Recent Innovative Techniques for Developments of Solar Dryer

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Abstract - *Drying means removing the moisture and water vapours contents in the product. Earlier were drying the food in the sense of keeping the food in a plate or on a ground i.e. the open drying system. In this paper recent innovative techniques which are used for developments of different types like direct, indirect, mixed mode, greenhouse, automatic, biomass, truncated pyramid type and tunnel solar dryers are discussed. Solar dryers are beneficial than open sun drying. Such drying under hostile climate conditions leads to severe losses in the quantity and quality of the dried products. The solar air collector is integrated with thermal energy storage, re-circulation of air, Convergent nozzle type flat plate collector, Double pass of hot air, finned plate and v-corrugated inside of solar air collector, this review will be valuable and appropriate for further development of efficient solar drying systems. Thermal modelling and mathematical modelling, CFD, ANBFIS, ANN and FUZZY, these modelling techniques are very significant to design and develop, increase drying efficiency, analyse and predict the performance for solar dryers. Dryers have been developed and used to dry agricultural products in order to improve shelf life.*

Key Words: Solar dryer, modeling techniques, recent developments, advancements in solar dryer, efficiency.

1. INTRODUCTION

Agricultural products are produced in high amounts but they cannot be consumed immediately, however many of these products can be preserved by means of special processing. Drying is one of the processes for extending economic life of agricultural products without losing their nutritional properties before consumption. Drying is defined as a preservation method applied at industrial scale in order to minimize the biochemical, chemical, and microbiological spoilage by reducing the water quantity and the water activity of fruits and vegetables [1]. Drying process is of great importance in food industries. Drying of agricultural products has a number of advantages, e.g. shelf life extension, quality improvement, and loss reduction. Moreover, due to water removal, final weight is much lower than the initial one which reduces transportation costs [2]. The process of dehydration consists of removal of moisture from the food by heat, usually in the presence of a controlled flow of air. The moisture content still available in fully dried products between 5 to 25% depends on food products. Successful drying depends on enough heat to draw out moisture, without cooking the food; Dry air to absorb the released moisture; and Adequate air circulation to carry off the moisture. In general thermal energy storage solar dryers are in use to store thermal energy, which include sensible heat storage, chemical energy storage, heat energy and latent heat storage [3].

The solar drier is an energy efficient option in the drying processes [4]. Numerous experimental studies reported the various methods designed for drying of agricultural materials using solar dryer [5-9]. Use of forced convection solar dryers seems to be a benefit compared to traditional method and improves the superiority of the product [10, 11]. Use of forced convection solar driers seems to be an advantage and improves the quality of the product considerably [12]. Normally thermal storage systems are employed to store the heat, which includes sensible and latent heat storage [13].

Solar drying is the oldest method of products drying. It is oldest method of food preservation. Solar drying is preservation of food and agriculture crops. Solar drying of agricultural products appears to be financially quite attractive for cash crops. Using solar drying technologies are very much advantages than using fossil fuels for product drying. Solar drying technologies are broadly classified in to three modes direct solar drying, indirect solar drying and mixed mode solar drying [14-20]. It is generally classified according to natural circulation and forced circulation [15, 20-22].

2. LITERATURE REVIEW

G. Cakmak and C. Yildiz [1] in the present study, thin-layer drying kinetics of seedy grapes investigated experimentally. The experiments have been conducted at three different air velocities. It has been determined that drying time shortens as drying air velocity increases and the drying process has occurred in decreasing drying period. In the developed dryer, drying activity is uniform and the products dried by a system with heat storage in swirl flow media achieve lower moisture values in shorter time. An FNN model was developed to determine the drying rate of seedy grapes.

A. Mohajer et. al. [2] in this study, the same DPSC collector which was designed by Assari et. al. was investigated to analyze its performance as a simultaneous solar dryer and solar water heater. In their study, hot air had been released to ambient, while in this study, it was applied as heating fluid in a forced convection indirect solar dryer for drying parsley, dill and coriander vegetables. Furthermore, hot water obtained from the system can be used for two purposes. The system is capable to be used as a domestic drying system as well as providing domestic consumptive hot water. The system reduces the costs and the required space of installation in comparison with two separate systems for water and air heating.

E. Natarajan and V. Shanmugam [12] an indirect forced convection with desiccant integrated solar dryer has been built and tested. The main parts of this system are a flat plate solar air collector, a drying chamber, desiccant bed and a centrifugal blower. This system can be operated in 2 modes, off sunshine hours and sunshine hours**.** When sunshine is available the hot air (fluid) from solar collector is passed into drying chamber for drying of products and at the same time from reflector mirror and solar radiations receives by desiccant bed. In off sunshine hours, dryer is operated by circulating air within drying chamber all the way through desiccant bed via a reversible fan. The effect is also investigated of reflective mirror on the drying potential of desiccant unit.

N. S. Rathore and N. L. Panwar [23] As drying of food material is primarily requiring a low temperature up to 65°C, solar energy is being considered as a most appropriate source of energy for drying. Solar tunnel dryer works at temperature between 55°C and 70°C, therefore solar dryers are also having scope for saving conventional fuel by conversation and absorption of solar energy based drying operation. Solar tunnel dryer bring into being pleasing for grape drying.

G. Cakmak and C. Yildiz [24] in this study solar energy supported, swirling flow new drying system is designed and artificial drying of grapes grown around Turkey is investigated. With the developed swirling flow dryer with airy solar collector it is examined that drying occurs homogenously and lower moisture values are obtained in when compared with classical drying system. At what time air directing elements are placed inside drying chamber and rotary element to the entry, it is examine that drying time gets shorter compare to that of normal drying. Thus, drying time which is 200 hour in natural conditions decrease to 80 hour with an air velocity of 1.5 m/s with the developed solar energy supported swirling flow dryer.

C. V. Papade and M. A. Boda [25] the use of solar dryer is limited because of drying is not possible due to frequent clouds in the day or in the evening. If we want drying product in evening time then there is one possible way that we have to store solar energy, in thermal energy storing material. The energy storing material can store either sensible or latent heat. The storing of energy in latent heat storing material is very useful because it stores maximum amount energy as compared to sensible heat storing materials at equal quantity of material.

N. Kumar et. al. [26] a truncated pyramid-type solar cooker/dryer is designed fabricated and tested. The incident light radiations concentrate towards bottom and (top) glazed glass surface with the help of truncated pyramid. One of the most important features of the proposed design is to completely wipe out the need for tracking the sun during cooking/drying, as tracking of sun does not give up enhanced performance. Minor modifications in design are recommended to achieve higher temperatures and reduce cooking/drying times.

M. Boda and C. Papade [27] An indirect type natural and forced convection solar dryer integrated with PCM has been developed and tested its performance for drying food products under the meteorological conditions of Solapur, India. The performance analysis of a solar dryer system with and without PCM is done for drying grapes. The addition of PCM increases the drying time later than sunset by 3 hours per daylight hours. The forced convection with energy storing material is more efficient, more suitable for reducing drying time, increasing drying rate, and produces high quality dried products.

J. Kaewkiew et. al. [28] the performance of a large-scale greenhouse type solar dryer for drying chilli was investigated. The material of solar drying system is polycarbonate which is having a parabolic shape. The base of the dryer is a concrete floor. This system has total 9 fans used for ventilation purpose and which are worked on 150 W solar panel (3 solar panels each 50 W). For drying of 500 kg of chilli with 74 percentage of moisture content solar dryer system requires three days and were natural sun (open) drying required five days. The estimated payback period of the greenhouse solar dryer is about 2 years.

N. Haque and M. Somerville [29] the pros and cons of various types of biomass dryers have been documented in their paper. Using dry biomass significantly reduces the cost of handling, transportation and pyrolysis. Fluidized bed, stationery bed, rotary, and flash dryers are mostly depends on biomass. The energy requirements and greenhouse gas emissions have been estimated for drying biomass.

T. B. Shaikh et. al. [30] the solar-biomass drying system has able to dry fresh maize within 15 hours. Maximum drying temperature of 47°C was obtained with solar and biomass heating source even though ambient temperature for the test period was between 24°C to 30°C. Their studies prove that effectiveness of agricultural dryers be able to increase through the use of a grouping of solar biomass heating method. It implies that improvements in design and construction of various components of system would lead to more efficient drying system for sustainable development of developing countries. Via combined solar biomass drying structure has the possible to diminish wastage of grains and increases the efficiency of drying system.

H. H. Al-Kayiem and Y. Md Yunus [31] the design and fabrication of a solar dryer integrated with a thermal backup unit are presented. The thermal energy backup unit comprises a solid fuel burner and a gas to gas heat energy exchanger. The thermal backup unit can successfully supply hot air at about 70°C. By using the thermal backup, therefore, the drying efficiency of the EFB was enhanced by 64%. The contribution of the TBU is found to be very effective. Further investigations are recommended for other types of products, like food, fish and herbs.

M. A. Boda et. al. [32] Objective of study was to design, develop and carryout detailed experimentation on a new type solar dryer. This is new because it is having a Convergent nozzle type flat plate collector. Convergent nozzle is helps to increase the outlet velocity of nozzle, same principle here used to increase the outlet velocity of flat plate collector. By increasing velocity the drying time is reduces. The experimentation is carried out on sliced onion and grapes. Now a day the new innovations are necessary in solar dryer to fulfil the necessities of drying industrial and agricultural products. The design considerations and assumptions are very important to design any system. To reduce the drying time, the methodology which are using is also very important.

H. Faramarzi et. al. [33] the aim of their study was to evaluate the operation of system of hot liquid transmission in an automatic solar dryer. In their research the automatic solar dryer in order to utilize solar energy for drying agricultural crops, was designed, constructed and tested. They evaluated the influence of time setting of pump timer in 3 levels like 5, 10 and 15 Minutes and the environment temperature in four levels of 24, 28, 32 and 36^{o}C on the function of the solar collector and the dryer chamber. The conclusion of their work that by increasing the environmental temperature rises in temperature of collector and dryer chamber was obtained.

D. Kamthania et. al. [34] the performance evaluation of a hybrid photovoltaic thermal double pass facade for space heating. The thermal model has been developed by using the energy balance equations. To calculate annual exergy and energy gain for hybrid photovoltaic thermal double pass façade a separate analysis were carried out. On the basis of numerical results it has been observed that the annual thermal and electrical energy are 480.81 kWh and 469.87 kWh respectively. Thermal energy generated by the system was 1729.84 kWh for one year period. It is also observed that the room air temperature increases by 5–6^{o}C than the ambient air temperature for a typical winter day.

G. Padmanaban et. al. [35] A laboratory level forced convection base solar dryer was designed & developed for drying Amla under the climatic condition of Coimbatore region, Tamil Nadu , India. The Solar dryer consists of a rectangular box type absorber & a drying chamber fitted with one blower. The experimental results explain that drop of drying time nearly 79% in similarity to open sun drying. The average time required to dry 1 kg amla from moisture content of 80% to 10.06% on wet basis was found to be 36 hours whereas in open sun drying it takes 7 days to achieve the same drying rate.

B. M. A. Amer et. al. [36] a hybrid solar dryer was designed and constructed using direct solar energy and a heat exchanger. This system has solar collector, energy reflector, heat exchanger can be used as a heat storage unit and drying chamber. The drying chamber was located under the solar collector. The dryer was operating throughout normal sunny days as a solar dryer, and throughout cloudy days as a hybrid solar dryer. A night drying is possible by using heat storage in water and this heat was collected during sunshine. The efficiency of the solar dryer was raise by recycle about 65% of the drying air in the solar dryer and draining a small quantity of it outside. The solar dryer was designed and tested for drying of slices of banana.

Yefri Chana et. Al. [37] normally conventional flat bed dryers have a demerit of non homogeneous drying, to avoid this (Yefri Chana et.al.) designed and developed a re-circulating type solar dryer with pneumatic conveyor as the re-circulating equipment. The grains transported within the pneumatic conveyor rapid heat and mass transfer occurs resulting in even and homogeneous drying process. They used a spherical model to predict the drying time. They have taken 104 kg of rough rice with initial moisture content of 28.4 % w.b. from this they obtained final moisture content 14.3 % w.b. within 5 hours. During their experiment drying temperature kept at 50.1^{o}C and RH of 21.73%. The dryer efficiency obtained was 22.4 %.

Aymen El Khadraoui et. al. [38] an indirect type forced convection solar dryer integrated with PCM designed, developed and investigated experimentally. This system consists of solar air collector with PCM storage cavity along with drying chamber. The experiments conducted to estimate the charging and the discharging properties of PCM storage cavity. The system performance is investigated in two different cases with and without PCM storage. The daily energy efficiency reached 33.9%, while exergy efficiency reached 8.5%. With paraffin wax as thermal energy storage material is an effective design to yield more favorable conditions for the drying process compared to without thermal energy storage.

A.G.M.B. Mustayen et. al. [39] indirect, direct, and mixed mode dryers that have shown potential in drying agricultural products in the tropical and subtropical countries are discussed in this paper. Their paper represents study of design, performance, and applications of different types of solar dryers which are available today. The best solutions to solve the issues associated with traditional drying are discussed, along with the ways by which to create simple, inexpensive, and low-cost solar dryers.

Prashant Singh Chauhan et. al. [40] Thermal modelling plays a significant role in ideal design and development of any system. It is also very useful tool in optimizing drying parameters to enhance the performance of systems under various modes. The dryer designed for a given mass of crop as well as location of installation from energy balance equations. This review will be valuable and appropriate for further development of energy efficient greenhouse drying systems. Thermal modelling helps in designing, the best possible dryer system by considering various governing and operating parameters.

Mahesh Kumar et. al. [41] the study of different types of solar dryer like, direct, indirect, hybrid and applications. Recently some investigations in this direction have been made such as merging of double pass, recirculation of heated air, finned plate and v-corrugated inside of solar air collector. They have suggested optimizing each and every step which is involved in solar drying for better technically and economically feasibility.

S. Vijayan et. al. [42] an indirect forced convection solar dryer integrated with porous sensible heat storage medium was developed. The effect of porous thermal storage and mass flow rate of air on the performance of the system for drying bitter gourd was studied. The thermal storage medium (pebble) was placed below the corrugated absorber plate, in the air passage as a porous medium. The porous sensible heat storage reduces the fluctuation of temperature of hot air from collector to the drying chamber, resulting in uniform drying.

S. Dhanushkodiet. et. al. [43] the main objective of their study was to analyze the drying behaviour of cashew nut experimentally using mathematical models. In order to describe and develop drying behaviour of cashew kernel in various modes of drying (solar, hybrid and biomass drying) have been studied using eleven thin layer drying mathematical models. It is further validated by comparing the predicted against the experimental work based on correlation co-efficient. The suggested system can be redesigned based on the mathematical model to enhance the drying process.

Mohamed A. Eltawil et. al. [44] a solar PV system powered mixed mode Solar Tunnel Dryer (STD) for drying potato chips was studied and developed. The STD performance was evaluated with load and without load; and with and without immersing thermal curtain over potato slices. The highest drying efficiency of 34.29 and 28.49% was in case of with and without immersing thermal curtain, respectively at same airflow rate. The developed STD provides potato chips in good quality and this is very good suitable for rural areas.

Sari Farah Dina et. al. [45] the most important objective of their work was to assess effectiveness of solar dryer which was integrated with desiccant thermal storage for drying cocoa beans. The results revealed that during sunshine hours, obtained the maximum temperature within the drying chamber.

Racha Dejchanchaiwong et. al. [46] small holder rubber producers typically dry rubber in the open air, a process that takes about seven days, allowing the rubber to deteriorate and thus decreasing the price obtained by the producers. The good solar dryer decreases the drying time by 2 to 3 days. In this study, performances of mixed-mode and indirect solar drying systems have been investigated for 30 natural rubber sheets. The two-term drying models are found to most excellent for the natural rubber sheet drying behavior in both indirect and mixed mod solar dryers. Performance of the mixed-mode dryer is superior to the indirect solar dryer. The dried sheets have a superior look in terms of colour and cleanliness than those from open air drying.

Roonak Daghigh and Abdellah Shafieian [47] a heat-pipe evacuated tube solar dryer with heat a recovery system studied, designed, constructed and experimentally evaluated. In this system water as working and recovery fluid used and air used as intermediate fluid. To make maximum use of solar energy intake of the dryer the heat recovery system was used.

Om Prakash et. al. [48] this solar dryer review paper is focused on the various modelling techniques viz. Computational Fluid Dynamics (CFD), Adaptive-Network-Based Fuzzy Inference System (ANFIS), ANN and FUZZY. These modelling techniques are very significant to design and develop, increase drying efficiency, analyse and predict the performance for predicting the temperature of crop moisture content, drying rate, quality of crop and colour of crops of different kinds of solar drying system. These techniques help for short of spending vast amount of time, energy and money in experimental works.

Sumit Tiwari et. al. [49] this is review paper on different types of drying systems was designed and developed across the worldwide. In this paper further they discussed different thermal modelling; mathematical modelling and performance evaluation. They concluded that, the low density crop drying is faster in comparison to high density crop drying and the cost of solar drying per kg is less in comparison to an electric drying for same crop.

D. K. Rabha and P. Muthukumar [50] this paper presents the performance studies on a forced convection solar dryer integrated with a paraffin wax based shell and tube latent heat storage unit. This consists of two double pass solar air heaters, a blower, a paraffin wax based shell and tube latent heat storage module and a drying chamber. The performance of each components of this system evaluated using exergy efficiency 18.3–20.5%, and energy efficiency 43.6–49.8% analysis.

S. Nabnean et. al. [51] they had a performance of a newly designed solar dryer for drying osmotically dehydrated cherry tomatoes. This solar dryer consists of heat exchanger, water type solar collector, water type heat storage unit and drying cabinet. This solar dryer system is also very good suitable for drying other products.

Alejandro Reyes et. al. [52] for dehydration of mushrooms a Hybrid Solar Dryer is designed and developed. The mushrooms were cut in 4 mm or 8 mm thick slices. At the outlet of the tray dryer 80 to 90% of air was recycled and the air temperature was adjusted.

David Gudiño-Ayala and Ángel Calderón-Topete [53] this paper presents results of an experimental work for pineapple drying in a new hybrid solar dryer. The dryer is a direct and integrated type with a black pan. In this a copper helical tube is used and that conducts heated water, from that generates extra heat for the drying process; this tube is located at the bottom of the pan. A pump is used for recirculation of hot water.

M. Yahya et. al. [54] the performance investigation of a solar dryer (SD) and a solar assisted heat pump dryer (SAHPD) for drying of cassava chips have been studied. The thermal efficiencies for SD was 25.6% and for SAHPD 30.9% SAHPD. The average Coefficient of Performance of the heat pump was 3.38 in a range of 3.23 to 3.47.

S. Deeto et. al. [55] the solar greenhouse dryer investigated for thin layer of coffee beans dehumidification with hot water storage. The thermal energy in the form of hot water is can be used and reused at a time of sunset.

3. SOLAPR DRYER

Conservation of agricultural products is important, as it has an important role in human beings' nutrition; it is known that the food to be dried is subjected to some loss from growing to consumption. There are a lot of methods applied for conservation of agricultural foods, increasing their economical life span and providing the amount of nutritional items at maximum level [24]. Drying is a process to remove water from a substance is one of the most frequently and widely used operating processes in daily life and is undeniably an energy intensive operation. More than a few victorious attempts for developing natural convection crop solar dryers, both of the tunnel and cabinet type, have been investigated over the years and are described in the literature [23]. For drying agricultural products solar drying method is most suitable. Though well developed, and still a good deal of work is continuing in this direction throughout the world. A variety of designs of solar dryers are developed and tested for their performance. Each differs in design and is developed for a definite product. Passive type of solar crop dryers is well realized and it overcomes the problems existing in open sun dryer and cabinet type of dryers [12]. Most of the agricultural products contain the higher moisture content of 25 to 80% but generally for agricultural products. This value of moisture content is very much higher than the required for long preservation [32]. Globally it is estimated that 84% of produced grains are wasted. In India 20-40% of food grains are spoiled, due to conventional preservation technique. Renewable hybrid drying system possibly most advantageous for food preservations at low-priced and will make use of at large in the current situation [30]. In a lot of countries, agricultural crops are dried under the open sun. Though, this way of drying degrades the superiority of the dried foodstuffs due to intrusion of external impurities and irregular drying rates. Various types of solar dryers have been designed, constructed, tested and developed across the world, yielding varying parameters of technical performance [12, 56]. The food crises in most developed countries are due in part to the inability to preserve food surpluses. Most of the farmers in world are facing problem with reducing the moisture content from crops to prevent spoilage during storage [27]. Some agricultural products require low heat to dry the products like tea, coffee, tobacco, cocoa beans, nuts, rice, and timber etc. conventionally, crop drying has been skilful by burning fossil fuels and wood in ovens or open air drying under screened sunlight [57].

4. CONCLUSIONS

In this paper recent innovative techniques which are used for developments of different types like direct, indirect, mixed mode, greenhouse, automatic, biomass, truncated pyramid type and tunnel solar dryers are discussed. Solar dryers are beneficial than open sun drying. A solar dryer produces better quality food with nutritious value which enhances food value and market value of product. From the duration of previous two to three decades lots of researchers have designed and developed efficient solar collectors, drying chambers, solar dryers. A few researchers have designed and developed heat storage mechanism the materials which are used PCM, sensible heat storage, and latent heat storage as a thermal backup for absorber and reduced the heat losses from absorber and collector. There are some researchers have been developed a solar flat plate collector for solar dryer system as Convergent nozzle type flat plate collector, re-circulation of hot air, Double pass of hot air, finned plate and v-corrugated inside of solar air collector, hybrid photovoltaic thermal double pass facade, and Heat pipe evacuated tube. Some researchers are evaluated a thermal efficiency, exergy efficiency, and energy efficiency of a different solar dryers. There are substantial losses of vital agricultural product in many rural areas. There are several factors like spoilage, mechanical injury to food (damage), transportation and sorting process, fungal and microbiological degradation which accounts for loss of agricultural products. Drying is essential for preservation in agricultural application. To minimize food losses many solar dryers are designed and developed across world. By using solar drying system better quality products are obtained. The working of solar dryers is depending entirely on solar energy which is widely available. There are various solar dryers like direct, indirect, mixed mode and hybrid. There is a need of farmers to dry grape by using economical and modern technology. The traditional way of drying is less efficient and time consuming or some time does not produce quality product. Now a day it is necessary to develop a simple, economical and effective solar dryer to encourage marginal and small farmers to use solar dryers. Before fabrication the modelling techniques like thermal modelling, mathematical modelling is very supportive in simulation of different types of solar drying system. This review will be valuable and appropriate for further development of efficient solar drying systems. Thermal modelling and mathematical modelling helps in designing, the best possible dryer system by considering various governing and operating parameters. Computational Fluid Dynamics, Adaptive Network Based Fuzzy Inference System, ANN and FUZZY. These modelling techniques are very significant to design and develop, increase drying efficiency, analyse and predict the performance for solar dryers.

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