*Available online at* www.ijpab.com

DOI: http://dx.doi.org/10.18782/2320-7051.5586

**ISSN: 2320 – 7051**

*Int. J. Pure App. Biosci.* **7 (2):** 303-326 (2019)

*Review Article*

International Journal of Pure & Applied Bioscience

# Application of Different Types Solar Dryers in Agriculture Crops- A Review

**Dronachari M.[1*] and Shriramulu[2]**

[1]Assistant Professor, College of Sericulture, UASB, Chintamani

[2]M.Tech (Ag.Engg), Department of Agricultural Engineering, CoA, GKVK, Bangalore

*Corresponding Author E-mail: dron0321@gmail.com

Received: 5.11.2018 | Revised: 8.12.2018 | Accepted: 17.12.2018

**ABSTRACT**

*Due to exponential rise in the price of fuel and depletion of fossil fuel, there is a need to look for other alternatives like nonconventional energy resources viz. solar energy. India is blessed with good sunshine hours. A review paper is made to use solar energy for drying of agricultural food products with different dryers available, such as direct type, indirect type, mixed mode and hybrid solar dryers, also reviews about different heat storage material used in solar dryers after sunshine hours. In India most of rural areas follows the open sun drying method for drying of agricultural material like grains, fruits and vegetables, but it has some disadvantages like time consuming, labour demanded and environmental contamination.*

***Key words:*** *Solar energy, Energy resources, Environmental contamination, Insect, Dust, Rain*

## INTRODUCTION

Solar energy is inexhaustible, ample and free of cost available all over the world. Due to this the attention has been gradually diverting to utilize the renewable energy for a number of applications. Open sun drying was followed in rural areas to dry agricultural products. In recent days solar dryers are used which protect farming produce from insect, dust and rain. Solar drying is economical as compared to artificial drying methods. Fruits and vegetables are easily contaminated because they contain water more than 80%. In developing countries loss of 30-40% fruits and vegetables produce, and more than US$1.5 billion/year of Loss of worth in India. Open air and uncontrolled sun drying is still the most common method used to preserve and process Agricultural product. But these methods cause serious problem of wind born dust, infestation by insect, product may be seriously degraded and become market valueless and resultant adverse economic effects on domestic and international market[34]. India is blessed with 300–330 sunny days in a year and solar radiation around 4–7 kWh/m2-day. Thus, it is one of the most promising sources of energy, unlike fossil fuels and nuclear energy, it is an environmentally clean source and freely available energy.

**Cite this article:** Dronachari, M. and Shriramulu, Application of Different Types Solar Dryers in Agriculture Crops- A Review, *Int. J. Pure App. Biosci.* **7(2):** 303-326 (2019). doi: http://dx.doi.org/10.18782/2320-7051.5586

Solar energy is always in an advantageous position compared with depleting fossil fuels. The energy demands can be met by simple systems that can convert solar energy into appropriate forms, by proper utilization of technologies[63]. Solar energy has potential to cater the present and future needs of mankind. It is being used by man from prehistoric times for drying their food products and to preserve them for longer period. Drying of agricultural products not only increases their shelf life but also provides benefits in terms of lighter weight for transportation and small space for storage and finally results in lower transportation and handling cost[27]. The use of solar energy in drying applications is becoming an important and feasible alternative since it decreases consumption of conventional energy by 27–80% at an average solar collector system efficiency of 40%[1].

**Drying**

Drying is the moisture removing process from the products. Drying reduces the bacterial growth in the products. The process of drying is based on the fact that when air is heated, its relative humidity decreases therefore is capable of picking up moisture from products of greater moisture when it passes through them. It will helpful for preserving the products for long time. Food drying is one of the oldest methods of preserving food for later use. Food drying is a very simple, ancient skill. It is one of the most accessible and hence the most widespread processing technology. Sun drying of fruits and vegetables is still practiced largely unchanged from ancient times. Traditional sun drying takes place by storing the product under direct sunlight. Sun drying is only possible in areas where, in an average year, the weather allows foods to be dried. Drying is one of the significant parts of every industry that consumes a big amount of energy per year. One of the well-known applications of dryers is drying agricultural products, in order to reduce the fossil fuel energy consumption, one practical way is utilizing solar dryers. Solar drying was used to dry agricultural products since ancient times. Agricultural products were exposed to the sunlight to dry[64]. Drying is the oldest preservation technique for agricultural products and it is an energy intensive process. High prices and shortages of fossil fuels have increased the emphasis on using alternative renewable energy resources[20]. The main purpose in drying farm produce is to reduce its water activity from the harvest level to the safe storage level in order to extend its shelf life. Once the produce has been dried, its rate of deterioration due to respiration, insects, and microbial activity and biochemical reactions should diminish leading to maintenance of quality of the stored product. Drying reduces post-harvest losses and transportation costs since most of the water are taken out from the product during the drying process. In India, sun drying is the most commonly used method to dry the agricultural material like grains, fruits and vegetables[66].

Solar dryers

A solar dryer is an enclosed unit, which is used to dry agricultural products. It is also required to keep the food safe from damage, birds, insects and unexpected rainfall. Solar dryers, also known as dehydrators, have been used throughout the ages to preserve grains, vegetables and fruits by removing moisture. Solar drying of agricultural produce permits.

(1) Early harvest;
(2) Planning of the harvest season;
(3) Long-term storage without deterioration;
(4) Taking advantage of a higher price a few months after harvest;
(5) Maintenance of the availability of seeds; and finally
(6) Selling a better quality product

Basically, there are four types of solar dryers:

1. Direct solar dryers
2. Indirect solar dryers
3. Mixed-mode dryers
4. Hybrid solar dryers

**Solar dryer evaluation**

(I. M. Augustus Leon,*et.al*) In order to compare different types of dryers and their various enhancement models, it is necessary to evaluate the performance based on certain parameters.

These parameters could be categorized as:

- Physical features of the dryer:

-Type, size, shape.
-Drying capacity/loading density.
-Tray area and number of trays.
-Loading/unloading convenience.

- Thermal performance:

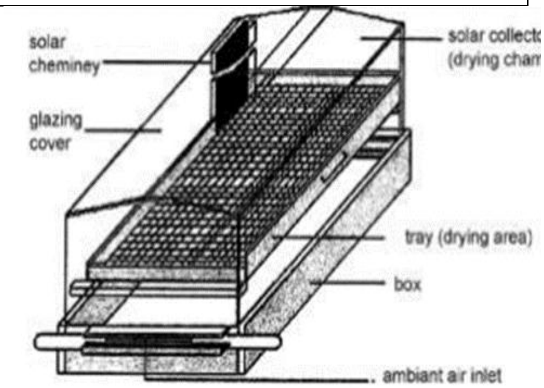
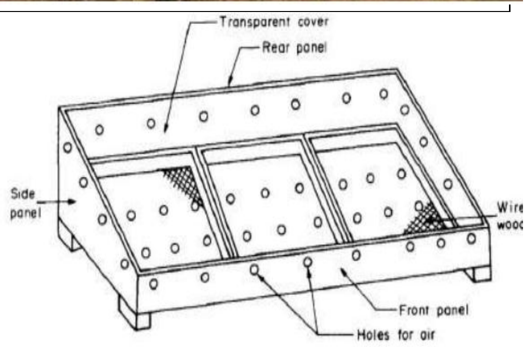
-Drying time/drying rate.
-Drying air temperature and relative humidity.
-Airflow rate.
-Dryer efficiency.

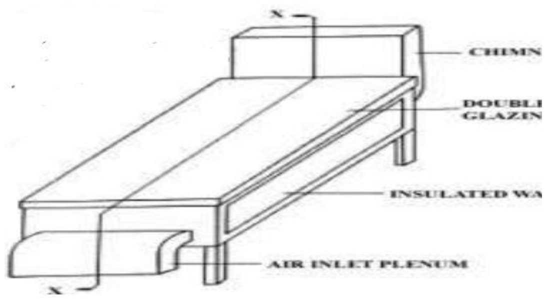
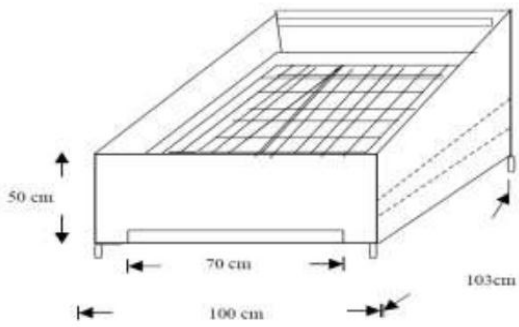
- Quality of dried product:

-Sensory quality (colour, flavor, taste, texture, aroma)
-Nutritional attributes.
-Rehydration capacity.

## 1. DIRECT SOLAR DRYER

In this class of dryer, the solar radiation is absorbed directly by the product intended to be dried. The hot air supply is provided through solar collectors which are employed in the drying unit in which the product is directly irradiated by solar energy through transparent sheet covering the east and west sides of the chamber. One of the disadvantages of this system is poor quality of product processed which may causes black surface on the product due to the direct solar radiation on the product. On the other hand the drying time is very fast and this class of dryers came with a simple design which can be assembled by farmers themselves using locally available materials.

| Author and product | Key Findings | Figure |
|---|---|---|
| H. Yobouet Andoh et al (2007) Cassava and sweet banana. | Moisture content was reduced from 80% to 13%. They concluded that the drying rate increases with drying air temperature and drying air mass flow. |  |
| Ben Akachukwu et al.(2014) Tomato, okra and carrot | For tomato, okra and carrot dryers achieved 54.55, 52.88 and 50.98 percent gain in drying time and 21.80%, 21.18% and 24.95% system drying efficiencies respectively. |  |
| Sodha et al.(1985) Mango | Moisture content reduced from 95% to 13% in 12 sunshine hours. |  |

| | | |
|---|---|---|
| Ezekwe Food products | Dryer equipped with wooden plenum and chimney which were accelerated the drying rate 5 times over the un drying. |   |
| EL- Amin Omda Mohamed Akoy et al. (1999) Mango | Dryer had a collector area of $16.8m^2$. They dried 195.2 kg of fresh mangoes from 81.4% to 10% wet basis. |   |

**Reviews of literature**

Ben Akachukwu *et al.*[19] developed a small scale direct mode natural convection solar dryer for drying tomato, okra and carrot using locally available and affordable materials. They sliced these crops and loaded them in the dryer at the same time. They compared the results with that of open sun drying and observed that sliced samples of tomato, carrot and okra dried with solar dryers, achieved 54.55, 52.88 and 50.98 percent gain in drying time respectively. They observed that tomato; carrot and okra dried in solar dryers attained 21.80%, 21.18% and 24.95% system drying efficiencies respectively as compared to open sun drying efficiencies of 10.59%, 12.71% and 15.19% for the same.

Designed a natural convection direct type solar dryer. They constructed the dryer using local materials and then tested it experimentally to dry foodstuffs (cassava, bananas, and mango). They analysed the behaviour of the dryer and the study mainly relates to the kinetics and establishment of drying heat balances.

Ezekwe[35] reported a modification of the typical designed cabinet dryer which was equipped with a wooden plenum. This plenum was used to guide the inlet air into the dryer. A long plywood chimney was also provided to enhance the natural circulation. This dryer was reported to have accelerated the drying rate by about five times over the open sun drying.

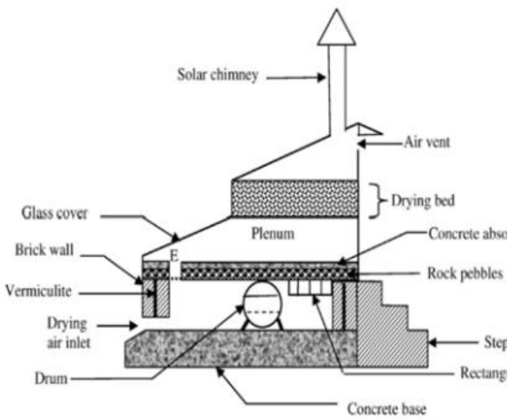
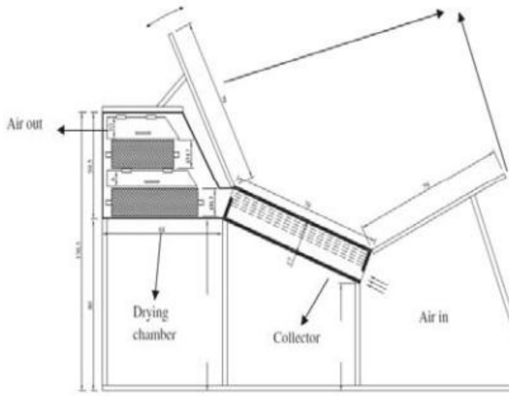
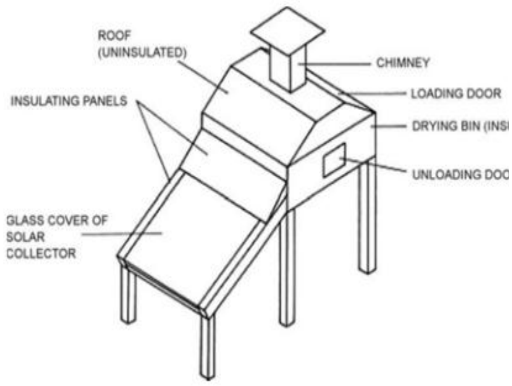
Sodha *et al.*[69], developed a theoretical and experimental study of the solar cabinet dryer (fig. 3). The experimental results showed that, on atypical summer day fruit mango flesh, with 95% initial moisture content dries up to 13% final moisture content in 12 sunshine hours. It was also concluded that the cabinet type driers were very useful for domestic applications for drying of fruits and vegetables (i.e. high moisture content products) in developing and underdeveloped countries.

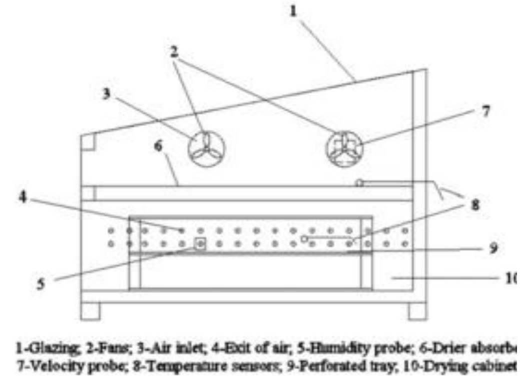
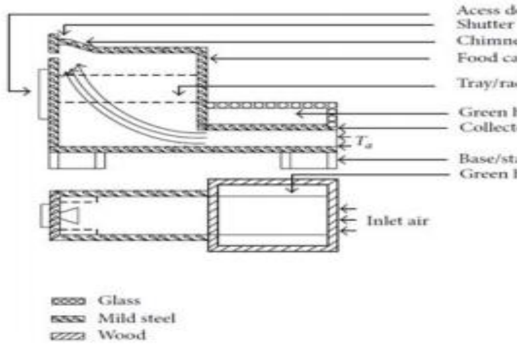
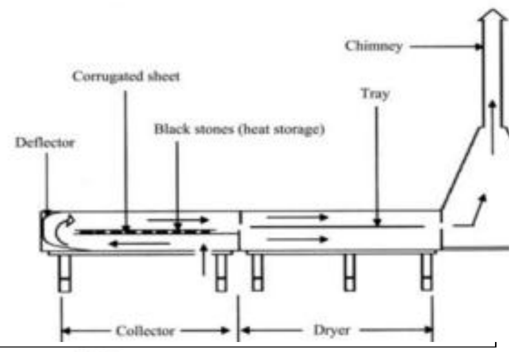
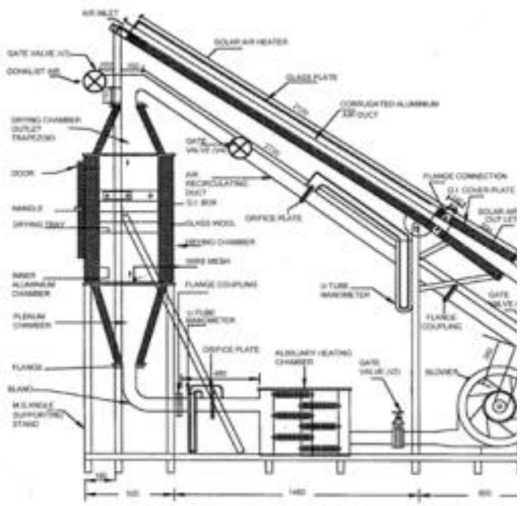
EL- Amin Omda Mohamed Akoy *et al.*[36], developed a natural convection solar dryer (Cabinet Type) to dry mango slices (fig. 5). The dryer specifications are also shown in the figure. The designed dryer had a collector area of 16.8m2 . They dried 195.2 kg of fresh mangoes from 81.4% to 10% wet basis. They dried mangoes in two days under ambient conditions during harvesting period of April to June.

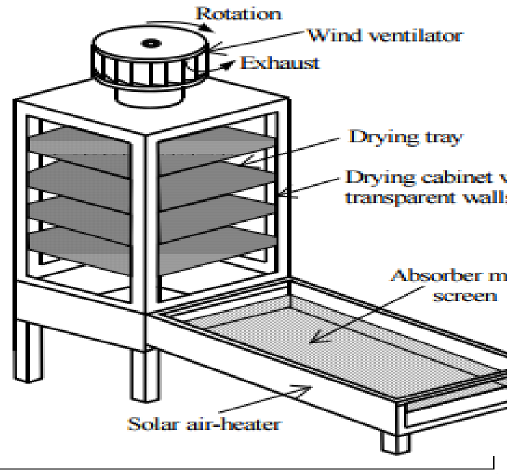
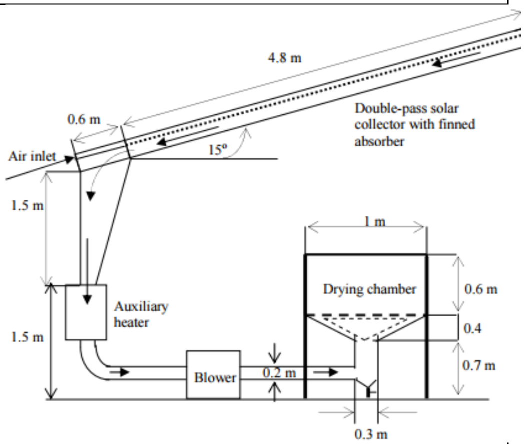
Diemuodeke E. Ogheneruona *et al.*[31], Designed and fabricated a direct natural convection solar dryer for drying tapioca. Through experimentation, the initial and final moisture content were found to be 79 % and 10 % wet basis, respectively. The average ambient conditions recorded were 32ºC and 74 % relative humidity with daily global solar radiation of 13 MJ/m2/day. They developed a prototype of the dryer with minimum collector area of 1.08 m2 and performed drying tests under various loading conditions.

## 2. INDIRECT SOLAR DRYER

In this type of dryer, the solar radiation acquired by the system is used to heat the air circulating around the product to be dried. The air is typically heated by the thermal energy converted from solar radiation absorbed with separate collector. In this operating mode, the sides of the drying chamber are insulated to prevent the loss of solar radiation through the sides. Product quality is improved by an increase of the drying speed. Indirect dryers are generally predestined for the manufacture by small industries in most cases.

| **Author and product** | **Remarks** | **Figure** |
|---|---|---|
| A. Madhlopa et al.( 2007) Sliced pineapple | Solar dryer integrated with collector storage and biomass-backup heaters. Moisture pickup efficiency was 13% in solar-biomass modes of operation. |   |
| Subarna Maiti et al. (2011) Papad | Collector efficiency without load was enhanced from 40.0% to 58.5%. They dried 'papad' to a moisture content of 12% in 5 h. dryer has collector area of 1.8$m^2$ and loading capacity of 3.46 kg. |   |
| Othieno et al. (1981) Maize | The dryer consisted of a single glazed passive solar air heater with 1 m2 single flat-plate collector. Moisture content reduced from 20% to 12% within 3 days and has capacity 90 kg. |   |

| | | |
|---|---|---|
| K.P. Vijayakumar et al. (2008) Bitter gourd | Moisture content reduced from 95%, to 5% within 6 h with 4 kg capacity. 1kg of bitter gourd as Rs. 17.52, while, in case of an electric dryer it was Rs. 41.35. |   |
| A. O. Adelaja et al. (2013) Food products | Collector efficiency to be 46.4% while system efficiency was 78.73%. The collector had moisture removal efficiency of 77.5% that was achieved in 20 hours. |   |
| J. E. Berinyuy et al. (2012) Sliced cabbage | Moisture content reduced from 95% to 9% in five days. The overall dryer efficiency was 17.68%, with a moisture extraction efficiency of 79.15% and airflow of 9.68 m3 /hr. |   |
| P.N. Sarsavadia (2007) Onion slices | Moisture content reduces from 86% to 7 % (wet basis). They concluded that by doing recirculation of exhaust air, the maximum saving in total energy up to 70.7% was achieved and energy required per unit mass of water removed was found between 12.040 and 38.777 MJ/kg water. |  |

| | | |
|---|---|---|
| S. Shanmugam et al.(2011) Sunflower seed | They compared the results of the physical model and the mathematical model and concluded that the percentage of the average error and the standard deviation for the dryer thermal efficiency was 0.78% and 1.33%, respectively. |  |
| R.K. Aggarwal (2012) Hill products | The solar dryer of 25kg capacity was attached with a solar cell for running the fan. Bulbs were also provided in the solar collector for heating air during cloudy days, evenings and mornings for faster drying, thereby reducing the drying time. |  |
| Bukola O. Bolaji.et.al. (2008) Pepper, yam chips | Average air velocity and daylight efficiency was 1.62 m/s and 46.7%. The maximum drying air temperatures was found to be 64oC inside the dryer. The weight losses were obtained 80% to55% in the drying of pepper and yam chips, respectively. |  |
| Fudholi et al. (2011) Marine products | The collector, drying system and pick-up efficiencies are found to be 35, 27 and 95 %, respectively. Moisture reduced from 90 % to 10 % in 15 h. |  |
| | | |

**Review of literature**

According to S.Misha et al. The tray dryer is widely used for drying of agricultural due its simple design and capability to dry products at high volume. The main drawback of tray dryer is uneven drying because of poor airflow distribution in the drying chamber. This paper discussed several design of tray dryer system for drying agricultural products and its performance.

P.N. Sarsavadia Developed a forced convection dryer with recirculation of air to study the effect of airflow rate, air temperature and fraction of air recycled on the total energy requirement of drying of onion slices. For drying of onion slices without using recirculation of air from initial moisture content of about 86% (wet basis) to final moisture content of about 7%(wet basis), the energy required per unit mass of water removed was found between 23.548 and 62.117 MJ/kg water. They concluded that by doing recirculation of exhaust air, the maximum saving in total energy up to 70.7% was achieved and energy required per unit mass of water removed was found between 12.040 and 38.777 MJ/kg water.

Sreekumar[63] Designed a roof-integrated solar air heating system for drying fruits and vegetables. The solar air heater had an area of 46 m2 and recorded a maximum temperature of 76.6 0C. It took 8 hours to dry sliced fresh pineapple loaded with 200 kg to reduce moisture content from 82% to 10%. He also concluded that the cost of drying 1 kg pineapple worked out to be Rs. 11 which was roughly half of that of an electric dryer while the payback period worked out to 0.54 year, that was much less than the life of dryer which was estimated to be 20 years.

Bukola O. Bolaji.*et.al*.[21], Designed, constructed and tested the solar wind-ventilated cabinet dryer, the average air velocity through the solar dryer was 1.62 m/s and the average daylight efficiency of the system was 46.7%. The maximum drying air temperatures was found to be 64oC inside the dryer. The weight losses were obtained 80% to55% in the drying of pepper and yam chips, respectively, in the dryer.

EL- Amin Omda Mohamed Akoy *et al.*[36] developed a natural convection solar dryer (Cabinet Type) to dry mango slices. The designed dryer had a collector area of 16.8m2. They dried 195.2 kg of fresh mangoes from 81.4% to 10% wet basis. They dried mangoes in two days under ambient conditions during harvesting period of April to June.

Subarna Maiti *et al*.[71] designed and developed an indirect, natural convection batch-type solar dryer fitted with north-south reflectors. They concluded that with the help of reflectors, the collector efficiency without load was enhanced from 40.0% to 58.5% under peak conditions during a typical day. They dried ‘papad’ a popular Indian wafer with desired extent of drying (ca. 12%, wet basis) which could be achieved within 5 h in this static dryer having 1.8 m2 area of the collector and computed loading capacity of 3.46 kg.

Othieno *et al*.[56], developed an indirect solar maize dryer. The dryer consisted of a single glazed passive solar air heater with 1 $m^2$ single flat-plate collector. The air heater was connected to an insulated drying cabinet equipped with a chimney. The entire dryer assembly was made from hardboard. To improve the efficiency, air heater was modified with a wider air gap (15 cm) to accommodate three layers of wire-mesh absorber between the glazing and the flat-plate absorber. The dryer was capable of drying 90 kg of wet maize from a moisture content of about 20% wet basis to 12% within 3 days on a sunny day.

Vijayakumar *et al.*[47], developed and tested a new type of efficient indirect natural convection solar dryer. In this dryer, the product was loaded beneath the absorber plate, which prevented the problem of discoloration due to irradiation by direct sunlight. Two axial flow fans, provided in the air inlet, were used to accelerate and control the drying rate. They loaded the dryer with 4 kg of bitter gourd having an initial moisture content of 95%, and concluded that the final desired moisture content of 5% was achieved within 6 h without losing the product colour, while it was 11 h for open sun drying.

Ahmed Abed Gatea developed a solar drying system of a cylindrical section and analysis of the performance of the thermal drying system. The system consists of a solar collector flat plate with length of 1.10 m and width of 1.10 m drying chamber cylindrical section and a fan was built and designed for the purpose of drying 70 kg of bean crop. The performance of the solar air collector using three air flow rates has been tested. The highest temperature (71.4°C) of the outlet solar collector has been obtained at 11 am. At radiation intensity 750 W/m² for air flow rate of 0.0401 kg/s was obtained and minimum temperature (40.0°C) was obtained when air flow rate was 0.0675 kg/s at radiation intensity 460 W/m² was obtained. The maximum value of average thermal efficiency 25.64% of the solar air collector obtained at air flow rate of 0.0675 kg/s, and minimum average thermal efficiency is 18.63% at air flow rate of 0.0405 kg/s.The initial moisture content of beans was 70% and final 14% when the air flow rate was 0.0405 kg/s 18% d.b at air flow rate of 0.0540 kg/s and 20% d.b at air flow rate of 0.0765 kg/s.

A solar dryer system has been constructed which consists of double-pass solar collector with finned absorber, the blower, the auxiliary heater and the drying chamber suitable for agricultural and marine products. The collector, drying system and pick-up efficiencies are found to be 35, 27 and 95 %, respectively. This system was developed specially for the drying of seaweed. Open sun drying of seaweed takes 10–14 days to obtain 10 % of final moisture level from 90 % original moisture content. With the solar dryer it is reduced to 15 h.

Sharma *et al*.[1], described the design and performance of an indirect type solar fruit and vegetable dryer developed and the experimental results suggested that even under unfavourable weather conditions, the unit is capable to produce good quality products and low investment required. This solar dryer is applicable for small farm. The performance of indirect passive solar dryers tends to be rather poor because of the low air flow rates which occur through such dryers. Two ways to improve the performance of such dryers are either to use the waste fuel to increase the buoyancy forces by heating the air in a chimney attached or to optimize the gap between the transparent cover and absorber plate of air heating collector.

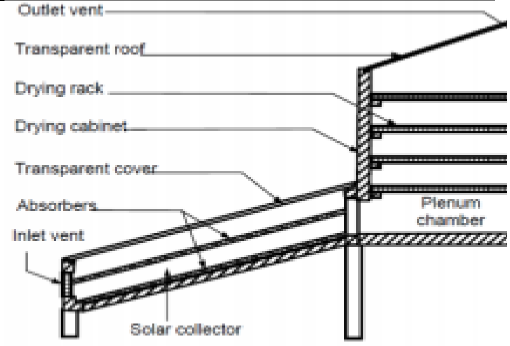
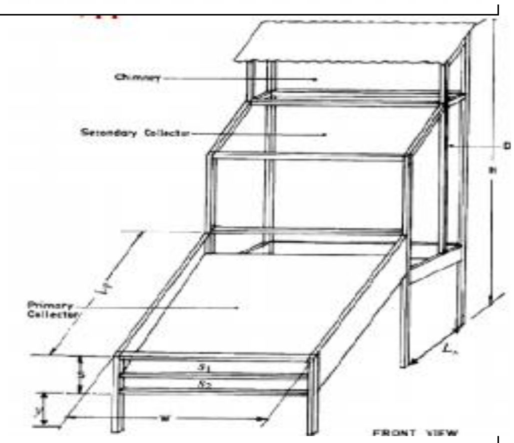
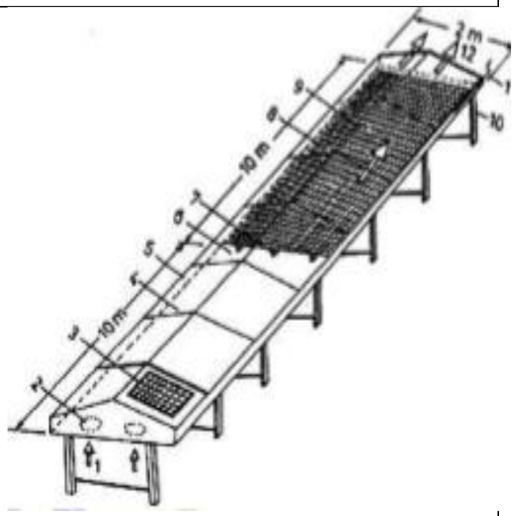
Sreekumar *et al*. [63], developed a new type of efficient solar dryer with two compartment. A detailed performance analysis was done by three methods, namely 1.annualized cost method 2.present worth of annual savings 3.present worth of increasing savings, and the drying cost for 1 kg of bitter gourd was calculated as Rs. 17.52, whereas it was Rs. 41.35, in the case of an electric dryer.

R.K. Aggarwal developed an indirect solar dryer for drying of hill products. The solar dryer of 25kg capacity was attached with a solar cell for running the fan. Bulbs were also provided in the solar collector for heating air during cloudy days, evenings and mornings for faster drying, thereby reducing the drying time. He also compared the market value of the dried products.

Kamlesh Kumar Tekam *et al.*[46], developed a forced convection indirect solar dryer integrated with P.V cells to run the electric fan. The system consisted of two main parts as heat collector unit and food dryer chamber. Electric motor was used to let the smoother air flow in/out of the food drying chamber and was run directly from PV cells. The experiments were performed to dehydrate apples and concluded that the developed system is capable of drying most of the agricultural products. The results were compared with that of open drying and concluded that, solar dryer system resulted in a reduction in the drying time to an extent of 43.46% in comparison to open sun drying.

## 3. MIXED MODE SOLAR DRYER

The mixed-mode solar dryer has no moving parts so it is called the passive dryer. This type of dryer acquires energy from the rays of the sun that enters through the collector lustring. The inside surface of the collector is painted black and the sun rays are harnessed by trapping the heat f the air that is collected inside the chamber. This kind of solar dryer verified the accelerated drying process and its ability to dry agricultural products by quickly reaching better conditional moisture level, thus making it ideal for food preservation. This kind of dryer consists of a separate solar collector and a drying unit. A transparent cover is affixed on top of the dryer, the solar collector, and the drying unit. The collector receives the solar radiation. This kind of dryer is often used for drying crops in the wet season. Comparing the three kinds of dryers, the mixed mode dryer is the best of the three because it has the highest drying rate followed by the box dryer.

| **Author and product** | **Remarks** | **Figure** |
|---|---|---|
| Bukola O. Bolaji and Ayoola P. Olalusi:(2008)<br>Yam chips | The drying rate, collector efficiency and percentage of moist removed (dry basis) for drying yam chips were 0.62 kgh-1, 57.5 and 85.4% respectively. The temperature rise inside the drying cabinet was up to 24o C |  |
| F.K. Forson.et.al (2006) | Collector area of $42.4m^2$ and expected drying efficiency of 12.5%. Under average ambient conditions of 28.2 ℃ and 72.1% relative humidity with solar irradiance of 340.4W/m2, a drying time of 35.5 h was realised and the drying efficiency was evaluated as 12.3%. |  |
| M.A. Hossaina and B.K. Bala (2005)<br>Red chilli | The dryer consists of (1.air inlet 2.fan;3.solar module;4.solar collector;5.side metal frame;6.outlet of the Collector7.wooden support; 8.plastic net; 9.roof structure 10.base structure for supporting The dryer;11.rolling bar; 12,outlet of the drying tunnel).Moisture content was reduced from 2.85to 0.05 kg/kg(db) in 20 h. |  |
| | | |

**Review of literature**

Bukola O. Bolaji and Ayoola P. Olalusi[21] Developed a simple and inexpensive mixed mode solar dry locally source materials. The temperature rise inside the drying cabinet was up to 24℃ (74%) for a hours immediately after 12.00 h(noon). The drying rate, collector efficiency and percentage of moist removed (dry basis) for drying yam chips were 0.62 kgh-1, 57.5 and 85.4% respectively. The dryer sufficient ability to dry food items reasonably rapidly to a safe moisture level and simultaneously it superior quality of the dried product.

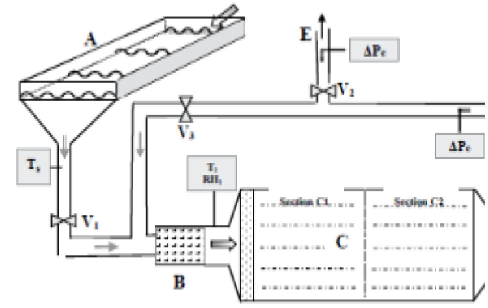
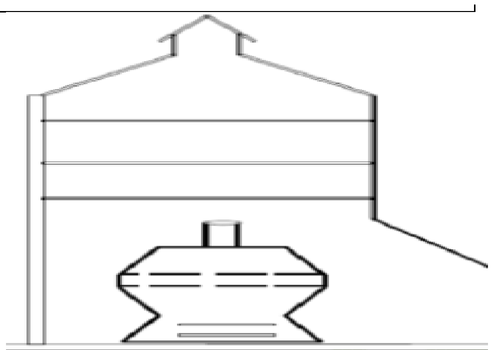
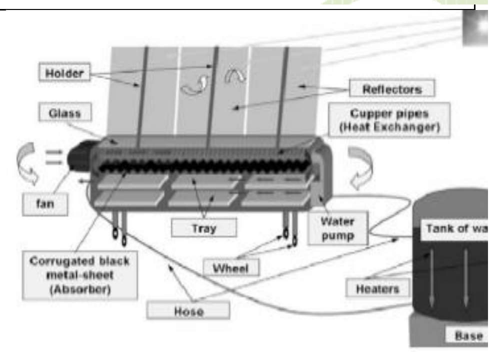
M.A. Hossaina and B.K. Bala Designed and developed A Mixed mode type forced convection solar tunnel drier to dry hot red and green chillies under the tropical weather conditions of Bangladesh.The dryer consists of (1.air inlet 2.fan;3.solar module;4.solar collector;5.side metal frame;6.outlet of the Collector7.wooden support; 8.plastic net; 9.roof structure for supporting the plastic cover; 10.base structure for supporting The dryer;11.rolling bar; 12,outlet of the drying tunnel.) Moisture content of red chilli was reduced from 2.85to 0.05 kg/kg(db) in 20 h in solar tunnel drier and it took 32 h to reduce the moisture content to 0.09 and 0.40 kg/kg (db) in improved and conventional sun drying methods, respectively.

(F.K. Forson,M.A.A. Nazha, F.O. Akuffo,H.Rajakaruna 2006 Designed a mixed -mode natural convection solar crop dryer (MNCSCD) for drying cassava and other crops. A batch of cassava 160 kg by mass, having an initial moisture content of 67% wet basis from which 100 kg of water is required to be removed to have it dried to a desired moisture content of 17% wet basis, is used as the drying load in designing the dryer. A drying time of 30–36 h is assumed for the anticipated test location (Kumasi; 6.71N, 1.61W) with an expected average solar irradiance of 400W/m2 and ambient conditions of 25 1C and 77.8% relative humidity. They concluded that a minimum of 42.4m2 of solar collection area, according to the design, is required for an expected drying efficiency of 12.5%. Under average ambient conditions of 28.2 1C and 72.1% relative humidity with solar irradiance of 340.4W/m2, a drying time of 35.5 h was realised and the drying efficiency was evaluated as 12.3% when tested under full designed load signifying that the design procedure proposed is sufficiently

## 4. HYBRID DRYER

In these dryers, although the sun is used to dry products, other technologies are also used to cause air movement in the dryers. For example, fans powered by solar PV can be used in these types of dryers.

| Author and product | Remarks | Figure |
|---|---|---|
| A.G.Ferreira *et al* (2007)<br>Banana slices | The dryer has 1.50 m of length, 1.20 m of width and 0.20 m of internal height. The drying chamber has 0.90 m of length, 1.20m of width and 0.96 m of height. The auxiliary heating system is composed of 20 incandescent lamps of 100 W each. Diameter chimney was 0.20 m, Eight trays (0.74 m x 0.52 m) were put inside the drying chamber, corresponding to an area of 3.08 m 2 .+ |  |

| | | |
|---|---|---|
| Reyes A *et al* (2014) Tomato | Dryer has 3 m2 solar panel and electric resistances. At the outlet of the tray dryer 80 or 90% of the air was recycled and the air temperature was adjusted 50 or 60ºC. The solar energy input resulted in 6.6-12.5% energy saving. |   Figure Hybrid-solar dryer. A. Solar panel; B. Electrical heate drying; D. Centrifugal fan; E. Exit air. $V_i$. Valves. |
| Okoroigwe E. C. *et al* (2013) Yam chips | Maximum tray temperature of 53°C. An optimal drying rate of 0.0142 kg/hr was achieved with the combined solar and biomass dryer, compared to the lower drying rate of 0.00732 kg/h for the solar drying and 0.0032 kg/h for the biomass drying. |  |
| B.M.A Amer *et.al* (2010) Banana slices | The efficiency of the solar dryer was raised by recycling about 65% of the drying air in the solar dryer. The capacity of the dryer was to dry 30 kg of banana slices in 8 h in sunny day from moisture content of 82% to t 18% (wb). |   |
| Saravanan *et al* Cashew nut | The system is capable of attaining drying temperature between 50º and 70ºC. Moisture content reduced from9% to 3% is achieved within 7 hours and the average system efficiency is estimated as 5.08%. |  |
| | | |
| | | |

**Review of literature**

Alejandro Reyes, *et, al.*, Evaluated the performance of the hybrid solar dryer using the fuzzy logic control system, 8-mm mushroom slices were dehydrated using only solar energy. Initial load was 15 (kg) and the drying period was 11 hours, diminishing the moisture content from 93% to 6%.

Amer *et al.*[24], A hybrid solar dryer was designed and developed using direct solar energy and a heat exchanger for drying ripe banana slices. The drying chamber is located under the collector. During sunny days, the dryer operates as a solar dryer and stores heat energy in water, whereas during days with less sunlight, the dryer works as a hybrid solar dryer. At night, the heat energy stored in water is used to continue drying, with electric heaters in the water tank supplying sufficient heat as backup energy. The dryer efficiency was improved by recycling approximately 65% of the drying air in the dryer system. The air temperature could increase from 30 °C to40°C above the ambient temperature.

Reyes A *et al.*[4], developed a hybrid solar dryer for drying tomato. Tomato pieces were dehydrated in a hybrid solar dryer provided with a 3 $m^2$ solar panel and electric resistances. At the outlet of the tray dryer 80 or 90% of the air was recycled and the air temperature was adjusted 50 or 60ºC. At the outlet of the solar panel the air temperature raised between 5 and 18°C above the ambient temperature. The solar energy input resulted in 6.6-12.5% energy saving.

A. G. Ferreira *et al*., developed a hybrid solar-electrical dryer was built, composed of a solar chamber (in which the air is heated) and of a drying chamber (Fig.). The solar chamber is inclined at 30° from horizontal, opened at its edges, with 1.50 m of length, 1.20 m of width and 0.20 m of internal height. The walls of the solar collector were built with galvanized steel plates, painted in black, thermally insulated with wool glass and covered with galvanized steel plates painted in grey. The solar chamber is covered with glass. The drying chamber has 0.90 m of length, 1.20m of width and 0.96 m of height. It was built using galvanized steel plates, thermally insulated with wool glass and covered with galvanized steel plates painted in grey. To complement solar heating, an auxiliary heating system was installed on the bottom of the drying chamber. The auxiliary heating system is composed of 20 incandescent lamps of 100 W each. To allow the drying air exit, a 0.20 m diameter chimney (with an exhauster) was installed on the top of the dryer. Eight trays (0.74 m x 0.52 m) were put inside the drying chamber, corresponding to an area of 3.08 $m^2$.

Saravanan *et al*. designed and fabricated a hybrid dryer consisting of a solar flat plate collector, a biomass heater and a drying chamber. 40 kg of Cashew nut with initial moisture of 9 % is used in the experiment. The performance test of the dryer is carried out in two modes of operation: hybrid-forced convection and hybrid-natural convection. Drying time and drying efficiency during these two modes of operation are estimated and compared with the sun drying. The system is capable of attaining drying temperature between 50º and 70ºC. In the hybrid forced drying, the required moisture content of 3% is achieved within 7 hours and the average system efficiency is estimated as 5.08%. In the hybrid natural drying, the required moisture content is obtained in 9 hours and the average system efficiency is 3.17%. The fuel consumption during the drying process is 0.5 kg/hr and 0.75 kg/hr for forced mode and natural mode, respectively.

Yahya *et al*.[77] have developed a solar dehumidification system for medicinal herbs has been developed. The system consisted of a solar collector, an energy storage tank and auxiliary heater, water to air heat exchanger, a water circulating pump, drying chamber, and adsorbent. It was made up of essentially three processes, namely regeneration, dehumidification, and batch drying. The relative humidity and temperature of the drying chamber were 40% and 35°C respectively.

**Dryers with heat storage material**

Principle

The material absorbs the available heat from the atmosphere when the ambient temperature reaches above the transition temperature. Similarly, it emits the same heat to the atmosphere when the ambient temperature falls below the transition temperature, thereby, maintain the ambient temperature equal (±1oC) to the transition temperature.

Classification of heat storage material

There are various techniques for storing solar energy in the form of sensible and latent heat. Thermal energy storage increases the reliability and hours of operation of a solar dryer.The heat storage capacity of a material depends on its latent and specific heat values. These values should be as high as possible to minimise the physical size of the heat storage[3].

A.Sensible heat storage

In sensible heat storage (SHS), thermal energy is stored by raising the temperature of a liquid or solid. These systems utilise the heat capacity of the material. The temperature of the material increases during charging and decreases during discharging.

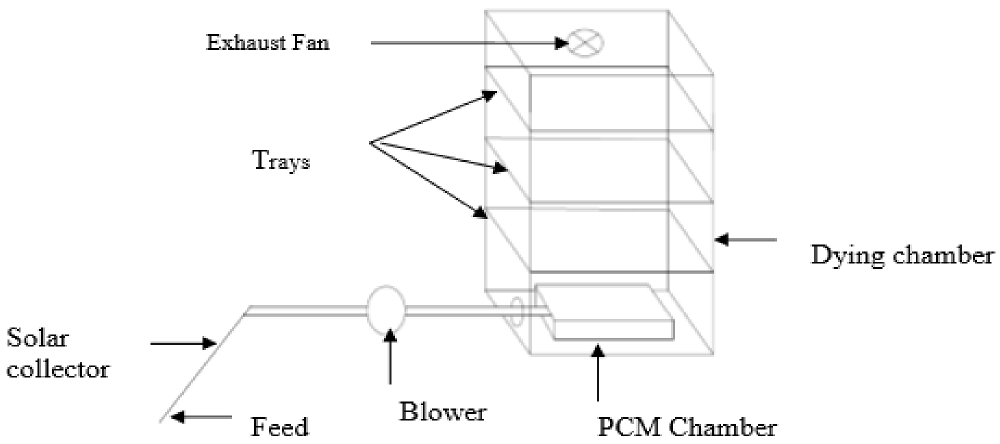
Ex; Water, rock, brick, concrete and engine oil

B.Latent heat storage

Latent heat storage (LHS) is based on the absorption or release of latent heat at a constant temperature when a storage material undergoes a change of phase from solid to liquid, liquid to gas or vice versa.

Ex; paraffins, non-paraffins, hydrate salts, eutectics, etc.

Aiswarya .M.S[6]. developed a solar dryer with PCM chamber, it consist of an inclined solar air heater with PCM located inside the drying chamber. The blower delivers a constant air mass flow rate to the drying chamber. The air passes through the solar air heater which heats the air and the heated air is allowed to flow into the drying chamber. When the air in the heater gets heated up and reaches the critical point of PCM they will melt and charging takes place. When the sunlight is not abundant the air temperature flowing inside the heater will reduce and thus the PCM will starts to freeze and thus discharging takes place. During discharging the PCM will freeze slowly and thus the dryer will get heat air for a longer time. The heated air from the air heater flows through a drying chamber whose walls are coated with aluminium paint to avoid heat losses. Inside the chamber there is a tray in which the products to be dried are held. Due to the movement of heated air over the trays the products gets dried.




| Type Heat storage material | Type of dryer | Remarks | References |
|---|---|---|---|
| Rock bed, | Solar collector-cum-rock bed storage system. | The drying time ranged from 22 to 25h to reduce the moisture content from 20% to the safe storage moisture level with an air flow rate of 4.9m3/s. | Butler and Troeger (1980) |
| in-built thermal storage | Inclined multi-pass solar air heater | A drastic drop in grain temperature with an increase in mass flow rate from 0.014 to 0.042kg/s. However, by increasing the mass flow rate beyond 0.042kg/s, only a little drop in grain temperature was observed. | Dilip and Jain (2004) |
| Black painted gravel | forced convection solar dryer | Moisture content from 53.4% to 3.6% (wb) in a 72h. ambient temperature and relative humidity in the range 25–30◦C and 58–98%, respectively | Fagunwa, Koya, and Faborode (2009) |

| | | | |
|---|---|---|---|
| rock bed storage (granite) | Solar dryer. | The solar collector is capable of transferring118W/m2 and air temperature of 32◦C. system stores 1.1kW/hr energy to enhance drying. The efficiency of the solar collector is 22%. | Ayensu and Asiedu-Bondzie (1986) |
| rock pebbles | Inclined solar air heater | Drying time and drying rate of tomato, onion, pepper, okra and spinach were 14, 15, 12, 11 and 1h, and 0.20, 0.020, 0.21, 0.22 and 0.77kg/h, respectively. The collector efficiency was 45% and the useful heat of heat storage was 48.9W/m2K. . The heat was utilised at night about 6h. | Babagana,Silas,andMustafa (2012) |
| Crushed basalt rocks | Tilted double-pass natural convection solar tunnel air heater. | Moisture reduced from 95% to 9% in 5 days. The reduction in drying time was between 30% and 50%. | Berinyuy,et.al (2012) |
| Mixture of sand and aluminium scraps | flat plate forced convection solar dryer | About 75% of high-quality copra could be produced. The average thermal efficiency of system about 24%. | Mohanraj and Chandrasekar (2008) |
| Sand | Natural convection solar dryer | The system has capacity of 10kg and chemically treated grapes or green peas dried during 20h of sunshine. The results showed that the maximum temperature in the drying chamber was about 60◦C. | El-Sebaii et al. (2002) |
| Sand | Solar tunnel dryer | The dryer reduces the moisture content of copra from 52%(wb) to 7.2% (wb) in 52h. Maximum inside temperature is 61℃. . | Ayyappan and Mayilsamy (2010) |
| Paraffin | Natural convention solar air heater | The peak cumulative efficiency and temperature rise were 50% and 15K. The maximum predicted cumulative useful and overall efficiencies of the system were within the range of 2.5–13 and 7.5–18%, respectively. | Enibe (2002) |
| Paraffin wax | Solar dryer | Performance of the solar dryer was considerably improved by heat storage and drying was possible at steady and moderate temperatures of 40–75◦C. | Lalit et.al.(2011) |
| Paraffin | solar dryer | Average time for drying 1kg of grape from 87.9% (wb) to 14% (wb) was 6 days. The average heat storage and instantaneous efficiency of the collector were 66% and 56%, respectively. | Song et al. (2011) |
| magnesium chloride | Solar air heater | System is capable to supply hot air at 80◦C for more than 4h with a temperature gradient of air 30◦C. | Arunasalam, Srivatsa, and Senthil (2012) |
| Calcium chloride hexahydrate | Novel solar dryer | The dryer reduced the moisture content of seeded grape from 3 to 0.09kg water/kg dry matter in 56h with an air velocity of 1.5m/s. | Cakmak and Yıldız(2011) |

| | | | |
|---|---|---|---|
| Paraffin | solar drying system | During the experiments velocity and temperature of air ranged between 1–2m/s and 70–90◦C respectively. Energy extractable from the LHS between 1920 and 1386kJmin/kg and the energy savings between 40% and 34% at air velocity of 1 and 2m/s, respectively. | Devahastin and Pitaksuriyarat (2006) |
| Water | Hybrid solar dryer | Drying air temperature rose from 25◦C to 35◦C above the ambient air. Using the water tank with the solar dryer, about 15◦C can be stored. | Amer et al. (2006). |
| Water | Solar kiln dryer | The storage system gives a gain in drying time of 50h during the month of April, 62h during August and 65h during December, which gives around 30% as an average save in the drying time. | Luna, Nadeau, and Jannot (2010) |
| Thermic oil | Agro solar dryer | Temperature maintained 65±3◦C in the drying chamber and length of operation of the solar dryer increased by 1–2h. The drying efficiency of the solar dryer for chillies is 21%. The drying period in the solar dryer was decreased by 40%. | Potdukhe and Thombre (2008) |
| desiccant bed | Indirect forced convection solar dryer | Drying time reduces by 10–12h, and rise in temperature about 10◦C. | Shanmugam and Natarajan (2007) |

**Review of literature**

M A Bek *et al.*, The Nerium Oleander was dried at its prescribed drying temperature (50±2.5ºC) in indirect solar dryer (ISD) using phase change material (PCM) as energy storage medium. 12 kg of paraffin wax were used as a latent heat thermal storage. From the experimental obtained results it is found that the ISD implementing PCM as thermal storage medium successfully maintains the temperature of drying air around 50 ºC for seven consecutive hour. It is also found that the temperature of drying air is higher than ambient temperature by 2.5-5 ºC after sunset for 5 hrs at least. This profile of the temperature of drying air helps reaching the final moisture content of Nerium Oleander after 14 hour

Tarigan and Tekasakul[73]. Reported on a natural convection solar dryer combined with a burner and bricks for heat storage as back-up energy. The dryer capacity is about 60 kg to 65 kg of unshelled fresh groundnuts. The drying efficiency of using solar energy and a burner with heat storage is 23% and 40%, respectively. The acceptable thermal efficiency and uniform drying air temperature through the trays are due to the insulation and gap enclosing the drying chamber and bricks that store heat.

M. Mohanraj *et al.*[50], developed an indirect forced convection solar dryer incorporated with sensible heat storage material for drying chilies. They concluded that the dryer integrated with heat storage material enables it to maintain a consistent air temperature inside the dryer. The chilli was dried from an initial moisture content of 72.8% to the final moisture content of about 9.2% in the bottom tray and about 9.7% (wet basis) in the top tray. The inclusion of heat storage material (Gravel) also increases the drying time by about 4 hours per day. They estimated the thermal efficiency of solar dryer to be about 21% and specific moisture extraction rate to be about 0.87 kg/kWh.

Gutti Babagana *et al.*[16], designed and constructed forced/natural convection solar vegetable dryer with heat storage and compared their performances. The collector efficiency was 45% and the useful heat of 48.9 W/m2K was used for about 6 hours in drying even during the night because of heat storage system. They observed that when using the forced convection mode, the drying time of tomato, onion, pepper, okra and spinach were 14 hrs, 15 hrs, 12 hrs, 11 hrs and 1 hr respectively, and when using the natural convection mode, the drying times were 24 hrs, 27 hrs, 25 hrs, 21 hrs and 2 hrs respectively. It was concluded that the forced convection system has higher drying capabilities as compared to natural convection system.

R. Velraj *et al*.[62], Developed a phase change material based thermal storage system for heating air used in a dryer. They used HS 58, an inorganic salt based phase change material to store excess heat which was then recovered during off sunshine hours. It is observed that at high mass flow rates, the collector efficiency is also higher due to the reduction in heat losses. They also observed that by selection of the phase change material with suitable phase change temperature, avoids overheating of air during the peak sunshine hours, thereby, avoiding the spoilage of food products due to excessive heating. They concluded that by supplying air at lower mass flow rate during the discharging process, maximum capacity of the storage system can be utilized and uniform supply of heat for a longer duration of time during off sunshine hours can be achieved.

**Fruits and vegetables**

Fruits and vegetables are essential food items as they play a vital role in the diet of humans. Fresh fruits and vegetables are highly perishable and bulky commodities because they contain high moisture. Hence, their transportation to distant places is costly and their condition on arrival in the importing country may be less than satisfactory. Postharvest loss of fruits and vegetables is very high. This could be due to their perishable nature, poor postharvest handling and lack of cheap and appropriate postharvest technology. Hence, much effort is needed in the area of generating efficient, low-cost, indigenous technology that minimizes postharvest loss of fruits and vegetables. One of these methods is to produce local value-added products through the development of micro- and small-scale agro-industries. Solar drying of fruits is one of such agro-industries that can enhance the shelf life of fruits and vegetables. Fruits and vegetables are dried to enhance storage stability, minimize packaging requirement and reduce transport weight. Preservation of fruits and vegetables through drying based on sun and solar drying techniques which cause poor quality and product contamination. Energy consumption and quality of dried products are critical parameters in the selection of drying process[76]. Vegetables and fruits are agricultural products that are known for their rich vitamins, high concentration of moisture and low fats. These are seasonal crops and are mostly available during the production season. The demand for vegetables by the growing population has not been met despite the increase. This is as a result of wastes that result from biological and biochemical activities taking place in the fresh product and unfavourable storage conditions, inefficient handling, transportation, inadequate post-harvest infrastructure and poor market outlets. Sun drying is still the most common method used to preserve agricultural products like grains and vegetables in most tropical and subtropical countries. The size and shape are also important parameters in the drying of fruits and vegetables. It is safe to note that most fruits and vegetables are dried using the thin-layer concept which means that the size of the material is reduced to dimensions that will enable uniform distribution of the drying air and temperature over the material. The shape factor is integrated into the kinetics models of drying to reduce the effect of product shape on the drying process[59].The various conditions affecting the drying of fruits and vegetables include air velocity, drying temperature, size and shape of the material, and the relative humidity. Amongst these conditions, the most influential in terms of drying fruits and vegetables are drying temperature and material thickness[59].

Many of the third world countries produce large quantities of fruits and vegetables for local consumption and export. According to the Food and Agricultural Organization, the estimates for 1990 were approximately 341.9 million metric tons. In Asia, India produces 27.8 million metric tons or 8.1%, while China has a production capacity of 21.5 million metric tons or 6.3% of the total world production. Many of these fruits and vegetables contain a large quantity of initial moisture content and are therefore highly susceptible to rapid quality degradation, even to the extent of spoilage, if not kept in thermally controlled storage facilities. Therefore, it is imperative that, besides employing reliable storage systems, postharvest methods such as drying can be implemented hand-in-hand to convert these perishable products into more stabilized products that can be kept under a minimal controlled environment for an extended period of time.

| **Fruits and vegetables** | | | |
|---|---|---|---|
| Products | Types dryer | Remarks | References |
| Tapioca | Direct natural convection solar dryer | The moisture content reduced from 79 % to 10 % (wb). The temperature 32ºC and 74 % RH with solar radiation of 13 MJ/m2/day. | Diemuodeke E. Ogheneruona *et. al* 2011 |
| Onion slices | forced convection dryer with recirculation of air | The moisture content reduced from 86% to 7% for this energy required is 12.040 & 38.77MJ/kg of water. | P.N. Sarsavadia 2007 |
| Sliced pineapple | roof-integrated solar air heating system | It took 8 hours to dry 200 kg, from moisture content 82% to 10%. | A.Sreekumar.2010 |
| Pepper and yam chips, | solar wind-ventilated cabinet dryer, | Air velocity, maximum temperature and daylight efficiency was 1.62 m/s, 64℃ and 46.7% respectively. The weight loss was from 80% to55%. | Bukola O. Bolaji.et.al.2008 |
| Fresh mango slices | Natural convection solar dryer (Cabinet Type) | They dried 195.2 kg from moisture content 81.4% to 10% (wet basis). | EL- Amin Omda Mohamed Akoy et al |
| Papad | Indirect, natural convection batch-type solar dryer with reflectors | Achieved collector efficiency from 40.0% to 58.5% and moisture content 12% (wet basis) within 5 h. | Subarna Maiti *et al*.(2011) |
| | | | |
| Bitter guard | Efficient indirect natural convection solar dryer. | Achieved moisture content from 95% to 5% within 6 h with 4kg capacity. | K.P. Vijayakumar *et al*.(2008) |
| Beans | Solar drying system of a cylindrical section | Moisture content reduced from 70% to14% at air flow rate 0.0405 kg/s. | Ahmed Abed Gatea (2010) |
| Seaweed | A solar dryer of double-pass solar collector with finned absorber, | The collector, drying system and pick-up efficiencies are found to be 35, 27 and 95 %, respectively. It reduces moisture from 90 % to 10 % in 15 h. | Fudholi *et al*. (2011) |
| Apple | Forced convection indirect solar dryer integrated with P.V cells. | System was resulted in 43.46% reduction in the drying time in comparison to open sun drying. | Kamlesh Kumar Tekam *et al*.(2013) |
| Yam chips | Mixed mode solar dryer | Drying rate, collector efficiency and percentage of moist removed (dry basis) for drying yam chips were 0.62 kgh-1, 57.5 and 85.4% respectively. | Bukola O. Bolaji and Ayoola P. Olalusi.2008 |
| Red chilli | A Mixed mode | Moisture content was reduced from 2.85 to 0.05 kg/kg(db) in | M.A. Hossaina and |

| | | | |
|---|---|---|---|
| | type forced convection solar tunnel drier | 20 h. | B.K. Bala (2005) |
| Mushroom slices | Hybrid solar dryer | Moisture content reduced from 93% to 6% in 11 h of 15 kg capacity. | Alejandro Reyes, et, al (2013) |
| Plums | A solar dryer | The initial moisture content of plums was 80%, reaching a 71% after 10 hours of drying | Alejandro Reyes, et al.(2014) |
| Grapes | Indirect forced convection solar drier integrated with recirculation of air. | Moisture content reduced from 80% to 10.6% (wb) in 22.6h at air flow rate of 3.197kg/s and drier efficiency was 20.92%. | C.Velmurugan, et, al.(2013) |
| Banana slices | A hybrid solar dryer | Moisture reduced from 82% to 18% (wb) within 8 h during a sunny day. | Amer et al.(2006) |
| Grapes, apricots and beans | Indirect-mode forced dryer | The moisture content of apricot, grapes and beans were reduced from 80% to 13% in $1\frac{1}{2}$day, 80% to 18% in $2\frac{1}{2}$ days and 65% to 18% in 1 day respectively. | Al-Juamily et al |
| Red and green chillies | Mixed mode type forced convection solar tunnel drier | Moisture content of red chilli was reduced from 2.85to 0.05 kg/kg(db) in 20 h. | J. Banout, et, al.(2010) |
| **Grains** | | | |
| Corn | In -bin corn dryer | Airflow supplied at a rate of 2.1 m3/min. Saving of 30% in fuel consumption can be achieved under corn loading of 1.28 ton at 50°C with air flow rate of 1526.8 m3/day. | Santos et al. (2005) |
| Maize | Indirect solar maize dryer. | They dried 90 kg from moisture content 20% to 12% in a 3 sunny days. | Othieno *et al*.1981 |
| Paddy | Oscillating bed solar dryer | Increment in temperature was 5.7°C – 13.2°C. Maximum pick-up efficiency and thermal efficiency were 72.3% and 35.3%respectively. Non parboiled paddy of 36kg dried in 1 day. | Kumar et al. (2011) |
| **Nuts** | | | |
| Pistachio nuts | Solar dryer | The dryer has drying capacity of 25 kg/m2 moisture content reduced from 40% to 6.0% in 36 h. Maximum temperature was recorded as 56°C inside the chamber. | Ghazanfari et al. (2003) |
| Ground nuts | Solar dryer | Moisture content reduced from 135% to 13% d.b.. However, it took about 3 days to dry 64 kg of groundnuts. The system efficiency was found to be 23%. | Tarigan and Tekasakul, (2005) |
| Cashew nut | solar cabinet dryer | Dryer was able to heat up the ambient air from 27.2°C to 78.7°C. Average drying efficiency was 64% as compared to sun drying at 39.7%. | Mursalim et al. (2002) |
| **Sericulture products** | | | |
| Silk worm pupae | solar dehydrator | When 16 kg silk worm pupae was loaded in the dryer loss of 70% moisture in 10 solar hours. The maximum and minimum RH values are 90.59% and 30.09 % respectively. Moisture removed at the rate of 0.70 $H_2O$/kg, and the maximum temperature is 61.79°C. | Y. Sujatha et.al (2016) |
| Silk worm pupae | Solar tunnel dryer | Moisture content reduced from 3.70 kg $H_2O$ $kg^{-1}$ dry matter to 0.20 kg $H_2O$ $kg^{-1}$ dry matter in 570 min at an air flow rate of 0.30 kg $s^{-1}$ and drying time was reduced by about 40%. Maximum drying and overall efficiencies were 30.14% and 19.68%, respectively. | Tawon Usub,et.al (2010) |
| Thin layer silk cocoon | Convective solar dryer | Drying time was decreased with the drying mass flow rate. The effective moisture diffusivity of mulberry was observed to vary between 3.47 × 10−12 and –1.46×10−9 m2 s−1 within the mass flow rate range of 0.0015–0.036 kg/ s. | Akbulut and Durmus (2009) |

## CONCLUSION

Solar drying of agricultural products is one of most important potential application of solar energy. In developing countries it is estimated about 30 to 40% of production of fruits and vegetables are losses during drying. The postharvest losses of agricultural products in the rural areas of the developing countries can be reduced drastically by using well-designed solar drying systems. Use of heat storage material in drying system will improve the efficiency of dryer and also dryer can be used after sunshine hours. Farmers should use solar dryers for drying their own agro produce and the use of solar dryers should be promoted by the respective Government authorities in the particular country. If we think of raisins production in India, still the 95% of the raisins are produced by the traditional open sun drying and shed drying, this inferior quality produce can be overtaken by superior quality produce by solar dryers. But to happen so, some steps should be taken to aware the farmers about the use solar dryers for their own fruits and vegetables produce.

**Future scenario**

The different type of solar dryers are designed and developed for drying of agricultural product, but those are solar dependable, works during sunshine hours for that reason, incorporating of sensible or latent heat storage material within the solar drying system to accelerate the drying process during night time and low intensity solar radiation periods. The latent heat storage media preferable compared to sensible heat storage because it achieve constant drying air temperature during drying.

## REFERENCES

1. Arata, A., Sharma, V.K., Spagna, G., Performance evaluation of solar assisted dryers for low temperature drying application-II Experimental results. Energy Convers Manage. **34(5):** 417–426. doi: 10.1016/0196-8904(93)90091-N. (1993).
2. Akbulut, A., Durmus, A., Thin layer solar drying and mathematical modelling of mulberry. *International Journal of Energy Resources* **33:** 687–95 (2009).
3. Abhat, A., Low Temperature Latent Heat Thermal Energy Storage: Heat Storage Materials. *Solar Energy*, **30:** 313-332 (1983).
4. A Reyes , Mahn, A., Cubillos, F., Huenulaf, P., Mushroom dehydration in a hybrid solar-dryer. Energy Conversion Management **70:** 31-39 (2013).
5. A Reyes , Mahn, A., Huenulaf, P., González, T., Tomato Dehydration in a Hybrid-Solar Dryer. *J Chem Eng Process Technol* 5: 196. doi: 10.4172/2157-7048.1000196 (2014).
6. Aiswarya, M.S., International Journal of Science and Engineering Volume 3, Special Number ICRAESM - 2015 PP: 124-134 (2015).
7. Ahmed AbedGatea. Design and construction of a solar drying system, a cylindrical section and analysis of the performance of the thermal drying system. Department of Agricultural Mechanization, College of Agriculture, University of Baghdad, Iraq, July (2010).
8. Fudholi, K., Sopian, M.H., Ruslan, M.A., Alghoul, M.Y., Sulaiman., Review of solar dryers for agricultural and marine products. Renewable and Sustainable Energy Reviews**. 14:** 1-30 (2010).
9. Augustus Leon, M., Kumar, S. and BhattacharyaA, S.C., comprehensive procedure for performance evaluation of solar food dryers. *Renewable and Sustainable Energy Reviews,* **6:** 367-393
10. El-Sebaii, A.A., Shalaby, S.M., Experimental investigation of an indirect-mode forced convection solar dryer for drying thymus and mint. Energy Conversion and Management. **74:** 109-116 (2013).
11. Ahmed Abed Gatea Performance evaluation of a mixed-mode solar dryer for evaporating moisture in beans. Journal of Agricultural Biotechnology and Sustainable Development. **3(4):** 65-71 (2011).

12. Arunasalam, A., Srivatsa, B. and Senthil, R., “ThermalPerformanceAnalysisonSolarIntegratedCollectorStorage.” UARJ **1(2):** 2278–1129 (2012).
13. Amer, B. A. A., Gottschalk, K. and Hahn, J., “New Design for Constructing a Proto-Type of Solar Dryer. In Paper presented at the 15th International Drying Symposium, Szent Istvan University, Budapest, Hungary,August 20–23, edited by I. Farkas,Vol. B, pp. 790–796 (2006).
14. Ayensu, A., and Asiedu-Bondzie, V., “SolarDryingwithConvectiveSelf Flow and Energy Storage.”Solar and Wind Technology **3(4):** 273–279 (1986).
15. 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, (FMFP10), IIT Madras, Chennai, India, NE–06, 1–10 (2010).
16. Babagana, G., Silas, K. and Mustafa, B.G. “DesignandConstructionofForced/Natural ConvectionSolarVegetable Dryer with Heat Storage.” *ARPN Journal of Engineering and Applied Sciences* **7(10):** 1213–1217 (2012).
17. Berinyuy, J.E., Tangka, J.K., and G.M., WekaFotso. “Enhancing Natural Convection Solar Drying of High Moisture Vegetables with Heat Storage.” *Agricultural Engineering International: CIGR Journal* **14(1):** 141–148 (2012).
18. Butler, J. L., and Troeger, J. M., Drying Peanuts Using Solar Energy Stored in a Rock bed. Agricultural Energy, Vol. I, Solar Energy, Selected Papers and Abstracts. St Joseph, MI: ASAE Publication. (1980).
19. Ben Akachukwu *et al.,* Agric Eng Int: CIGR Journal Open access at http://www.cigrjournal.org Vol. 16, No.1 (2014).
20. Bala1*, B.K. and Serm Janjai2 Stewart Postharvest Review An international journal for reviews in postharvest biology and technology © Stewart Postharvest Solutions (UK) Ltd. Online ISSN:1945-9656 www.stewartpostharvest.com Solar drying of agricultural products (2013).
21. Bukola, O. Bolaji and Ayoola P. Olalusi., AU J.T. **11(4):** 225-231 (2008).
22. Bennamoun, L, Belhamri, A. Design and simulation of a solar dryer for agriculture products. J Food Eng **59(2–3):** 259–66 (2003).
23. Banout, J., Havlik, J., Kulik, M., Kloucek, P., Lojka, B., Effect of solar drying on the composition of essential oil of sacha culantro (Eryngium foetidum L) grown in the peruvian amazon. *J Food Process Eng* **33:** 83-103 (2010).
24. Amer, B.M.A., Hossain, M.A., and Gottschalk, K., “Design and performance evaluation of a new hybrid solar dryer for banana,” Energy Conversion and Management **51(2010):** 813–820 (2010).
25. Bala, B.K., Mondol, M.R.A. and Das Choudhury, B.L., Solar drying of mango using solar tunnel drier. *Journal of Agricultural Engineering* **38(14):** (2002).
26. Cakmak, G. and Yıldız, C., “TheDryingKineticsofSeededGrapeinSolar DryerwithPCM-Based Solar Integrated Collector.” *Food and Bio products Processing* **89(2):** 103–1108 (2011).
27. Ertekin' , C., Yaldiz , O., Journal of Food Engineering Drying of eggplant and selection of a suitable thin layer drying model Volume 63, Issue 3, August, Pages 349–359 (2004).
28. Velmurugan, C., Sivakumar, S., Ashwin Bala, N., Kumar, H. and Prithviraj, S., Experimental & Analytical Investigation on Modified Solar Dryer with Recirculation of AirInternational *Journal of Engineering Research and Technology*. ISSN 0974-3154 Volume 6, Number 4 (2013), pp. 441-448 (2013).
29. Devahastin, S., and Pitaksuriyarat, S., “UseofLatentHeatStoragetoConserveEnergyDuringDryinganditsEffect on Drying Kinetics of a Food Product.” Applied Thermal Engineering **26 (14–15):** 1705–1713 (2006).

30. Dilip, J. and Jain, R.K., "Performance Evaluation of an Inclined Multi-Pass Solar Air Heater within-Built Thermal Storage on Deep-Bed Drying Application." *Journal of Food Engineering* **65(4):** 497–509 (2004).
31. 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 ISSN 1583- 1078; Issue 18, January-June p. 95- 104 (2011).
32. Enibe, S. O., "Performance of a Natural Circulation SolarAir Heating System with Phase Change Material Energy Storage." Renewable Energy **27:** 69–86. Environmental Process Systems Ltd.Accessed on June 21, 2014( 2002).
33. Ertekin˙, C. and Yaldiz, O., Drying of eggplant and selection of a suitable thin layer drying model Journal of Food Engineering Volume 63, Issue 3, August 2004, Pages 349–359 (2004).
34. Esper, A. and Muhlbauer, W., Solar tunnel dryer. *Plant Res. And development*, **44(4):** 16- 64 (1996).
35. Ezekwe, C.I., Crop drying with solar air heaters in tropical Nigeria. ISES, Solar World Forum, Brighton, UK. Oxford: Pergamon Press; p. 997– 1005 (1981).
36. 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.
37. Ekechukwu, O.V., Review of solar-energy drying systems—I: an overview of drying principles and theory. *Energy Convers Manage* **40(6):** 593–613 (1999).
38. Forson, F.K., Nazha, M.A.A., Akuffo, F.O., Rajakaruna, H., Design of mixedmode natural convection solar crop dryers: Application of principles and rules of thumb; Department of Mechanical Engineering, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana Department of Mechanical Engineering, De Montfort University, Queens Building, Leicester LE1 9BH, UK; Renewable Energy 32 (2007) 2306–2319; Received 9 August 2006; accepted 15 December 2006 Available online 22 February (2007).
39. Ghazanfari, A., Tabil Jr, L., Sokhansaj, S., , Evaluating a Solar Dryer for In-Shell Dry-ing of Split Pistachio Nuts, Drying Technology, **21(7):** pp. 1357-1368 (2003).
40. Hossain, M.A., Bala, B.K. and Woods, J.L., Simulation of solar drying of chilli in solar tunnel drier. *International Journal of Sustainable Energy* **24(3):** 143-153 (2005).
41. Jan Banout, Petr Ehl., Using a Double-pass solar drier for drying of bamboo shoots. Journal of Agriculture and Rural Development in the Tropics and Subtropics. **111(2):** 119-127 (2010).
42. Jain, D. and Tiwari, G.N., Thermal aspects of open sun drying of various crops. Energy, **28(1):** 37–54 (2003).
43. Jain, D., and Jain, R.K., Performance evaluation of an inclined multi pass solar air heater with in-built thermal storage on deep-bed drying application. *Journal of Food Engineering* **65(4):** 497–597 (2004).
44. Berinyuy, J. E., Tangka, J. K., WekaFotso, G. M., Enhancing natural convection solar drying of high moisture vegetables with heat storage. Agric Eng Int: CIGR Journal. 14(1) (2012).
45. Kumar, P., Shammugan, S., Veerappan, A.R., An Experimental Study on Drying of Non-Parboiled Paddy Grains Using an Oscillating Bed Solar Dryer, Energy Engineering, 108(2), pp. 69-80 (2011).
46. Kamlesh Kumar Tekam, Dr. Bhupendra Gupta. Experimental study and Analysis of solar dryer using of PV Cell and electric fan. International Journal of Engineering Trends and Technology. 4(3) (2013).
47. Vijayakumar, K.P., Sreekumar, A., Manikantan, P.E., Performance of indirect solar cabinet dryer. *Energy Conversion and Management*. **49:** 1388-1395 (2008).
48. Luna, D., Nadeau, J. P. and Jannot, Y., "Model and Simulation of a Solar Kiln

with Energy Storage." *Renewable Energy* **35(11):** 2533–2542 (2010).
49. Lalit M. Bal, SantoshSatya, S.N. Naik, VenkateshMeda., Review of solar dryers with latent heat storage systems for agricultural products. *Renewable and Sustainable Energy Reviews*. **15:** 876- 880 (2011).
50. Mohanraj, M., and Chandrasekar, P., "Drying of Copra in Forced Convection Solar Drier." Biosystem Engineering. **99(4):** 604–607 (2008).
51. Mursalim, Supratomo, Dewi, Y.S., Drying of Cashew Nut in Shell using Solar dryer, Science and Technology, 3(2), pp. 25-33 (2002).
52. Augustus Leon, M., Kumar, S., Bhattacharya, S.C., A comprehensive procedure for performance evaluation of solar food dryers. *Renewable and Sustainable Energy Reviews*. **6:** 367-393 (2002).
53. Madhlopa, G. Ngwalo. Solar dryer with thermal storage and biomass-backup heater. *Solar Energy*. **81:** 449-462 (2007).
54. Mohanraj, M., Chandrasekar, P., Performance of a Forced Convection Solar Drier Integrated with Gravel as Heat Storage Material for Chili Drying. *Journal of Engineering Science and Technology*. **4(3):** 305-314 (2009).
55. Zaman, M. A. and Bala, B. K., *Thin layer solar drying of rough rice*, Solar Energy, **42:** 167–171 (1989).
56. Othieno, H., Grainger, W., Twidel, J.W., Application of small-scale solar crop dryers to maize drying in Kenya. In: Proceedings of the 2nd Conference on energy for rural and island communities, Inverness, UK.pp. 377-86 (1981).
57. Okoroigwe, E. C., Eke, M. N. and Ugwu, H. U., Design and evaluation of combined solar and biomass dryer for small and medium enterprises for developing countries. *International Journal of Physical Sciences ISSN* 1992 - 1950© Academic Journals (2013).
58. Gbaha, P., Yobouet Andoh, H., Kouassi Saraka, J., Kaménan Koua, B. and Touré , S., "Experimental investigation of a solar dryer with natural convective heat flow", Renewable Energy, vol. 32, issue 11, pages 1817-1829 (2007),
59. Pandey, H., Sharma, H.K., Chauhan, R.C., Sarkar, B.C., Bera, M.B., Experiments in food process engineering. New Delhi: CBS Publisher and Distributors PVT. p 139–45 (2010).
60. Sarsavadia, P.N., Development of a solarassisted dryer and evaluation of energy requirement for the drying of onion. *Renewable Energy*. **32:** 2529- 2547 (2007).
61. Aggarwal, R. K., Indirect Solar Drier for Drying of Hill Products, Asian Economic and Social Society ISSN (P): 2304-1455, ISSN (E): 2224-4433. 2(2) (2012).
62. Velraj, R., "Thermodynamic Analysis Of a Diesel Engine Integrated With a PCM Based Energy Storage System". (2010).
63. Sreekumar, A., Solar drying for food processing, A Solar Future for India, WISE Press: India (2011).
64. Sreekumar., Techno-economic analysis of a roof integrated solar air heating system for drying fruit and vegetables. *Energy Conversion and Management*. **51:** 2230-2238 (2010).
65. Raman, S. V. V., Iniyan, S., Goic, R., "A review of solar drying technologies", Renewable and Sustainable Energy Reviews, 16, pp. 2652-2670 (2012).
66. SINGH, P., SINGH, S. & SINGH, B.R., effect of drying methods and pre treatments on the drying characteristics of garlic. International Journal of Research in Engineering & Technology (IMPACT: IJRET) ISSN(E): 2321-8843; ISSN(P): 2347-4599 Vol. 2, Issue 7, Jul, 141-156 © Impact Journals (2014).
67. Shalaby, S.M., Bek, M.A., El-Sebaii, A.A., Solar dryers with PCM as energy storage medium: A review. Renewable and Sustainable Energy Reviews. **33:** 110-116 (2014).
68. Shanmugam, S., Kumar, P. and Veerappan, A. R., Evaluation of thermal efficiency of oscillating-bed solar dryer

through drying of sunflower seeds. Journal of Renewable and Sustainable Energy. 3 pp. 1-8 (2011).

69. Sodha, M.S., Dang, A., Bansal, P.K., Sharma, S.B., An analytical and experimental study of open sun drying and a cabinet type drier. *Energy Conversion Management* **25(3):** 263–71 (1985).
70. Amedorme, S.K., Apodi, J., and Agbezudor, K., 2013. Design and Construction of Forced Convection Indirect Solar Dryer for Drying Moringa Leaves. Scholars Journal of Engineering and Technology (SJET), Sch. *J. Eng. Tech*.**1(3):** 91-97.
71. Subarna Maiti, Pankaj Patel, Kairavi Vyas, Kruthika Eswaran, Pushpito 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. **85:** 2686-2696 (2011).
72. Song, M., Songlin, Y., Biguang, Z., and Dong, Z., "Experimental Research of Grape Drying Using Solar Dryer with Latent Heat Storage System." International Conference on Computer Distributed Control and Intelligent Environmental Monitoring, 740–742, (CDCIEM), Changsha. IEEE. doi:10.1109/CDCIEM.2011.33 (2011).
73. Tarigan, E. and Tekasakul, P., A Mixed-mode Natural Convection Solar dryer with Biomass Burner and Heat Storage Backup Heater, *In* ANZSES Renewable Energy for a Sustainable Future - A challenge for a post carbon world, Otago University, Dunedin, New Zealand, 28 - 30 November 2005. Pp. 1-9 (2005).
74. Tawon Usub, Charoenporn Lertsatitthankorn, Nattapol Poomsa-ad, Lamul Wiset, Sirithon Siriamornpun, Somchart Soponronnarit , Volume 88, Issues 2-3, Pages 149–160 (2010).
75. Shanmugam, V., Natarajan, E., Experimental study of regenerative desiccant integrated solar dryer with and without reflective mirror. Applied Thermal Engineering. **27(8-9):** 1543-1551 (2007).
76. Sagar, V. R. and Suresh Kumar, P., J Recent advances in drying and dehydration of fruits and vegetables: a review Food Sci Technol. Jan; 47(1): 15–26. Published online 2010 Feb 6. doi: 10.1007/s13197-010-0010-8 (2010).
77. Yahya, M., Sopian, K., Theeran, M.Y., Othman, M.Y., Alghoul, M.A., *et al*. Experimental and Theoretical Thermal Performance of Double Pass Solar Air Heater with Porous Media, Proceedings of the 7th WSEAS, International Conference on system science and simulation in Engineering (ICOSSSE '08), Venice, Italy, November 21-23: pp 335 – 340 (2008).
78. Y. Sujatha Dr. Issac Prasa, Dr. K. Prahlada Rao. *International Journal of Innovative Research and Advanced Studies (IJIRAS)* **3(9):** (2016).