

Prospects of Solar Energy Drying Technologies: A Critical Review

M.H. Kabir¹, P.M D'Souza², Md Jafri Ahsan³

P.G. Student, Dept. of Farm Machinery and Power Engineering, VSAET, Sam Higginbottom Institute of Agriculture, Technology and Sciences, (Deemed-to-be-University) Allahabad, U.P, India¹.

Assistant Professor, Dept. of Farm Machinery and Power Engineering, VSAET, Sam Higginbottom Institute of Agriculture, Technology and Sciences, (Deemed-to-be-University) Allahabad, U.P, India².

Research Scholar, Dept. of Soil, Land and Water Engineering, VSAET, Sam Higginbottom Institute of Agriculture, Technology and Sciences, (Deemed-to-be-University) Allahabad, U.P, India³.

ABSTRACT: Drying is very important process useful for agricultural products. Drying is the moisture removing process from the products. Drying reduces the bacterial growth in the products. It is helpful in preserving the products for long time. Solar drying is the oldest method of products drying. The traditional open sun drying utilized widely by rural farmers has inherent limitations: high crop losses ensue from inadequate drying, fungal attacks, insects, birds and rodents encroachment, unexpected down pour of rain and other weathering effects. In such conditions, solar-energy crop dryers appear increasingly to be attractive as commercial propositions. Different solar drying methods are direct solar drying, indirect solar drying, and mixed mode solar drying. The device used for drying process with application of solar energy called the Solar dryer. Solar dryer are also classified with mode of air circulation. A comprehensive review of different drying techniques and air circulation modes reported previously is presented.

KEYWORDS: Solar drying technologies, direct type solar dryers, indirect type solar dryers, mixed mode solar dryers.

I. INTRODUCTION

Due to current trends towards rising cost of fossil fuels and uncertainty regarding future cost and availability, use of solar energy in drying of agricultural products will probably increase and become more economically feasible in the near future. Open sun drying is traditional method to preserve agricultural products in tropical and subtropical countries. Considerable saving can be made with this type of drying since the source of energy is free and sustainable. In many rural locations in Africa and most developing countries, grid-connected electricity and supplies of other non-renewable sources of energy are either unavailable, unreliable or, for many farmers, too expensive. Thus, in such areas, crop-drying systems that employ motorised fans and/or electrical heating are inappropriate. The large initial and running costs of fossil fuel powered dryers present such barriers that small-scale farmers rarely adopt them. The traditional open sun drying utilized widely by rural farmers has inherent limitations: high crop losses ensue from inadequate drying, fungal attacks, insects, birds and rodents encroachment, unexpected down pour of rain and other weathering effects. Many alternative energy sources can be used instead of fossil fuels. The decision of what type of energy source should be used must, in each case, be made on the basis of economic, environmental, and safety considerations. Because of its desirable environmental and safety aspects, solar energy is widely used instead of other alternative energy forms even when the costs involved are slightly higher.

II. METHODS OF SOLAR DRYING TECHNOLOGIES

Drying of fruits and vegetables offers a challenging task due to the different structural characteristics of these products. The removal of water from these products must be accomplished without compromising the physico-chemical

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 10, October 2016

properties and quality of the dried products. To obtain the desired quality products, some fundamental concepts associated with food dehydration such as water activity, sorption isotherms and glass transition temperature, among other concepts need to be understood. A selection of appropriate drying methods and systems must be analyzed based on the entire drying process. For example, there is a need to define the types and characteristics of raw materials to be dried, and the specifications of the finished product. Also, the desired production capacity, shape and particle size distribution, and drying characteristics of the product should also be critically assessed (Vega-Mercado et al. 2001). Several dehydration methods and types of dryers are commercially available for drying a wide range of food products. Solar dryers are classified into several categories, based on certain specific criteria. (Vega-Mercado et al., 2001) divided dehydration technologies into four generations: first generation (i.e kiln, tray, truck tray, rotary flow conveyor and tunnel); second generation (i.e. spray and drum drying); third generation (i.e. freeze-drying and osmotic dehydration); and fourth generation (i.e. Refractance), high vacuum, fluidization, microwaves, and RF). Mujumdar (2008) and Law & Mujumdar (2008) classified dehydration into four categories, namely, drying strategy, drying medium, method of handling of solids, and mode of heat input. Jarayamanan & Das Gupta (2006) suggested three basic types of drying processes for fruits and vegetables such as sun or solar drying, atmospheric and continuous, sub-atmospheric drying, and low- temperature and low-energy drying process.

III. TYPES OF SOLAR DRYING SYSTEM

Regardless of the classifications and categorization of drying technologies, the application of a particular drying technique for fruits and vegetables depends on the type of raw material and its characteristics and intended use of the dried material. In most cases, the acceptance of drying methods and designs is highly dependent on the capacity, efficiency, investment cost, operational drying cost, and impact on the environment.

a) **Direct type dryers:** In direct or natural convection type dryers, the agricultural product is placed in shallow layers in a blackened enclosure with a transparent cover. The product itself directly absorbs the solar radiations. The food product is heated up and the moisture from the product evaporates and goes out by the natural convection/circulation. Ezekoye and Enebe (2006) evaluated a domestic direct mode solar dryer with constructed components mounted on a skeleton and screwed such that the various components are detachable and dismantled for easy movement. Optimum temperature of 67.0°C is achieved with the dryer at no-load test and could dry pepper and groundnuts for a maximum of five and eight days respectively. Ajao and Adedeji (2008) fabricated and tested a motorized direct low temperature crop dryer consisting essentially of wood and double layered transparent glass which serves as a solar collector. Drying rate assessment for maize, yam sliced and okra gave superior drying rate than open sun method. Ikejorfor and Okonkwo (2010) developed an active solar dryer with adjustable airflow rates and heat storage unit with drying chamber made of three detachable perforated metal screens for spreading products and covered with a transparent material to allow direct solar radiation on products. Test evaluation using cassava, yam, sweet potatoes, cocoyam, ginger and turmeric in their chips forms of 3mm thick shows drying period range of 24-29 hours for solar dryer and 42-50 hours with open sun drying. Ojike et al (2011) investigated the influence of open-air sun drying, Green house passive solar dryer, Sun-tracking passive solar dryer and Latitudinal box passive solar dryer systems on the vitamin content of Pawpaw (*Carica papaya*) experimentally. In all cases, open-to- air-dried samples recorded the least concentrations of vitamins with solar dryers recording varying concentrations with latitudinal box dryer having the best result for vitamins retention. Jude et al (2013) fabricated and evaluated a direct absorption solar dryer using local materials. Preliminary investigations under controlled conditions of drying in Obinugwu, Imo State, Nigeria shows drying chamber temperature of 59°C with corresponding ambient temperature of 33°C. Direct solar dryers have small capacity for holding crops, slow drying rate, overheat crops leading to poor quality of dried products, reduced transmissivity of glass due to evaporation and condensation of moisture on glass cover, and low efficiency (part of the solar energy input is used to induce air flow and the product itself acts as an absorber (El-Sebaai and Shalaby, 2012).

b) **Indirect type dryers:** In these dryers the food product is placed in a drying chamber. The air is heated in solar air heaters and then blown through the drying chamber. In some of the designs, dryers receive direct solar radiations and also heated air from solar air heaters. In these dryers manipulation of temperature, humidity and drying rate is possible to some extent. Various designs of indirect solar dryers have been developed and tested with some varying degree of performances. Al- Juamili et al (2007) tested an indirect-mode forced convection dryer system in Baghdad, (Iraq)

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 10, October 2016

consisting of two identical air solar collectors having V-corrugated absorption plates of two air passes with a single glass cover with total collector area of 2.4m and drying chamber dimensions of 1x0.33x2m(width, depth and height). Performance test result using grapes, apricots, and beans reduce the moisture content of apricot from 80 to 13% in 1.5days of drying while the moisture content of grapes was reduced from 80 to 18% in 2.5days of drying. Beans were reduced from 65 to 18% in one day. They concluded that the most effective factor influencing drying rate is the temperature of the air inside the cabinet. Ehiem et al (2009) designed and developed an industrial fruit and vegetable dryer consisting of a drying chamber, blower and heat exchanger unit for reducing vegetable wastage and improving their storage conditions. Using tomatoes of small, medium and large sizes; mean drying capacity of 258.64 kg for tomatoes per batch at an average drying chamber temperature of 50°C and varying air flow rates (18.3 m/s, 18.8 m/s and 19.5 m/s); drying time and drying rate of 0-14 hours and 40 g/hr were achieved respectively with thermal efficiency of 84 %. Lotfalian et al (2010) studied an indirect passive solar dryer for drying Lemon and Orange fruits using iron and aluminum solar collectors experimentally. Test result shows 6% higher rate of moisture evaporation for iron collector than aluminum collector type. Dried produce maintain good colour and scent while the tendency towards buying solar dried lemons and oranges were 5.6 and 4.2 times respectively higher than traditionally dried fruits. In another development, Mu'azu et al (2012) designed, constructed and evaluated a 20kg capacity forced air- convection vegetable dryer consisting of tray dryer, heat exchanger, air blower and combustion chamber. Dried husk, maize cobs, dry plant stalk or peanut shell on farm were burnt in the combustion chamber and the flue gas produce channeled into annular section of double-pipe heat exchanger where it exchanged heat with the flue gas from the combustion chamber. The heated air enters the bottom of the tray dryer and continuously removed moisture from the vegetable arrange on the perforated shelves. Using okra of sliced size 3 and 6mm, and 3mm for tomatoes, there was reduction in drying time as against open sun drying and proximate analysis of solar dried products compared favorably with the literature values. Gutti et al (2012) designed and constructed a natural/forced convection solar vegetable dryer using locally available materials and incorporated a heat storage unit for ensuring drying during night hours. The solar collector absorber plate was made of corrugated aluminium, painted black to improve its absorption and insulated with thick plywood to prevent heat loss. The drying cabinet structural frame was built from a well- seasoned gmelina wood and plywood sheet and outlet vent (chimney) provided towards the upper end at the back of the cabinet to facilitate and control the convection flow of air through the dryer. Forced convection drying system gave higher drying capabilities compared to the natural convection system and the stored useful heat used for about six hours in drying during the night. Andrew et al (2013) developed and studied an indirect natural convection solar dryer with biomass backup burner for drying pepper berries. The essence of the biomass backup burner is to reduce the drying time and prevent molds built up on dried products. The developed solar dryer took 11 hours of daytime solar radiation and 6 hours of nighttime with biomass burning for drying berries and dried products were of high nutritive quality (within the American Seed Trade Association standards). It took 5-7 days for same drying process for sun method and was dependent on the availability of solar radiation. The dryer was found suitable for small-scale rural farmers living far from national grid. Umogbai and Iorter (2013) designed, constructed and evaluated the performance of an indirect passive solar dryer for drying maize cobs experimentally. The drying chamber is a box-like structure made of wood with the top tapering towards a chimney where condensed air could move out. The sides were made of plywood coated with white emulsion paint with an inner drying tray made of wire mesh with collector top made of 4mm thick layer of colorless glass sheet (100 x 70 cm) serving as the cover plate. A 0.5 mm thick (100 x 70 cm) zinc sheet painted black served as the absorber plate. Freshly harvested maize cobs with moisture content 30.3 % were reduced to 13.3 % within 3 days using the solar dryer while it took 6 days for open sun method. The dryer can be made in commercial sizes for rural community to fast track drying operations due to its cheapness.

c) **Mixed Mode Solar Dryers:** Mix mode solar dryer is the combination of direct and indirect type of solar dryer. Product is dry by direct exposure to the sunlight and also by hot air supply on it. Air is heated in a collector and then this hot air is supplied to the drying chamber and drying chamber top is made up of glass cover. Which can directly absorbs solar radiation. In this way drying rate is higher as compared to direct solar drying. Hossain and Bala (2007) tested a forced convection mixed mode type solar tunnel drier for drying red and green chilli consisting of a transparent plastic covered flat-plate collector and a drying tunnel connected in series to supply hot air directly into the drying tunnel with loading capacity of 80 kg of fresh chillies. Moisture content of red chilli was reduced from 2.85 to 0.05

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 10, October 2016

kg/kg (dry basis) in 20 hrs and about 0.06 kg/kg (dry basis) moisture content obtained from initial moisture content of 7.6 kg/kg (dry basis) in 22 hrs for green chilli. Forsona et al (2007) evaluated a developed mixed-mode natural convection solar crop dryer (MNCSCD) for drying cassava with anticipated drying time of 30–36 hrs in Kumasi, Ghana. Fundamental components of the dryer are: air-heater (primary collector-a single pass air-heater with double duct, SPDDSAH) through which the air is heated as it flows over and under the absorber plate that is heated in turn by direct absorption of incident radiation thus providing twice as much surface area for heat transfer to the air compared to either the single-pass air-heater with rear duct or front duct; a drying chamber and a chimney. The drying chamber houses three drying racks, each consisting of two drying beds arranged vertically in line. Test result at full designed load condition of 160kg, ambient temperature of 28.2°C, 72.1% relative humidity and 340.4W/m solar irradiance gave 35.5 hrs and 12.3% for drying duration and efficiency respectively. Bolaji and Olalusi (2008) investigated a mixed-mode solar dryer for food preservation using locally sourced materials. The dryer is made up of solar collector, drying cabinet and drying trays. The heat absorber plate (inner box) is constructed using 2 mm thick aluminum plate, painted black and mounted in an outer box built from well-seasoned woods to withstand termite and atmospheric attacks. The space between the inner box and outer box were filled with foam material of about 40 mm thickness and thermal conductivity of 0.043 W/m to prevent heat loss. The solar collector assembly consisted of airflow channel enclosed by transparent cover (glazing). An absorber mesh screen midway between the glass cover and the absorber back plate provided effective air heating. Single layer 4 mm thick transparent glass sheet of effective surface area 0.8m² was used. The roof and the two opposite side walls of the cabinet were covered with transparent glass sheets of 4 mm thick, which provided additional heating. Drying trays were constructed from double layer of fine chicken wire mesh with fairly open structure to allow drying air to pass through the food items. The dryer was tested using yam chips. Results reveal that the temperatures inside solar collector and drying chamber were much higher than the ambient temperature during most hours of the day-light with temperature rise inside the drying cabinet up to 74% for about three hours immediately after 12.00h (noon). The drying rate and system efficiency were 0.62 kg/h and 57.5% respectively. The rapid drying rate of the system clearly shows its ability to dry food items speedily to safe moisture level and better performance than open sun drying. Bolaji et al (2011) utilized the benefits of using a rotary wind ventilator for forced convection solar dryer in remote area where electricity and other power sources are non-existent. The dryer is made of solar air-heater of black absorber plate insulated with foam material to minimize heat losses. An absorber mesh screen is placed midway between the glass cover and the black absorber plate for effective air heating as solar radiation that passes through the transparent cover is absorbed by both the mesh and black-plate. The drying chamber holds drying trays in layers, a rotary wind ventilator located at the top circulates the heated air in the drying chamber. The performance of the dryer with and without the wind ventilator led to considerable reduction in drying time and increased system efficiency in comparison to open sun drying method. Ogunkoya et al (2011) investigated an inexpensive mixed mode solar dryer for drying perishables (pepper, tomatoes, okro, etc.) using locally sourced materials. Test evaluation in the month of November for Northern Nigeria location shows effective drying of fresh pepper, okro and tomatoes within 3 hours. Ahmed (2011) in his work, developed and evaluated a mixed-mode solar dryer consisting of a solar collector, two fins and drying chamber section with four trays. He concluded that drying rate depends on climatic conditions, air velocity and properties (thermal and physical) of biogases pulp. Onigbogi et al (2012) constructed a small-scale solar dryer based on meteorological data of Abeokuta (Nigeria) with locally available materials. The dryer consists of solar collector and a drying chamber. The drying chamber contains rack of three cloth (net) trays integrated together. Drying chamber temperature of 50.5°C is obtained for corresponding ambient temperature of 34.50° C. Moisture content removal of 43.2% and 40.6% were achieved for maize and plantain respectively as against 28.2% and 27.89% using the sun drying method. Chandrakumar and Jiwanlal (2013) developed and evaluated the performance of a forced convection mixed-mode solar dryer using smooth and rough plate solar collectors. The essence was to compare the performance of the smooth and the roughed plate collectors in conducting drying. The thermal performance of the smooth solar collector was found to be poorer because of low convective heat transfer from the absorber plate to air. Artificial rib roughness on the underside of the absorber plate has been found to considerably enhance the heat transfer coefficient. The roughed absorber plate of the dryer attained a temperature of 69.2°C when it was studied under no-load conditions. The maximum air temperature in the dryer under this condition was 64.1°C. The dryer could dry 3 kg of grapes having initial moisture content of 81.4% to final desired moisture content. Advantages of Solar drying system.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 10, October 2016

IV. MERITS AND DEMERITS

a) **Merits:** The higher the temperature, movement of air, and lower humidity, increases the rate of drying. Dryers are waterproof so the product is protected against flies, rain and dust, product can be left in the dryer overnight or during rain. The quality of the product is better in terms of nutrients, hygiene and colour, It permits early harvesting and reduces the field losses of the products, It permits better planning of harvesting season, It reduces spoilage in storage drastically, It permits the farmer to sell his product at a better price during early period of harvesting season, Quality of the product gets enhanced significantly and hence farmer gets more money for his product, and Transportation is easy with dried product.

b) **Demerits:** The main disadvantage of the solar dryer is the limited time of solar isolation during the day, long drying times, totally dependent on good weather, Need maintenance after particular period of time and initial investment cost is very high.

IV. CONCLUSION

Solar dryers are the best alternative option to avoid disadvantages of conventional drying methods. Solar dryer is designed particularly for drying agricultural products. In this paper a comprehensive review of different drying techniques (direct, indirect, mixed mode) and air circulation modes reported previously is presented. It is found that time required for drying in mixed mode solar dryer is less than other types of dryer. Indirect drying gives better result than direct solar dryer.

REFERENCES

- [1] Ahmed Abed Gatea (2011). Performance evaluation of a mixed-mode solar dryer for evaporating moisture in beans. *Journal of Agricultural Biotechnology and Sustainable Development*. 3(4): 65-71.
- [2] Ajao K.R and Adedeji A.A (2008). Assessing the Drying rates of some Crops in Solar Dryer and Safety of Sun-dried Tomatoes. Part II. Effects of Storage on Nutritional and Sensory Quality of Sun-dried Tomatoes Pretreated with Sulfur, Sodium Metabisulfite or Salt. *Journal of Food Science*.71 (1): 31-37.
- [3] Al-Juamili K.E.J., Khalifa A. N and Yassen T. A (2007). Testing of the performance of a fruit and vegetable solar drying system in Iraq. *The Ninth Arab International Conference on Solar Energy (AICSE-9)*, Kingdom of Bahrain: 163 -170
- [4] Bolaji B.O and Olalusi P.A (2008). Performance Evaluation of a Mixed-Mode Solar Dryer. *AU J.T*.11 (4):225-231.
- [5] Bolaji B.O, Olayanjub T.M.A and Falade T.O (2011). Performance Evaluation of a Solar Wind-Ventilated Cabinet Dryer. *Western Indian Journal of Engineering*.33 (1/2): 12-18.
- [6] Chandrakumar B Pardhi and Jiwanlal L Bhagoria (2013). Development and performance evaluation of mixed-mode solar dryer with forced convection. *International Journal of Energy and Environmental Engineering*.2 (23): 1-8
- [7] El-Sebaai A.A. and Shalaby (2012). Solar drying of agricultural products: A Review. *Renewable and Sustainable Energy Reviews*.16: 37– 43.
- [8] Ezekoye B. A. and Enebe O. M. (2006). Development and performance evaluation of modified integrated passive solar grain dryer. *The Pacific Journal of Science and Technology*.7: 185-190.
- [9] Forsona F.K, Nazhab M.A.A, Akuffoa F.O and Rajakarunab H (2007). *Renewable Energy*.32: 2306–2319.
- [10] Gutti B, Kiman S and Mustafa B. G (2012). Design and Construction of Forced/Natural Convection Solar Vegetable Dryer with Heat Storage. *Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences*.7 (10): 1213-1217.
- [11] Gutti B., Kiman S. and Murtala A. M. (2012). Solar Dryer - An Effective Tool for Agricultural Products Preservation. *Journal of Applied Technology in Environmental Sanitation*.2 (1): 31-38.
- [12] Hossain M. A. and Bala B.K (2007). Drying of hot chilli using solar tunnel drier. *Solar Energy*. 81:85-92.
- [13] Ikejorfor, M.C and Okonkwo, W.I (2010). Design and Development of an Active Solar Dryer with Adjustable Air flow Rates for Agricultural Products. *Journal of Agricultural Engineering and Technology JAET*.18 (2):70- 76.
- [14] Jude O. Ozuomba, Ngozi A. Okonkwo, Bibian C. Uzor and Jude I. Uba (2013). Fabrication and characterization of a direct absorption solar dryer. *Advances in Applied Science Research*.4 (3): 186-194.
- [14] Lotfalian A., Ghazavi M.A. and Hosseinzadeh.B (2010). Comparing the Performance of Two Type Collectors on Drying Process of Lemon and Orange Fruits through a Passive and Indirect Solar Dryer. *Journal of American Science*.6(10):248-251.
- [15] Mu'azu K., Bugaje I.M and Mohammed I.A (2012). Performance Evaluation of Forced Air-Convection Vegetable Drying System. *Journal of Basic and Applied Scientific Research*.2 (3): 2562-2568.
- [16] Ojike O, Nwoke O.O and Okonkwo W.I (2011). The influence of different solar drying systems on the vitamin content of Pawpaw (*Carica papaya*). *Australian Journal of Agricultural Engineering, AJAE*.2 (1):8-11.
- [17] Umogbai, V.I and Iorter, H.A (2013). Design, construction and performance evaluation of a passive solar dryer for maize cobs. *African Journal of Food Science and Technology*. 4(5): 110-115.
- [18] Vega-Mercado, H., Gongora-Nieto, M. M., & Barbosa-Canovas, G. V. (2001). Advances in dehydration of foods. *Journal of Food Engineering*, 49, 271-289.