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Performance evaluation of fabricated mixed mode natural convection solar dryer

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Abstract
The performance evaluation of mixed mode natural convection solar dryer for drying agricultural products was studied. A mixed mode natural convection solar dryer was designed and fabricated with the locally available materials and commissioned at Sangareddy (17.6294 °N, longitude of 78.0917 °E), Telangana, India. The performance of solar dryer was evaluated through no-load and full-load conditions tests in the summer months. The temperature profile, air humidity of dryer at No-load and full load condition was studied. Under load conditions, the dryer has been used in experimental drying tests varying from 0.5 kg to maximum capacity of 1.5 kg of agricultural products (grapes, tomatoes). This prototype dryer was designed and constructed to have a maximum collector area of 0.558 m^2.

Keywords: Mixed mode type, natural convection dryer, temperature profile, air humidity

1. Introduction
Agricultural products especially fruits and vegetables are highly perishable in nature and are seasonal. About 50% of produced fruits and vegetables are lost after been harvested (FAO, 1989) [9] and they cannot be stored for longer period. Drying is one of the oldest methods of food preservation practiced by humans and it extends the shelf life of the food product. It also makes the seasonal food available throughout the year to meet the thirst of food lovers (Reddy *et al*., 2018) [13]. It also reduces transportation cost by lowering the weight and volume, packing size, storage space (Demir and Sacilik, 2010; Arepally *et al*., 2017a) [4, 12]. Solar energy being the renewable energy is used by human by directly drying the food produce in the hot sun. It requires large area, results in uneven control of drying, involves high labour cost and also product quality is degraded because of dust, insects, birds and other foreign matter (Basunia and Abe, 2001; Arepally *et al*., 2017b) [3, 11]. To overcome these difficulties, improvement of sun drying has led to evolution of solar drying protecting the food from contamination and weather conditions while retaining the nutritional qualities as such (Ukegbu and Okereke, 2013) [17]. Therefore, the introduction of solar dryer systems become popular to reduce losses of agricultural food material and to improve the quality of the dried product significantly when compared to the traditional drying methods (Yaldiz *et al*. 2001; Togrul and Pehlivan, 2003; Ravula *et al*., 2017a) [18, 16, 12] and also they are cheaper and more practical when compared to mechanical dryers, for example, the conventional drying process of fruits, using hot air, is generally expensive due to the water phase change and also requires high energy requirement (Ravula *et al*., 2017b) [11]. However, solar dryers must be properly designed in order to meet the particular drying requirements of crops of interest and to give satisfactory performance with respect to the energy requirement (Akpinar *et al*., 2004) [2].
The direct solar dryers involve the thin layer of product spread over large space to expose to solar radiation. This type of drying method is useful for grains. In indirect solar dryers or convective solar dryers, the atmospheric air is heated in flat plate collector or concentrated type solar collector in which the hot air or the heated air flow in the cabin where products are dried. Moisture from the produce is lost by convection and diffusion. This method of drying is used to avoid direct exposure to the solar radiation. In this kind of drying process, the chamber temperature and thickness of drying samples are the main factors taken into consideration (Diamante and Munro, 1993) [6]. In mixed mode type, the product is dried with both direct exposure to solar radiation and hot air supplier on it. In this process the product is dried according to convective moisture loss. Kornsakoo and Exell introduced a cheap and simple mixed mode dryer for farmers.

This type of dryer is often used for drying crops in the wet season (Mustayen *et al.,* 2014) [10]. However, solar dryers must be properly designed in order to meet the particular drying requirements of crops of interest and to give satisfactory performance with respect to the energy requirement (Akpinar *et al*., 2004) [2]. As per 2015-16, some of the vegetable production in India is shown in Table 1.

Tomato (*Lycopersicon esculentum*) is considered as one of the most important vegetables occupying second position amongst the vegetable crops in terms of production (Abano *et al*., 2011) [1]. It is a perishable vegetable that contains higher moisture content so that it is necessary to dehydrate it without changing nutritional and sensory characteristics to use in off season. Dried tomatoes can be made into powder and is used as an ingredient in the manufacturing of different food products. At the market, rejection rates for tomatoes are 23% for good grades (Singh and Singla, 2011) [15]. The present aim was to study the performance evaluation of developed mixed mode natural convection solar dryer under no-load and full load condition.

Table 1: Vegetable cultivation and production in India as per 2015-16

Data	Area, '000' ha	Production, '000' tonnes	Yield, kg/ha
Potato	2134	43770	20510.78
tomato	760	18399	24209.21
Onion	1225	20991	17135.51
Brinjal	664	12552	18903.61
Total	4783	95710	20010.45

(Source: Department of Agriculture and Cooperation, Govt. of India (Horticulture Division)

2. Materials and Methods

To carry out the performance evaluation of solar dryer, the parameters considered under no-load and full load conditions were temperature, relative humidity of drying chamber, solar insulation and wind velocity, respectively.

2.1 Temperature

Temperature of the air is an important parameter to describe the how drying of material is being done inside the dryer. Furthermore, temperature of the air cannot be maintained constant in the developed solar dryer throughout the process because of intermittent nature of solar radiation. So, it is necessary to determine the temperature of the air at regular intervals using digital thermometer.

2.2 Relative Humidity

In-outdoor Thermo-hygrometer (Fast Tech, Model: TH-101E) was used for measuring the RH of the drying air. The digital hygrometer is in the range of 0% to 100% with an accuracy of ±5% (40-75% RH), ±7% (25%- 40% RH), and ±9% (1%-24% RH and 76%-100% RH). The higher the humidity, the longer the drying will take. More air will be required and the temperatures need to be higher. The moist air can't hold as much moisture as less humid air could and as a result drying takes longer than it might in a dry climate. This humidity also makes higher temperatures desirable for our climate.

2.3 Wind Velocity

A digital anemometer (Lutron company, Model: AM-4202) was used to measure wind velocity. The operating temperature range is from 0 °C to 60 °C with the resolution of 0.1 °C and has an accuracy of ±0.8 °C. The operating range of Wind velocity is from 0.4 ms^{-1} to 30 ms^{-1} with the resolution of 0.1 ms^{-1} and has an accuracy of ± (2%+0.2 ms^{-1}).

2.4 Solar Insolation

A solar power meter (TENMARS, Model: TM-207) is a pyranometer of silicon p-n junction type of measuring device used to measure combined direct and diffuse radiation. The maximum range of this instrument is 2000 Wm^{-2} and resolution is of 0.1Wm^{-2} and has an accuracy of ±10 Wm^{-2}.

3. Results and Discussion

3.1 No-load condition

The fabricated solar dryer was shown in Fig. 1. Experiments on No-load test for mixed mode solar dryer has been conducted to find temperature profile, relative humidity and air velocity in the dryer. Experiments have been carried out during the month of April-May 2015. The parameters studied under no-load condition was shown in Table 2.

It has been observed that the maximum temperature inside the dryer is 51 °C at 13:15 h while the minimum temperature is 37 °C at 09:15 h (Fig. 2). Relative humidity for the corresponding temperatures are 52% and 68% respectively (Fig. 3). Similarly, outside the dryer, the ambient temperatures have been observed to be 40 °C and 30 °C. Hence, inside the drier, there is an increase in temperature of about 11 °C as compared to the outside ambient temperature. At the same time, solar radiation observed to be 1206 W/m^2 and 983 W/m^2 respectively which happens to be day's maximum and minimum (Fig. 4). Outside the dryer, the relative humidity observed to be 55% and 78% respectively. The temperature observed to be maximum during 11:15 h to 15:15 h because of maximum solar insolation during this time. Correspondingly, RH has been decreasing as temperature is increasing. During this time of the year there has been very low wind and the wind velocity observed to be increasing with the temperature.

Table 2: No Load condition parameters for the solar dryer

S. No	Time, h	Solar insolation, Wm^{-2}	Temperature, ˚C	RH, %	Wind velocity, m/s
1	09:15	983	37	68	0.3
2	10:15	1053	38	65	0.2
3	11:15	1099	42	60	0.2
4	12:15	1105	45	58	0.1
5	13:15	1185	51	52	0.2
6	14:15	1206	50	50	0.1
7	15:15	1146	48	57	0.2
8	16:15	1096	46	60	0.4

Fig 1: Solar dryer

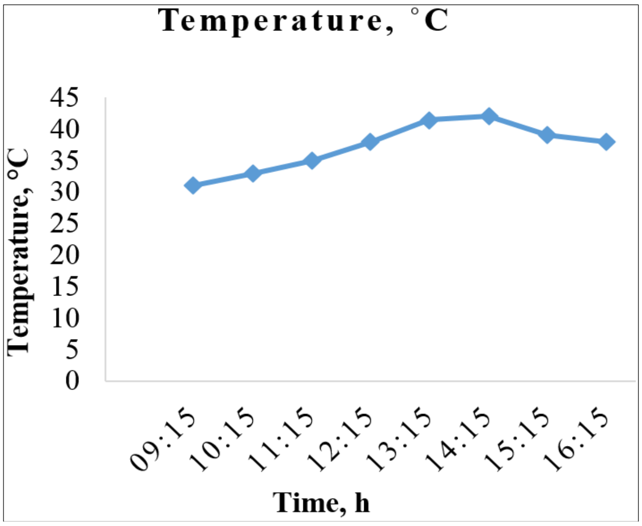

Fig 2: Variation of temperature with time at No-load condition

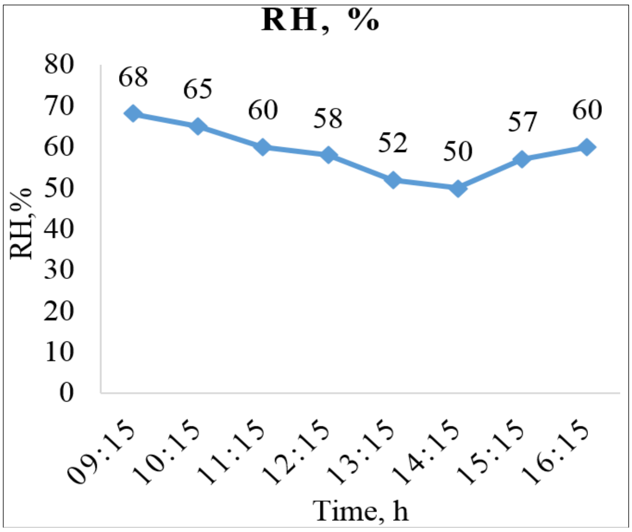

Fig 3: Variation of RH with time at No-load condition

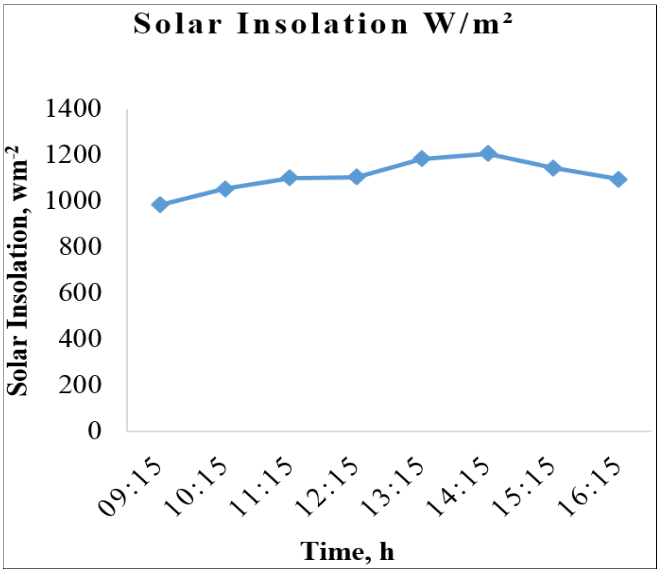

Fig 4: Variation of solar insolation with time at No-load condition

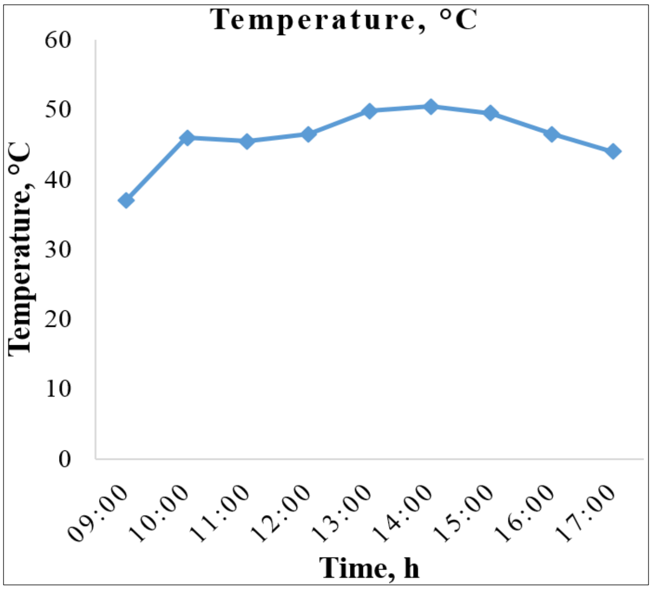

Fig 5: Variation of Temperature with time at 500 g load

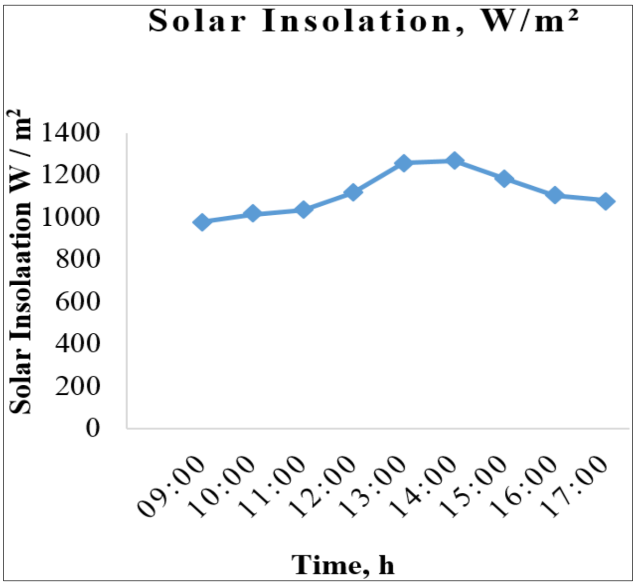

Fig 6: Variation of Solar insolation with time at 500 g load

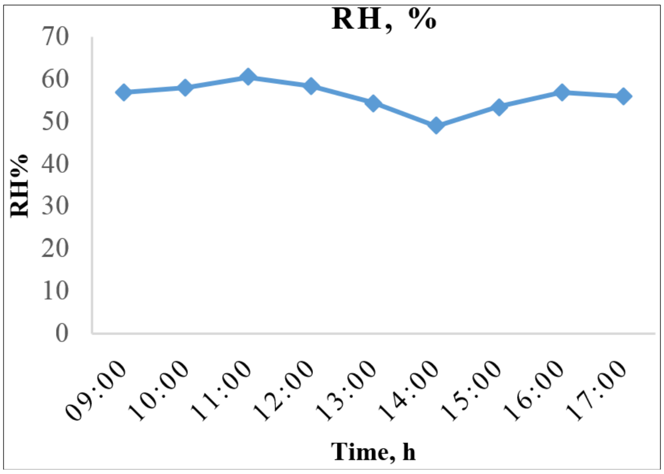

Fig 7: Variation of RH with time at 500 g load

3.2 On-load condition

The performance of solar dryer is evaluated during the month of April-May, 2015 for drying of tomatoes. The on-load test is conducted for three consecutive days. The test includes measuring of solar radiation, temperature, relative humidity, wind velocity inside and outside the solar dryer. The drying process is stopped after eight hours of drying. Fresh and ripened tomatoes are washed, and slices of 5 mm thickness are cut and placed in the solar dryer. Three different loads of tomatoes have been tested for drying and performance evaluation.

3.3 Solar drying at 500 g load

During drying of 500g of tomatoes inside the drier, it is observed that the maximum and minimum temperature inside the solar dryer is 50.5 °C and 44 °C at 2:00 PM and at 5:00 PM respectively at an ambient temperature and solar insolation of 41 °C and 33 °C and 1269 W/m^2 and 1080 W/m^2 respectively. The graphs are as shown in Fig 5 and 6 respectively. The relative humidity was also shown in the Fig. 7.

4. Conclusion

High quality and aesthetically appealing dried agricultural produce can be produced from solar drying. Under No-load test, it has been observed that the maximum temperature inside the dryer is 51 °C at 13:15 h while the minimum temperature is 37 °C at 09:15 h. Relative humidity for the corresponding temperatures are 52% and 68% respectively. Similarly, outside the dryer, the ambient temperatures have been observed to be 40 °C and 30 °C. Hence, inside the drier, there is an increase in temperature of about 11 °C as compared to the outside ambient temperature. The air temperature inside the dryer was higher than outside by 37–50.5 ºC.

5. References

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