ANALYSIS OF DIRECT, INDIRECT AND HYBRID SOLAR DRYER

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ABSTRACT

The purpose of the paper is to gain knowledge and compare the various kinds of Solar Crop Dryer (SCD) used to dry agricultural crops. There are many types of SCD and conventional methods that are being researched. Analyzing and comparing various kinds of SCD shows that sun utilization is a promising technology. The availability of space in urban areas, irregular sunshine, high initial cost and facilities problem are the major obstacles to their acceptance by Indian farmer. Research and development should overcome all of these limitations. In order to improve the approval of farmers, it is essential to design a large scale and inexpensive SCD. Research & development in solar drying technology has made significant progress. An overview of the development of solar drying technology is suitable for agricultural growth.

KEYWORDS: Solar Dryer, Indirect Solar Crop Dryer, Agriculture Food Product, Farmer & Economical

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INTRODUCTION

Agricultural food products are dried using solar dryers which is more acceptable due to their low cost compared to conventional and motorized drying systems, mainly in the region where there is more sunshine during the harvest season. In developing countries, small farmers face food loss when they produce more than 80% of their food products. Farmers from the old age usually used Open Sun Drying (OSD) to preserve agricultural crops such as grains, fruits and vegetables. Compared to other drying methods, open sun drying is a time consuming process and causes considerable damage to food products. The quality of the product has not been preserved due to the infestation of insects, enzymatic reactions and increased micro-organisms. Adverse weather conditions such as rain, wind, humidity and dust cause difficulties such as spoiling food products while drying in the open sun. Agricultural products are spoiled due to birds & animals and decay, decay by insect infestation and fungal growth. Also, this process requires large area, labor and more time consuming. Small-scale farmers use high initial cost and maintenance like artificial mechanical dryers that are powered by fossil fuels. In such situations, solar-powered crop dryers are attractive compared to other conventional dryers due to their advantages such as economy, time saving and quality. Climate conditions have prompted farmers to use solar dryers which have a great impact on crop damage and degradation during drying in the open sun.

Solar dryers can be effectively proven through experiments in many countries used for drying agricultural products on solar dryers. The question before the farmer is what kind of SCD should be adopted. The drying process use to remove the moisture from a food product so that the food products do not corrode for a long time. [2] The drying process continues until the moisture vapor pressure in the food products is equal to the moisture pressure in the atmosphere [1, 2]. Thus, the removal of moisture from the product into the environment and the rates

of absorption from the environment are balanced, and the amount of moisture in the grain in this situation is known as equilibrium moisture. Under ambient conditions, the drying process is very slow due to high relative humidity, low air temperature and unbalanced humidity being insufficiently low for safe storage [1, 2]. One of the best ways to design a solar crop dryer in such a way is to adapt it to the characteristics of the air, to maintain the quality of food products, and to operate in any climate. [2] Drying at permissible temperature and humidity helps agricultural products to dry quickly up to harmless moisture content and to ensure good quality of food products [2]. Properly designed solar crop dryers can be used in developing countries [3-7] to maintain the quality of much needed agricultural products. The biggest drawback of solar drying systems is the availability of solar energy during the day and the effects of weather conditions. Properly designed solar crops can be used using heat storage [8]. There are various techniques for storing solar heat energy in various forms of energy like thermal, electrical and mechanical etc. [9]

The main goal of this paper is to analyze the performance and compare the use of different types of solar dryers for drying agricultural food products. SCD with various techniques used for agricultural food products are explained below.

Passive Solar Crop Dryer (PSCD)

Vegetables and Fruits like potato, Chilli, mango, pineapple, banana etc are drying in small batches in PSCD like cabinet and greenhouse dryer appropriately [11].

Direct-Type Passive Solar Crop Dryers (DSCD)

In the cabinet dryer, Temperature increased inside the dryer is above the crop and because of that overall drying is possible.

Butler et al. [12] designed solar Collector-cum-rock bed storage system. Experimental performance is noted in table I. G. Dutta et al. [13] have done experiment on a cabinet type solar dryer. During test, the maximum plate temperature reaches up to 115°C under the no load condition and maximum 55°C temperature with 20 kg of wheat at noon hours. M. Fournier et al. [14] introduced the "shell" dryer that work on local conditions and ease of use was an African SCD uses natural flow of air. Vinod Kumar Sharma et al. [15] presented DSCD works on natural as well as forced convection principle. The DSCD working on natural convection are very well suited for domestic household to dry a food product at small scale. Tiwari et al. [16] worked on DSCD having rocks to store sensible heat for grain like wheat crop (avg. size 5to8 cm dia., density 1750 kg/ml and specific heat 0.81kJ/kg K solar dryer. After experiment study, it was pointed out that (1) the steady state condition with storage was found after about 2 hours. (2) Initially, the drying rate was maximum and reduced with the decrease of moisture content, (3) thermal storage helped to maintain the temperature of the drying material in a safe range, which helps to improve the quality of food product. H. Hallak et al. [17] presented a innovative DSCD with a staircase design. Thermal efficiency of solar air collector recorded between value of 0.26 and 0.65. [Figure.1]

Figure 1 Side view of DSCD with Air Flow Pattern.

Aakwasi Ayensu et al. [18] designed a DSCD made up of easily available wooden, metallic and glass materials. It works on the principles of convective heat flow with heat transfer 118 W/m^2 . P. Gbaha et al. [19] designed a DSCD with natural convection heat transfer principle. The moisture present in cassava and bananas (approximately 80%) reduced to value of 13% in 19 and 22 hours respectively. Kamil Sacilik et al. [20] presented a Solar Tunnel Crop Dryer (STCD) and conducted experiments on organic tomato under the environmental conditions of Ankara, Turkey. H.P. Garg et al. [21] presented a semi-cylindrical STCD with good thermal performance of the collector. M.A. Basunia et al. [22] constructed a prototype of the SCD. The dryer has a base area of 0.790 m^2 and an entire solar collector area 2.60 m^2 . The experimentation data of various researchers are mentioned in table I to compare the main characteristics of direct solar crop dryer.

1.1.2 Natural Solar Greenhouse Crop Dryers (NSGCD)

Initially, the Brace Research Institute invented a passive SGCD. Doe et al. [23] designed a tent dryer by using the polyethylene polymer sheet. The air flow controlled and passes through a lower side of front of tent and small holes are provided at the crown of tent to remove the moist air. Sachithananthan et al. [24] developed a greenhouse made up of semi-cylindrical metal frame covered by clear plastic sheet. Then, it was modified by using absorber plate at floor. Small openings are provided along the both sides of bottom and outlet located at the crown with plastic nets to protect from bug and dusts. Fleming et al. [25] accounted a distinctive SGCD with an apparent dome shape compartment having a cylindrical shape chimney fixed on one side and at other end, a door provided to pass air throughout the chamber. Rathore et al. [26] has developed and experimented over a modified hemi-cylindrical SCD by using grapes. (Jaijai et al, [27] worked on same dryer by using polycarbonate sheet structure. Afriyie et al. [28] has found good results after the experimentation on model and optimization of a SCD with chimney. S.Janjai et al. [29] developed a SCD, in which roof was converted into a solar air collectors for drying spicy products. The roof of a farm house incorporated with fiberglass-covered solar collectors supplied a hot air to the dryer. Rathore et al. [30] has built a STCD having hemi cylindrical shape for drying agricultural & horticulture product. The time essential for drying to chemically untreated grapes at Moisture Content (MC) 16% were seven days. The temperature difference was about $10\text{--}28^\circ\text{C}$ inside the tunnel dryer during the sunny day are enough to dry agricultural product. Detail studies on DSCD with various types of collector and comparison was done and presented in Table I. From the above evaluation, it is suggested to use DSCD for drying a crop; the ambient temperature air gained the heat varies with solar air collector size, tilt angle and inlet passage. From Table I, it is observed that the time taken in DSCD is less than OSD.

Table 1: Experimentation Results of various types of DSCD

Author Name	Type	Moisture content (MC)		Time in (hr. or day)		Time Saving (hr. or day)	Air Flow Rate/Velocity	Final Temp. To °C	η (%)		
		Initial	Final	O S D	SCD				η _c	η _d	η _p
Butler	DSCD	20%	safe storage	-	22 to 25 h	-	4.9 m3/s.	-	-	-	-
Aghare ed Tayeb	Rotary dryer	54.3 - 22% (wb)	6.5% - 10% (wb)	-	corn- 5.30.h & Peanut - 3 h	-	-	-	-	-	-
Buelow & Davis Lipper	DSCD	20% & 30% (wb)	9 - 10%(wb)	-	corn- 5.30.h & Peanut - 3 h	-	-	10°C to 15 °C rise	-	-	-
G. Dutta	Cabinet type SCD	33%(db)	11.5%(db)	-	Plate temp - 115	40%	-	-	-	-	-
J. Mumba	SCD with Photovoltaic Cell	33.35(db)	20% (db)	-	one day	-	-	-	-	-	-
P. M. Chauhan	Deep bed dryer	28(db)	11(db)	-	without storage -3 days with storage - 2 days	-	Ma=210kg/hr	-	-	-	-
H. Hallak	DSCD	-	-	-	-	--	-	-	26%	-	-
E. A. Arinze	DSCD with Axial flow fan	-	-	-	3 & 6 days resp.	-	-	12°C to 16°C rise	75%	-	-
Aakwas i Ayensu	-	-	Less than 14%	-	-	-	-	45 at 40% RH	-	-	-
M.A. Basunia	-	37.07 to 37.69%(db)	-	-	-	-	-	22.3°C- 34.9°C	-	-	-
A. Madhlo pa	-	85%(wb)	13%(wb)	-	-	-	-	31.7°C to 40.1°C	-	-	-
S. Janjai	Roof integrated solar dryer	-	-	-	4 days & 3 days resp.	-	-	-	-	35%	-
Kamil Sacilik	Solar tunnel dryer	93.35(wb)	11.50(wb)	-	4 days	1 day	-	-	-	-	-
V. Shanmugam	-	-	Appx. 60%MR	-	-	2h & 4h for green peas & Pineapple.	-	Rise in temp 10°C	-	43% to 55	20% to 60

										%	%
P. Gbaha	DSCDD		20%			19 & 22 hr. resp.					
F.K Forson	MMNCSCD	67%	17%			30 to 36 hr				12.50%	
M. A. Hossain			2.85 to .05kg/kg (db)		20 hr.	20hr12 days					
Potdukhe and Thombr e						40%				34%	21%

1.2. Indirect Solar Crop Dryers (ISCD)

The Limitations of DSCD

(i) Drying capacity is less (ii) Long drying time, (iii) The property of glass like transmissivity reduces due to accumulation of vapor on the glass cover (iv) Due to overheating of the crop, quality of drying product not maintained properly. In order to solve the above problems, many researchers developed and tested an ISCD.

V. K. Sharma et al. [31] reported a ISCD with multi shelf used for drying food product and performance studies in which it is clearly mentioned the importance of chemical treatment in drying process. P. M. Chauhan et al. [32] developed a deep bed dryer integrated with a solar air collector in the company of rock bed storage to get heated air for a long time during drying process. From experimentation, it is observed that the MC reduced to 11 percent from 28 percent (db) in Solar Air Heater (SAH) without storage takes 27 collective daylight hours, whereas the SAH accompanied with rock bed storage took 2 days and 2 nights collective hours at velocity of air flow of 0.0694 kg/m²s. R.K. Goyal et al. [33] developed a new model of a cabinet dryer integrated with a reverse absorber in flat plat SAH as a thermal source for air to dry the Fruits, Grain and vegetables. In reverse flat plate absorber, solar collector was extended with reflector which concentrated the solar radiation on reversed absorber. The heat accumulation by air in the reversed SAH was better.

A. Madhlopa et al. [34] designed an ISCD, used a SAH contained two absorber. 21.30% of solar irradiation has been transformed into heat power and used to increase the temperature of air around 31 °C to 41 °C at midday. The MC about 85% (w/w) in slice of mangoes reduces up to equilibrium MC (12% (w/w) on wet basis). Sukhmeet Singh et al. [35, 43] developed the moveable passive direct/ indirect type solar dryer with a multi-trays design, transitional heating. Uniform drying is possible in all trays. A partial loading gives the efficiency almost the same on all drying. Jain and Jain [36] in their experimentation has observed that up to distinctive value of collector length, breadth and tilt angle of collector, the temperature of grain increase and heat energy storage system also works significantly for drying application in off sunshine hours [Figure 2]. Jain [37] designed and analyzed a multi-compartment with a triple-pass SAH accompanied with heat storage for paddy crop drying. Drying rate was different in the entire drying compartment because of which difference found temperatures of grain.

Pangavhane et al. [38] proposed a natural circulation ISCD integrated with SAH and drying compartment. The SAH consisted of dark painted aluminium fin (.5 mm thick) on the plate, glazing and necessary insulated floor. To enhance the heat transfer rate, U - Shaped corrugations was provided on the painted plate in air flow direction. The fins are used

increase the surface area of absorber plate to increase heat transfer rate. Door was provided to stop the air flow at night because of higher relative humidity. As compared to OSD, 43% of drying time of grapes were reduced in ISCD. Parikh and Agrawal [39] the experiment was conducted on developed two trays SCD for fresh chilli & potato chips. Heat loss to surrounding was reduced by using Glass and polycarbonate glazing. Maiti et al. [40] developed an ISCD (natural convection) with mirror. Effect of reflector was noted, i.e. thermal efficiency improved by 10% to 18.5%. The system was more popular for drying an Indian wafer called 'papad'. Abhay et al. [41] developed an ISCD consisted a chimney with V-shaped roughened absorber plate SAH. Experiments were performed on banana and noted a better result. Essalhi et al. [42] compared the performance of developed ISCD for drying grapes with OSD drying.[43].Experimentation data of ISCD with flat plate collector are shown in Table II and comparison was done. From analysis, ISCD is better for drying grain, fruit and vegetables; it is also observed from Table II, the time taken to remove MC is less in ISCD than OSD. F. K. Forson et al. [44] invented a mixed-mode SCD used for drying cassava and other crops. The observations during the experimentation are noted in table no. I

Table 2: Experimentation Results of ISCD having Flat Plate Collector

Author Name	Moisture Content (Wb%)		Time (hr.or day)		Time Saving (Hr. or day)	Air Flow rate/velocity	To °C	η (%)	
	Initial	Final	OSD	ISCD				η_c	η_d
Pangavhane DR	78	15	7 days	4 days	3 days	0.013–0.025 kg/s	52 to 65	48–56	–
Parikh D, Agrawal GD	28	12.	–	8h	–	–	55	–	18
Parikh D, Agrawal GD	–	–	–	–	–	–	52	–	24
Maiti S, Patel P	83	12	–	5h	–	0.037 kg/s	65	50	4
Lingayat A	78	18	–	–	–	1 m/s	62	32	22
Essalhi H, Benchrifia	80	20	25 days	15 days	10 days	0.71m/s	47	–	–
Erick César L-V	94	6.5	–	26 hr	–	0.03 kg/s	62	55	9

Figure 2: Deep bed ISCD with Multi-Pass SAH & Thermal Storage.

Jain [45] developed a newly concept analytical model to study the SCD integrated with reversed absorber, reflector and passive heat storage (Figure.3). The dimensions of SCD have an effect on rise or fall of crop temperature. The

storage of heat during daylight is worked prominently to increase drying hours and retained a drying air temperature fluctuation. Potdukhe and Thombre [46] The forced air ISCD with new type of absorber using solution to store heat energy, due to that increase in the temperature around $62\text{ }^{\circ}\text{C}$ to $68\text{ }^{\circ}\text{C}$ of air in the drying chamber. The drying efficiency and collector efficiency of ISCD for chillies is 21% and 34% respectively. Weight reduction of product occurred 47.3% for first tray in all tests. Drying time required in ISCD reduced by 75% and 40% in conventional dryer than OSD. Shobhana Singh et al. [47]) ISCD and Mix mode ISCD was designed and constructed. SCD with forced convection air circulation gives higher No Load Performance Index as compared to that of natural convection. The MISCD gives more value of No Load Performance Index than ISCD.

Figure 3: Schematic view of DSCD with Reversed Absorber and Thermal Storage.

Wei Chen et al, [48] designed the indirect-mode SCD with chimney and porous absorber gives a significant rise in heat transfer rate.

2. ACTIVE SOLAR DRYING SYSTEMS

Active solar dryer systems are divided into three varieties such as DSCD, ISCD and Hybrid solar crop dryer (HSCD).

2.1. DSCD -Active

The DSCD -type active means force circulation unit.

2.1.1 Absorption Dryers

Huang et al., [49] proposed a semi-cylindrical SCD. The main components of SCD were SAH with corrugated glass, stationary drum with a black outer surface as a drying chamber. Trim and Co [50] constructed a SCD by using plastic transparent cover at outside and black plastic inside the dryer. Akachuku [51] presents a single-glass wood-dried oven polyethylene solar-designed dryer inside the horticultural interior absorbing colored rug on a piece of wood. M A. Hossain et al. [52] have developed a STCD with a blower. Two fans are provided to circulate the air inside the solar tunnel dryer which has controlled by photovoltaic module. During experimentation, the MC of red pepper was reduced to 50gm /kb (DB) in 20 hours. For green chilli, MC was dropped to 60 gm /kb (DB) in 22 hours. The time saves in drying as compared to OSD was about 12 to 14 hours. In both the cases A.P. Omojaro et al. [53] investigated and modified a single and double pass SAH by using fins on steel wire mesh absorber. Result shows that, the efficiency of dryer depends on mass of air

flowing per hour. If the mass flow rate increases, the efficiency increases up to a certain limit.

2.2.1. ISCD -Type Active

E.A. Arinze et al. [54] presented a mobile SCD for a gain producing region as a commercial option. The solar energy collection efficiency was about 75% which is relatively greater than other SAH without fins. M. Mohaneaj et al. [55] SCD performance was tested by using chilli at Pollachi, India. A SCD with a blower was used to dry product. [Figure 4], MC in chilli after drying reduces from around 72.80% (wet basis) to approximate value of 9.0 % in 24 hours. The mean drier efficiency of a solar dryer measured equal to 21 percent. Moisture absorption rate from product was equal to 870gm/kWh. Kadam and Samuel [56] the average collector efficiency reported about 61.50%. Al-Juamilly et al. [57] made-up an ISCD was accompanied with blower. Experiment was performed and found better results. El-Beltagy et al. [58] conducted tests on model ISCD with different shapes of pre-treated strawberry and reported that time takes to drying was minimized because of slicing and pre-treatment. Singh [59] developed a forced convection ISCD which was used to dry thin layer silk cocoon (*Bombyx Mori*). Cocoon MC was dropped due to rise in temperature up to 12% from 60% (wb). Sundari et al. [60] Used evacuated tube collector SCD consisting of a drying compartment with drought and fan. It maintained the quality of product as compared to other dryers.

Boghali et al. [61] presented HSCD with electric power. Especially, experiment was conducted in winter session. The results were found 1) Average efficiency about 13 to 31 percent at 1m/s wind speed. 2) 12.50 to 33 percent at 1.50 m/s and 3) 25 to 47.50 percent at 2 m/s wind speed. Akbulut and Durmus [62] used mulberries (*Morus*) for experimentation on ISCD. The experimentation was done and the details about the performance are mentioned in Table III. Midilli [63] presented a nature of drying using pistachio in ISCD and OSD. It was observed that OSD takes more time and the quality was not maintained. Sreekumar [64] developed a SAH used for the application of drying in which maximum temperature up to 76°C can be attained. MC in Pineapple slices can be reduced below the 10% in 8 hours. Karsil [65] examined the effectiveness of different and separate ISCDs. Two ISCD provided with fins at angles 75° and 70°, third with simple collector and fourth contains tube. It was found that the collector had the highest efficiency with a fine angle of 75°.

Disa et al. [66] 0.8 cm thick mango pieces were tested for drying. The MC obtained shows results was 13.7999% (WB). Hegde et al. [67] Evaluates the efficiency of dryers during drying of banana slice. The efficiency of the upper and lower flow configurations were calculated at 27.50% and 38.221%, respectively. Condor et al. [68] the test was done with onion slices for about 1 hour to reach the final MC of 61% (WW) from the initial MC of 8.26%. The optimum efficiency of the collector for low temperature tests was observed at 0.4 kg / sec. The optimum value reached above 50°C at 0.23 kg / sec

Figure 4: Schematic View of Active ISCD

Wang et al. [69] was introduced an ISCD with an auxiliary heating sources. The ISCD accompany with fan, an automatic control system and a drying chamber. The results were recorded 1) Avg. Thermal efficiency were about 31% to 34%. 2) MC removal rate equal to 1670 gm of water / kWh at 52°C. The humidity was reduced from 77.38% to 20% (WW). The effect of microstructural changes on the compressed behavior and three stages of ripening of dates (e.g. Khalal, Rutab, and Tamar) were analyzed by Seranguar et al. during mandatory convective ISCD. [70].

More information on the drying parameters and performance of ISCD forced synthesis settings is provided in Table III. Helps to improve heat transfer between air and material; increase in the drying rate than passive ISCD and OSD. Forced drying efficiency improved to 33.8% (Table III) in synthesis ISCDs which is lower than natural synthesis settings (4-23.7%) (Table 2).

Table 3: Experimentation Results of Force Convection ISCD[94]

Author Name	Moisture Content (wb%)		Time(day)		Time Saving (day)	Air Flow rate/velocity	η (%)		SAC Exit temp. T _o °C
	Initial	Final	OSD	ISCD	Time Save (day)		η_c	η_d	
Kadam DM	92	6	—	2.5 days	—	4.8 kg/s	55	17	—
Al-Juamily KEJ	65	18	—	1 day	—	0.80 m/s	—	—	—
Al-Juamily KEJ	80	18	—	1.5day	—	0.30 m/s	65	—	20
Al-Juamily KEJ	80	13	—	2.5 days	—	0.3 m/s	60	—	33
El-Beltagy A	88	19	—	2days	—	—	—	—	47
Singh PL	60	12	7days	2days	5 days	480 m ³ /h	—	9–9.5	50–75
Umayal Sundari A	91	6.3	1 days	1day	—	1.5m/s	—	—	101
Boughali S	93	11	—	1.25day	—	—	—	2.5–35	50
Akbulut A, Durmuş	80	8	12days	1to 2days	11–13 day	1.5,7.8,14,20,26,33,36 g/s	—	—	—
Midilli A	70	27	1 day	1day	—	1.2 m/s	—	—	50 ± 10
Midilli A	70	29	1 day	1day	—	1.2 m/s	—	—	—
Sreekumar A.	82	10	1 day	—	—	1.2 m/s	52.55	—	40–67
Hegde VN	77	35	—	2day	—	0.03 m ³ /s	29.63	5	45
Dissa AO	80	14	—	3 days	—	0.02 kg/s	35.1	—	33–52
Condorí M	—	—	—	2 day	—	0.06 kg/s	30	30–35	50

Wang W	77	20	–	1.25day	–	0.07 kg/s	53.5	34	52
Seerangurayar T	80	11	–	–	–	–	–	–	–

Vijay Khawale et al. [71] developed a Multi pass SCD with a reversed absorber, gives a better performance than ISCD [Figure 5] Fudholi et al. [72] constructed a Double Pass Solar Crop Dryer (DPSCD) for seaweed. Final MC contain in red chilli were 10% (wb) in 15 hours. Efficiency of two pass SCD system was 35% which is greater than single pass SCD by 8%. Banout et al. [73] investigated DPSCD for chillies (*C. Annuum*). Final MC is less than 10% from 90.21% (wb). As a result, drying efficiency was 12.50% which is greater than ISCD. Fudholi et al. [74] introduced DPSCD with a supplementary heating source. Red chilli was dried to MC 10% (wb) in 33 hours from initial MC 80%. Collector and dryer efficiency was 28% and 13% respectively.

Figure 5: Schematic Diagram of Multi Pass Reversed Absorber ISCD

Sarsavadia [75] created the forced Convention ISCD to analyze the effects of different temperatures, air flow, and air fractions on the overall energy requirements for drying onion pieces. The ISCD was equipped with SAH and had triangular folds and barriers. On the top of the absorber, Exhaust air was used repeatedly in the SCD. The test was performed at an air temperature of 55° C, 65° C, 75° C and mass flow rate of 0.135, 2.43 and 5.25 kg / s. 90% of the air was processed during the drying test. Arrangements were made to conduct experiments without air circulation. The onion pieces were dried from the MC - 86% (WB) to the MC - 7% (WW). It was found that the total energy savings due to recycling of working liquid (air) was 70.70%

Chan et al. [76] developed a new drying room and a type of vacuum included in the solar collectors. SCD consist of centrifugal fan, efficient process, feed and pneumatic. The true system was used as a drying chamber that included a hopper with a vortex. The assembly was tested with 104 and 200 kg rice. The results of the study showed that at an RH and temperature of 21.73%, and 50 ± 0.2 ° C and it takes 5 hours for 104 kg of rice to reduce MC from 28.40% to 14.30% (wb). At the same time, it takes 8 hours to reduce MC in 200 kg of rice with the same temperature and humidity as before with 27.60% to 14.30% (WB). Similar analyses have been performed by Mokhtarian et al. [77] the initial MC 45% (WB) pistachio was used for drying. Pistachio drying time was found to be reduced by 30% using air recycling compared to

systems without air recycling.

Ezeike [78] designed a modular SCD with three-pass and single absorber SAH, a drying chamber with dehumidification system. The upper tray is equipped with a deflector to distribute hot air evenly. The dehumidification room was equipped with silicone desiccant, and able to withstand the effective drying in case of rain or low incidence radiation. The system has been tested with chips and rice. The slice was dried in weight from 64.90% to 10.66% in 31 hours and the rice was dried from 24.93% in weight at 5.31% in 5 hours.

Table 4 records the evaluation of multi-pass SAH and their efficiency parameters. It is found that for multi-pass SAC, the cost of fabrication is significant and requires more designed methods than single-pass solar wind collector dryers. Due to the shorter drying time, the drying cost (including operation, maintenance and labor costs) per kg of product is lower than that of a single-pass SAD in a multi-pass SAD. It is observed that the type of product was used different specific power consumption, the drying time and the capacity of the dryer. The temperature of the multi-pass dryer is within 47-101 °C (Table IV) although it is within 20-101 degrees (Table III) for single pass ISCD dryers. The hot air contact area is larger in a multi-pass dryer than in a single-pass dryer; therefore, there is an increase in heat gain, at the same time there could be chances of higher heat loss. The efficiency of forced drying increased to 47.50% (Table IV) in the ISCD forcing convection which is lower in the forced convection (33.80%) (Table III).

Table 4: Experimentation Results of a Multi Pass ISCD

Author Name	Type of air passes	Moisture Content (wb %)		Drying time saving (days)	ma (kg/s)	η (%)				SAH Exit Temp. To °C
		Initial	Final			η_c	η_d	η_p	η_{ex}	
	Mf									
Fudholi A	Double Pass	90	10	1.5	0.05	35	27	95	1-93	–
Banout J,	Double Pass	90	10	3.2	0.221	61.62	24.04	22.04	–	51.89
Fudholi A	Double Pass	80	10	3.3	0.07	28	13	45	–	57
Sarsavadia PN	Partial Recirculation 86	7	–	0.135	–	24.5–44.5	–	–	–	75
Chan Y, Dyah N	Partial Recirculation 28.4	14	5	–	10.7	–	31.7	–	–	50.1
Chan Y, Dyah N	Partial Recirculation 27.6	14	8	–	9.475	–	47.5	–	–	47
Mokhtarian M	Multi Pass	65	10.5	3.1	73–81	73–81	–	–	–	90–101
Mokhtarian M	Multi Pass	26	5.3	1	–	–	–	–	–	–
Ezeike GOI	Double Pass	40	5	0.106	–	–	–	–	–	–
Hossain MA	Double Pass	76.	8.5	3.1	0.042	48.2	21.9	–	–	–
Vijay Khawale	Multi Pass	79.1	9.1	2.2	0.0269	38.02	49.22	64.16	–	47-65

2.2.2 Storage Type Dryers

V. Shanmugam et al. [79] SCD with a solid desiccant (7500gm CaCl₂) as a storage material in SAH was tested for green peas which ran in different air flows. Equilibrium MC was reached in 14 hours at mass rate 30 gm/m²s. The performance

was satisfactory and Desiccant showed at 3% recording efficiency and more-or-less uniformity at 10.30am was noticed during drying. Specific moisture lifting rates are available in the range of 550 to 820 gm / kW. Devahastin and V. Shanmugam et al. [80] designed and tested in an indirect mandatory convection using a desiccant integrated sun dryer. The usable temperature with the mirror increased by 10°C, which decreased the dry time of green peas and pineapples by two hours and four hours respectively. Drying and absorption efficiency of SCD was in the range of 42% to 56% and 21 to 61% respectively. About 60% MC absorbed by solar heated air and remaining was removed by desiccant. Arrangement of mirror above desiccant bed increased absorptive property of desiccant. Galsah Kakmak et al. [81] The SCD includes mainly a SAH with an extended surface, solar heat storage accompanied with phase change material and a drying room with vortex elements. The vortex element was placed to accelerate the mass flow rate of air in the drying room. Middle model [82, 83] provides the most suitable results for each dried state during the drying of seeded grapes. SS Krishnanath et al. [84] Thermal storage systems were integrated with Banowat and double pass SAH. SAH with a length of 0.750 m, a width of 0.50 m and a height of 0.182 m was made of sheet steel. A paraffin wax was used to store heat energy in thermal heat storage unit. The surface absorber or rug leveled absorber helps to accelerate the air flow in SAH and increase the heat transfer rate. The performance of SCD has improved in recent years due to artificial indulgence compared to SAH [85, 86].

Hybrid-Type Active Solar Crop Dryers (HSCD)

Amer et al. [88] developed a HSCD consisting of SAH with connector and used to dry banana. Eddie J. Amir et al. [89] a versatile modified solar tunnel dryer designed for dry regions to manage tropical climate conditions. SAH with biomass stove and drying cabinet significantly worked in cloudy and rainy days. The results showed that the drying time reduced by 41% in cocoa, coffee and coconut. J. Mumba et al. [90] developed and tested on SAH with air fan, driven by photovoltaic solar cells. The air turbulence increased by using photovoltaic powered air pump enables to dry 90 kg maize shots on a dry basis of humidity 33.3% to less than 20% per day in the initial batch. The maximum temperature of dry air was controlled and equal to 60 ± 3 ° C. This avoids the over-heating and crack in the crop for the powerless regions of developing countries; Benon Bena et al. [91] Bena and Fuller [87] described a SCD accompanied with SAH and simple biomass burner. This was used for drying fruits and vegetables in powerless areas. The drying efficiency of the all solar component was 22%. In other experiments, burner efficiency was found to be 27% in creating useful heat for drying. Salah Eltief et al. [92] proposed SCD with V-grooved SAH, a drying chamber and two radial fans with additional heating and variable speed. Test conducted on SCD and analysis of performance and comparison was done. M A. Amer et al. [93] A HSCD integrated with photovoltaic power accompanied with SAH was designed. About 35% of hot air was consumed for drying food product and remaining air was recycled in SCD. Due to recycling of air, the thermal efficiency of dryer was increased. It helps to increase the air temperature by 30 to 40 degrees centigrade above room temperature. During sunny days, SCD was used to evaporate the initial humidity of 82% within 8 hours at a final humidity of 18% (WW) from 30 kg collar pieces. Alejandro Rayes et al. [94] Introduced a HSCD, equipped by 3m² photovoltaic cell and electrical resistors for drying mushrooms (Paris variety). The use of solar energy saves 3.50-1.50% of the total energy.

CONCLUSIONS

Different types of SCD were compared and shown their performances in Table no. I, II & III. Searches obtained by different researchers were easily compared. Drying farm food using a solar crop dryer is more economical and time-saving operation. In order to increase the acceptance of solar dryers among the farmers, it is necessary to develop attractive solar dryers of large capacity and low cost. However, much research is still needed for large-scale application in agriculture. It

must be versatile to share the cost of a dryer. It can be used to dry different kind of food product so that it becomes affordable to farmer. For day and night drying operation, a system must be developed with back up of the heat storage. A supportive heat storage and forced synthesis is suggested for consistency and high-quality control, for drying agricultural food in large capacity.

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