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Comparative Analysis of Cabinet Type Solar Dryer with Different Collector Geometries

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Abstract-In present work flat plate, v-groove and fin type collectors were constructed. Each collector was integrated with separate cabinet dryer. Experimental tests were carried out on tomato slices, green chilli and potato slices in natural convection mode. The aperture area of all types of collectors, cabinet sizes, numbers of trays (4 no.) in each cabinet and mass flow rate of air through collector were kept same. All tests were carried out in metrological conditions of Chandwad having latitude (20.31^{o}N), longitude (74.4^{o}E) and elevation (580M). Tomatoes were dried down from approximately 93% (w.b.) to 10% (w.b.) moisture contain in 12 hours 9 minutes, 10 hours 45 minutes and 10 hours in dryers integrated with flat plate, V-shape and fin type collector respectively in natural convection mode. The moisture content of chilli from an initial value of 78% (w.b) to a final value 9% (w.b.) reduced by natural convection mode in 24 hours, 23 hours, 23 hours in dryers integrated with flat plate, V-shape and fin type collector respectively. The moisture content of potato slices reduced from an initial value of 80% (w.b.) to a final value 10% (w.b.) by natural convection mode in 5 hours 15 minutes in dryer integrated with flat plate collector; while both dryers integrated with fin type collector and V-shape collector took 5 hours respectively. The fin type collector has highest average collector efficiency, drying rates and collector outlet temperature among all tested collector types in both natural and force convection mode.

Keywords- Solar dryer, flat plate, v-groove, fin type, collector efficiency, drying rate.

I. INTRODUCTION

The conventional energy resources are gradually coming to end; oil will be first to depleted, followed by natural gas & coal [1]. Developing country like India is facing large energy issue. The importance of crude oil increases rapidly which becomes dominant. Now it is important to study and investigate existing & develop alternatives energy sources. Consequently human race must give emphasis on the use of renewable energy. Sun is the promising alternative over conventional energy sources and it needs to be used more extensively. Solar energy is the most abundant and promising energy resources existing on earth.

The major application of solar energy is its use for drying of agricultural products [2]. It is estimated that about 600 to 900 million people do not have enough food to eat and this number is likely to increase with the increase in population. There are obviously two ways of solving this problem; First, by increasing area under cultivation and second, reducing the food demand by controlling population growth.

The third alternative which is equally important but not given adequate attentions is loss of food during and after harvesting. There are several ways of preserving the food such as dehydration, freezing, canning etc. Solar drying is oldest technique used for drying agricultural foods, vegetables fruits, etc. Drying compensates the shortage in supply and reduces post harvesting losses. Since it is a realistic means and highly effective, solar drying is most suitable for use in developing countries.

Conversely, in order to maintain and improvise the sustainability of this technique, an apposite technology is needed.

Drying processes involves reducing moisture from the food product, conducted by vaporizing water from food product. Thus microorganisms are unable to grow as drying removes moisture from food product. In open sun drying food product is simply spread on floor or ground exposing food to

sunlight. The process is independent of any other source of energy except sunlight and hence the cheapest method. However, there are losses like the long wavelength radiation loss from the surface of crop to ambient air through moist air and also convective heat loss due to the blowing wind through moist air over the crop surface. Also, it does not fulfill the required quality standards and sometimes the products cannot be sold in the international market. With the awareness of inadequacies involved in open sun drying, a more scientific method of solar-energy utilization for crop drying has emerged termed as solar drying [3].

Karsli [4] conducted experimental study to compare the performance of four types of air heating flat plate solar collectors: a finned collector with an angle of 75° and 70°, a collector with tubes and a base collector. The results showed that efficiency changed between 26% and 80% for collector-I, between 26% and 42% for collector-II, between 70% and 60% for collector-III, and between 26% and 64% for collector-IV. Author concluded that efficiency of solar air collectors significantly depends upon intensity of solar radiation and geometry of the collector. Karim and Hawlader [5] carried out analytical and experimental investigation to determine the performance of v-groove solar air collector for drying applications under the metrological conditions of Singapore. Authors reported that results of analytical study agreed very well with experimental study. Simulation result indicated that efficiency increases constantly with flow rate up to 0.035 kg/m2-s and, thereafter, increases at a decreasing rate. Chabane et al. [6] carried out experimental investigation to determine the performance of solar air heater with internal fins attached to the back of absorber plate, as a semi-cylindrical form. Authors reported that the heat transfer rate directly varies with the time of the day. The modification produced in the geometrical form due to presence of fins creates an enhancement in the area available for heat transfer which consequently results in the increase of heat transfer rate. Gao et al. [7] carried out analytical studies on thermal performance of cross-corrugated and flat-plate solar air heater. During the experimental work there are two types of heaters arrangements. In type 1 arrangement wavelike shape of upper absorbing plate is along the flow direction of air while that of bottom plate is perpendicular to flow direction. In type 2 air heater arrangement wavelike shape of upper absorbing plate is perpendicular the flow direction of air while that of bottom plate is along with flow direction. Authors concluded thermal performance of the type 2 heater is just slightly superior to that of the type 1 but both types of heaters have a much superior thermal performances than that of flat-plate one. Akpinar and Kocyigit [8] carried out an experimental investigation of performance of a plate collector with several obstacles (Type I, Type II, and Type III) and without obstacles (Type IV). Authors concluded that maximum difference temperature increase through four types of solar air heaters (I-IV) was 45.9, 50.5, 44.1 and 33.1oC for 0.0074Kg/s, 47.4, 55.4, 48.5 and 38.3 for 0.0052Kg/s, respectively.

From this literature survey, it has been observed that performance of cabinet type solar dryer depends on metrological conditions, solar radiation intensity, and geometry of air collector. Various researchers have carried out investigation on different collector geometries. However, comparative analysis of these geometries in same metrological condition has not been carried out. Present work is intended to investigate the performance of different collector geometries same metrological conditions to find out the effect of collector geometry on dryer cabinet performance, drying rate and quality of dried food products.

II. EXPERIMENTAL SETUP AND CONDITIONS

Present experimental investigation has been carried out at Chandwad, Dist. Nashik, Maharashtra (India). Chandwad having latitude angle is 20.21^{o}N. Angle of tilt of collector is 35.21^{o}.

Average daily radiation at Chandwad on horizontal surface is = 470 W/m^2. Important technical specifications of various solar collectors used are given as follows:-

Particular/Specification	Collector Type		
	Flat Plate Collector	V-Groove Plate Collector	Fin Type Collector
Width	0.6 m	0.6 m	0.6 m
Length	1.2m	1.2m	1.2m
Surface area	0.72 m^2	1.11078 m^2	1.108512 m^2
Absorber material (thickness)	GI Sheet (0.001m)	GI Sheet (0.001m)	GI Sheet (0.001m)
Cabinet	0.6m x 0.6m x 0.32m	0.6m x 0.6m x 0.32m	0.6m x 0.6m x 0.32m
Back insulation	Glass wool	Glass wool	Glass wool
Cover Plate (Transmissivity)	Glass (0.83)	Glass (0.83)	Glass (0.83)
Drying trays (in Nos.) (Spacing)	4 (0.10 m)	4 (0.10 m)	4 (0.10 m)
Drying trays (Size)	0.6 m x 0.33 m	0.6 m x 0.33 m	0.6 m x 0.33 m

Figure: 1 Pictorial View of Fin, Flat-Plate, V-Groove Type Collectors Integrated With Separate Cabinet.

These collectors are always tilted and oriented in such a way that it receives maximum solar radiation during the desired season of used. The best stationary orientation is to the south. Therefore, solar collectors in this work are oriented towards south facing and tilted at 35.31º to the horizontal.

III. EXPERIMENTAL PROCEDURE

Experiments were carried out between 10:00 AM and 4:00 PM. Tomato, potato, green chilli were dried in these cabinet type dryers by natural convection mode. Before drying, the initial moisture content of fresh food commodity was measured by oven test. According to type of food commodity, samples were prepared. Appropriate pretreatment was carried out. The pretreatment was done on both tomato and potato samples before solar drying. First citric acid solution was prepared by mixing the citric acid with water at 2% by weight. The tomato slices were dip into citric acid solution with soaking time of 3-4 seconds [9]. These pretreated samples were then placed on trays. Similarly pretreatment was done on potato samples before caring out experimental work. Measured quantity of samples was placed on trays. Thus loading of dryer cabinets was done. Then the setup was placed outside in the sunlight.

Next step was to record different observations such as temperature at inlet and outlet of collector, temperature at drying cabinet inside and outside, velocity of air at inlet of collectors, solar insolation and weight of sample. All the observations were recorded after interval of one hour. Experimental tests were carried out till the weight of test samples reached to equilibrium state.

IV. INSTRUMENTATION FOR MEASUREMENT

Six pre calibrated RTD (Pt-100) temperature sensors with ± 0.5°C accuracy were fixed at different locations of solar dryer and connected to digital temperature indicator. Along with RTD sensors three digital temperature sensors were used to find out collector outlet temperature.

Solar intensity was measured using LI-200 pyranometer with 1% accuracy. The humidity of air at the entry and exit of drier was measured with the help of hygrometer having accuracy of ± 1%. The velocity of air was measured with the help of anemometer having ± 0.01m/s accuracy. A digital electronic balance of 5 Kg capacity having an accuracy of 0.01g was used to weight the samples.

(a) *(b)* *(c)*

Figure: 2 Different Types of Collectors used during experimentation
(a) Flat Plate (b) Fin Type Plate (c) V-Groove Type

V. PERFORMANCE TERMS

Followings are an important terms used to evaluate performance of collector and dryer cabinet.

Collector efficiency:

Collector efficiency is defined as the ratio of useful heat gain by air flowing through collector over any time period to the incident solar radiation on plane of collector over the same period.

$$\eta_c = \frac{Q_u}{I \times A_c \times \tau \times \alpha} \quad (1)$$

$$\eta_c = \frac{m \times C_p \times (T_1 - T_a)}{I \times A_c \times \tau \times \alpha} \quad (2)$$

Where,

η_c =Efficiency of collector.
m = mass flow rate of air in kg/s.
I = Intensity of solar radiation in $W/m^{2.}$
A_c = Area of collector in m^2.
T_1 = Temperature at collector outlet in ^{0}C.
T_a = Temperature at collector inlet in ^{0}C.
C_p = Specific heat of air in J/kgK.
$\tau \times \alpha$= absorbance-transmittance.

Drying Chamber Efficiency:

$$\eta_d = \frac{(T_2 - T_3)}{(T_1 - T_a)} \quad (3)$$

Where
η_d =Efficiency of drying chamber.
T_1 = Temperature at collector outlet in ^{0}C.
T_2= Cabinet temperature in ^{o}C.
T_3= Cabinet outlet temperature in ^{o}C.
T_a = Temperature at collector inlet in ^{0}C.

System Drying Efficiency:

System drying efficiency is defined as the ratio of energy utilized to evaporate moisture in cabinet to the actual heat supplied to the collector. The system drying efficiency is a measure of the overall effectiveness of a drying system so it also called as overall dryer efficiency.

$$\eta_{sd} = \frac{m \times C_p \times (T_2 - T_3)}{I \times A_c \times \tau \times \alpha} \quad (4)$$

Drying Rate:

The rate of drying can be determined by using following relation. The weight of sample as it dries as a function of time.

$$DR = \frac{(M_i - M_f)}{t}$$

(5) Where
M_i = Initial moisture content in % w.b.

M_f = Final moisture content in % w.b.
t = time in hour.

VI. RESULTS AND DISCUSSION

Tomato Drying:

Experimental trial was conducted between 10:00 AM to 4:00 PM for two days. Following conditions were taken into account to report the present results. Initial weight of tomato samples were 1 Kg for each cabinet and initial moisture content of tomato samples were 93% (wb), Final allowable moisture was 10% (wb).

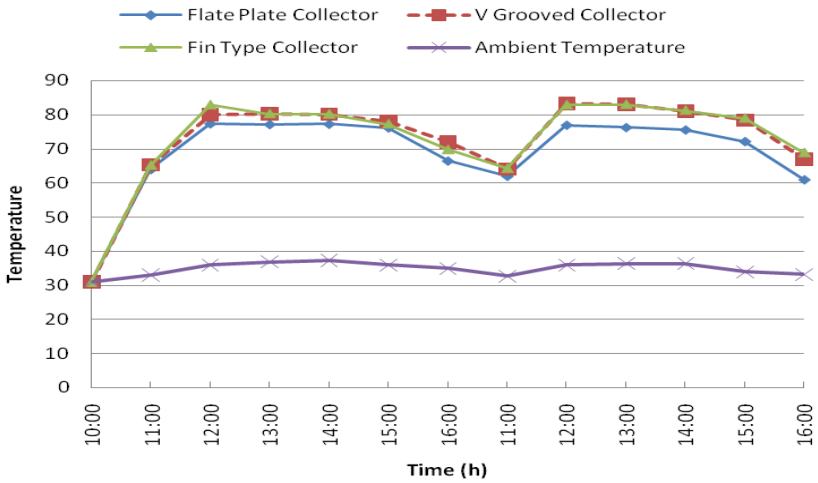


Figure: 3 Variation of collector outlet temperature against drying time for tomato drying by natural convection

The variations of temperature of air at outlet of flat plate, V grooved, fin type solar collectors and ambient temperature during drying of tomato are shown in Fig. 3. The drying air average temperature recorded at inlet of the drier was about 35^{o}C. The maximum and minimum drying air

temperatures recorded at the outlet of flat plate, V grooved, fin type solar collector were measured to be about 77.3 and 62ºC, 83.3 and 64.1ºC, 83 and 64.3ºC during peak and off sun sunshine hours respectively. The average drying air temperature to be found was 68.75, 72.56, 72.78ºC at outlet of flat plate, V grooved, fin type solar collector respectively. The average temperature difference between inlet and outlet drying air of flat plate, V grooved, fin type collector was found to be 33.8, 37.61, 37.83^{0}C respectively.

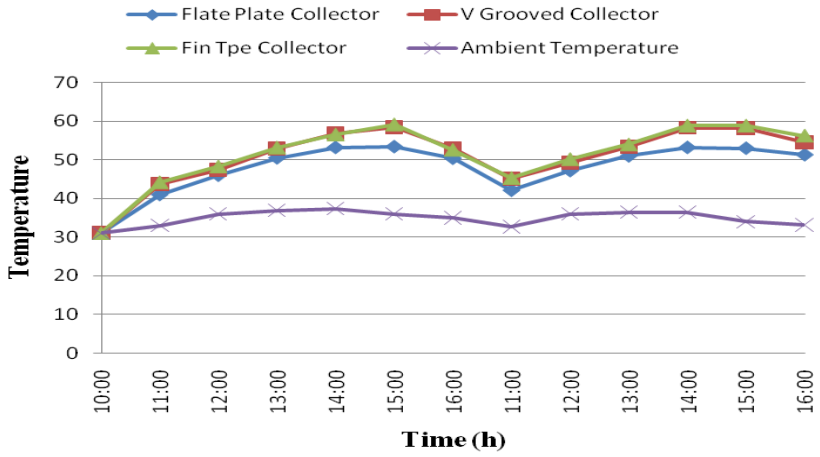


Figure: 4 Variation of cabinet temperature against drying time for tomato drying

The average temperature of drying cabinet of flat plate, V grooved, fin type collectors were recorded 47.95, 50.87, 51.44ºC respectively as shown in Fig.4. The average temperature difference between ambient air and drying cabinet of flat plate, V grooved, fin type collector was found to be 13, 15.29, 16.49^{0}C respectively.

The variation of moisture content (wet basis) of tomato slices with drying time is illustrated in Fig.5. In open sun drying, the products has an initial moisture content of 93%, is reduced to 10% for time period of 16 hours, while in cabinet type dryers having flat plate, V grooved, fin type collector products has an initial moisture content of 93%, are reduced to 10% for time period of 12 hours and 9 minutes, 10 hours and 45 minutes, 10 hours respectively.

Variation in average efficiency of different collectors during natural convection mode is illustrated in Fig.6. Fin type collector has highest average efficiency of 42.76% followed by V grooved type collector and flat plate type collector having average efficiencies 42.48%, 39.06% respectively. Solar dryer having fin type collector plate has maximum average cabinet efficiency of 17.54% among other solar dryers with different collector plate. While cabinet efficiency of solar dryers having V grooved and flat plate type collectors are found to be 17.35% and 17.64% respectively.

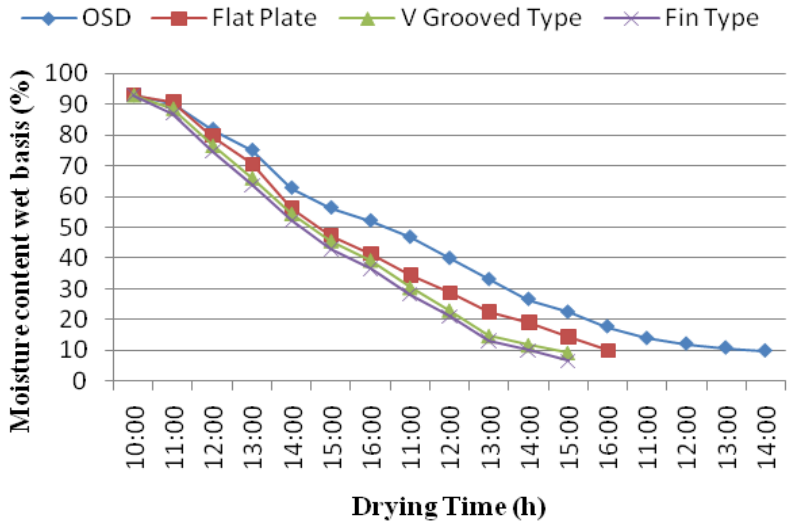


Figure: 5 Variation of moisture (%) against drying time in different dryers for tomato drying

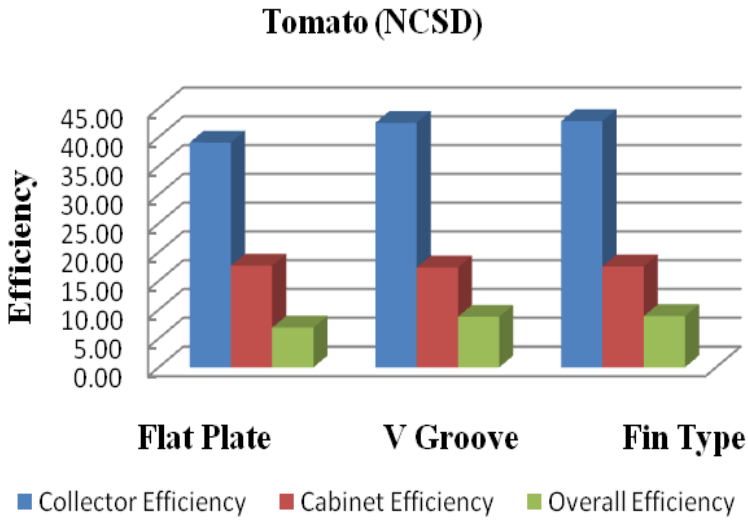
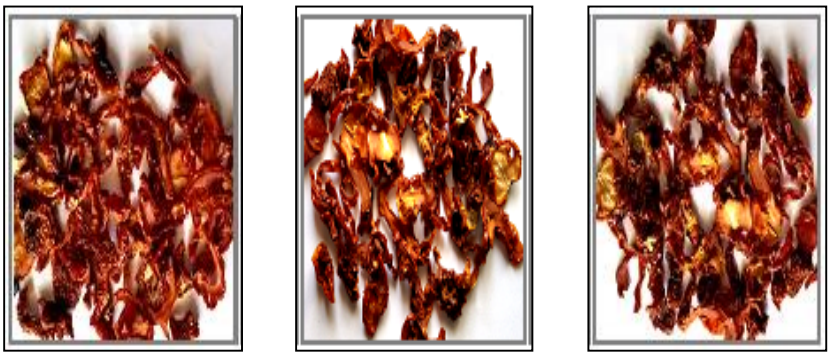


Figure: 6 Comparison of collector, cabinet, overall efficiencies of different dryers for tomato drying



(a) *(b)* *(c)*

Figure: 7 Dried tomato samples using different cabinet type dryers
(a) Flat plate (b) V-groove type (c) Fin type

Dried tomato sample in natural convection mode by different types of collectors shown if Fig. 7. The sample dried by fin type and v-groove type collectors has good quality and shows better results.

Chilli drying:

Experimental trial was conducted between 10:00 AM to 4:00 PM for four days. Following conditions were taken into account to report the present results. Initial weight of tomato samples were 1 Kg for each cabinet. Initial moisture content of chilli samples were 78% (wb), Final allowable moisture content was 9% (wb).

The variation of moisture content (wet basis) of tomato slices with drying time is illustrated in Fig.8. In cabinet type dryer having flat plate collector products has an initial moisture content of 78%, was reduced to 9% for time period of 24 hours. V grooved, fin type collectors cabinet products has an initial moisture content of 78%, was reduced to 9% for time period of 23 hours in both types of cabinet dryers.

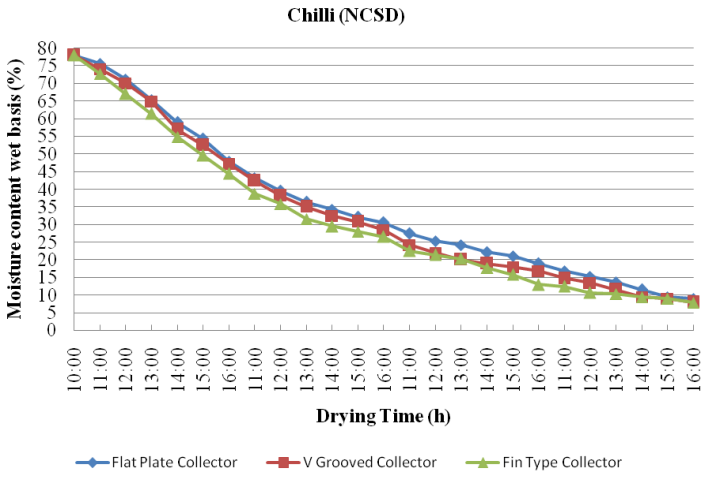


Figure: 8 Variation of moisture (%) against drying time in different dryers for chilli drying

Variation in average efficiency of different collectors during natural convection mode is illustrated in Fig. 9. Fin type collector has highest average efficiency of 46.15% followed by V grooved type collector and flat plate type collector having average efficiencies 44.97%, 40.70% respectively. Solar dryer having flat plate collector has maximum average cabinet efficiency of 18.41% among other solar dryers with different collector plate. While cabinet efficiency of solar dryers having fin type collector plate and V grooved plate type collectors are found to be 17.38% and 16.49% respectively.

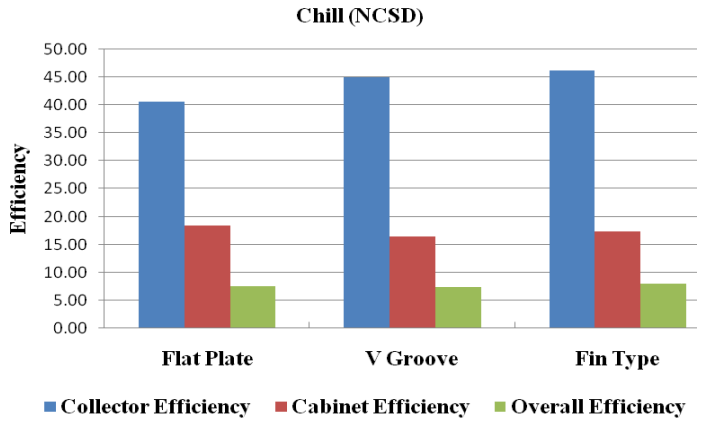


Figure: 9 Comparison of collector, cabinet, overall efficiencies of different dryers for natural convection chilli drying

(a) *(b)* *(c)*

Figure: 10 Dried chilli samples by different type of collectors
(a) Flat plate *(b) V-groove type* *(c) Fin type*

Dried chilli sample in natural convection mode by different types of collectors shown if Fig. 10. The sample dried by fin type and v-groove type collectors has good quality and shows better results.

Potato drying:

Initial weight of potato samples were 500 gm for each cabinet. Initial moisture content of tomato samples were 78% (wb), Final allowable moisture content was 9% (wb).

Variation in average efficiency of different collectors during natural convection mode is illustrated in Fig.11. Fin type collector has highest average efficiency of 37.34% followed by V grooved type collector and flat plate type collector having average efficiencies 36.43%, 33.17% respectively. Solar dryer having flat plate collector has maximum average cabinet efficiency of 24.54% among other solar dryers with different collector plate. While cabinet efficiency of solar dryers having fin type collector plate and V grooved plate type collectors are found to be 23.68% and 23.56% respectively.

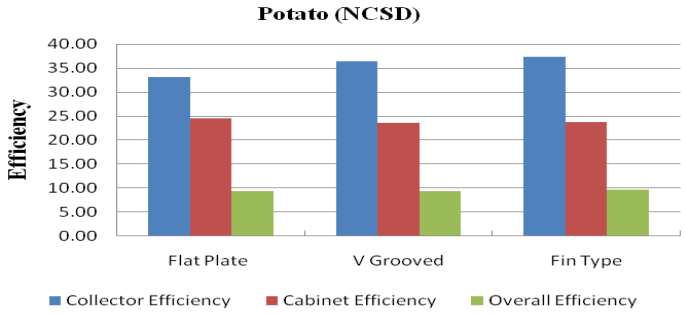


Figure: 11 Comparison of Collector, Cabinet, Overall Efficiencies of Different Dryers for Natural Convection Potato Drying.

(a) Flat plate (b) V-groove type (c) Fin type

Figure: 12 Dried Potato Slices In Natural Convection Mode.

The dried potato sample using v-groove type collector has good quality over dried potato sample using fin type and flat plate collector in natural convection mode.

VII. CONCLUSION

1. The moisture content of tomato slices reduced from an initial value of 93% (w.b) to a final value 10% (w.b.) by natural convection mode took 12 hours 9 minutes, 10 hours 45 minutes , 10 hours and in dryers integrated with flat plate, V-shape and fin type collector respectively.
2. The moisture content of chilli from an initial value of 78% (w.b) to a final value 9% (w.b.) reduced by natural convection mode in 24 hours, 23 hours and, 23 hours in dryers integrated with flat plate, V-shape and fin type collector respectively.
3. The moisture content of potato slices reduced from an initial value of 80% (w.b) to a final value 10% (w.b.) by natural convection mode in 5 hours 15 minutes in dryer integrated with flat plate collector; while both dryers integrated with fin type collector and V-shape collector took 5 hours respectively.
4. The average collector and system drying (overall) efficiencies for tomato drying are found to be; 39.06% and 6.89% for flat plate, 42.97% and 8.95% for V-shape, 42.76% and 8.88% for fin type collector.

5. The average collector and system drying (overall) efficiencies for chilli drying are found to be; 40.7% and 7.49% for flat plate, 44.97% and 7.42% for V-shape, 46.15% and 8.02% for fin type collector.
6. The average collector and system drying (overall) efficiencies for potato drying are found to be; 33.17% and 9.2% for flat plate, 36.43% and 9.31% for V-shape, 37.37% and 9.64% for fin type collector.
7. During experimentation, maximum temperature of air at outlet side of flat plate, V-shape, fin type collector was found to be 77^0, 83^0C and 84^0C respectively.
8. During experimentation, average temperature in dryer cabinets integrated with flat plate, V-shape, fin type collector was found to be 47^0, 51^0C and 51.6^0C respectively.
9. From experimental results drying rates are found to be 0.0735, 0.0830, 0.0892 Kg/Kgh for dryer with flat plate type, V-type, fin type collector respectively in natural convection mode. This shows that drying rate is improving in dryer integrated with fin type collector followed by V-type collector and flat plate collector.

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