International Journal of Engineering, Science and Mathematics
Vol. 7Issue 1,January 2018,
ISSN: 2320-0294 Impact Factor: 6.765
Journal Homepage: http://www.ijesm.co.in, Email: ijesmj@gmail.com Double-Blind Peer Reviewed Refereed Open Access International Journal - Included in the International Serial Directories Indexed & Listed at: Ulrich's Periodicals Directory ©, U.S.A., Open J-Gage as well as in Cabell's Directories of Publishing Opportunities, U.S.A

REVIEW OF SOLAR DRYING TECHNOLOGY FOR AGRICULTURAL CROPS

R K Aggarwal
Department of Environmental Science
YSP University of Horticulture & Forestry, Nauni-Solan (HP) India

Abstract
Increasing population, climate change and post harvest losses lead to scarcity of food particularly in developing countries. Improvement in storage facilities and drying of crops are utmost need of hour. Various types of solar driers have been developed worldwide, but could not be adopted by the small farmers due to various reasons. In the present study, development of direct, indirect and mixed modes solar driers have been discussed. The review revealed that most of the solar driers have been developed only for particular crops, due to which the solar drier could not be used throughout the year making these driers costly and out of the reach of small farmers. None of the solar driers so far developed has temperature regulator system due to which the solar drier could not be used for drying of various fruits and vegetables.
Key words: Solar drier, post harvest losses, thermal storage, temperature controller

1.0 Introduction

The world population stands as 7.5 billion according to population reference bureau August, 2017. It will be difficult to provide food for increasing population despite of fact that scientists are working hard to increase agriculture production in present scenario of climate change whereas there are post harvest losses [1,2]) for example the maximum post-harvest losses for tomatoes are 45.3% followed for mangos 43.5% and lowest for coffee (15.7%) [3]. Poor storage infrastructure, processing and marketing in many countries of the Asia-Pacific region results to average wastes between 10 and 40 % [1]. As per estimation 20-30% of food grains and 30-50% of vegetables & fruits are lost after post harvesting. The food problem can be met out only either increasing the food production or reducing the post harvest losses. In order to reduce the post harvest losses, solar drying of crop is traditional and effective method as solar radiation is locally, freely available as well as, reduces transportation cost. Although, the traditional drying in open is of low cost and it does not involve technology, but, it has many drawbacks such as, contamination of the product due to dirt and insects, effect of birds and mice, spoilage due to erratic weather, uncontrolled temperature, damage by wild animals, labour intensive and low market rates [4,5,6]. Also, loss of vitamins, nutrients and unacceptable colour changes due to direct exposure to ultraviolet rays, it takes long time to dry [7]. However, drying in solar drier has many advantages such as significant enhancement in quality of the dried product, reduction in drying time, improves drying hygiene, no effect of insects, protection from erratic weather & wild animals, higher market rates of dried products and reduces CO_2 emissions [5]. The solar dryers of variegated types can be made locally and of any size, design and capacity [8,9,10]. The solar drier helps to overcome the problem of open sun drying, which consists of a collector, a drying chamber and an exhaust fan or chimney [11]. The main purpose of drying is to improve the shelf life of dried products [12,13,14,15,16]. The main design parameters of solar drier are, solar radiation, temperature, relative humidity of air, moisture content to be removed out of the crop and quantity of crop to be dried. Several types of indirect solar dryers developed have resulted higher quality products in terms of color, texture or taste, reduced drying times and greater efficiency compared to the traditional open sun drying [17,18,19,20,21,22,23,24,25].

There are two types of solar driers viz. forced and natural convection solar drier. The forced convection solar drier is considered to be efficient, reliable, faster and can dry large quantity of crop products as compared to natural convection solar drier [26,27]. The forced convection drier uses external device for air circulation between air heater and drying chamber and can be of bin type, tunnel type, belt type, column type, or rotary type. The forced circulation drier sometime has thermal storage unit, heat recovery wheel, or auxiliary heating arrangement. Efficient and low cost solar dryer for drying of agriculture products have been developed by [28,29,30,31,32,33]. Avesahemad [34] has developed forced convection dryer using thermal energy storage for grapes in Miraj area.

In the present study, various drying technologies have been discussed to find out suitable option in terms of solar drier with blower, thermal storage system and temperature regulator or controller so that, various crops could be dried throughout the year.

2.0 Initial work done in India

A solar drier developed by NPL, New Delhi in 1954 was used for the drying of coal fines. Later on, in 1955 concentrators were introduced for producing jaggery from sugar cane and palm juice. The concentrators were further used by Khadi & Village Industries Commission (KVIC), Ahmedabad in 1968 for dehydration of neera palm to convert into palmgur (jaggery). Forest Research Institute (FRI), Dehradun, has developed solar timber kiln in 1972 for seasoning of timber. Central Arid Zone Research Institute (CAZRI), Jodhpur has also developed a solar dryer in 1972 for drying fruits and vegetables. In 1978, Annamalai University, Chennai has developed solar dryer of 1000 kg capacity for the drying of paddy. National Industrial Development Corporation (NIDC) of India, has developed solar dryer in 1980 for drying of grain.

3.0 Development of different types of solar driers

3.1 Direct solar driers:

The direct solar dryer (Fig. 1) is made up of wood, iron sheet or even mud, which is painted black from inside for maximizing solar gain, covered with 4mm thick glass to receive solar radiations. The solar radiations are directly absorbed by the product kept on trays placed inside the box. The natural circulation type of solar dryers are of low cost, easy to construct, install and operate. The holes or vents are provided at the bottom on the south side (inlet) and top of north side (outlet) of dryer for better air circulation. The sides and bottom of drier are insulated to reduce heat loss. Sodha et. al. [35] have developed a solar cabinet dryer for the drying of mango flesh in which the moisture content was reduced from 95% to 13% in 12 sunshine hours. Ezekwe [36] has provided wooden plenum in solar dryer to introduce the inlet air into the dryer and a chimney made up of plywood to enhance the air circulation. Diemuodeke et al. [37] have developed a direct solar dryer for drying tapioca in which the moisture content was reduced from 79% to 10% which has minimum collector area of 1.08 m^2. Amin et al. [38] and Akoy et al. [39] have developed a cabinet solar dryer for the drying of mango slices. Singh et al. [40] have developed a multi-shelf natural convection solar dryer with intermediate heating. Yobouet et al. [41] have designed a natural convection direct type solar dryer for the drying of cassava, bananas and mango, in which moisture content of cassava and banana was reduced from 80% to 13% in 19 and 22 hours, respectively. Ben et al. [42] and Vidya et al [43] have developed direct solar dryer for drying of various agricultural crops.

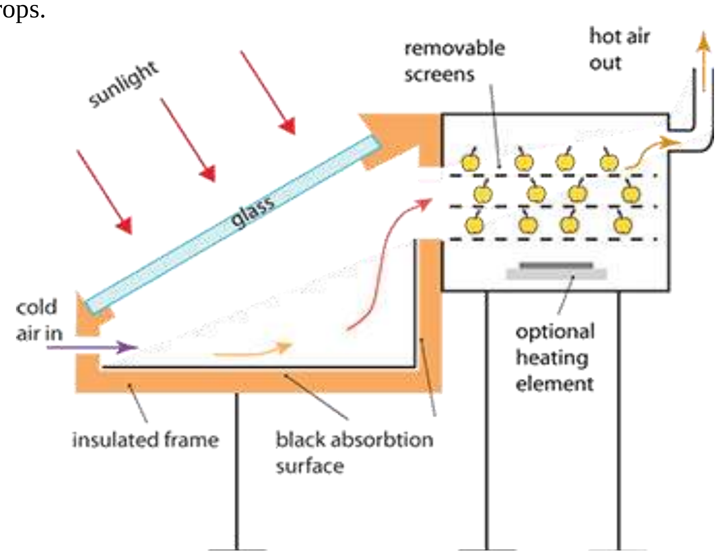


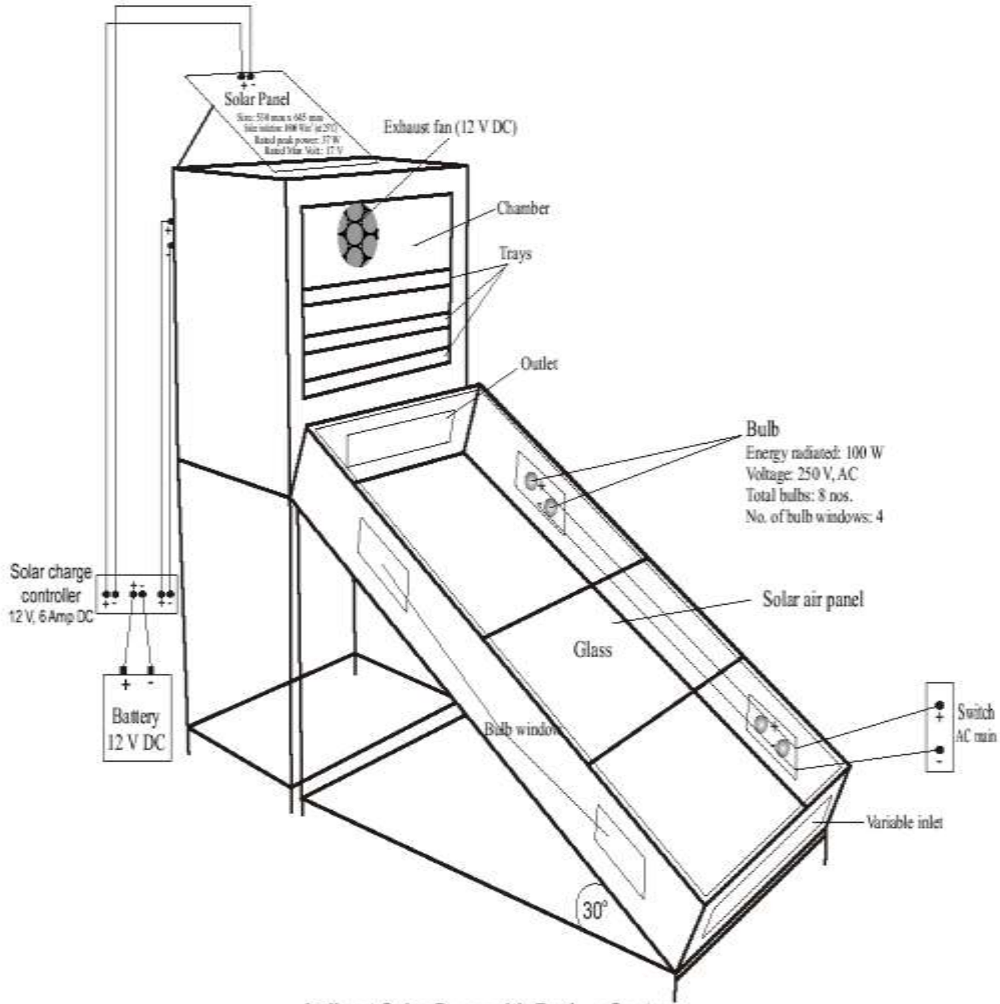
Fig 1. Direct solar drier

3.2 Indirect solar drier

Indirect solar dryer (Fig. 2) has two components, solar collector and drying chamber. The solar collector is just like direct drier without trays. The trays are provided in drying chamber. The air is heated in solar air heaters and then blown to the drying chamber. In indirect solar dryer, the change of temperature, humidity and drying rate is possible to some extent [44]. Ezeike [45] has used dehumidification chamber containing silica gel to continue drying during low insolation for drying of paddy and yam slice in which, triple pass flat plate air heater has two absorber plates. Pangavhane et. al. [46] have developed indirect solar dryer for the drying of grapes and found 43% reduction in drying time. Oosthuizen [47] has introduced a small fan in indirect passive solar drier powered by solar photovoltaic system. Li Z et. al. [48] have used solar drier with 6m^2 collector area and three solar powered fans for the drying of salted preserved greengages. Hossain et al. [49] have also introduced reflector made of aluminium to increase the efficiency of solar collector by 10% in solar dryer of 20 kg capacity for drying of tomato which is capable of working throughout the year in Potsdam-Bornim, Germany. Șevik [50] has used double pass solar air heater with fins for the drying of carrot which extended the surface area of the absorber plate to increase its efficiency, due to increase of heat transfer coefficient and output temperature of air from collector. Abdullah [51] has constructed indirect solar drier which has AC hertz converter for the drying of mulberry. Kouhila [52] has analysed the effect of air temperature and airflow rate on the drying kinetics of Gelidium Sesquipedale in indirect solar dryer and found that the air temperature was main factor influencing the drying kinetics. Amedorme [53] has also developed indirect direct solar drier for drying of moringa leaves. An indirect solar drier was developed for food preservation by Vaishnavi [54]. An indirect type solar dryer was developed in NIT Warangal to dry the banana slices [55]. An indirect solar drier of 25 kg capacity attached with solar module was developed for drying of fruits and vegetables [56].

3.3 Mixed or hybrid type solar dryer

The mixed- mode solar driers were developed by [57] for the drying of ginger, [58] for the drying of rough rice, [59] for food preservation, [60] for the drying of cassava and [61] for the drying of potato slices. Zomorodian et al. [62] have developed a semi-continuous active mixed-mode type drying system which consists of six solar air heaters in Iran. Drying system has been given timer to activate rotary discharge valve and has electric heating channel. Chandrakumar et al [63] have developed a mixed-mode solar dryer using smooth and rough plate solar collector, artificial rib roughness below absorber plate that resulted in high heat transfer coefficient. Smitabhindu et al. [33] have used the roof of the building for the installation of solar air heater, which consists of polyurethane back insulator and glass cover of 26m^2 area and drying chamber having 15 trays has been kept inside the building in Bangkok, Thailand for the drying of bananas. The hot air was fed to drying chamber using electrical blower and LPG burner used for additional heating during low insolation. Kalbande et al. [64] have developed a solar-biomass hybrid dryer in which a biomass combustor retrofitted to natural convection solar tunnel dryer and Prosopis juliflora as fuel in biomass combustor cum hot air generator. Gunkesaran et al [65] have developed hybrid solar dryer, a combination of biogas & solar system which increased cost due to separate biogas plant.



Indirect Solar Dryer with Backup System

3.4 Development of typical solar drier

Doe et al. [66] later designed the widely reported poly-ethylene tent dryer consisting of a ridged bamboo framework clad covered with a polythene sheet. Sachithananthan et al. [67] reported a greenhouse of plastic sheet cladding over a semi-cylindrical metal frame. Fleming et al. [68] reported a typical greenhouse type solar dryer with a transparent semi-cylindrical chamber and a cylindrical solar chimney. Rathore et al. [69] have analyzed a modified design of hemi-cylindrical solar tunnel dryer for drying of grapes. Afriyie et al. [70] have reported chimney ventilated solar crop dryer. Juamily et al. [71] constructed two identical air solar collectors having V-groove absorption plates of two air passes and a single glass cover for drying fruits and vegetables in Iraq. Hawlader [72] studied the V-groove, fins and flat-plate collectors for crop drying applications. Umayal et al [73] have developed a forced convection solar drier with evacuated tube collector at Thanjavur, Tamilnadu, India for drying of aonla fruit. Mehdi et al [74] showed that mixed mode natural convection solar drier was found to be best for drying Cuminum. The efficiency of evacuated tube collector has been found to be very high as compared to the efficiency of flat plate collectors [75,76]. A rotary column cylindrical dryer with solar air heater for the drying of apricot was developed by Sarsilmaz et al.[77]. Maiti et al. [78] have developed the indirect solar dryer having N-S reflector in a V-through alignment and observed 17.8% increase in efficiency of solar air heater which took 5hours for preparing Indian wafer Papad. Rajagopal et al [79] have used evacuated tube collector in indirect type forced convection solar dryer for copra at Coimbatore district, Tamilnadu, India. A greenhouse type solar drier of 1000 kg capacity was developed for the drying of chilgoza cones to extract seeds in snow bound tribal areas of India [80].

3.6 Solar drier with thermal storage system

Bolaji [81] investigated an indirect solar dryer using a box type absorber collector with opaque crop bin, and a chimney to provide thermal storage. Ehiem et al. [82] designed and developed an industrial fruit and vegetable dryer with thermal storage system. Bolaji et al.[83] utilized the benefits of using a rotary wind ventilator for forced convection solar dryer and foam was used for insulation. An absorber mesh screen is placed midway between the glass cover and the black absorber plate for effective air heating. Bala et al [84] have dried pineapple using solar tunnel drier at Bangladesh Agricultural University, Mymensingh, Bangladesh. Chandrakumar et al [85] have developed a forced convection mixed-mode solar dryer using smooth and rough plate solar collectors. Sahu et al [86] used broken transverse ribs on absorber plate of a solar air heater. Saravanakumar et al [87] have developed a solar collector integrated with a FP-SAH with heat storage unit and revealed that a mixture of gravels with iron scrap found to be better storage materials. Chabane et al. [88] investigated thermal performance of a single pass solar air heater which has fins to increase the heat exchange. A solar vegetable dryer incorporated with a heat storage unit was developed by Gutti et al [89]. Ayyappan et al [90] have integrated a natural convection solar tunnel dryer with sensible heat storage material (sand) for copra drying. Jain [91] presented a solar crop dryer having reversed absorber plate type collector and thermal storage with natural flow. Tiwari et al. [92] have introduced two storage systems, one is crop dryer cum water heater and second crop dryer rock bed storage system. Chauhan et al. [93] studied the drying characteristics of coriander with rock bed storage unit. Mohanraj et al [94] developed an indirect forced convection solar drier integrated with heat storage material for copra drying. Kamble et al. [95] studied drying of chilli using solar cabinet dryer coupled with gravel bed heat storage system. A solar air heater with long term heat storage system using Granular carbon was studied by Saxena et al. [96]. Farid et al. [97] constructed a latent heat storage module consisting of 45 cylindrical capsules fixed made of copper tubes. Fatah [98] developed a solar air heater with copper tubes filled with thermal energy storage material. Fath [99] has designed solar air heater with corrugated set of tubes filled with a phase change material (paraffin wax) as a thermal energy storage material. Enibe [100] has used paraffin as PCM in heat storage system. Takakura and Nishina [101] tested polyethylene glycol and $CaCl_2.6H_2O$ as PCMs in greenhouse heating. Benli and Durmus [102] have used $CaCl_2.6H_2O$ as phase change material for space heating of greenhouse. The hot air delivered by 10 pieced solar air collectors passed through the PCM to charge the storage unit. Vlachos et al [103] have developed a tray dryer with a heat storage cabinet and a solar chimney. Bhardwaj, et al [104] have investigated an indirect solar dryer integrated with phase change material for drying Valeriana Jatamansi. Singh et al. [105] have used thermocole for insulation, whereas, Mursalim et al. [106] used saw dust for insulation. El-Sebaii et al. [107] have provided thermal storage system in indirect solar dryer for the drying of fruits and vegetables. Madhlopa and Ngwalo [108] have developed biomass powered indirect solar dryer having thermal storage system (rock pile) at Malawai for drying of crops. Shanmugam and Natarajan [109] have developed forced convection and desiccant-integrated solar dryer in which desiccant unit can hold 75 kg of $CaCl_2$ based solid desiccant which contains 60% Bentonite, 10% Calcium Chloride, 20% Vermiculite, and 10% Cement. Shanmugam and Natarajan [110] have again developed same solar drier with reflective mirror on desiccant unit and found reduction in drying chamber by 20%. Mohanraj and Chandrashekhar [111] have developed an indirect forced convection drier with heat storage system (gravel) for chilli drying in Pollachi, India. Mehta et al. [112] have developed an indirect solar drier with thermal storage for drying ginger in Udaipur, India.

4.0 Conclusions

The review on solar driers revealed that, solar drier has blower to provide dry air at the inlet of solar drier, temperature controller to regulate temperature during all weather conditions and low cost thermal storage system to retain heat during day time and release after sunset, is not available worldwide. It is the need of the hour that the solar drier with thermal storage system and temperature regulator should be integrated so that drier could be used for various crops throughout the year and this will also be helpful in reducing the post harvest losses so that food can be provided to poorest people. This will also improve the quality of packed food and increase the income of small farmers.

Acknowledgement: The facilities provided by Department of Environmental Science, YSP University of Horticulture & Forestry, Nauni-Solan (HP) India are highly acknowledged.

5.0 References

[1]. Rosa Rolle S. Postharvest management of fruit and vegetables in the Asia-Pacific region. Asian Productivity Organization, Tokyo, Japan (2006.

[2]. Abdullahi Y, Momoh M, Garba MM, Musa M. Design and construction of an adjustable and collapsible natural convection solar food dryer. Int J Comput Eng Res 2013; 3(6):1–8.

[3]. Mohammed Kasso and Afework Bekele. Post-harvest loss and quality deterioration of horticultural crops in Dire Dawa Region, Ethiopia, Journal of the Saudi Society of Agricultural Sciences 2016:1-9.

[4]. Hii C L, Jangam S V, Ong S P, Mujumdar A S (eds). Solar drying: Fundamentals, applications and innovations. TPR Group Publication, Singapore 2012.

[5]. Umogbai VI, Iorter HA. Design, construction and performance evaluation of a passive solar dryer for maize cobs. Afr J Food Sci Technol 2013; 4(5):110–115.

[6]. M.G. Campos. Good practices in grain Storage. 9th International Working Conference on Stored product protection, France 2007.

[7]. A report on food processing in Bihar the road ahead. IL&FS analysis; RAU and state government publications: 28-31.

[8]. Mujumdar AS, Law CL. Drying technology: trends and applications in postharvest processing. Food and Bioprocess Technol. 2010; 3(6):843–852.

[9]. Fudholi A, Sopian K, Ruslan M H, Alghoul MA, Sulaiman MY. Review of solar dryers for agricultural and marine products. Renewable and Sustainable Energy Reviews 2010; 14:1–30.

[10]. Ezekoye B. A. and Enebe O. M. Development and performance evaluation of modified integrated passive solar grain dryer. The Pacific Journal of Science and Technology 2006; 7:185-190.

[11]. Madhlopa A, Jones SA, Kalenga Saka JD. A solar air heater with composite absorber systems for food dehydration. J Renewable Energy 2002; 27:27-30.

[12]. Esper, A. and Muhlbauer, W. Solar tunnel dryer. Plant Res. And development 1996; 44(4):16- 64.

[13]. M.A. Aravindh and A. Sreekumar. Solar Drying—A Sustainable Way of Food Processing Energy Sustainability Through Green Energy, Green Energy and Technology 2015:27-46.

[14]. Amruta R. Eswara and M. Ramakrishnarao. Solar energy in food processing—a critical appraisal, J Food Sci Technol. 2013; 50(2): 209–227.

[15]. Om Prakash and Anil Kumar. Historical Review and Recent Trends in Solar Drying Systems. International Journal of Green Energy 2013; 10(7):690-738.

[16]. Sumit S. Dharmarao, M.S. Pawar. Development of Solar Dryer for post harvest treatment of Cereals, NCETSTM,MREC 2014.

[17]. Imre, L. Solar drying. In: Handbook of Industrial Drying, Mujumdar, A. S. (Ed.). Marcel Dekker, Inc., New York, 1995: 373-452.

[18]. Das S K and Kumar Y. Design and performance of solar dryer with vertical collector chimney suitable for rural application, Energy Convers. Mgmt, 1989; 29(2): 129-135.

[19]. Tsamparlis M. Solar drying for rural applications. Drying Technology1990; 8(2): 261-285.

[20]. Imre, L.; Fabri, L.; Gemes, L.; Hecker, G. Solar Assisted Drier for Seeds. Drying Technology 1990; 8(2):343–349.

[21]. Tiris, C.; Ozbalta, N.; Tiris, M.; Dincer, I. Experimental Testing of a New Solar Dryer. International Journal of Energy Research 1994; 18:483–491.

[22]. Pratoto, A.; Daguenet, M.; Zeghmati, B. Sizing Solar-Assisted Natural Rubber Dryers. Solar Energy 1997; 61(14):287–291.

[23]. Esper, A. and Muhlbauer, W. Solar drying an effective means of food preservation. Renewable Energy, 1998; 5(1-4): 95-100.

[24]. Arinze EA, Sokhansanj S, Schoenau GJ, Trauttmans Dorff FG. Experimental evaluation, simulation and optimization of a commercial heated-air batch hay drier. J Agric Eng Res 1996; 63:301–314.

[25]. Bala, B.K.; Mondal, M.R.A. Experimental Investigation on Solar Drying of Fish Using Solar Tunnel Dryer. Drying Technology 2001; 19(2):427–436.

[26]. Mohanraj M, Chandrasekar P. Performance of a forced convection solar drier integrated with gravel as heat storage material for chilly drying. J Eng Sci Technol 2009; 4(3):305–314.
[27]. Banout J, Ehl P. Using a double-pass solar drier for drying of bamboo shoots. J Agric Rural Dev Trop Subtrop 2010; 111(2):119–127.
[28]. Bennamoun L, Belhamri A: Design and simulation of a solar dryer for agriculture products. J Food Eng 2003; 59: 259–266.
[29]. El-Shiatry MA, Muller J, Muhlbauer W. Drying fruits and vegetables with solar energy in Egypt. AMA 2002; 4: 61–64.
[30]. Akoy E, Ismail M, El-Fadil AA. Design and construction of a solar dryer for mango slices. In: Proceedings of International Research on Food Security, Natural Resource Management and Rural Development-Tropentag. Bonn, Germany: University of Bonn 2006.
[31]. Sarsavadia PN. Development of a solar-assisted dryer and evaluation of energy requirement for the drying of onion. Renew. Energy 2007; 32: 2529–2547.
[32]. Ramana Murthy MV. A review of new technologies, models and experimental investigations of solar driers. Renewable and Sustainable Energy Reviews 2009;13(4):835–844.
[33]. Smitabhindu R, Janjai S, Chankong V. Optimization of a solar-assisted drying system for drying bananas. Renew. Energy 2008; 33: 1523–1531.
[34]. Avesahmad Sayyadnaimutulla Husainy and P.R. Kulkarni. Performance analysis of solar grape dryer with thermal storage by PCM, IRJET 2015; 2(7):54-60.
[35]. Sodha MS, Dang A, Bansal PK, Sharma SB. An analytical and experimental study of open sun drying and a cabinet type drier. Energy Conversion Management 1985; 25(3):263–71.
[36]. Ezekwe CI. Crop drying with solar air heaters in tropical Nigeria. ISES, Solar World Forum, Brighton, UK. Oxford: Pergamon Press, 1981:997– 1005.
[37]. Diemuodeke E. Ogheneruona, Momoh O.L. Yusuf. Design and Fabrication of a Direct Natural Convection Solar Dryer for Tapioca. Leonardo Electronic Journal of Practices and Technologies 2011;18: 95-104.
[38]. EL- Amin Omda Mohamed Akoy, Mohamed Ayoub Ismail, El-Fadil Adam Ahmed and W. Luecke. Design and Construction of a Solar Dryer for Mango Slices. Conference: Tropentag 2006 Prosperity & poverty in a globalized world: Challenges for Agricultural Research. Bonn, Germany, October 11-13, 2006.
[39]. Akoy EOM. Experimental characterization and modeling of thin-layer drying of mango slices. International food research journal 2014; 21(5):1911-1917.
[40]. Singh S, Singh PP, Dhaliwal SS. Multi-shelf portable solar dryer. Renewable Energy 2004; 29:753–65.
[41]. P. Gbaha, H. Yobouet Andoh, J. Kouassi Saraka, B. Kaménan Koua and S. Touré. Experimental investigation of a solar dryer with natural convective heat flow. Renewable Energy 2007; 32(11): 1817-1829.
[42]. Eke, Ben Akachukwu. Development of Small Scale Direct Mode Natural Convection Solar Dryer for Tomato, Okra and Carrot. International Journal of Engineering and Technology 2013; 3(2): 199-204.
[43]. R. Vidya Sagar Raju, R. Meenakshi Reddy, E. Siva Reddy. Design and Fabrication of Efficient Solar Dryer Int. Journal of Engineering Research and Applications 2013; 3(6): 1445-1458.
[44]. Vipin Shrivastava, Anil Kumar, Prashant Baredar. Developments in Indirect Solar Dryer: A Review. International Journal of wind and Renewable Energy 2014; 3(4):67-74.
[45]. G.O.I. Ezeike. Development and performance of a triple-pass solar collector and dryer system. Energy in Agric 1986; 5:1–20.
[46]. D.R. Pangavhane, R.L. Sawhney, P.N. Sarsavadia. Design, development and performance testing of a new natural convection solar dryer. Energy 2002; 27:579–590.
[47]. P.H. Oosthuizen. An experimental study of simulated indirect solar rice dryer fitted with a small fan. J Eng Intl Dev 1996; 3:22-29.
[48]. Z. Li, H. Zhong, R. Tang, T. Liu, W. Gao, Y Zhang. Experimental investigation on solar drying of salted greengages. Renewable energy 2006; 31:837-847.
[49]. M. A. Hossain and K. Gotischalk. Development and evaluation of an indirect solar drier for tomato, The Proceedings of the 5th Asia-Pacific Drying Conference 2007: 709-717.
[50]. S. Șevik. Design, experimental investigation and analysis of a solar drying system. Energy Convers Manage 2013;68: 227–234.
[51]. A. Akbulut, A. Durmus. Energy and exergy analyses of thin layer drying of mulberry in a forced solar dryer. Energy 2010; 35: 1754–1763.
[52]. L. Ait Mohamed, C.S. Ethmane Kane, M. Kouhila, A. Jamali, M. Mahrouz, N. Kechaou. Thin layer modelling of Gelidium sesquipedale solar drying process, Energy Convers Manage 2008; 49: 940–946.
[53]. S.K. Amedorme, J. Apodi, and K. Agbezudor. Design and Construction of Forced Convection Indirect Solar Dryer for Drying Moringa Leaves. Scholars Journal of Engineering and Technology (SJET) Sch. J. Eng. Tech. 2013; 1(3):91-97.

[54]. Vaishnavi Bharat Chougule, Abijit Ashok Bhairappa, Rahul Dattatreya Hanchate, Ganesh S. Kasegaonkar and Potdar V.V. Design and fabrication of a solar drying system for food preservation. National Conference on Innovative Trends in Engineering & Technology – 2016 11th & 12th March 2016.
[55]. Abhay Lingayat, Chandramohan V.P., V.R.K. Raju Design. Development and Performance of Indirect Type Solar Dryer for Banana Drying. Energy Procedia 2017; 109: 409 – 416.
[56]. Aggarwal Rajeev Kumar, Sharma Madan Mohan and Sharma Ashwani Kumar Indirect. Solar Drier with Electric Back Up System for Quality Hill Products. *Natural Resources* 2010; 1: 88-94.
[57]. Manoj P. Undure, Vaibhav B. Patil, Digvijay D. Shinde, Avesahemad S.N. Husainy. International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE) 2017; 2(2): 62-66.
[58]. Basunia, M. A.; Abe, T.. AMA, Agricultural Mechanization in Asia, Africa and Latin America 2009; 40(3):23-29.
[59]. Bukola O. Balaji and Ayoola P. Olalusi. Performance evaluation of a mixed mode solar dryer. AU J.T. 2008; 11(4): 225-231.
[60]. F.K. Forson and F.O. Akuffo. Design of mixed mode natural convection solar crop dryer: Application of principles and rules of thumb.Renewable Energy 2007; 32:2306-2319.
[61]. Tripathy PP, Kumar S. Modeling of heat transfer and energy analysis of potato slices and cylinders during solar drying. Applied Thermal Eng. 2009; 29: 884–891.
[62]. A. Zomorodian, D. Zare, H. Ghasemkhani. Optimization and evaluation of a semi-continuous solar dryer for cereals (rice etc). Desalinization 2007; 209:129–135.
[63]. Chandrakumar B Pardhi and Jiwanlal L Bhagoria. Development and performance evaluation of mixed-mode solar dryer with forced Convection. International Journal of Energy and Environmental Engineering 2013; 4(23):1-8.
[64]. Kalbande, S.R., C.N.Gangde and A.Dhondage. Techno-economic evaluation of solar-biomass hybrid drying system for turmeric (Curcuma longa L.). FIRE Journal of Science and Technology 2013; 2: 97-107.
[65]. K gunkesaran, sannugam & P. suresh. Modeling & analytical Experimental study of hybrid solar dryer integrated with biomass dryer for drying IPCSIT 2012; vol.28 IACSIT, press, Singapore.
[66]. Doe, P. E., Ahmed, M., Muslemuddin, M., Sachithananthan, K. A. A polythene tent dryer for improved sun drying of fish. Food Tech Aust 1977; 29: 437-441.
[67]. Sachithananthan, K., Trim D., Speirs C I. A solar dome dryer for drying of fish, FAO Fisheries Paper, Rome, Italy. RAB/81/002/INT/L8. 1983.
[68]. Fleming, P. D., Norton. B., Ekechukwu, O. V., Onyegegbu, S. O., Probert, SD, A large-scale facility for experimental studies of natural-circulation solar- energy tropical crop dryers. In: Proc Int Drying Symp (Drying '86). Cambridge, Mass, U.S.A., Hemisphere Pub Coy Washington 1986: 685-693.
[69]. Rathore, N.S. and Panwar, N L. Experimental studies on hemi cylindrical walk-in type solar tunnel dryer for grape drying. Applied Energy 2010; 87: 2764-2767.
[70]. Afriyie, J. K., Rajakaruna, H., Nazha, M. A. A., Forson, FK X. Simulation and optimization of the ventilation in a chimney-dependent solar crop dryer, Solar Energy 2010; 85: 1560-1573.
[71]. Al-Juamily KEJ, Khalifa AJN, Yassen T. A. Testing of performance of fruit and vegetable solar drying system in Iraq. Desalination 2005;209:163–170.
[72]. Karim MA, Hawlader MNA. Drying characteristics of banana: theoretical modelling and experimental validation. J. Food Eng. 2005; 70: 35–45.
[73]. Umayal AR, Neelamegam P and Subramaniam CV. Performance of evacuated tube collector solar dryer with and without heat storage. Iranica Journal of Energy & Environment 2013; 4(4):336-342.
[74]. Mehdi Moradi and Ali Zomorodian. Thin layer solar drying of Cuminum Cyminum Grains by means of solar cabinet dryer. American-Eurasian J. Agric. & Environ. Sci. 2009; 5(3): 409-413.
[75]. Chr. Lamnatou, E. Papanicolaou, V. Belessiotis and N. Kyriakis. Experimental investigation and thermodynamic performance analysis of a solar dryer using an evacuated-tube air collector. Applied Energy 2012; 94; 232-243.
[76]. Avadhesh Yadav and V.K. Bajpai. An experimental Study on evacuated tube solar collector for heating air in India. World Academy of Science, Engineering and Technology 2011; 79: 81-86.
[77]. Sarsilmaz C, Yildiz C, Pehlivan D. Drying of apricots in a rotary column cylindrical dryer (RCCD) supported with solar energy. Renewable Energy 2000; 21:117– 127.
[78]. S. Maiti, P. Patel, K. Vyas, K. Eswaran, P.K. Ghosh. Performance evaluation of a small scale indirect solar dryer with static reflectors during non-summer months in the Saurashtra region of western India. Solar Energy 2011; 85: 2686-2696.
[79]. T.Rajagopal, S.Sivakumar, R.Manivel. Development of Solar Dryer Incorporated With Evacuated Tube Collector, International Journal of Innovative Research in Science, Engineering and Technology 2014; 3: 2655-2658.

[80]. Aggarwal Rajeev).Design, fabrication, installation and field evaluation of 1000kg capacity solar drier for chilgoza seed extraction. *RERIC International Energy Journal* 1998; 20(2): 67-76.

[81]. Bolaji B.O. Development and performance evaluation of box- type absorber solar air collector for crop drying. Journal of Food Technology 2005; 3(4):515– 600.
[82]. Ehiem J.C., Irtwange S.V and Obetta S.E. Design and Development of an Industrial Fruit and Vegetable Dryer. Research Journal of Applied Sciences, Engineering and Technology 2009; 1(2):44-53.
[83]. Bolaji B.O, Olayanjub T.M.A and Falade T.O. Performance Evaluation of a Solar Wind-Ventilated Cabinet Dryer. Western Indian Journal of Engineering 2011; 33(1/2):12-18.
[84]. Bala, BK, Mondol, MRA, Biswas, BK, Das Choudhury, BL, Janjai, S. Solar drying of pineapple using solar tunnel drier. Renew Energy 2003; 28: 183-190.
[85]. Chandrakumar B Pardhi and Jiwanlal L Bhagoria, Development and performance evaluation of mixed-mode solar dryer with forced convection. International Journal of Energy and Environmental Engineering 2013; 2(23):1-8.
[86]. Sahu, M.M. and J.L. Bhagoria, Augmentation of heat transfer coefficient by using 90 broken transverse ribs on absorber plate of solar air heater. Renewable Energy 2005; 30:2057–2063.
[87]. Saravanakumar, P.T. and K. Mayilsamy. Forced convection flat plate solar air heaters with and without thermal storage. Journal of Scientific and Industrial Research 2010; 69(12): 966–968.
[88]. Chabane Foued, Noureddine Moummi and Said Benramache. Experimental analysis on thermal performance of a solar air collector with longitudinal fins in a region of Biskra, Algeria. Journal of Power Technologies 2014; 93(1):52– 58.
[89]. Gutti B., Kiman S. and Murtala A. M. Solar Dryer - An Effective Tool for Agricultural Products Preservation. Journal of Applied Technology in Environmental Sanitation 2012; 2(1): 31-38.
[90]. Ayyappan S and Mayilsamy K. Solar tunnel drier with thermal storage for drying of Copra. Proceedings of the 37th National & 4th International Conference on Fluid Mechanics and Fluid Power, IIT Madras, Chennai, India ,2010.
[91]. Jain Dilip, Modeling the Performance of the Reversal Absorber with Packed Bed Thermal Storage Natural Convection Solar Crop Dryer. Journal of Food Engineering 2006; 78:637-647.
[92]. Tiwari, G.N., P.S. Bhatia, A.K. Singh and R.F., Sutar. Design parameters of a shallow bed solar crop dryer with reflector. Energy Conversion and Management 1994; 35(6):542–635.
[93]. Chauhan, P.M., S.C. Choudhury and H.P. Garg. Comparative performance of coriander dryer coupled to solar air heater and solar air-heater-cum-rock bed storage. Applied Thermal Eng 1996; 16:475–486.
[94]. Mohanraj, M. and P.Chandrasekar. Drying of copra in forced convection solar drier. Biosystem Engineering 2008; 99:604–607.
[95]. Kamble, A. K., I. L. Pardeshi., P. L. Singh and G. S. Ade. Drying of chilli using solar cabinet dryer coupled with gravel bed heat storage system. Journal of Food Research and Technology 2013; 1(2): 87-94.
[96]. Saxena, A., N. Agarwal and G. 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.
[97]. Farid, M.M. and R.M. Husian. An electrical storage heater using the phase change method of heat storage. Energy Conversion and Management 1990; 30(3): 219–230.
[98]. Fatah,HES. Thermal performance of a simple design solar air heater with built-in thermal energy storage system. Energy Conversion and Management 1994; 36:989–999.
[99]. Fath,H.E. Thermal performance of simple design solar air heater with built- in thermal energy storage system. Energy Conversion and Management 1995; 36:989–97.
[100]. Enibe,S.O. Performance of a natural circulation solar air heating system with phase change material energy storage. Renewable Energy 2002; 27:69–86.
[101]. Takakura T, Nishina H. A solar greenhouse with phase change energy storage and a microcomputer control system. Acta Hortic 1981;115:583–90 (Energy in Protected Cultivation).
[102]. Benli H and A Durmus, Performance analysis of a latent heat storage system with phase change material for new designed solar collector in greenhouse heatings. Solar Energy 2009; 83: 2109-2119.

[103]. N. A. Vlachos, T. D. Karapantsios,A. I. Balouktsis,3 and D. Chassapis. Design and testing of a new solar dryer. Drying Technology 2002; 20(5): 1239–1267.

[104]. A.K. Bhardwaj, Ranchan Chauhan, Raj Kumar, Muneesh Sethi, Adit Rana. Experimental investigation of an indirect solar dryer integrated with phase change material for drying valeriana jatamansi (medicinal herb). Case Studies in Thermal Engineering 2017; 10:302-314.

[105]. Singh P P, Singh S, Dhaliwal S. S, Multi-shelf domestic solar dryer. Energy Conversion & Management 2006; 47:1799– 815.

[106]. Mursalim, Supratomo, Dewi Y S, Drying of cashew nut in shell using solar dryer. Science & Technology 2002; 3(2):25– 33.

[107]. A.A. El-Sebaii, S. Aboul-Enein, M.R.I. Ramadan, H.G. El-Gohary. Experimental investigation of an indirect type natural convection solar dryer. Energy Convers Manage 2002; 43: 2251–2266.

[108]. A. Madhlopa, G. Ngwalo. Solar dryer with thermal storage and biomass-backup heater. Sol Energy 2007; 8: 449–462.

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

[110]. Shanmugam, V. and E. Natarajan. Experimental study of regenerative desiccant integrated solar dryer with and without reflective mirror. Applied Thermal Engineering 2007; 27(8-9): 1543–1551.

[111]. M. Mohanraj, and P. Chandrasekar. Performance of a forced convection solar drier integrated with gavel as heat storage material for chili drying. Journal of Engineering Science and Technology 2009; 4: 305.

[112]. Arpita Mehta and Sudhir Jain. Performance of forced convection type solar dryer with thermal storage for ginger drying. International Journal of Agricultural Engineering 2013; 6(1): 14-19.