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Performance Evaluation of a Mixed-mode Solar Dryer

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Abstract—*In order to ensure food security to all and minimize the post harvest losses, it is essential to preserve the food products for the future. Drying is one of the food preservation techniques. Traditionally drying is carrying out in open sun. Open sun drying has some limitations such uneven drying, inclusion of contaminants, discoloration of the dried products etc. In this paper, performance evaluation of a fabricated mixed-mode solar dryer has been carried out. This dryer has been fabricated by using local available materials. To investigate the performance of the dryer, potato slices were taken for drying. The moisture contents of the potato were between 75 % to 85 %. Temperature at various points and relative humidity of the air in the dryer were measured; and these values were compared with those of the ambient air. The drying of potato slices in dryer as well as in open sun drying was also compared. From experiments, it was observed that the temperature in the drying cabinet was higher, humidity was lower and drying in dryer was faster than those in ambient condition.*

Keywords*: drying, mixed-mode, moisture content, relative humidity, solar dryer.*

1. INTRODUCTION

Food preservation is very necessary to achieve the maximum food security and to minimize the post-harvested losses. Food can be preserved by freezing, canning, pickling, saltering, lacto fermentation, oil immersion, alchohal immersion and drying. Drying is a traditional method of food preservation, as fruits, vegetables, fish, grains, agricultural products etc [1]. Drying is defined as a moisture removal process due to simultaneous heat and mass transfer [2]. According to Ekechukwu (1999), it involves extraction of moisture from the product by heat and removal of that moisture by a flowing air mass [3].

Most of the electricity being used at the industrial level is based on the fossil fuel energy, which is depleting rapidly. Therefore, renewable energy is the future of the energy requirements. Solar energy is one of the most important renewable energies and preferred to others because it is abundant, inexhaustible, non-pollutant, cheap and environment friendly**.** The use of solar energy is quite feasible in the tropics, where at least six hours of sunshine is received every day at about 500-800 W/m^2 of average solar radiation intensity [4].

Solar energy has been used to dry foods for thousands of years. India belongs to the tropical region and receives an enormous amount of solar energy. On an average, the solar energy of the order of 5 kW h/m^2/ day for over 300 days/ year [5]. Hence there are huge opportunities to use solar energy for drying purpose.

The dryers using solar radiation to dry the product are known as solar dryers. In solar dryer, solar energy is used as either the sole source of the required heat or as a supplement source [6]. Different types of solar dryers are available in various size and design depending on the requirements. The method of collecting solar energy and transferring it to the product is used to identify the type of solar dryer as direct, indirect and mixed type [7].

In direct type of dryers, the material to be dried is placed in a transparent enclosure of glass or transparent plastic. The solar radiations directly heat the material to be dried, and heat also builds up within the enclosure due to the 'greenhouse effect.' The drier chamber is usually painted black to absorb the maximum amount of solar radiation [6]. In the indirect type of dryers the food is dried by heated air instead of direct exposure to solar radiation. It is consisted of a cabinet integrated with a solar air heater (solar collector).The heated air travels from solar collector to cabinet exit due to the density difference. Mixed-mode dryer combines the features of both direct and indirect solar dryers. The mixed-mode dryers consist of both collector and chamber assembly with transparent wall(s) and roof. The cabinet receives solar energy directly through wall(s) and roof in addition to the energy from solar collector.

In the region of northern India, there is no documented evidence of use of solar dryers either at household level or at industrial level. This may be due to less awareness of the people about the benefits associated with the solar dryer. Thus it is necessary to propagate the benefits of the solar dryer and its feasibility in the northern India. Therefore, in order to check the feasibility of solar dryer, the performance of a

mixed-mode solar dryer with transparent roof has been carried out in this paper.

2. METHODOLOGY

The experiments were conducted on the terrace of Department of Mechanical Engineering, Kamla Nehru Institute of Technology, Uttar Pradesh (26°17'N and 76°16'E). The fabricated mixed mode solar dryer is shown in Fig. 1. The tests were conducted generally between 10.00 AM to 5.00 PM. The investigations were done for the flat plate collector under no load and single tray load (upper). The experiment was performed with the food product potato slices (chips). The potatoes were taken peeled, washed and sliced in an approximate thickness between 3-6 mm. In open drying, to provide same amount of solar irradiation, the drying area in open was maintained accurately equal to the collector area plus transparent roof area. In order to produce the similar situation as in the traditional drying, potato slices were spread on a cloth in open sun, which was already weighed by digital weighing machine. For single tray experiment, the tray was loaded with 500 gm and same weight of potato slices were laid down on the cloth in open. The weight of potato slices with tray was taken at the interval of one hour. All the authenticated ambient data such as temperature, humidity, velocity and solar insolation were taken by Solar Radiation Resource Assessment (SRRA) pyranometer installed by government of India on the roof of Mechanical Engineering Department, KNIT, Sultanpur. At each hour the measurements of temperature, humidity and weight of tray along with open dried potato slices with cloth was taken and the results were plotted.

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Fig. 1: Mixed –mode solar dryer

3. RESULTS AND DISCUSSION

The various parameters were recorded for mixed-mode solar dryer in the month of March 2016 are shown in Table 1. From Table 1, it is observed that the drying cabinet temperature is higher (10 – 40 ^{o} C) as compared to ambient. The observation of moisture content and instantaneous mass of the potato slices are shown in Table 2. The initial moisture of the potato slices was determined on wet basis. The initial moisture content is the ratio of the difference of initial and fully dried mass; and initial mass of the potato. The instantaneous moisture content was determined from the above mentioned criteria by replacing initial mass with instantaneous mass. The performance of dryer as compared to open sun is presented in Fig. 2.

Table 1: Flat plate collector with mixed mode, natural convection at single tray load

Date: 19/03/2016 flat plate collector(with mixed mode) natural convection single trayload												
Time	Collector	collector glass		Chamber		top glass		fan out		Humidity	Ambient		Irradiation
	Tc	Tig	Tog	Ti	To	Tgi	Tgo	Tf	Vf	ho %	Ha	Ta	Ia
9.00	66.00	46.90	39.50	40.10	37.90	38.30	33.20	31.10	0.00	26	53.07	29.57	590.41
10.00	79.10	58.40	47.60	57.90	55.30	47.70	40.30	41.50	0.00	20	46.68	31.19	731.84
11.00	88.80	66.60	54.10	68.80	64.30	56.10	46.40	49.10	0.00	10	42.04	33.11	819.66
12.00	91.10	69.30	55.50	74.50	72.30	62.10	49.40	53.60	0.80	10	41.70	33.50	828.02
13.00	91.00	70.00	57.10	77.60	76.10	62.70	51.90	53.90	0.00	10	39.41	34.18	757.06
14.00	84.80	64.40	54.00	72.40	73.80	60.70	51.10	54.80	0.00	10	39.87	34.50	646.01
15.00	73.30	56.30	48.50	63.70	67.40	55.30	47.30	53.30	0.00	10	42.20	34.69	470.18
16.00	60.30	49.40	43.60	54.80	60.20	50.00	42.80	49.50	0.60	10	42.71	34.45	257.55
17.00	48.00	42.10	39.40	47.80	48.40	42.70	38.40	42.70	0.80	10	48.28	32.91	69.80

Fig. 2 shows the variation of moisture content (% wb) with time. This variation is exponential in nature and is similar to the findings reported by Srikiatden and Roberts (2008) and Tesfamichael and Assefa (2013) [8, 9].

Table 2: Comparison of solar dryer performance with open sun drying for single tray loading

Time	Moisture content (% wb)		Instantaneous mass (gm)	
	Open sun drying	Solar dryer	Open	Solar dryer
9.00	80.60	80.60	500	500
10.00	79.23	77.44	467	430
11.00	67.99	66.08	303	286
12.00	38.61	41.92	158	167
13.00	29.71	19.17	138	120
14.00	21.77	11.01	124	109
15.00	21.14	9.35	123	107
16.00	20.49	5.83	122	103
17.00	19.83	5.83	121	103

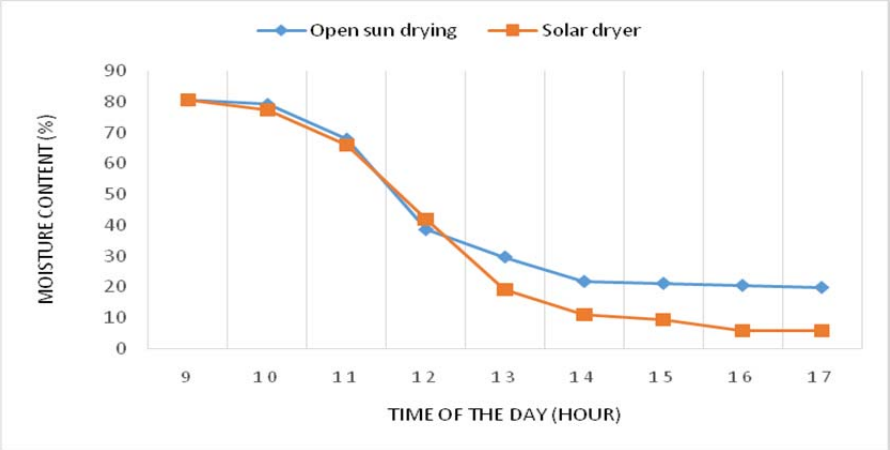

Fig 2. Moisture content reduction with time in open sun drying and in solar dryer

The relative humidity inside the drying cabinet in full load condition was observed at the interval of 30 minute. The data of relative humidity of ambient air were taken from SRRA.

Fig. 3 shows the variation of relative humidity of drying cabinet with time in comparison to ambient relative humidity. From Fig. 3, it is seen that the relative humidity of air inside the drying cabinet is lower than that of the ambient air. The relative humidity as shown is decreasing with time for both drying cabinet air and ambient air.

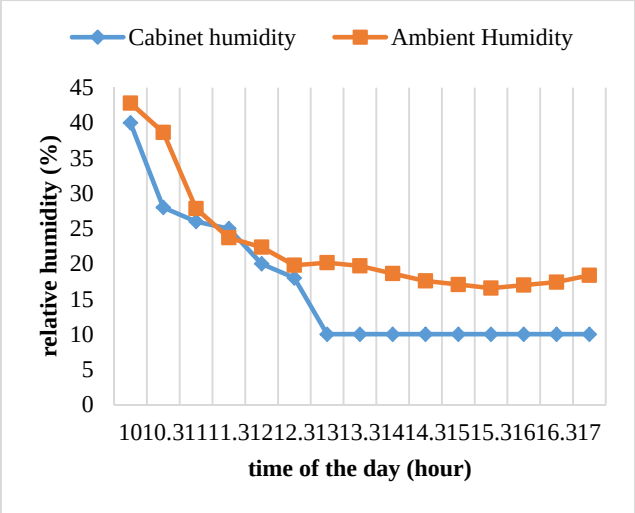

Fig. 3: Relative humidity variation of cabinet on full load and ambient condition

It is observed that the equilibrium moisture content with a higher value was achieved in the open sun drying than that in solar drying. This observation can be explained on the basis of relative humidity of the drying air. Since the relative humidity of the drying air inside the cabinet is less than that of the ambient, therefore, in cabinet the drying air is able to extract more moisture as compared to ambient air.

4. CONCLUSION

1. The temperature inside the drying cabinet is higher than that of the ambient.
2. The equilibrium moisture content observed was lower for solar dryer than that in open sun.
3. The value of equilibrium moisture content was not same for dryer and open sun hence it is not a constant value. The equilibrium moisture content is depending on relative humidity of the drying air.

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