Solar Drying In Hot and Dry Climate of Jaipur, India

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Abstract-Objective of the present study was to design, develop and carry out detail experimentation and then analyze solar cabinet dryer. For this various types of solar dryers, their principles and design methods, modeling, drying temperature, efficiency, utilization and payback period were reviewed. In the present study, double shelf type cabinet dryer was constructed and coupled with flat plate solar air heater for drying of green chilies and potato chips in mixed mode in two spell of 12 days (in summer) and 35 days (in winter) at Mechanical Engineering Department, M. N. I. T., Jaipur, latitude (26.01° N). Hourly measurements of solar intensity, relative humidity, wind speed and temperatures at fifteen different points were taken. Seven cases (for different combination of glazing and insulation) were studied experimentally for moisture loss and drying time. Higher hot air temperature rise and efficiency along with shorter drying period was observed with glass glazing as compared to polycarbonate sheet.

Keywords-Solar cabinet dryer, flat plate air heater, solar drying, green chilies, potato chips

1. Introduction

In India, agriculture is a major source of employment, income and foreign exchange. It offers great opportunities to stimulate economic growth. Capitalizing on these opportunities requires modification of agricultural processing systems and application of sustainable energy technologies. Solar drying is an excellent way to preserve food and for a sustainable world. Drying of crops is useful in most areas of the world, especially those without a high humidity during the harvesting season. If solar drying of produce were widely implemented, significant savings to farmers would be achieved and these savings could help strengthen the economic situation as well as change the nutritional condition of numerous developing countries. As a result, considerable research and development activities have taken place to identify reliable and economically feasible alternative clean energy sources. The choices for the alternate energy sources are: energy from sun, wave, wind and geothermal etc but solar energy being the most promising.

Open drying or natural sun drying has several disadvantages like spoilage of product due to adverse climatic condition such as rain, wind, moist, dust, storm etc. Loss of material due to birds and animals, deterioration of the material by decomposition, insects and fungus growth in open sun drying is quite common. The process is highly labor intensive, time consuming and requires large area.

Farkas et al., 1999 [8] have performed experimental study on a modular solar dryer in Hungary which helped in improving the product quality. Singh et al., 2003 [13] used multishelf potable dryer for drying of fenugreek leaves and observed maximum stagnation temperature of 75°C. Shanmugam et al., 2006 [11] designed and fabricated a desiccant integrated solar dryer to investigate its performance under the hot and humid climatic conditions of Chennai, India during the month of June. Hossain et al., 2009 [9] redesigned, fabricated and installed a mixed mode type forced convection solar tunnel dryer at the Department of Farm Power and Machinery, Bangladesh Agricultural University, Bangladesh for drying of red and green chilies under the tropical weather conditions. The dryer had a loading capacity of 80 kg of fresh chilies. Barnwal et al., 2008 [5] used hybrid photovoltaic thermal integrated dryer for drying grapes under forced flow mode and made comparisons between open drying, drying under shade and greenhouse conditions. Janjai et al., 2009 [10] experimented on peeled longan and banana with greenhouse dryer and the dryer was ventilated by three fans of 50W capacity each. The drying air temperature varied between 31°C to 58°C for peeled longan and 30°C to 60°C for drying of banana. Drying time for peeled longan and banana were three and four days respectively with solar dryer as compared to five to six days in open sun drying. It is observed from the various studies that solar drying under hot and dry climatic conditions was not carried out.

For the present study an experimental set up of solar dryer is erected at Mechanical Engineering Department, M.N.I.T., Jaipur, India. Jaipur (26°.53' latitude and 75.52° longitude) receives high solar intensity (600-1000 W/m^2) for more than 330 days in a year and an attempt has been made to carry out the drying study for conserving the perishable foods.

2. Design and Development

Design of solar dryer is based on the climatic conditions of the place (like ambient temperature, humidity and solar intensity), nature of the product to be dried and its quantity etc. Indirect type of double shelf cabinet dryer was designed and constructed and coupled with already available flat plate solar air heater for air heating (figure 1). The dryer is placed on a steel frame stand of (height 0.5 m) with caster wheels to make it mobile. Hot air is supplied through PVC pipe (7.5 cm OD) at the bottom of drying chamber and air moved upward through aluminium wire mesh of the shelves.

Fig.1. Photograph of solar air heater, cabinet dryer and two glazing frames

A 0.373 kW electric blower is used for circulation of air through air heater and dryer. Chimney was fitted at the outlet of dryer for better circulation of air through the shelves and to reduce the power consumption of blower. Capacity of the dryer was 2 kg and potato chips and green chili were dried.

Table 1. Design details of solar air heater and cabinet dryer

S.No	Detail of solar dryer	Dimensions
1	Total area of collector	1. 27 m x 0.93 m
2	Aperture area of collector	1.21 m x 0.88 m (1.06 m^2)
3	Collector inclination	42° (latitude + 15°)
4	Absorber plate	GI sheet coated with black paint
5	Emissivity of absorber plate	0.13
6	Bottom side of collector	2 cm thick wooden plate
7	Baffles	4 number, size 0.4 m x 0.03 m
8	Number of Thermocouple	Nine, on the lower side of absorber plate
9	Position of thermocouple	3 rows (row gap is 50 cm), 10 cm from the edges, pitch 0.34 m
10	Blower motor	0.373 kW, 1500 RPM
11	Dryer	Cubical, 0.50 m x 0.50 m x 0.50 m
12	Shelves	Two number, 0.50 m x 0.50 m x 0.20 m
13	Thickness of plywood	0.012m

2.1. Collector glazing and insulation

Top glazing is the important in solar air heater as it prevents convective and radiative heat losses from upper side of absorber plate. Two frames of glass and poly carbonate sheets were fabricated and installed at a gap of 3 cm from the absorber plate and thermocol sheet of 2.5 cm thickness was used as insulation on the bottom of the collector to minimize conductive heat losses. Initially there was no insulation on the back of collector. Four equally spaced baffles of size 0.4 m x 0.03 m were arranged in zigzag manner in air stream on the bottom plate of collector to cause more uniform air flow and to absorb more energy.

2.2. Drying chamber and chimney

Effective drying of the product is dependent on the design of drying chamber. A cubical shaped drying chamber with two drawer type of shelves with aluminum net fitted on the bottom side of the shelf was fabricated as shown in figure 2. Hot air coming from the solar collector passed over the products kept in the drawer shelves and dried the products by removing moisture. Frustum of cone type chimney of height 0.58 m having square cross section with side of bottom section 0.115 m and top section 0.095 m is used with dryer. Outgoing moist air is removed using draft effect of chimney fitted at the top of the dryer. Chimney is used to facilitate the escape of exhaust hot air from the drying chamber.

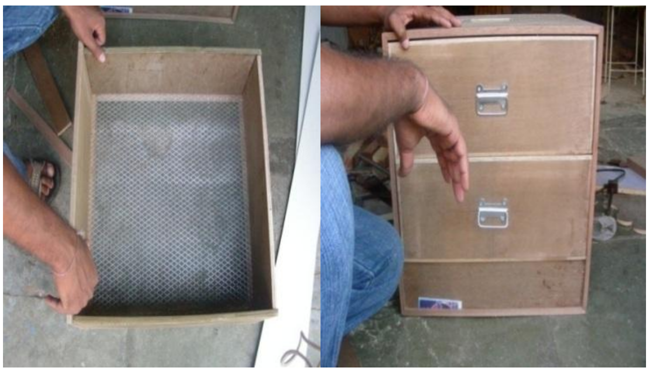

Fig. 2. Aluminum mesh used in shelf and two drawer shelves of drying chamber

3. Instrumentation and experimental study

Experiments were performed on the dryer without using insulation and glazing during first spell (11th to 21st May, 2010)and with glazing and insulation during second spell (18 Dec., 2010 to 22 January, 2011) on green chili and potato chips.

3.1. Instrumentation and Experimental Study

K type (Chromel–Alumel) of thermocouple wires were chosen owing to its high sensitivity at a reasonable cost. Temperatures were measured at fifteen points of dryer and collector. Out of these nine different temperatures were taken for absorber plate, one of hot air coming out from collector, two temperatures in the shelves of the dryer and two for inlet and outlet of solar dryer and chimney respectively. Ambient air temperature was also measured regularly. A six channel digital temperature indicator was used to measure these temperatures and analog hygrometer is used to measure relative humidity. A hot wire anemometer is used to measure the wind speed and a digital solarimeter is used for the measurement of global solar radiations.

3.2. Experimental Observations

Initially in the first spell of reading there was no glazing cover and bottom insulation on the solar air heater and cases of without and with load were considered. Product was loaded at 8 a.m. and dryer took about an hour to achieve steady state condition and then hourly readings were taken from 9 a.m. to 5 p.m., at the end of day the products were packed in a polythene bag and product weight was recorded. Second spell of experimentation was conducted with various combinations of insulation and glazing (i.e. glass and polycarbonate sheet) for determining drying time under controlled conditions of solar dryer. The product drying time for open sun drying and in mixed mode was also studied simultaneously.

Seven cases of different combinations of glazing and insulation (themocol) used with and without product load is considered. These cases considered are: case 1- Dryer without glazing and insulation and no product load, case 2- Dryer without glazing and insulation but with product load, case 3- Use of polycarbonate glazing, bottom insulation and with product load, case 4- Use of glass glazing, insulation and product load, case 5- Initially open drying then control drying as in case 4, case 6- Only insulation and with product load (without glazing) and case 7- Open drying only. Some of the observations are presented in table 2 and 3 for case 3 for green chilies and potato chips respectively and in table 4 (case 4) for drying of green chilly. For solar drying green chilies (initial wet mass of 2 kg) and potato chips (wet mass 1 kg) of uniform thickness and size were taken and spread in two shelves of the dryer.

Table 2. Hourly temperature variation for green chilies on Dec. 29, 2010 (case 3)

S.No.	Time	Temperature, °C														
		Nine temperature of absorber plate									SAH outlet	Dryer inlet	Lower shelf	Upper shelf	Chim. outlet	Ambient air
		T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}	T_{13}	T_{14}	$T_{amb.}$
1	10:00	39	38	32	41	40	39	40	39	33	30	28	26	25	23	15.7
2	11:00	49	49	55	56	55	50	53	48	49	39	37	36	34	32	17.8
3	12:00	55	54	69	69	65	63	59	59	54	50	48	47	45	43	19.2
4	13:00	61	66	79	78	75	71	70	66	64	55	52	52	51	50	20.9
5	14:00	73	74	79	80	78	74	78	74	75	52	50	48	48	47	21.7
6	15:00	61	69	74	73	69	62	66	60	63	45	45	44	44	42	22.1
7	16:00	56	54	59	60	60	55	50	58	50	41	40	39	39	37	19.7
8	17:00	41	41	39	45	40	40	38	39	35	33	31	29	27	26	16.2
9	Mean	54.3	55.6	60.7	62.7	60.2	56.7	56.7	55.3	52.8	43.1	41.3	40.1	39.1	37.5	19.1

Table 3. Hourly temperature variation for potato chips on Jan. 2, 2011 (case 3)

S.No.	Time	Temperature, °C														
		Nine temperature of absorber plate									SAH outlet	Inlet of dryer	Lower shelf	Upper shelf	Chim. outlet	Ambient air
		T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}	T_{13}	T_{14}	$T_{amb.}$
1	10:00	35	35	32	46	40	41	44	36	51	30	28	29	28	26	18.5
2	11:00	56	49	61	64	60	53	64	47	64	45	43	42	40	38	22.5
3	12:00	67	58	69	68	70	59	70	62	70	49	48	48	47	47	21.6
4	13:00	77	64	76	72	75	64	79	68	78	52	51	50	50	50	23.8
5	14:00	74	68	78	70	73	76	73	72	76	57	55	55	54	53	26.2
6	15:00	62	61	70	66	66	74	64	71	69	51	50	48	46	45	21.7
7	16:00	52	50	59	59	66	69	54	62	57	44	42	42	42	40	20.2
8	17:00	47	46	52	45	45	52	42	49	51	34	33	32	30	31	16.3
9	Mean	60.5	54.5	65	60.8	62.7	61.5	61.9	58.4	65	46.1	44.5	43.7	42.9	42.2	21.0

Table 4. Hourly temperature variation for green chilies on Jan. 5, 2011 (case 4)

S.No.	Time	Temperature, °C														
		Nine temperature of absorber plate									SAH outlet	Inlet of dryer	Lower shelf	Upper shelf	Chim. outlet	Ambient air
		T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}	T_{13}	T_{14}	$T_{amb.}$
1	10:00	49	39	52	43	40	45	49	36	51	38	35	34	33	32	18.5
2	11:00	56	58	61	64	60	53	64	47	64	45	43	42	40	38	22.5

3	12:00	67	65	74	70	76	76	70	72	70	49	48	48	47	47	21.6
4	13:00	70	70	80	80	79	79	77	76	82	59	57	57	54	52	23.8
5	14:00	69	74	78	70	73	76	73	72	81	57	54	52	50	49	23.5
6	15:00	62	61	70	66	70	74	64	71	69	51	50	48	46	45	21.7
7	16:00	52	50	59	59	66	69	54	62	57	44	42	42	42	40	20.2
8	17:00	47	46	52	45	45	52	42	49	51	40	38	39	38	38	16.3
9	Mean	59.0	57.8	65.7	62.1	63.6	65.5	61.6	60.6	65.6	47.0	45.1	44.1	42.6	41.8	21.0

3.3. Solar Intensity, Wind Speed, Relative Humidity

Hourly measurements of solar intensity, relative humidity and wind speed were also taken. Solar intensity varied between 7114 W/m2 to 870 W/m2 during first spell (table 5) and wind speed was about 0.95 m/s. Relative humidity of ambient air was high during the morning hours due to foggy conditions and it increased after passing through the dryer due to removal of moisture from the products but air gets heated up through air heater, hence relative humidity of spent air coming out from chimney is 4 to 5% lesser than the inlet ambient air. Daily average solar intensity varied between 262 – 670 W/m2 for winter season of second spell (figure 3).

Table 5. Average solar intensity, wind speed, RH on daily basis for first spell

Date	Solar intensity, W/m^2	Wind speed, m/s	R.H (inlet) %	R.H(outlet) %
11/5/10	791	0.975	29.3	26.75
12/5/10	813	1.05	28.7	25.5
13/5/10	809	1.30	28.6	26.5
14/5/10	777	0.96	29.6	24.3
17/5/10	711	0.92	32.4	27.5
18/5/10	750	0.93	30.4	25.7
19/5/10	870	0.96	26.4	23.8
20/5/10	822	0.92	29.9	25.0
21/5/10	831	0.87	26.1	23.7

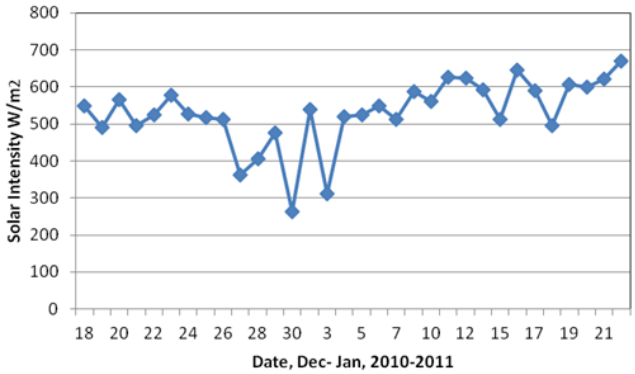

Fig. 3. Solar intensity variation for second spell

4. Results and Discussion

First set of measurements were taken during the summer and simple dryer without glazing and insulation was used for the drying of the products. In order to improve the performance of dryer and to reduce the drying period another set of readings were taken with cover glazing of polycarbonate and glass sheet and insulation during winter season. From hourly temperatures at different points daily average values were calculated as presented in table 6 for summer spell.

Table 6. Summary of daily average temperatures for first spell (summer) of drying

Date	Absorber plate		SAH outlet	Dryer in	Shelf 1	Shelf 2	Chimney out	Amb.	Temp. rise
2010	T_{max}	T_{avg}	T_{10}	T_{11}	T_{12}	T_{13}	T_{14}	T_{amb}	T_{10} -T_{amb}
May 11	74	57.9	34.5	32.8	32.3	31.1	30.6	28.5	6.0
May 12	72	57.5	47.2	46.5	45.7	45.2	44.3	38.8	8.4
May 13	63	57.1	45.1	44.0	43.6	42.8	42	38.3	6.8
May 14	69	58.3	47.3	46.3	46.0	45.6	45.2	38.0	9.3
May 17	68	58.3	47.1	45.2	44.6	44.3	44.2	38.6	8.5

May 18	71	59.8	48.5	47.1	46.6	46.3	46.0	38.5	10.0
May 19	72	59.9	47.7	47.6	46.5	46.0	46.2	40.2	7.5
May 20	69	55.4	46.6	46.2	45.5	45.2	44.6	37.2	9.4
May 21	70	60.4	48.1	47.1	46.8	46.4	47.1	40.1	8.0

Temperature rise of air was 6-10ºC during summer season (1st spell) and it increased to 17-29ºC when glass and polycarbonate covers were used as glazing material even at low solar intensities during winter season (2nd spell). It is observed from figure 4 that there is sufficient temperature difference between shelf and ambient, which is required for effective drying through the dryer. Temperature of air is higher in lower shelf than upper shelf. Some troughs are noticed in temperature plots of ambient and shelf due to insufficient sun and cloudy weather conditions.

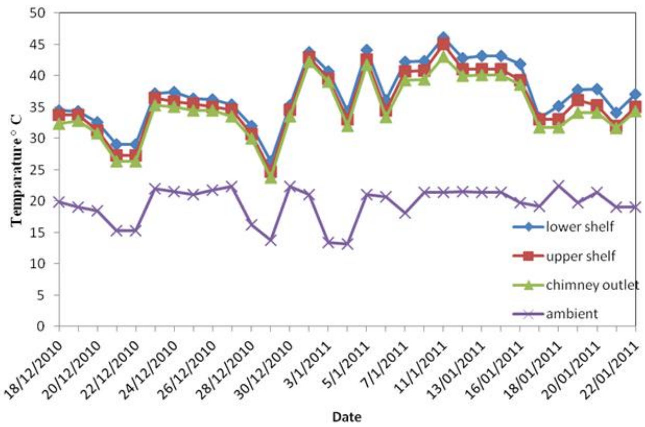

Fig.4. Variation of daily average temperatures during second spell of experimentation Variation of daily average temperatures during second spell of experimentation

Temperature of air in lower and upper shelf for different cases considered is plotted in figure 5 and 6.

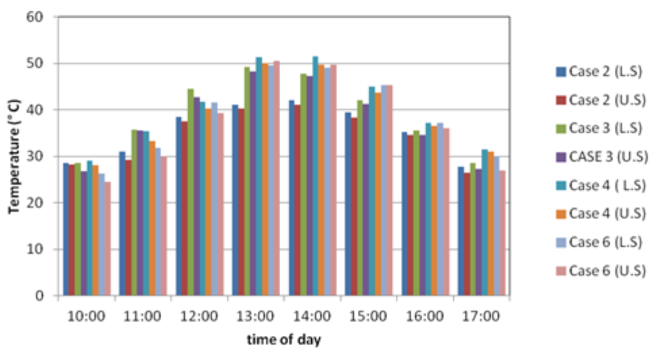

Fig. 5. Average temperature of lower and upper shelf of cabinet (green chilly drying)

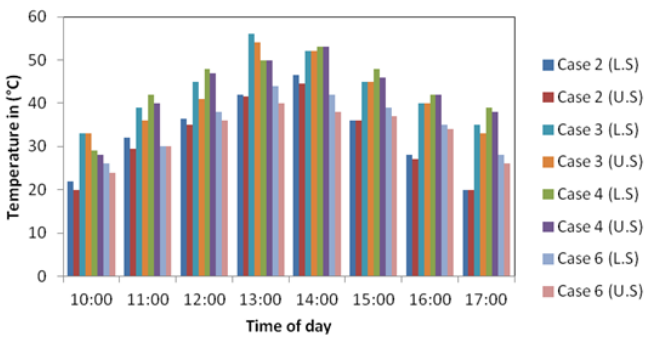

Fig. 6. Average temperature of lower and upper shelf of cabinet (potato chips drying)

These plots clealy indicate that glass glazing (case 4) gives highest shelf temperature through out the day follwed by polycarbonate sheet (case 3). Also the use of glazing and insulation hasincreaded shelf temperature (case 3 & 4) as compared to simple dryer without glazing and insulation (case 2). During the noon time from 11 am to 3 pm temperatures were quite high and dryer perfiormence was highest.

Moisture loss during summer (spell-1) and winter season (spell-2) without glazing and insulation is shown in figure 7 for green chili.

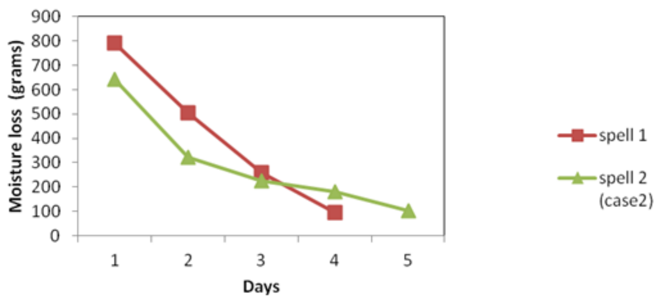

Fig. 7. Daily moisture loss for chilly for case 2

Solar dryer efficiency observed for green chilly drying was 24% and 19% with glass and polycarbonate sheet glazing respectively (highest on first day with consequent lowering for the coming days) for different cases as shown in figure 8. In hybrid drying (case 5) efficiency was lower on first day due to open sun drying as compared to other days when controlled drying in cabinet dryer was carried out.

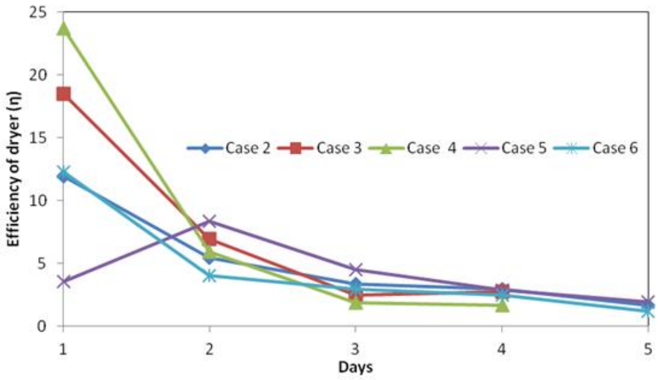

Fig. 8. Efficiency of solar dryer for drying of green chilly

Drying of potato chips completed in one day for most of the cases considered except for case 2 and case 6 where it completed on second day and performance was highest with efficiency of 18.2 % with glass glazing as shown in figure 9.

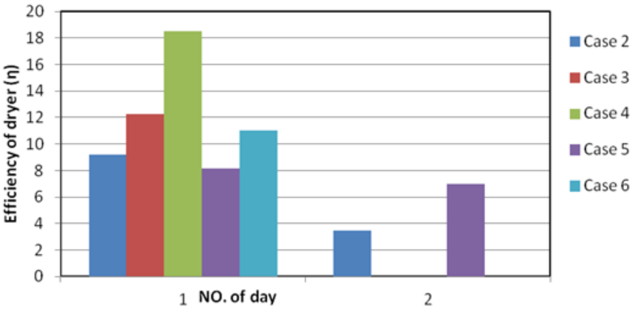

Fig. 9. Efficiency plot for potato chips drying (second spell)

Drying time of potato chips and green chilly is plotted in figure 10 for winter season for different cases. Glass glazing and thermocol insulation (case 4) takes lowest drying time for both the products followed by polycarbonate glazing (case 3). These results show that use of glazing and insulation in drying improves performance of dryer and reduces drying time.

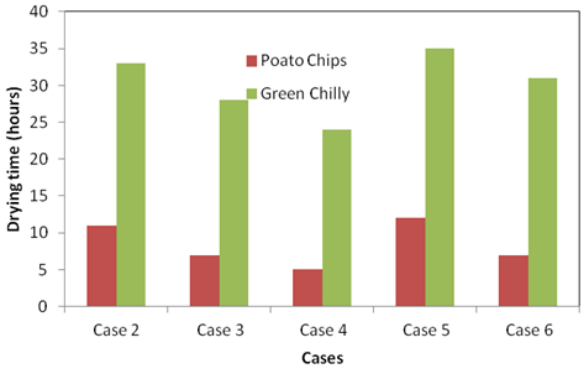

Fig. 10. Drying time for different cases (spell 2)

The experimental study shows that maximum air temperature rise is achieved in case 4 and 5 when glass sheet is used as glazing and thermocol sheet as insulation. Drying time of products is also lowest with glass glazing followed by polycarbonate glazing. When drying is carried out in simple dryer (case 1 and 2) the air temperature rise is lower and drying time is higher. In open drying (case 7) drying time for potato chips and green chilly is almost double that of case 3.

5. Conclusion

Double shelf cabinet dryer was designed, fabricated and connected to flat plate solar air heater. Indirect solar drying of potato chips and green chilly was carried out in two spells. Study in winter (first spell) was performed on simple dryer (without cover and insulation) and during second spell of experimentation seven cases for various combinations of glass and polycarbonate sheet as glazing and thermocol as insulation were studied. Hourly temperatures at fifteen different points along with solar intensity, wind speed were measured and moisture loss from the products, drying time and dryer efficiency were estimated.

Following were the main observations: (i) temperature of absorber plate during 1st spell in summer was lower even with higher solar intensity (i.e. 50° to 57°C) as compared to winter (58 to 67ºC). (ii) temperature rise of air increased from 11°C to 18°C and without glazing and insulation to 25 to 29°C with the use of glazing and insulation (iii) use of glass and polycarbonate sheet as glazing cover improved dryer efficiency from 9 to 12% in case of simple dryer to 23.7% with glass glazing and 18.5% with polycarbonate sheet and drying time reduced.

It is recommended to use cabinet solar dryer for drying of agricultural products with glazing and insulation instead of simple dryer.

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