were

1) Experiment in load condition
2) To study the thermal behavior of designed direct solar dryer in ambient conditions.
3) To compare the weight reduced per reading.
4) To evaluate the heat utilization.

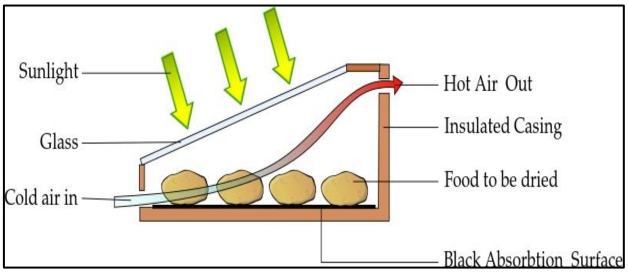


Fig. 1: Working principle of direct solar dryer

There was coating inside the wall of direct solar dryer for removing the heat losses. All the experiments have been carried out in different cases. Solar collector is not used in this dryer. Dryer is tested without solar collector.

II. Material and Method

The volumetric dimension of the box type direct solar dryer is 78.5×61.5×30 cm. The front portion area is 62.5×30 cm. The back portion area is 61.5×19 cm. and top portion area is 78.5×62.5 cm. The thickness of the box type direct solar is 10 mm. For the inlet air, 24 circular holes were provided just below the tray having the diameter 8mm and for the exhaust air 24 circular vents are provided in the back wall with a diameter of 8mm. The coated wall of box type direct solar dryer reflects the solar radiation over the tray during the crop drying. Insulation will eliminate the chances of heat loss from the wall.

Fig. 2: Direct solar dryer experimental setup

The objective of the designing the solar dryer was to store the solar radiation during the sunshine hours and further that stored heat energy was supplied to heat the inlet air. Now this heated inlet air can be utilized to remove moisture from the crop.

The tray is made of wood and aluminum wire is placed inside the direct solar dryer at proper place, so as to ensure a reasonable level of air circulation under and around the drying material. Figure shows the box type direct solar dryer without solar collector.

A. Instruments

The solar radiation has measured on by using power meter, having experimented accuracy ±10w/m. and meaning range 0-2000w/m. Weight reduce is measured by weighing meter having accuracy 0.01gm and measuring range 0 to 5 kg. Inside temperature is measured by thermocouple having accuracy $\pm 2.2^0$cand measuring range -50^0c to 1200^0c. Ambient temperature is measured by anemometer having accuracy $\pm 1.2^0$c and measuring range 0 to 50^0c. Air velocity is measured by anemometer having accuracy ≤20m/s and measuring range 0.4 to 30m/s.

B. Experimentation

The experiments were conducted in loading conditions without solar collector at Trinity institute of technology and research (Bhopal, India) situated at 23.5^0N latitude & 77.25^0E longitude. All the experiments were performed during 11 am to 3 pm. The direction was east to west during the experiment to maintain the maximum utilization of incident solar radiation throughout the day.

The efficiency of the drying system is calculated by multiplying the efficiencies of the individual components of the system in order to complete the installation and make the dryer work in active mode, the aim is to control the main variables in the test. Anemometer is used to measure the air speed.

C. Efficiency Calculations

Collection efficiency is defined as the ratio of heat received by the drying air to the insolation upon the absorber surface and estimated by using following equation [23].

$$\eta_c = \frac{m \times Cpa \times (To - Ti)}{Ac \times I}$$

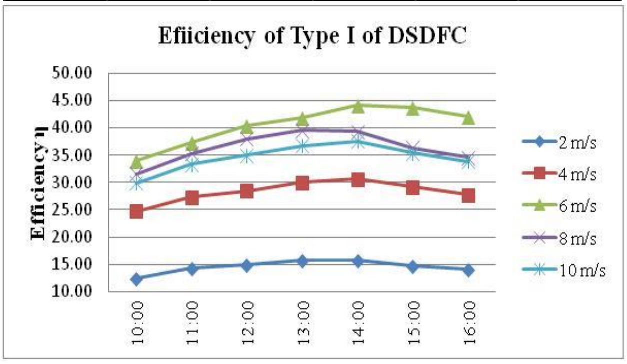
Amount of heat required to evaporate the moisture inside the product is called as drying efficiency and estimated by using following equation. [24]

$$\eta_d = \frac{Mw \times hl}{(Ac \times I + Pd) \times t}$$

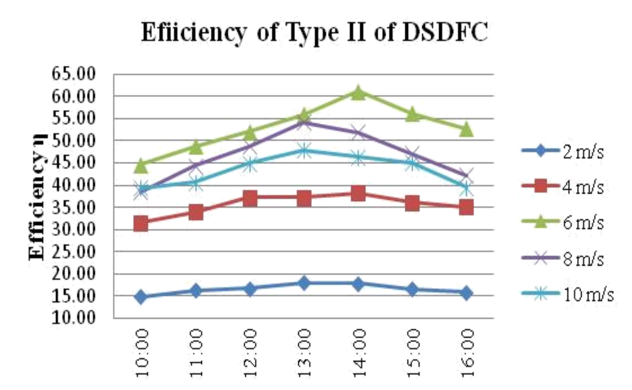
Where $M_w = M_i - M_f$

III. Results

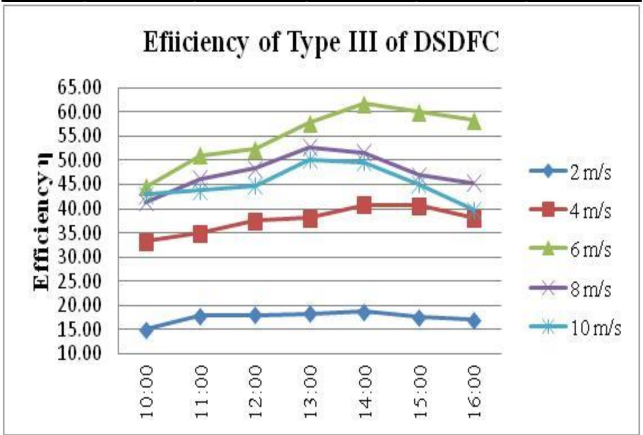
TYPE I					
DATE	20/04/17 to 24/04/17		VELOCITY:- 2 /4/6/8/10 m/s		
	2 m/s	4 m/s	6 m/s	8 m/s	10 m/s
TIME	η	η	η	η	η
10:00	12.36	24.71	33.98	31.61	29.92
11:00	14.21	27.35	37.22	35.31	33.37
12:00	14.86	28.45	40.34	38.03	34.94
13:00	15.68	29.98	41.81	39.58	36.74
14:00	15.68	30.66	44.08	39.35	37.59
15:00	14.71	29.2	43.71	36.3	35.43
16:00	14.1	27.75	41.99	34.62	33.84



TYPE II					
DATE	26/04/17-30/04/17	VELOCITY:- 2 /4/6/8/10 m/s			
	2 m/s	4 m/s	6 m/s	8 m/s	10 m/s
TIME	η	η	η	η	η
10:00	14.89	31.51	44.64	38.51	39.39
11:00	16.25	33.97	48.75	44.32	40.62
12:00	16.69	37.23	51.99	48.78	44.93
13:00	18.05	37.23	55.85	54.16	47.95
14:00	17.91	38.29	61.14	51.87	46.32
15:00	16.63	36.03	56.13	47.12	45.04
16:00	15.82	35.15	52.73	42.18	39.55



TYPE III					
DATE	07/05/17-11/05/17	VELOCITY:- 2 /4/6/8/10 m/s			
	2 m/s	4 m/s	6 m/s	8 m/s	10 m/s
TIME	η	η	η	η	η
10:00	14.95	33.19	44.5	41.36	42.88
11:00	17.92	34.95	51.03	46.17	43.85
12:00	18.05	37.48	52.35	48.28	44.78
13:00	18.27	38.06	57.78	52.78	50.22
14:00	18.74	40.77	61.73	51.65	49.57
15:00	17.57	40.61	59.99	46.95	45.1
16:00	16.96	38.15	58.27	45.35	39.86



NOMENCLATURE

- η_c Collector efficiency in %.
- η_d Dryer efficiency in %.
- To Temperature at collector outlet in 0C.
- T_i Temperature at collector inlet in 0C.
- m Mass flow rate of air in kg/s.
- m_w Mass of evaporated moisture in kg.
- m_p Initial mass of product in kg.
- M_i Initial moisture content in % wet basis.
- M_f Final moisture content in % wet basis.
- A_c Collector area in m2.
- I Solar insolation in W/m2.
- C_{Pa} Specific heat of air in kJ/kgK
- t Time in second.
- P_d Blower power in kW

IV. CONCLUSION

In this experimental work the performance evaluation of direct solar dryer under forced convection mode in no load, partial load and full loading conditions has been done in different cases. The analysis signifies that the observed data was precise adequate to determine the performance of direct solar dryer. Results indicates that direct solar dryer with high air velocity would be effective for drying as compared to earlier developed direct solar dryers with low air velocity. The radiation losses through the coated wall were reduced with the help of reflector and maximum utilization of solar radiation was achieved. The thermal losses were also reduced with the help of coated wall. The direct solar dryer prototype has been designed and constructed for the drying of humid agro industrial by products in active operation mode. Previous to the evaluation of the drying kinetics, the experimental analysis carried out has been shown to establish the most suitable operation strategies. The influence of the solar radiation and mass flow in the direct solar dryer has also been studied as shown that, for a constant air flow, the increase in radiation causes an increase in temperature in the of the chamber and, for a constant value of the solar radiation, the increase in air flow implies a reduction in the temperature of the chamber. The evolution of the temperature and the air velocity for different modes has also been studied. The analysis of the drying kinetics of the tomato or potato slices confirms the better performance than the conventional drying obtaining a reduction of the drying times. The direct solar dryer developed in this work will allow to research and improve the solar drying process of other agro industrial waste.

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