RESEARCH ARTICLE OPEN ACCESS

A Review on Different Solar Dryers and Drying Techniques for Preservation of Agricultural Products

Kaustav Bharadwaz
1/8A, Arnott Street, Clayton, Victoria-3168, Australia

Abstract:

To maintain the right balance between the supply and demand of food for growing human population, it is essential to reduce food item losses. Increasing the food production capabilities of small farmers in village areas of developing countries is difficult, but there is a scope to get more by reducing the post-harvest losses. Drying has become one of the crucial processing technique in the preservation of agricultural products and very useful even for small farmers to reduce the post harvest losses. Drying under open sunlight has a lot of drawbacks associated with it in the form of requirement of more space and time, infestation by the insects and microorganisms, interference by grazing animals and humans, rain, blowing wind, etc. Solar dryers are specialized devices that use energy from the sun for drying fruits, vegetables, meat and fishes etc. With the advancement in solar energy technology, it is possible to design low-cost environment friendly solar dryers for agricultural products and it is essential to promote such facility even at the village level not only to reduce the post harvest losses but also to preserve food items for longer without altering the quality. This paper discusses the different solar dryers and the drying techniques that are used primarily for agricultural products.

Key words-**Solar dryers, drying techniques, open sun drying, agricultural products**

I. INTRODUCTION

Globally the human population is expected to grow beyond 9 billion by the year 2050, and about 70% extra food production will be required to feed them [1]. The population rise is expected to be more in developing countries and the demand for food is increasing due to population explosion, urbanization, climate change and land use for non-food crop production etc. Besides, the post harvest losses of agricultural products are also high in the developing countries due to poor infrastructure and resources available to use the modern storage techniques and lack of awareness about the usefulness of the techniques. Globally about one-third of the food produced (approx.1.3 billion ton),worth about US $1 trillion, is lost during post-harvest operations every year [2]and it also predicts that if the current practices continue then the loss would be around 2.1 billion metric tons by 2030. India is one of the largest producers of fruits and vegetables in the world. The cumulative wastages of fruits and vegetables in India are estimated to be 5.8% to 18%. As per the study, post-harvest losses of major agricultural products including fruits and vegetables in India alone were estimated to the tune of about Rs. 44,000 crore per annum [3]. The availability of low cost and effective storage structures can motivate farmers to store their agricultural products like cereals, vegetables and fruits etc instead of selling right after harvesting at lower price. Proper storage will retain normal colour, nutritive value and gives opportunity to sell at higher prices during lean period besides giving sustainable food security.

The potential of using solar energy in agricultural sector is increasing and solar assisted drying could be the most promising application of solar energy especially in the developing countries. The main purpose of drying is to reduce the moisture content of the products to a level that prevents deterioration within a certain period of time, normally regarded as the ―safe storage period [4]. A comprehensive review of the fundamental principles and theories governing the drying process, along with basic definition has been published elsewhere [4]. The most commonly used method to preserve agricultural products in developing nations is open sun drying [5]. However, direct sun drying has many disadvantages and it leads to losses in the quantity and quality of the dried product [6]. Direct sun drying requires large open space area and it very much dependent on the availability of sunshine, products are susceptible to contamination with foreign materials such as litters, dusts and are exposed to insects, birds and rodents. In comparison to natural sun drying, solar dryers generate higher temperatures, lower relative humidity, lower product moisture content and reduced spoilage during the drying process. In addition, it takes up less space, takes less time and relatively inexpensive compared to artificial mechanical drying method. Thus, solar drying is a better alternative solution to all the drawbacks of natural drying and artificial mechanical drying. Solar drying is also cost-effective and a safe method for drying agricultural food products. In order to make use of solar energy in an efficient manner to meet man's demand for energy and food supply, a solar dryer is one of the best possible ways. Solar dryers have many advantages over sun drying when correctly designed. They give faster drying rates by heating the air to 10-30^{0}C above ambient, which causes the air to move faster through the dryer, reduces its humidity and deters insects and microbial spoilage. The faster drying reduces the risk of spoilage, improves quality of the product and gives a higher throughput, so reducing the drying area that is needed. However, care is needed when drying fruits to prevent too rapid drying, which will prevent complete drying and would result in case hardening and subsequent mould growth. Solar dryers also protect foods from dust, birds and animals. They can be constructed from locally available materials at a relatively low capital cost and there is no fuel cost.

Solar dryers are specialized devices that use energy from the sun for drying fruits and vegetables. Solar dryers also find several applications in industries such as textiles, wood, paper, pharmaceutical, and food-processing industries. They have low operating and maintenance costs, and they last typically for 15-20 years with minimum maintenance. Solar dryers can be classified based on the air circulation mode such as natural and forced circulation solar dryers; based upon the type of drying such as direct solar dryers, indirect solar dryers, mixed-mode solar dryers, and hybrid solar dryers; based on the type of operation such as batch or continuous, etc .It has been reported that certain parameters are generally measured to evaluate the performance of the dryers [7]. These parameters could be categorized as physical features of the dryer such as type, size, shape, drying capacity/loading density, tray area and number of trays, loading /unloading convenience, thermal performance such as drying time/drying rate, relative, airflow rate, dryer efficiency and quality of dried product such as sensory quality (colour, flavour, taste, texture, aroma), nutritional attributes, rehydration capacity and cost of dryer and payback period. Different workers [8,9] have reported considerable reduction of drying time with solar drying technique than open sun drying. Besides, drying in solar dryer yielded good quality hygienic dried products.

II. TYPES OF SOLAR DRYERS AND DRYING TECHNIQUE

Direct solar dryers: In direct solar dryers, the material to be dried is placed in an enclosure with a transparent cover over it. Direct sunlight can reach the inside of the dryer through the transparent cover. The transparent glass cover employed can help in reducing direct convective losses to the ambient which additionally plays a crucial role in increasing the temperature of the agricultural product and cabinet temperature [10]. Heat is generated by direct absorption of solar radiation on the product itself as well as on the internal surfaces of the drying chamber (Fig.1).

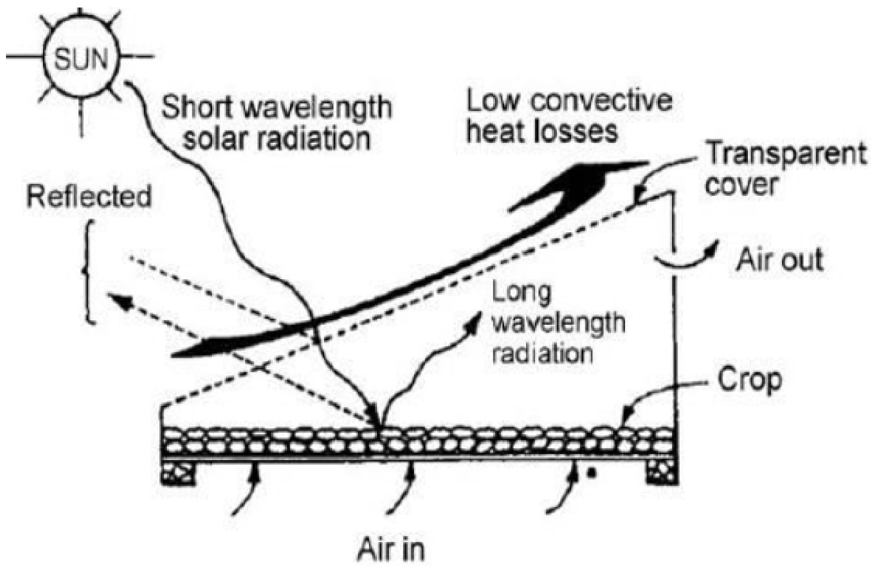

Fig.1Working principle of direct Solar drying [10]

This type of dryer is typically used in those areas which receive a sufficient amount of sunlight throughout the year. However, there are certain disadvantages associated with the use of these dryers. Transmissibility of the transparent glass cover is reduced due to moisture compression inside it [11]. The caramelization of the product used for drying can occur due to direct contact with sunlight for a sustained period of time which ultimately reduces the nutritive quality of the product. Also, the rate of drying is very low in direct solar dryersdesigned and fabricated a direct natural convection solar dryer for drying tapioca [12]. Through experimentation, the initial and final moisture content were found to be 79 % and 10 % wet basis, respectively. The average ambient conditions recorded were 32ºC and 74 % relative humidity with daily global solar radiation of 13 MJ/m2/day. They developed a prototype of the dryer with minimum collector area of 1.08 m2 and performed drying tests under various loading conditions. A small scale direct mode natural convection solar dryer for drying tomato, okra and carrot using locally available and affordable materials was developed by Eke [13]. He sliced these crops and loaded them in the dryer at the same time. Comparing the results with that of open sun drying and observed that sliced samples of tomato, carrot and okra dried with solar dryers, achieved 54.55, 52.88 and 50.98 percent gain in drying time respectively. Gbaha et al., [14] designed a natural convection direct type solar dryer and constructed the dryer using local materials and then tested it experimentally to dry foodstuffs (cassava, bananas, and mango). They analysed the behaviour of the dryer and the study mainly relates to the kinetics and establishment of drying heat balances. They concluded that the moisture content of cassava and sweet banana was reduced from 80% to the safety threshold value of 13% in 19 and 22 h, respectively. They concluded that the drying rate increases with drying air temperature and drying air mass flow. Cabinet type solar drier was found to be suitable for drying fruits and vegetables. Sodha et al., [15] also developed adirect solar cabinet dryer and used for drying mango slices. The experimental results showed that, on atypical summer day mango slices with 95% initial moisture content dries up to 13% final moisture content in 12 sunshine hours. It was also concluded that the cabinet type driers were very useful for domestic applications for drying of fruits and vegetables (i.e. high moisture content products) in developing and underdeveloped countries. Singh et al., [16] developed a natural convection solar dryer which has four main components, multi-tray rack, movable glazing, shading plate and trays. The multi-rack is inclined depending upon the latitude of the location. The movable glazing consists of a movable frame and a UV stabilized plastics sheet. The dryer is portable and of low cost to make it economically viable. It can be used in cottage industries in remote places.

Indirect solar dryers: In indirect solar dryers, solar radiation is not directly incident over the material employed for drying. Heated air is collected in a separate solar collector from where it enters the drying chamber where the drying process initiates. The food items to be dried are arranged horizontally in stacks of trays which are placed inside the drying chamber. The heated air flows over the items that provide the heat for moisture evaporation by convective heat transfer between the hot air and the food item [17].

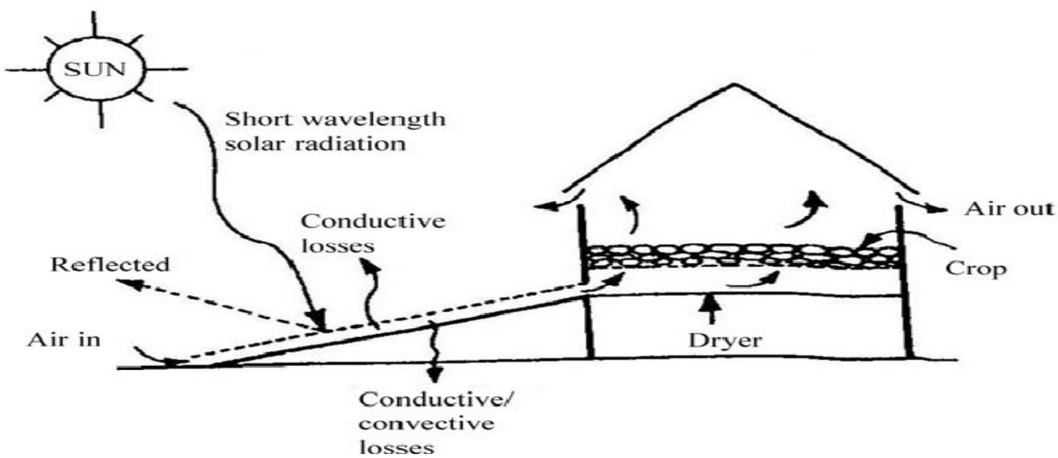

Fig.2 Working principle of Indirect solar dryer [17]

Compared to direct solar dryers, indirect solar dryers are more efficient and have faster drying rates. Indirect solar dryers can be classified into natural convection indirect type solar dryers and forced convection solar dryers. In forced convection indirect solar drying mechanism external sources such as mechanical blowers are used to pump enough heated air from the collector to the heating chamber to progressively reduce the time required for drying. The major disadvantages of this type of dryer are the overall maintenance costs involved. Bolaji [18] investigated an indirect solar dryer using a box-type absorber collector. The box-type absorber collector was inclined at an angle of 20 degrees to the horizontal and was constructed using a glass cover and a black absorber plate. The 20 degree inclination angle provided little resistance to the heated air to rise up the unit. A maximum efficiency of 60.5% was reported with the dryer.Atalay[19] designed an indirect solar dryer for apple slice drying. The dryer was attached with packed bed thermal energy storage system. To recover the waste heat from the dryer used a recuperator and it was used for mixing the fresh air with waste heat to improve more moisture diffusion. So the drying rate increases up to 60%. Initial moisture in apple slice was 20% but to prevent it from spoiling it should be reduced to 10%. Size of the apple slice was maintained 2 to 5mm for the 8Kg of capacity. Total 12 experiments were performed to take all readings. Mathematical model analysis was also doneto measure the moisture removal rate and solar collector efficiency. Dhanushkodi et al., [20] designed indirect forced convection solar dryer for cashew drying and the capacity of the dryer was 40kg to50 kg. During the performance analysis, dryer efficiency, collector efficiency, drying rate, thermal efficiency, and flow rate of air, inlet or outlet air temperature was measured. Moisture reduction from 10% to 4% within time of 6 hours was observed. Results showed that forced convection was very effective in drying process. The effectiveness of solar dryer can be further increased by placing parabolic reflector on both sides of dryer. Sreekumar et al. [21] described the development and testing of a new type of efficient solar dryer, with two compartments: one for collecting solar radiation and producing thermal energy and the other for spreading the product to be dried, particularly meant for drying vegetables and fruit. Madhlopa et al.,[22] reported that sliced fresh mangoes having an initial moisture content of 85% can be dried at 31.7^{0}C–40.1^{0}C for 20 h to a final moisture content of 13% in an indirect type natural convection solar dryer. Sharma et al., [23] described the design and performance of an indirect type solar fruit and vegetable dryer developed and the experimental results suggested that even under unfavourable weather conditions, the unit is capable to produce good quality products.

A forced convection indirect solar drying system for food preservation was designed and developed by Bharadwaz et al., [24]. Locally available materials were used for the design of the dryer so as to make it cost-effective. Heated air from the solar collector was forced inside the dryer by a mechanical pump. Baffles were placed inside the solar collector for non-linear movement of air from inlet to outlet. Stainless steel trays were placed in rows of stacks horizontally inside the dryer for placing the food items. Desiccant silica gel packets were also placed inside the drying chamber which further acted as a source in absorbing water/ moisture. An exhaust vent was provided at one section of the dryer for movement of the heated air generated inside the dryer (Fig.3&4). Variation of temperatures in solar collector, drying chamber and ambient temperature which was observed during the experiment was shown in Fig.5.The figure clearly showed higher temperature in collector and drying chamber. The thermal efficiency of the dryer was recorded to be 13.8% approx. and the average collector efficiency was found out to be 38.5%. The higher temperature, movement of air and lower humidity, increases drying rate of the dryer.

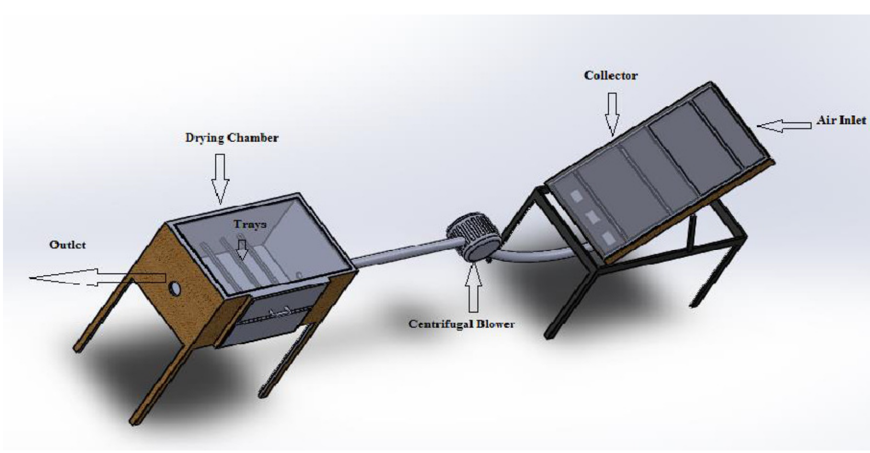

Fig- 3: Orthogonal view of the indirect solar dryer [24]

Fig.4 Complete experimental setup of the indirect solar dryer [24]

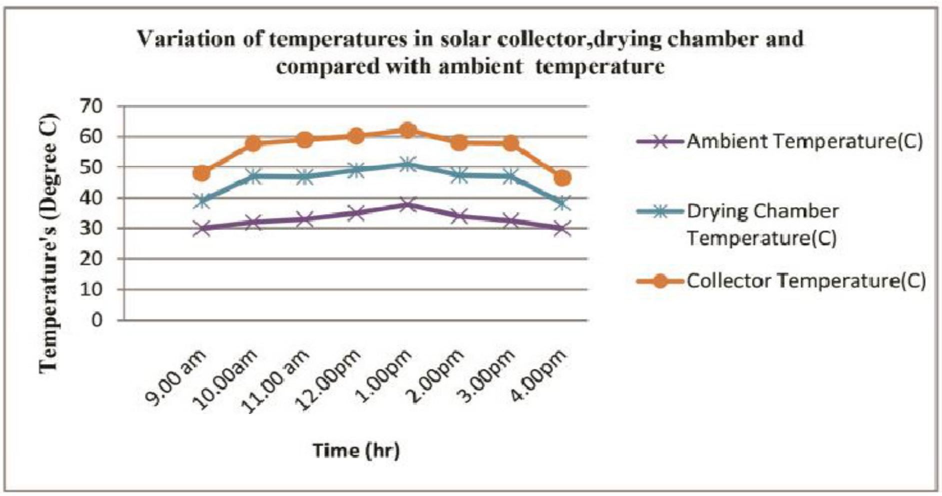

Fig.5 Variation of temperatures in solar collector, drying chamber and ambient temperature [24]

Several workers [25,26] found out that forced convection solar dryers are more efficient than natural convection dryers. Also, products can be dried faster in forced convection solar dryers than in the natural convection solar dryers and end products obtained from forced convection drying have superior quality. A natural forced convection solar dryer was designed and constructed by Gutti et al., [27] for drying vegetables. The dryer was constructed using locally available materials and an additional heat storage unit was incorporated for supporting drying during the night hours. The solar collector absorber plate was made of corrugated aluminium and was painted black to enhance the heat absorption rate. The drying cabinet was constructed out of wood and an outlet vent was provided towards the upper end at the back of the cabinet to facilitate and control the convective flow of air through the drying cabinet.

An indirect natural convection solar dryer with biomass backup burner for drying pepper berries was developed and studied by Rigit et al., [28]. The main objective behind employing a biomass backup burner was to reduce the time required for drying and prevent molds built upon the dried products. The overall dried products observed were of high nutritive quality and the dryer was found to be suitable for farmers living far from the national grid.

Mixed mode solar dryers: In mixed mode solar dryer, the heated air is collected in a separate solar collector and at the same time, the drying cabinet absorbs solar radiation directly through the transparent walls or roofs [29].A mixed-mode solar dryer was designed and developed by Gatea[29] for evaporating moisture in beans. The solar dryer consisted of three main parts- the collector, two fins, and a drying chamber with four trays. Higher moisture evaporating from the beans was achieved in the first tray, as moisture content was reduced from 60 to 8% during the 6 h compared with the other three trays. It was found to be more efficient mode of drying compared to direct and indirect solar drying mechanisms and saves time considerably. Bolaji and Olalusi[30] designed and developed a mixed-mode solar drying system for food preservation. The overall efficiency of the system was found to be 57.5% and the drying rate was 0.62kg/hr respectively. Lakshmi etal., [31] did the experimental performance analysis on mix mode solar dryer for black turmeric with 15kg capacity. Analysis made to find the thin layer model for turmeric drying could save around 60% time compared to normal sun drying. Overall efficiency was found higher in mix mode solar dryer. This type of mix mode solar dryer was a best option for other medicinal plant products. Design and construction was prepared very simple and very useful for the village farmer. Moisture removed was 73.3% to 8.5% in mixed mode solar dryer. Quality analysis of product was also carried out for colour, flavour and oxidant activity.

H**ybrid solar dryer:** It is a more complex mechanism of solar drying. A hybrid solar dryer comprises of a solar collector, a reflector, a heat exchanger cum heat storage unit and drying chamber. In this type of dryer, the process of drying can be continued during off-sunshine hours by stored heat energy [32]. So, the process of drying is continued, and products are saved from infestation by microorganisms [33]. Bhattacharya et al., [34] developed a hybrid solar dryer employing direct solar energy and a heat exchanger. The drying system comprises a solar collector, reflector, heat exchanger cum heat storage unit and a drying chamber. The drying chamber was placed beneath the collector which further operated as a solar dryer during normal sunny days and as a hybrid solar dryer during cloudy days. Drying was also carried out at night using stored heat energy, which was collected during the daytime.

Besides the above solar dryers, a reverse absorber cabinet dryer was proposed and analysed by Goyal and Tiwari [35]. A downward-facing absorber was placed below the drying chamber at a suitable distance from the bottom of the drying chamber. A cylindrical reflector was placed under the absorber fitted with the glass cover on its aperture to minimize convective heat losses from the absorber. The inclination of the glass cover was taken as 45° from horizontal to receive maximum radiation. The area of absorber and glass cover was taken equal to the area of the bottom of the drying chamber. Solar radiation after passing through the glass cover was reflected by a cylindrical reflector toward an absorber. After absorber, a part of this was lost to the ambient through a glass cover and remaining is transferred to the flowing air above it by convection. The crop is heated and moisture is removed through a vent provided at the top of the drying chamber. A solar drying system consisting of composite absorber systems was also developed by Madhlopa et al., [22]. The solar drying system consisted of a flat plate collector, wire mesh absorber, glass cover,chimney and drying chamber. A heater was integrated into the drying chamber for dehydrating the food samples. Test results indicated the thermal efficiency of the flat plate collector and the wire mesh absorber as 17% & 21% respectively, at flow rate of 0.0083 kg/s. The above are few examples of use of solar dryers and drying techniques for agricultural products as it is difficult to review all the published works on solar dryers in this short review. Use of solar dryers mostly depends on weather and more particularly on solar irradiation and tropical countries should take advantage of utilizing the non exhaustible solar energy for drying food products by designing cost effective solar dryers for rural farmers.

III.CONCLUSIONS

Solar radiation can be highly effective and utilized for drying of agricultural products in tropical and developing countries. Several studies have demonstrated that the solar dryers designed and constructed expressed sufficient ability to dry agricultural products in a better and efficient manner than open sun drying method. Locally available cheap materials can be used in manufacturing of solar dryers making it available and affordable to all and especially for rural farmers. This will go a long way in reducing food wastage and at the same time food shortages. Solar drying is environment friendly, cost effective and it reduces cost and time. The food items are also well protected in the solar dryer than in the open sun, thus reducing the case of pest and insect attack and also contamination. However, the performance of existing solar food dryers can still be improved upon especially in the aspect of reducing the drying time and in developing suitable device to store heat energy within the system for longer. Also, meteorological data should be made available to users of solar dryers to ensure maximum efficiency and effectiveness of the system. Such information will help a local farmer when to dry his agricultural products and when not to dry them.

REFERENCES

[1] H.C.J.Godfray, J.R. Beddington,I.R.Crute, L.Haddad, D. Lawrence, J.F.Muir, J.Pretty, S..Robinson, S.M.Thomas and C. Toulmin, " Food security: The challenge of feeding 9 billion people", *Science*, vol. 327, pp. 812–818, 2010.

[2] J.Gustavsson,C.Cederberg, U.Sonesson,R. van Otterdijk and A.Meybeck, "Global Food Losses and Food Waste", *Food and Agriculture Organization of the United Nations,* Rome, Italy,2011.

[3] A.Kumari, P.P.Pankaj and P.Baskarm,"Post harvest losses of Agricultural products:Management and future challenges in India". In Recent Trends in Post harvest management. First Edn.Mangalam Publishers, New Delhi pp.141-153,2015.

[4] O.V.Ekechukwu, " Review of solar energy drying I: an overview of drying principles and theory", *Energy Convers Manage*, vol.40 ,pp. 593–613,1999.

[5] A.A.El-Sebaii and S.M.Shalaby, " Solar drying of agricultural products: A review", *Renewable and Sustainable Energy Reviews*,vol. 16,pp.37-43,2012.

[6] D.R.Pangavhane, R.L.Sawheny, and P.N.Sarsavadia, " Design, development and performance testing of a new natural convection solar dryer*", Energy*, vol.27,pp. 579–90,2002.

[7] M.A.Leon, S. Kumar and S.C. Bhattacharya, "A comprehensive procedure for performance evaluation ofsolar food dryers", *Renewable and Sustainable Energy Reviews* , vol.6, p. 367,2002.

[8] A.Fudholi,M.Y.Othman, M.H. Ruslan and K. Sopian, " Drying of Malaysian Capsicum annuum (red chili) dried by open and solar drying", *International Journal of Photoenergy,*p.9 ,2013,https://doi.org/10.1155/2013/167895.

[9] S. Tabassum, M.S.Bashar,M.S.Islam,A.Sharmin,S.C. Debn.,S.A.A.Khanom and M.Khanam," Design and development of a solar dryer for food preservation", *Bangladesh Journal Science Industrial Research*,vol 54,pp.155-160,2019.

[10] U.A.Saleh, F.I.Onuigbo,S.Abdulrahman and A.E. Ayodeji,A.E.“ Construction of a direct solar dryer for perishable farm products”, .*International Journal of Scientific Research Engineering and Technology*,vol6,pp.108-116,2017.

[11] A.Zomorodian and M.Dadashzadeh,“ Indirect and mixed mode solar drying mathematical models for sultana grape”, *Journal of Agricultural Science and Technology*,vol. 11,pp.391-400,2009.

[12] E.O.Diemuodeke and O.L.Y. Momoh, “Design and Fabrication of a Direct Natural Convection Solar Dryer for Tapioca”, *Leonardo Electronic Journal of Practices and Technologies*, vol. 18,pp. 95- 104,2011.

[13] B.A. Eke, “Development of Small Scale Direct Mode Natural Convection Solar Dryer for Tomato,Okra and Carrot”, *International Journal of Engineering and Technology*,vol. 3, 2013.

[14] P.Gbaha,J.K.Saraka and B. Koua, “Experimental investigation of a solar dryer with natural convective heat flow”, *Renewable Energy*,vol.32,pp.1817-1829,2017.

[15] M.S. Sodha, A. Dang, P.K. Bansal and S.B.Sharma, “An analytical and experimental study of open sun drying and acabinet type drier”, *Energy Conversion Management*, vol.25, pp.263–271,1985.

[16] S.Singh, P.P.Singh and S.S.Dhaliwal, “Multi-shelf portable solar dryer”, *Renewable Energy* ,vol.29,pp.753–65,2004.

[17] C.R.Chen, A. Sharma, and N.Vu Lan, “Solar-energy drying systems: A review”. *Renewable and Sustainable Energy Reviews*, vol.13,pp.1185-1210.,2009.

[18]B.O. Bolaji, “Development and performance evaluation of box type absorber solar air collector for crop drying. *Journal of food technology*”,vol 3,pp.515-600,2005.

[19] H.Atalay, “Performance analysis of a solar dryer integrated with the packed bed thermal energy storage (TES) system”, *Energy* , vol.172,pp.1037-1052,2019.

[20] S.Dhanushkodi,V.H.Wilson and K.Sudhakar, “Thermal Performance Evaluation of Indirect Forced Cabinet Solar Dryer for Cashew Drying”, American-Eurasian Journal of Agriculture and Environment Science,vol.14,pp.1248-1254,2014.

[21] A.Sreekumar, P.E.Manikantan and K.P. Vijayakumar, “Performance of indirect solar cabinet dryer. *Energy Convers Manage*, vol.49,pp.1388–1395,2008.

[22] A.Madhlopa, S.A. Jones and J.D.K.Saka, J.D.K. “A solar air heater with composite-absorber systems for food dehydration”, *Renewable Energy*, vol.27,pp. 27–37,2002.

[23] V.K. Sharma,A.Colangelo and G. Spagna, “Experimental investigation of different solar dryers suitable for fruit and vegetable drying”, *Renew Energy*, vol.6,pp.413–24,1995.

[24] Kaustav Bharadwaz, D. Barman,D.Bhowmik.and Z. Ahmed,“Design,fabrication and performance evaluation of an indirect solar dryer for drying agricultural products”,*International Research Journal of Engineering and Technology*,vol.4,pp.1684-1692,2017.

[25] M. Mohanraj and P. Chandrasekar, “Performance of a forced convection solar drier integrated with gravel as heat storage material”,*Journal of Engineering Science and Technology*,vol. 4,pp.305-314,2009

[26] J.Banout and P. Ehl, “ Using a double pass solar drier for drying bamboo shoots. *Journal of Agriculture and Rural Development in the Tropics and Subtropics,*vol. 111,pp.119-127,2010.

[27] B.Gutti, S.Kiman and A.Murtala, “Solar dryer-an effective tool for agricultural products preservation. *Journal of applied technology in environmental sanitation,*vol. 2,pp.31-38,2012.

[28] A.R.H. Rigit,A.Q.,Jakhrani and S.A. Kamboh, “Development of an indirect solar dryer with biomass backup burner for drying pepper berries”. World Applied Sciences Journal, vol.22, pp.1241-1251,2013.

[29] A.A.Gatea, “Design,construction, and performance evaluation of solar maize dryer”, *Journal of Agriculture Biotechnology Sustainable Development*,vol.2,pp.039-046,2010.

[30] B.O.Bolaji and P.A. Olalusi, “Performance evaluation of a mixed mode solar dryer”,.*AU Journal of Technology,*vol.11,pp. 225-231,2008.

[31] D.V.N. Lakshmi,P.Muthukumar,A. Layek and P.K.Nayak, "Drying kinetics and quality analysis of black turmeric (Curcuma caesia) drying in a mixed mode forced convection solar dryer integrated with thermal energy storage", *Renewable Energy*,vol.120,pp. 23-34,2018.

[32] B.M.A. Amer,M.A. Hossain and K. Gottschalk, "Design and performance evaluation of a new hybrid solar dryer for banana", Energy conversion and management, vol.51,pp. 813-820,2010.

[33] E.A. Arinze,G.J.Schoenau and S. Sokhansanj, "Design and experimental evaluation of a solar dryer for commercial high-quality hay production", *Renew Energy*, vol.16,pp. 639-642,1999.

[34] S.C.Bhattacharya, M.A. Leon and S. Kumar, "A comprehensive procedure for performance evaluation of solar food dryers", *Renew and Sustainable. Energy reviews*,vol. 6,pp. 367-393,2002.

[35] R.K. Goyal and G.N. Tiwari, "Performance of a reverse flat plate absorber cabinet dryer: a new concept. Energy Convers Manage, vol.40,pp. 385–92,1999.