International Journal of
Science and Engineering Investigations
vol. 5, issue 59, December 2016
ISSN: 2251-8843

Advancement in Solar Dryer for Agriculture Food Product: a Review

Vijay R. Khawale[1], Shashank Thakare[2]
[1]Asst. Professor, Mechanical Department, Dr. Babasaheb Ambedkar College of Engineering and Research, Nagpur, India
[2]Professor, Mechanical Department, Prof. Ram Meghe Institute of Technology and Research, Amravati, India
([1]vrk4671@rediffmail.com, [2]sbthakare2007@gmail.com)

Abstract- The aim of paper is to study the advancement of solar dryers used for drying agricultural food product. Several types of solar dryers, operation and traditional methods are studied. Technical and economical results show that solar drying of agriculture food product drying is possible. Solar drying is an emerging technology. Space availability difficulty in urban areas, sunshine irregularity, higher initial costs and convenience issues are the main hurdles in its propagation and unwillingness to acceptance. For reducing all these factors, further research and development work should be continued. To improve the acceptability of farmer it is necessary to develop a large scale and low cost attractive solar dryer, Research and development work on solar drying technology has been made significant progress. A review on advancement of solar drying technology is appropriate for future development.

Keywords- Solar dryer, Agriculture food product, Natural convection, Force convection, Thermal storage

I. Introduction

Solar drying has been verified to be an inexpensive and useful option to traditional and mechanical drying systems, particularly in locations with good sunshine during the harvest season. The reduction of food losses is a problem for small farmers in developing countries who produce more than 80% of the food. Most commonly Open sun drying is used to preserve agricultural food products like grains, fruits and vegetables. Since open sun drying is a comparatively slow process and substantial losses can occur. Quality of product affect due to insect infestation, enzymatic reactions, microorganism growth, and mycotoxin development. This process has many disadvantages like spoilage of food product due to unfavorable weather conditions like rain, wind, moist, and dust, loss of material due to birds and animals, deterioration of the material by decomposition, insect infestation and fungal growth. Also the process is highly time consuming, labor intensive, and requires large area.

The large initial and running costs of fossil fuel powered artificial mechanical drying came into practice are rarely adopted by small scale farmers. In such conditions, solar-energy crop dryers appear increasingly to be attractive as commercial propositions. Climatic conditions have a great influence on the extent of crop losses and deterioration during sun drying has increase the interest in utilization of solar dryers.

Experiments conducted in many countries for drying agricultural product have clearly shown that solar dryers can be effectively used. It is question of adopting the right type of solar dryer. The drying is a process of reducing the moisture content of the product to a level that prevents deterioration within a certain period of time, normally regarded as the ``safe storage period'' [2].These processes continue until the vapour pressure of the moisture held in the product equals that held in the atmosphere [1, 2]. Thus, the rates of moisture desorption from the product to the environment and absorption from the environment is in equilibrium, and the crop moisture content at this condition is known as the equilibrium moisture content. Under ambient conditions, the drying process is slow, and in environments of high relative humidity, the equilibrium moisture content is insufficiently low for safe storage [1, 2]. The best approach is to incorporate into the design of the dryers such structural features that would guarantee that extreme conditions to not prevail in the dryer under the envisaged climatic conditions and crop properties [2]. Drying under controlled conditions of temperature and humidity helps the agricultural products to dry reasonably rapidly to safe moisture content and to ensure superior quality of the product [2]. Properly designed solar dryers may provide a much-needed appropriate alternative for drying of some of the agricultural products in developing countries [3–7]. The intermittent nature of the solar energy, which is the main source of energy in solar drying, is indeed one of the major shortcomings of the solar drying system can be alleviated by storing excess energy during the peak time and use it in off sun hours or when the energy availability is inadequate [8]. There are numerous technologies for storing solar energy in various forms including mechanical, electrical and thermal energy [9]. India is blessed with good sunshine. Most parts of the India receive average daily solar radiation in the range of 5–7 kWh/m², and have more than 275 sunny days in a year [10].

The main objective of this paper is to review the advancement work on solar dryers for agricultural food product. It is hoped that this review may be useful for further development work. Various types of solar dryers used for agricultural food product are discussed briefly.

II. PASIVE SOLAR DRYING SYSTEM

Cabinet dryer and greenhouse dryer are the example of passive solar drying system. Passive drying of crops is still in common practice in many Mediterranean, tropical and subtropical regions especially in Africa and Asia or in small agricultural communities. Fruits and vegetables such as banana, pineapple, mango, potato, etc are drying in small batches appropriately [11].

A. Direct type passive solar dryer

In the cabinet dryer, of the total solar radiation impinging on the glass cover, Temperature inside the cabinet is above the crop due to that overall drying is possible. Butler et al. [12] designed a solar collector-cum-rock bed storage system. From experimental performance it has been absorbed that the time for peanut drying varies from 22 to 25 h to reduce the moisture content from 20% to the safe storage moisture level with an air flow rate of 4.9 m3/s. G. Dutta et al. [13] have done experiment on a cabinet type solar dryer and analyze the temperatures inside the drier, the moisture content and the drying rates. During test, under the no load condition the plate temperature reaches a maximum of 115°C at noon hours, while with 20 kg of wheat the maximum temperature is about 55°C. Originally the wheat contents moisture (dry basis) about 33%. Drying takes place until equilibrium moisture content (e.m.c.) equal to 11.5% (dry basis). M. Fournier et al. [14] introduced the "shell" dryer was an African solar food dryer which uses natural convection. Its design had been defined by users, in terms of local working conditions and ease of use. Vinod Kumar Sharma et al. [15] present a three different types of solar dryer based on the principle of natural as well as forced convection. The performance of cabinet-type natural convection solar dryer is very well suited to drying small quantities of fruit and vegetables on the domestic/household scale. The integrated solar-collector/drying system can be used for limited crop volumes on the farm itself. The indirect-type multi-shelf dryer is suitable for use on a large scale. Tiwari et al. [16] worked on experimental model of a grain drying for wheat crop having sensible heat storage using rocks (average size 5–8 cm diameter, density I750 kg/ml and specific heat 0.81 kJ/kg K) solar dryer. It is observed that due to the storage effect the fluctuation in temperature is significantly reduced. On the basis of experimental simulation, the following conclusions have been drawn: (1) the steady state condition is reached after about 2 h for a given storage capacity for drying the wheat crop with and without thermal storage and I kg of wheat grain (drying material), (2) the moisture content of the drying material decreases with increase in time for a given temperature, (3) the drying rate is reduced with the decrease of moisture content, (4) the steady state condition will take a larger time to achieve for high thermal capacity of the rock bed thermal storage, and (5) by using thermal storage, the maximum temperature of the drying material is reduced within a safe range, thereby improving the quality of the agricultural product. H. Hallak et al. [17] presented a novel direct mode solar dryer with a staircase design [Fig.1]. It efficiency values as a solar collector ranged between 0.26 and 0.65. The drying rate is very competitive with experimental work for other types of dryers.

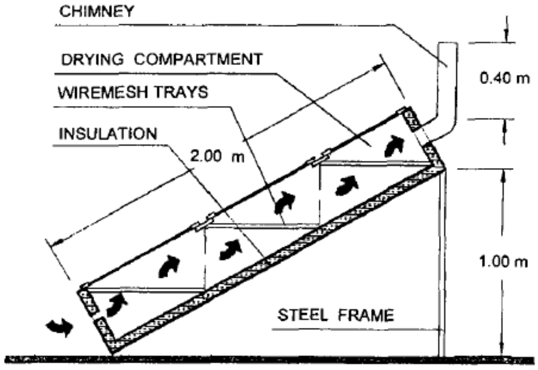

Figure 1. Side view of dryer with dimension and air flow pattern.

Aakwasi Ayensu et al. [18] was designed a solar drying system [Fig.2] on the principles of convective heat flow, constructed from local materials (wood, metals and glass sheets) and used to dry food crops (cassava, pepper, okro, groundnuts, etc.). The solar collector could transfer 118 W/ m² heat power to the drying air. The heat exchanges within the dryer were determined from a psychometric chart. Ambient air at 32°C and 80% relative humidity (RH) could be heated to 45°C at 40% RH for drying. The final moisture content in dried crop was less than 14%. Empirical drying equation of the form M(t) = Mo exp(-kt) describes the dehydration process.

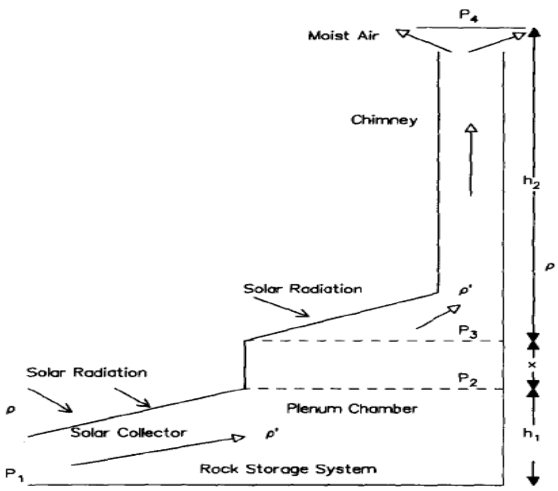

Figure 2. Schematic diagram of fixed bed dryer with, solar collector plenum chamber

P. Gbaha et al. [19] was designed a direct type natural convection solar dryer. In order to evaluate dryer thermal performances, the influence of significant parameters such as solar incident radiation, drying air mass flow and effectiveness governing heat and mass transfers were analyzed. Experimental data was represented by empirical equation of the form M(t) = Mi exp(-kt) for representation of drying process.

Experimentally it was found that, drying of cassava and bananas reduced the moisture content approximately to 80% in 19 and 22 h, respectively to reach the safety threshold value of 13. Kamil Sacilik et al.[20] was conducted a thin layer solar drying experiments of organic tomato under the ecological conditions of Ankara, Turkey using solar tunnel dryer. During the experiments, solar tunnel dryer was used for drying organic tomatoes to the final moisture content of 11.50% from 93.35% w.b.in four days of drying as compared to five days of drying in the open sun drying. The effect of the drying temperature and relative humidity on the drying model constant and coefficients were also determined. H.P. Garg et al. [21] have been presented a thermal performance of the collector of a semi-cylindrical solar tunnel dryer (STD). The design parameter, length and radius of the collector, the volume flow rate and the rise in the inlet air temperature have been optimized for natural circulation mode. M.A. Basunia et al. [22] constructed a prototype of the solar dryer and conducted a thin-layer solar drying experiments at Matsuyama, Japan, with medium grain rough rice. The dryer having a base area 0.79 m² and a total solar collector area 2.6m². The range of average drying air temperature was 22.3ºC - 34.9°C, and the relative humidity were between 34.5% and 57.9%. The initial moisture contents were in the range of 37.07% - 37.69% dry-basis. The drying data were then fitted to the Page, C. [23] model, based on the ratios of the differences between the initial and final moisture contents and the equilibrium moisture content (EMC).

B. Natural greenhouse Dryersr

The earliest form of passive solar greenhouse dryer was developed by the Brace Research Institute. Doe et al.[24] designed the widely reported poly-ethylene tent dryer. The air flow into the tent was controlled by rolling unrolling of the cladding at the bottom edge of front side and the vents at the top served as the exit for the moist exhaust air. Sachithananthan et al. [25] reported a horticultural greenhouse of clear plastic sheet cladding over a semi-cylindrical metal frame. The modification were with a black galvanized iron sheet absorber at floor, inlet vents along the full length of both sides of base and exit with plastic nets at the top to protect from insects and dust. Fleming et al. [26] reported a typical greenhouse type solar dryer with a transparent semi-cylindrical chamber with a cylindrical solar chimney posted vertically at one end and a door for air inlet and access to the chamber at other end. Rathore et al. [27] has conducted various experimental studies on a modified design of hemi-cylindrical solar tunnel dryer for drying of grapes also few researchers (Jaijai et al, [28] have used a polycarbonate cover for its construction. Afriyie et al. [29] has reported the study of simulation and optimization of a chimney ventilated solar crop dryer. S.Janjai et al. [31] was developed a solar dryer, using hot air from roof-integrated solar collectors for drying herbs and spices. The roof of a farm house incorporated with fiberglass-covered solar collectors supplied a hot air to the dryer. Each solar collector consists of iron frames, a back insulator and a transparent corrugated fiberglass cover. The total area of the solar collectors is 72 m². The dryer was used to dry 200 kg of rosella flowers and lemon-grasses within 4 and 3 days, respectively. The solar air heater does well both as a solar collector and a roof of a farmhouse and an average daily efficiency of 35%. N.S. Rathore et al. [32] has been built a walk-in type hemi cylindrical solar tunnel dryer for drying agricultural & horticulture product at College of Dairy and Food Science Technology, Udaipur, India. The drying time for chemically untreated grapes was seven days to dry at 16% (wb) moisture content. The temperature gradient was about 10–28 ºC inside the tunnel dryer during the clear day, which is quite sufficient to dry agricultural product.

C. Indirect-Type Passive Solar Dryers

The main disadvantages of the cabinet or direct solar dryers are: (i) small capacity of the dryer (ii) required drying time is long, (iii) transmissivity of the glass cover is reduced due to evaporation of moisture and accumulate on glass cover (iv) overheating of the crop may take place because of that the quality of the product may deteriorate. In order to solve the above problems, many researchers had been developed and tested an indirect solar dryer. V. K. Sharma et al. [33] reported a design details and the performance studies carried out with indirect type multi-shelf fruit and vegetable dryer The experimental results very clearly indicate the importance of chemical pretreatment in the drying mechanism. P. M. Chauhan et al. [34] has been presented a deep bed dryer [Fig.3] coupled to a solar air heater and rock bed storage unit to receive a hot air during sunshine and off sunshine hours respectively. The result revealed that for reducing the moisture content from 28.2%(db) to 11.4% (db) the solar air heater takes 27 cumulative sunshine hours i.e. about 3 sunshine days, whereas the solar air heater and the rock bed storage combined take cumulative hours, i.e. about 2 days and 2 nights at an air flow velocity of 250 kg/hm2.

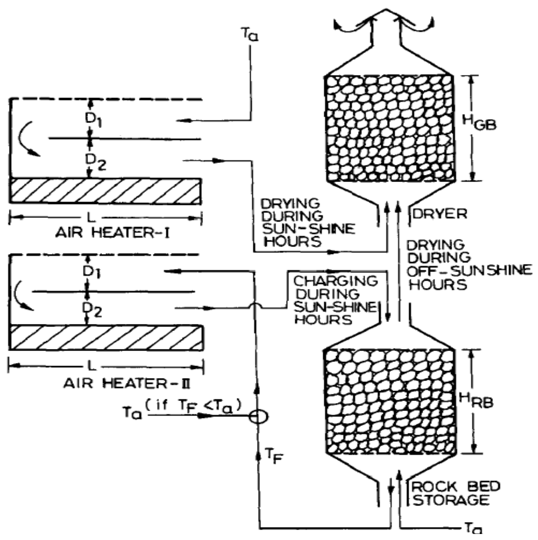

Figure 3. Deep bed dryer

R. K. Goyal et al. [35] used a concept of reverse flat plate collector as a heating medium of air for the drying of agricultural products in a cabinet dryer. The reverse flat plate absorber was a non-concentrating collector which can collect solar heat at high temperature unlike conventional non concentrating collectors. Fig.4 shows Schematic diagram of the reverse absorber cabinet dryer (RACD). The performance of this system was compared with that of conventional cabinet dryers. It was found that the reverse flat plate absorber dryer gives the better performance.

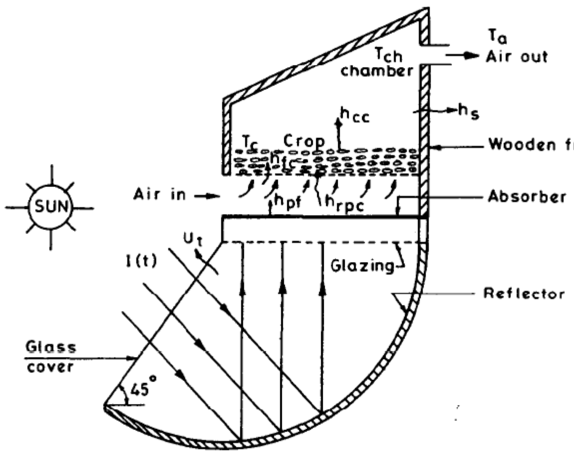

Figure 4. Schematic diagram of the reverse absorber cabinet dryer (RACD)

O. V. Ekechukwu et al. [36] reviewed the behavior of a large-scale, natural-circulation, integral-type, solar-energy dryer which has been performed over the entire range of weather conditions. The design, construction and installation of the dryer [Fig.5]

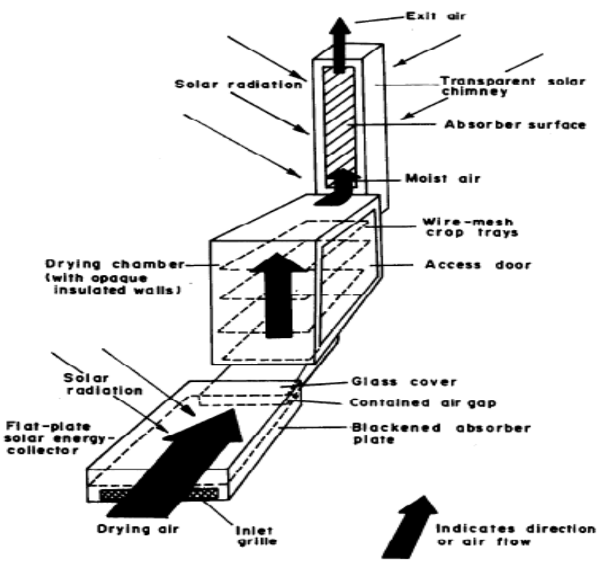

Figure 5. Schematic illustration of a distributed (indirect) type natural-circulation solar-energy dryer

Madhlopa et al. [37] designed a solar air heater, comprising two absorber systems in a single flat-plate collector, on the principles of psychrometry. Analysis of both fresh and dried mango samples for moisture content (MC), pH and ascorbic acid were done. Up to 21.3% of solar radiation was converted to thermal power in air heater, and raised the drying air temperature of about 31.7 °C to 40.1 °C around noon. The dryer reduced moisture content in sliced of fresh mangoes from about 85% (w/w) to 13% (w/w) on wet basis, and retained 74% of ascorbic acid. Sukhmeet, Singh et al. [38,43] was developed the moveable solar dryer with a multi-shelf design, intermediate heating, passive, integral and direct/ indirect type. Uniform drying is possible in all trays due to air heating in-between all trays. A main characteristic of this dryer is that the product can be dried under shade or otherwise as per requirement. Low cost design which makes it economically viable. The maximum stagnation temperature was 75 ºC in the month of November at Ludhiana (31ºN). A semi-continuous mode of loading has been investigated to overcome the problem of reduction in efficiency on second and third drying day, in which the efficiency remains almost the same on all drying days. Jain and Jain [39] it has been observed that up to typical value of parameters (collector length, breadth and tilt angle) of collector, the grain temperature increases. The thermal energy storage system also acts significantly during the off-sunshine hours for crop drying applications [Fig.6].

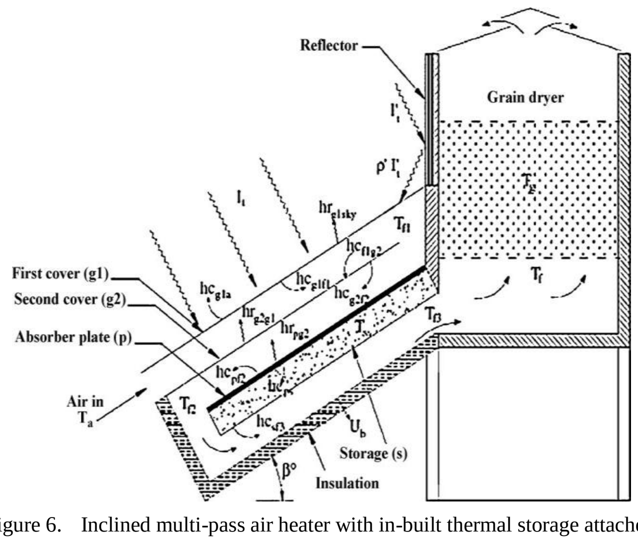

Figure 6. Inclined multi-pass air heater with in-built thermal storage attached with deep-bed drying system.

Jain [41] designed and analyzed a multi-tray crop drying attached to an inclined multi-pass solar air heater with in-built thermal storage for drying of the paddy crop (Fig.7). The thin layer drying equation has been used to analyze the drying rate and hourly reduction in moisture content in the different trays. Different drying rate were observed in different drying trays due to the variation in crop temperatures. F.K. Forson et al. [42] was designed a mixed-mode natural convection solar crop dryer (MNCSCD) and used for drying cassava and other crops in an enclosed structure was presented. A drying time of 30–36 h was assumed for the anticipated test location (Kumasi; 6.71N, 1.61W) with an expected average solar irradiance of 400W/m² and ambient conditions of 25ºC and 77.8% relative humidity. According to the design a minimum When MNCSCD tested under full designed load, average ambient conditions of 28.2ºC and 72.1% relative humidity with solar irradiance of 340.4W/m², a drying time of 35.5 h and the drying efficiency 12.3% was evaluated and the design procedure proposed is sufficiently reliable. Jain [43] investigated a transient analytical model to study the new concept of a solar crop dryer having reversed absorber plate type collector and thermal storage with natural airflow (Fig.8). The crop temperature depends on width of the air flowing channel and height of packed bed. The thermal energy storage works significantly during the non-sunshine hours and is very applicable in reducing the fluctuation in temperature for drying.

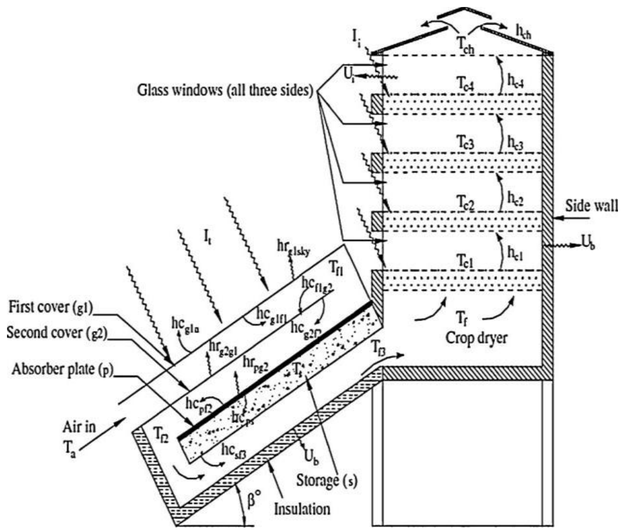

Figure 7. Multi-tray crop dryer with inclined multi-pass air heater with in-built thermal storage

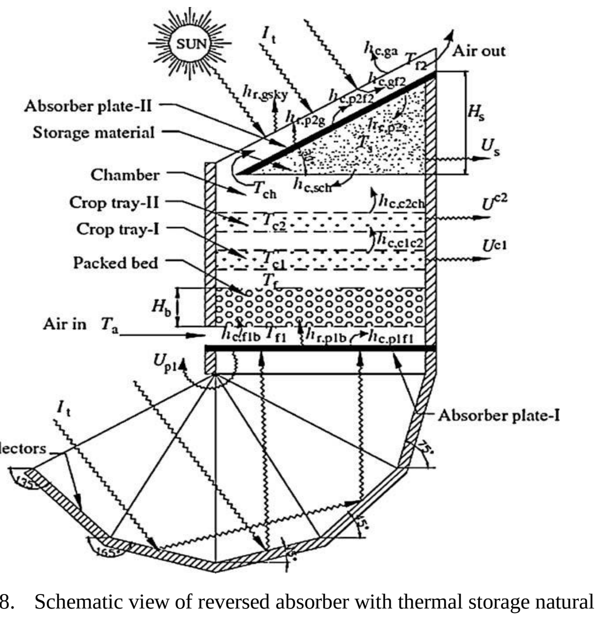

Figure 8. Schematic view of reversed absorber with thermal storage natural convective solar crop dryer

Potdukhe and Thombre [44] investigated, designed and simulated a new type of solar dryer, The novel absorber utilizing thermic fluid as inbuilt storage had helped to attain higher drying air temperatures in the drying chamber around 65 ± 3 ºC with the length of absorber as 0.826 m. It can maintain uniform drying air temperature for longer period, which is a noteworthy feature of dryer non-existent in the natural convection solar dryers. This will ensure higher drying rate without damage to agricultural products. This also exhibits excellent control over the airflow rate and the drying rates by the dryer. The drying efficiency of the new type of solar dryer for chilies is 21% and the collector efficiency of the new type of solar dryer for chilies is 34%. Higher percentage weight reduction (47.3%) occurred for the first tray in all the tests when the spacing between the two trays was 46 cm. The drying period in the solar dryer was reduced by 75% and 40% compared with open-sun drying and using conventional dryer, respectively. The dryer is most suitable for agriculture products which are sensitive to direct exposure to solar radiation. Shobhana Singh et al. [45] have been performed steady state thermal tests, models of direct (cabinet), indirect and mixed mode solar dryer was designed and constructed for natural and forced air circulation. The dryers with air passage between absorber plate and glass cover with no-load were operated for the range of 300–800 W/m² and 0.009–0.026 kg/s of absorbed thermal energy and air mass flow rate respectively under indoor simulation conditions. The forced convection operated solar dryer gives higher no-load performance index (NLPI) as compared to that of natural convection. The comparative performance analysis of solar dryers for both natural and forced air circulation indicates that the mixed mode dryer exhibits maximum value of NLPI followed by indirect and cabinet ones. Wei Chen et al, [46] has been design the indirect-mode solar dryer with chimney assembled with porous absorber. The specific heat capacities (C) and thermal conductivity (ks) have remarkable effects on the average temperature of solar porous absorber in the drying system. The inclined angle of porous absorber influences the airflow and temperature field in the solar dryer greatly. With the height of solar dryer changing from 1.41 m to 1.81 m, the higher airflow velocity and the lower temperature at chimney exit can be achieved.

III. ACTIVE SOLAR DRYING SYSTEM

Active solar dryers are known to be suitable for drying higher moisture content foodstuffs such as papaya, kiwi fruits, brinjal, cabbage and cauliflower slices. A variety of active solar-energy dryers exist which could be classified into either the direct -type, indirect-type or hybrid dryers.

A. Direct-Type Active Solar Drying Systems

The direct-type active solar dryers are designed with an integrated solar energy collection unit.

1) Absorption Dryers

Huang et. Al [47] designed a semi-cylindrical structure made of a Tedlar coated clear corrugated fiber-glass and an internal dry chamber of rotary or stationary drum with a black-painted outer surface to effect solar absorption. Trim and Ko

[48] developed another design with a clear plastic outer cover and a black plastic interior and Akachukwu [49] described the dryer with a solar kiln design for timber drying with a single glazing of horticultural-grade polythene with an internal black-painted corrugated metal absorber over the timber stack. M.A. Hossain et al. [50] developed a mixed mode type forced convection solar tunnel drier to dry hot red and green chilies under the tropical weather conditions of Bangladesh. The flat-plate collector and drying tunnel are connected in series to supply hot air directly into the drying tunnel with two fans operated by a photovoltaic module. The drier had a loading capacity of 80 kg of fresh chilies. In solar tunnel drier, moisture content of red chili was reduced from 2.85 to 0.05 kg / kg (db) in 20 h and it took 32 h in open sun drying method. In case of green chili using solar tunnel dryer about 0.06 kg/ kg (db) moisture content was obtained from an initial moisture content of 7.6 kg/ kg (db) in 22 h and 35 h to reach the moisture content to 0.10 and 0.70 kg/ kg (db) in open sun drying method A.P. Omojaro et al. [51] was investigated a single and double pass solar air heater with fins attached and using a steel wire mesh as absorber plate. Result shows that, with increasing air mass flow rate the efficiency increase. For the same flow rate the efficiency of the double pass was higher than the single pass by 7–19.4%. For air mass flow rate of 0.038 kg/s, maximum efficiency of single and double pass air heater was 59.62% and 63.74% respectively. Moreover, the thermal efficiency further decreases by increasing the height of the first pass of the double pass solar air heater. As the air mass flow rate increase, the temperature difference between the outlet flow and the ambient, DT, reduces.

B. Indirect-Type Active Solar Drying Systems

E.A. Arinze et al. [52] have been presented design features and experimental performance evaluation of a new mobile solar grain dryer suitable for the grain-producing areas as a commercial option. The energy collection efficiency of about 75% for the solar collector was relatively high in comparison with typical values for flat-plate collectors without fins. Ziegler et al. [53] worked on sorption storage of solar heat using a layer of wheat as the desiccant by means of a deep-bed drying model. The use of grain as the desiccant has important economic and processing advantages. The required strategy of control is based on the mixing of ambient air and solar heated air that has also flown though the desiccant bulk. A relative humidity of the drying air of 65% can be maintained day and night except for those hours when the relative humidity of ambient air is below 65%. M. Mohaneaj et al. [54] its performance was tested under the metrological conditions of Pollachi, India by drying chili. In a forced convection solar drier [Fig.9], moisture content in chili after drying reduces from around 72.8% (wet basis) to about 9.1% in 24 h. The average drier efficiency of a solar dryer was estimated to be about 21% and the specific moisture removal rate was calculated to be about 0.87 kg/kWh. Chr. Lamnatou et al. [55] was presents a solar dryer with an evacuated tube collector and analyze thermodynamic performance. Thin-layer drying models and recent model of Diamante et al. [56] were fitted to the experimental drying curves, which showed good correlation coefficients for all the tested products. Based on laws for minimum entropy generation an optimal collector surface area was analyzed. The relation of parameters like mass flow number, along with the maximum collector and fluid exit temperatures with generation of entropy were studied.

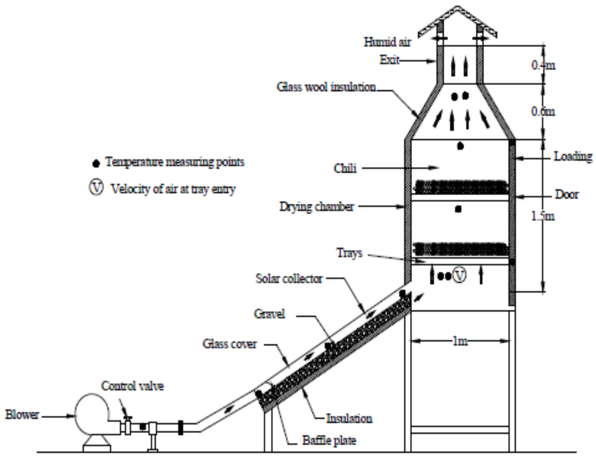

Figure 9. Schematic View of Experimental Setup

C. Storage type dryers

V. Shanmugam et al. [57] was designed and fabricated an indirect forced convection and desiccant integrated solar dryer. The desiccant unit was designed to hold 75 kg of CaCl2-based solid desiccant consisting of 60% bentonite, 10% calcium chloride, 20% vermiculite and 10% cement. At different air flow rate, drying experiments has been performed for green peas. The equilibrium moisture content Me, at an air flow rate of 0.03 kg/m2 s was reached in 14h. The performance was satisfactory showing pickup efficiency of 63% at 10.30 AM and more or less uniform during desiccant drying. During desiccant drying uniform drying of product in all the trays was achieved. The specific moisture extraction rate was found in the range of 0.55 to 0.82 kg/kW h. Devahastin and Pitaksuriyarat [58] studied the possibility of using latent heat storage with paraffin wax as a phase change material to preserve excess solar energy during drying and release it when solar energy availability is inadequate or not available and its effect on drying kinetics of a food product (sweet potato). Charge time decreased with an increase of the inlet air temperature and air velocity. The amount of extractable energy per unit mass flow rate of inlet ambient air was 1920 and 1386 kJ min/ kg when using inlet air velocity of 1 and 2 m/s, respectively. This LHS could save thermal energy during drying of sweet potato by approximately 40% and 34% when using inlet air velocity of 1 and 2 m/s, respectively. V. Shanmugam et al. [59] has been built and tested an indirect forced convection with desiccant integrated solar dryer. The useful temperature rise of about 10 ºC was achieved with mirror, which reduced the drying time by 2 h and 4 h for green peas and pineapple, respectively The drying efficiency of the system varies between 43% and 55% and the pick-up efficiency varies between 20% and 60%, respectively. Approximately, 60% of moisture was removed in all the drying experiments by air heated using solar energy and the remainder by the desiccant.. The addition of reflective mirror on the desiccant bed makes faster regeneration of the desiccant material. Gülsah Cakmak et al. [60] Drying system has been mainly included an expanded-surface solar air collector, a solar air collector with phase-change material (PCM) and drying room with swirl element. The swirl element was located to give the swirl effect to air flow in drying room. It was observed that Midilli model [61, 62] provided the most appropriate results for each drying state in the seeded grape drying. S.S. Krishnananth et al. [63] were fabricated and integrated a double pass solar air heater with thermal storage system. A double pass solar air heater of 750 mm length, 500 mm width and 182 mm height was fabricated using mild steel plate. Paraffin wax is used as a thermal storage medium. Abhishek Saxena et al.[64] developed a solar air heaters for crop drying, timber seasoning, and space heating applications at low and moderate temperatures. Inside the solar heater, ‘‘Granular carbon’’, has introduced as a long term heat absorbing media. The system was feasible to perform drying in night or bad climatic conditions because of using halogen lights. The thermal performance of this system with all configurations was found better in comparison of conventional solar air heater on both natural and forced convection.

D. Hybrid-Type Active Solar Dryers

Bena and Fuller [65] described a direct-type natural convection solar dryer combined with a simple biomass burner suitable for drying fruits and vegetables in regions without electricity. Condori et al., [66], Amer et al. [67] has recently designed and evaluated a hybrid solar dryer for drying of banana, consisting of a heat exchanger and heat storage facility. Eddy J. Amir et al. [68] modified a multi-purpose solar tunnel dryer, originally developed for the use in arid zones, to enable operation under tropical weather conditions. To heat the drying air during cloudy and rainy days, particularly in the rainy season, a biomass furnace with heat exchanger was integrated into the solar drying system. Results showed that compared to natural sun drying, the drying time of cocoa, coffee and coconut could be reduced up to 40%. Investigations further showed that even during the rainy season it was possible to dry the products to the final moisture content which is needed for storage and marketing. J. Mumba et al. [69] was designed developed and tested a solar grain dryer with air circulation powered by photovoltaic solar cell to d. c. fan. This photovoltaic powered air circulation brings passive control over the drying air temperature. This drier is suitable for rural farm applications where electricity and fossil fuel are either absent or expensive for the average farmer. In one day, the drying of 90 kg maize grain per batch from an initial moisture content of 33.3% to less than 20% dry basis was feasible. The controlled drying air temperature has an upper limit of 60±3°C to prevent grain overheating and cracking.

For non-electrified areas of developing countries Benon Bena et al. [70] developed a direct-type natural convection solar dryer with a simple biomass burner combined to demonstrate a drying technology suitable for small-scale processors of dried fruits and vegetables. The overall drying efficiency of the unit was calculated to be 9%. The drying efficiency of the solar component alone was found to be 22%. Other trials estimated the efficiency of the burner in producing useful heat for drying to be 27%. Ho-Hsien Chen et al. [71] developed an experimental closed-type dryer associated with a photovoltaic system (PV). Salah A. Eltief et al. [72] was analyzed the performance of the drying chamber of a solar assisted drying system. The solar assisted drying system consists of V-groove collector, drying chamber, the auxiliary heater and two variable speed centrifugal fans. B.M.A.Amer et al. [73] was designed and constructed a hybrid solar dryer using direct solar energy and a heat exchanger. About 65% of the drying air recycles in the solar dryer and exhausted a small amount of it, which was raised the efficiency of the solar dryer. It can raise up the air temperature from 30 to 40 ºC above the ambient temperature. During sunny day, the dryer was used to evaporate initial moisture content of 82% to the final moisture content of 18% (wb) in 8 h from 30 kg of banana slices. In open sun drying method reduced only 62% (wb) moisture content in same time period. Alejandro Reyes et al. [74] presented a hybrid solar dryer (HSD) provided with a 3 m^2 solar panel and electric resistances used for drying a mushrooms (Paris variety). The use of solar energy saves a 3.5-12.5% of total energy.

IV. CONCLUSION

In this study a review of the available literature on solar dryer system with the view of enabling an easier comparison of the findings obtained by various researchers has been conducted. However a lot of research works still needs to be done for large scale application in farming. Solar drying of agricultural food products has proved technically and economically feasible. It is necessary to develop a large scale and economically attractive solar dryer, to improve the acceptability of the solar dryer among the farmer. It must be of multipurpose use to share the cost of the dryer. During the night period, it is necessary to develop a system having back up of thermal storage. An auxiliary heat and forced convection are recommended for assuring reliability and better control respectively, for large scale agricultural food drying.

REFERENCES

[1] McLean KA. Drying and storage of combinable crops, Sucolk Farm Press, 1980.

[2] Ekechukwu OV. Experimental studies of integral-type natural-circulation solar-energy tropical crop dryers. Ph.D. thesis Cranreld Institute of Technology, United Kingdom, 1987.

[3] Mahapatra AK, Imre L. Role of solar agricultural drying in developing countries.Int J Ambient Energy 1990; 2:205–10.

[4] Sodha MS, Chandra R. Solar drying systems and their testing procedures: a review. Energy Convers Manage 1994; 35:219–67.

[5] EkechukwuOV,Norton B. Reviewof solar-energy drying systems II: an overview of solar drying technology. Energy Convers Manage 1999; 40:615–55.

[6] Hossain MA,Woods JL, Bala BK. Optimisation of solar tunnel drier for drying of chilli without color loss. Renew Energy 2005; 30:729–42.

[7] Zhiqiang Y. Development of solar thermal systems in China. Solar Energy Mater Solar 2005; 86:427–42.

[8] Dincer I. Evaluation and selection of energy storage systems for solar thermal applications, Int J Energy Res 1999; 23:1017–28.

[9] Khartchenko NV. Advanced energy systems, Berlin: Institute of Energy Engineering & Technology University; 1997

[10] Mani A, Rangarajan S. Solar radiation over India. New Delhi: Allied Publishers;1982

[11] Hughes, B. R., Oates, M., 2011, Performance investigation of a passive solar-assisted kiln in the United Kingdom, *Solar Energy*, 85, pp. 1488-1498.

[12] Butler JL, Troeger JM. Drying peanuts using solar energy stored in a rockbed. Agricultural energy vol- I solar energy, selected papers and abstracts. ASAE Publication, St Joseph, Michigan; 1980

[13] G. Datta, H. P. Garg, R. A. Ray and J. Prakash. Performance prediction of a cabinet- type solar drier. Solar & Wind Technology 1988; 5(3); 289 -292

[14] M. Fournier. The "shell" dryer-modelling and experimentation. Renewable energy,1995 6(4), 459463.

[15] Vinod kumar Sharma, Antonio Colangelo and Giuseppe Spagna. Experimental Investigation of different solar dryers suitable for fruits and vegetable, Renewable energy 1995; 6(4); 413 - 424

[16] Tiwari GN, Singh AK, Bhatia PS. Experimental simulation of a grain drying system. Energy Convers Manage 1994; 35(5):453–8.

[17] H. Hallak, J. Hilal, F. Hilal and R. Rahhal The staircase solar dryer: Design and charecteristic Renawable energy; 1996; 7(2); 177 183.

[18] Ayensu. Dehydration of food crops using a solar dryer with convective heat flow, Solar Energy 1997; 59(4–6):121–6.

[19] Gbaha P, Yobouet Andoh H, Kouassi Saraka J, Kamenan Koua B, Toure S. Experimental investigation of a solar dryer with natural convective heat flow. Renew Energy 2007; 32(11):1817–29.

[20] Kamil Sacilik, Rahmi Keskin, Ahmet Konuralp Elicin, Mathematical modelling of solar tunnel drying of thin layer organic tomato, Journal of Food Engineering.2006; 73; 231–238.

[21] Garg H P, Sharma VK, Mahajan RB, Bhargave AK. Experimental study of an inexpensive solar collector cum storage system for agricultural uses, Solar Energy 1985; 35(4):321–31.

[22] M.A. Basunia, T. Abe, Thin-layer solar drying characteristics of rough rice under natural convection, Journal of Food Engineering, 2001; 47; 295-301.

[23] Page, C. (1949), Factors inuencing the maximum rate of drying shelled corn in layers. M.S. Thesis, Purdue University, West Lafayette, IN, USA

[24] Doe, P. E., Ahmed, M., Muslemuddin, M., Sachithananthan, K. A., 1977, A polythene tent dryer for improved sun drying of fish, Food Tech Aust; 29, pp. 437-441.

[25] Sachithananthan, K., Trim D., Speirs C. I., 1983, A solar dome dryer for drying of fish, FAO Fisheries Paper, Rome, Italy. RAB/81/002/INT/L8

[26] Fleming, P. D., Norton. B., Ekechukwu, O. V., Onyegegbu, S. O., Probert, S. D., 1986, A large-scale facility for experimental studies of natural-ciruclation solar-energy tropical crop dryers. In: Proc Int Drying Symp (Drying '86). Cambridge, Mass., U.S.A., Hemisphere Pub Coy Washington, pp. 685-693.

[27] Rathore, N.S. , Panwar, N.L., 2010, Experimental studies on hemi cylindrical walk-in type solar tunnel dryer for grape drying, Applied Energy, 87, pp. 2764-2767.

[28] Janjai, S., Intawee, P., Kaewkiew, J., Sritus, C., Khamvongsa, V., 2011, A large-scale solar greenhouse dryer using polycarbonate cover, Renewable Energy, 36, pp. 1053-1062.

[29] Afriyie, J.K., Rajakaruna, H., Nazha, M. A. A., Forson, F.K., 2011, Simulation and Optimisation of the ventilation in a chimney-dependent solar crop dryer, Solar Energy, 85, pp.1560-1573

[30] Ekechukwu, O.V., 1999, Review of solar-energy drying systems I: an overview of drying principles and theory, Energy Conversion and Management, 40, pp. 593–613.

[31] S. Janjai, P. Tung. Performance of a solar dryer using hot air from roof-integrated solar collectors for drying herbs and spices. Renewable Energy, 2005; 30; 2085–2095.

[32] N.S. Rathore, N.L. Panwar. Experimental studies on hemi cylindrical walk-in type solar tunnel dryer for grape drying. Applied energy, 2010; 87; 2764–2767.

[33] V. K. Sharma, A. Colangelo and G. Spanga. Investigation of an indirect type multi shelf solar fruit and vegetable dryer, Renewable Energy. ; 2(6); 577 586

[34] Chauhan PM, Choudhury C, Garg HP. Comparative performance of coriander dryer coupled to solar air heater and solar air-heater-cum-rockbed storage. Appl Therm engg1996;16(6):475– 86.

[35] R. K. Goyal and G. N. Tiwari. Parametric study of a reverse flat plate absorber cabinet dryer:A new concept. Solar Energy . 1997; 60(1) 41-48.

[36] O. V. Ekechukwu and B. Norton. Experimental studies of integral-type natural circulation solar- energy tropical crop dryers. Energy Conuers. Mgmf. 1997; 38(14); 1483-1500.

[37] A. Madhlopa a, S.A. Jones b, J.D. Kalenga. Saka A solar air heater with composite– absorber systems for food dehydration. Renewable Energy; 2002; 27:27–37

[38] Sukhmeet Singh, Parm Pal Singh, S.S. Dhaliwal. Multi-shelf portable solar dryer, Renewable energy, 2004; 29; 753–765

[39] Jain D, Jain R K. Performance evaluation of an inclined multi-pass solar air heater with in-built thermal storage on deep-bed drying application. J Food Eng 2004; 65:497–509.

[40] Jain D. Modeling the system performance of multi-tray crop drying using an inclined multi-pass solar air heater with in-built thermal storage. J Food Eng 2005;71: 44–54.

[41] Parm Pal Singh, Sukhmeet Singh, S.S. Dhaliwal, Multi-shelf domestic solar dryer Energy Conversion and Management. 2006; 47; 1799–1815.

[42] F.K. Forsona, M.A.A. Nazhab, F.O. Akuffoa, H. Rajakarunab. Design of mixed-mode natural convection solar crop dryers: Application of principles and rules of thumb. Renewable Energy: 2007; 32; 2306–2319.

[43] Jain D. Modeling the performance of the reversed absorber with packed bed thermal storage natural convection solar crop dryer. J Food Eng 2007; 78: 637–47.

[44] Potdukhe PA, Thombre SB. Development of a new type of solar dryer: its mathematical modeling and experimental evaluation. Int J Energy Res 2008; 32:765–82.

[45] Shobhana Singh, Subodh Kumar. Testing method for thermal performance based rating of various solar dryer designs. Solar Energy.2012; 86; 87–98

[46] Wei Chen, Man Qu. Analysis of the heat transfer and airflow in solar chimney drying system with porous absorber. Renewable Energy.2014;63: 511-518.

[47] Huang, B. K., Toksoy, M., 1981, Greenhouse solar system for selective year-round solar-energy utilization in agricultural production, *Agric Energy*, pp. 1-152.

[48] Trim, D. S., Ko, H. Y., 1982, Development of a forced-convection solar dryer for red peppers, *Tropical Agriculture* (Trinidad), 59(4), pp. 319-323.

[49] Akachukwu, A. E., 1986, Solar kiln dryers for timber and agricultural crops, *Int J Ambient Energy*, 7(2), pp. 95-101.

[50] M.A. Hossain a,, B.K. Bala. Drying of hot chilli using solar tunnel drier, Solar Energy, 2007; 81: 85–92

[51] A.P. Omojaro, L.B.Y. Aldabbagh. Experimental performance of single and double pass solar air heater with fins and steel wire mesh as absorber. Applied Energy, 2010; 87; 3759–3765.

[52] E. A. Arinze, S. Sokhansanj, G. J. Schoenau and Vie Ellis. Design and experimental evaluation of a new commertial type mobile solar grain dryer provided with high efficiency fined- plate collector WREC 1996.

[53] Ziegler Th, Richter I-G, Pecenka R. Desiccant grain applied to the storage of solar drying potential. Drying Technol 1999;17(7–8):1411–27.

[54] M. Mohanraj, P. Chandrashekhar Performance of a forcedconvection solaar material for chili drying Journal of Engineering Science and Technology. 2009; 4(3); 305 - 314

[55] Chr. Lamnatou , E. Papanicolaou, V. Belessiotis, N. Kyriakis. Experimental investigation and thermodynamic performance analysis of a solar dryer using an evacuated-tube air collector. Applied Energy.2012; 94; 232–243.

[56] Diamante LM, Ihns R, Savage GP, Vanhanen L. A new mathematical model for thin layer drying of fruits. Int J Food Sci Technol 2010;45:1956–62.

[57] V.Shanmugam E. Natarajan. Experimental investigation of forced convection and desiccant integrated solar dryer. Renewable Energy, 2006; 31; 1239–1251.

[58] Devahastin S, Pitaksuriyarat S. Use of latent heat storage to conserve energy during drying and its effect on drying kinetics of a food product. Appl Therm Eng 2006; 26:1705–13.

[59] Shanmugam V, Natarajan E. Experimental study of regenerative desiccant integrated solar dryer with and without reflective mirror. Appl Therm Eng 2007; 27:1543–51.

[60] Gülsah Cakmak, Cengiz Yıldız. The drying kinetics of seeded grape in solar dryer with PCM-based solar integrated collector , food and bioproducts processing.2011; 89; 103–108.

[61] Midilli, A. and Kucuk, H., 2003, Mathematical modelling of thin layer drying of pistachio by using solar energy. Energy Convers Manage., 44: 1111–1122.

[62] Midilli, A., Kucuk, H. and Yapar, Z., 2002, A new model for single layer drying. Dry. Technol., 20: 503–1513.

[63] S.S. Krishnananth, K. Kalidasa Murugavel Experimental study on double pass solar air heater with thermal energy storage, Journal of King Saud University – Engineering Sciences. 2012

[64] Abhishek Saxena , Nitin Agarwal , Ghansyham Srivastava. Design and performance of a solar air heater with long term heat storage. International Journal of Heat and Mass Transfer. 2013; 60: 8–16.

[65] Bena, B., Fuller, R.J., 2002, Natural convection solar dryer with biomass back-up heater, *Solar Energy*, 72 (1), pp. 75–83.

[66] Condori, M., Echazu, R., Saravia, L., 2001, Solar drying of sweet pepper and garlic using the tunnel greenhouse dryer, *Renewable Energy*, 22, pp. 447–460.

[67] Amer, B.M.A., Hossain, M.A. , Gottschalk, K., 2010, Design and performance evaluation of a new hybrid solar dryer for banana, *Energy Conversion and Management*, 51, pp. 813-820.

[68] Eddy J. Amir, K. Grandegger, A. Esper, M. Sumarsono, C. Djaya and W. Muhlbaur. Development of a multi-purpose ssolar tunnel dryer for use in humid tropics. Renewable Energy. 1991; 1(2); 167 176.

[69] J. Mumba. Design and development of a solar grain dryer incorporating photovoltaic powered air circulation. Energy Conuers. Mgml. 1996; 37(5); 615-621.

[70] Benon Bena and R. J. Fuller Natural Convention Solar Dryer With Biomass back up heater Solar Energy,2002; 72(1);75–83.

[71] Ho-Hsien Chen, Carlos Eduardo Hernandez, Tzou-Chi Huang. A study of the drying effect on lemon slices using a closed-type solar dryer. Solar Energy; 2005;78; 97–103

[72] Salah A. Eltief, M.H. Ruslan, B. Yatim. Drying chamber performance of V-groove forced convective solar dryer. Desalination; 2007; 209: 151–155.

[73] B.M.A. Amer, M.A. Hossain, K. Gottschalk. Design and performance evaluation of a new hybrid solar dryer for banana. Energy Conversion and Management.2010; 51; 813–820.

[74] Alejandro Reyes, Andrea Mahn, Francisco Cubillos, Pedro Huenulaf. Mushroom dehydration in a hybrid-solar dryer, Energy Conversion and Management, 2013; 70: 31–39.