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A REVIEW OF SOLAR DRYERS DESIGNED & DEVELOPED FOR CHILLI

Biplab Paul [1] , S P Singh [2]
[1] *Shri Ram Institutes of Sciences and Technology, Jabalpur, MP, India*
[2]*School of Energy and Environmental Studies (SEES), Devi Ahilya Vishwa Vidyalaya (DAVV), Indore, MP,India.*
[1]paulbiplab_18@rediffmail.com, paulbiplab18@gmail.com

ABSTARCT:
Solar drying is an integral part of rural life for various products, especially vegetable, fruits & spices which are produced in rural areas and have no scientific means of preserving such raw products. This paper is an attempt to review the solar drying process & solar dryers used for chilli drying worldwide which includes types of solar dryer, drying process & techno economical feasibility of drying process.
Open sun drying is very much common between farmers compared to solar drying by solar dryer due to various reasons especially economic viability. Research is going on for improvement in process, types of dryer used for improving efficiency and cost of drying.

Keywords: *Solar Dryer, Chilli drying*

1. INTRODUCTION

Solar drying of agricultural product is essential and most viable solution to the world's food problem involves reducing the food loss, which occurs due to various reasons such as lack of suitable technology, improper cultivation and fertilization, lack of marketing channels, improper transportation, high post harvest losses, etc., causing a food loss from 10 to 40%. The food preservation by solar drying is the only method to reduce the food loss that is being adopted since many centuries**.(M.V. Ramana Murthy ., 2008)**. Various types of solar dryers had been designed to overcome this problem. The type of dryer depends on the product and the drying process required for that particular type of product.
Basically the drying process involves the migration of water from the interior of the product to be dried on to the surface for its evaporation and therefore it is a heat and mass transfer phenomenon **(P.Barnwal et al., 2008)**. The convective heat transfer coefficient is an important parameter which determines the heat and mass transfer**.** The convective heat transfer coefficient varies from crop to crop and the mode of drying. In case of green chillies the convective heat 1.31 W/m^2 K, **(Anwar et al., 2001a,b).** The basic essence of drying is to reduce the moisture content of the product to a level that Prevents deterioration within a certain period of time. Drying is a dual process of -heat transfer to the product from the heating source. And mass transfer of moisture from the interior of the product to its surface and from the surface to the surrounding air **(O.V Ekechukwu et al1999).**
India receives an enormous amount of solar energy: on average, of the order of 5 kWh/m^2 day for over 300 days/yr (**M. S. Sodha et al., 1993)**. This energy should be efficiently used for solar drying of agricultural product such as chilli, grapes, onion etc.
Chillies are important ingredient as far as Indian food is concerned about 0.454 million tones of chilli can be dried using solar energy. The aperture area of solar dryers required for drying chilli is the estimated about 2774850 m^2. The estimates for unit cost of solar drying are found to be Rs 4.23/kg for chili , itself speaks the potential of solar drying of chilli **(Atul Kumar et al., 2004).** Dehydration of chilies is a difficult task which had to be accomplished keeping various parameters in mind such as nutrient content, colour, texture etc. Some vitamin loss is inevitable in drying of all types. Vitamin C and other vitamins that are heat or light sensitive are destroyed to a degree depending on the conditions in the drying process. Low operating temperature and indirect heating using a solar dryer can preserve the most nutrients. It is, therefore, suggested that the finished product should not only be evaluated on economic grounds, but with nutritional criteria as well. For chillies maximum temperature in side the dryer permissible is 65°C with initial & final moisture content is 80% & 5% respectively**(V.K.Sharma et al., 1993).** The temperature of dryers should never exceed 70°C, 0therwise the product t ton be dried will tend to cook rather than dry**(H.Halak et al., 1995).** Drying temperature above 65°C has to be avoided in order to prevent colour changes

induced by high temperature. **Ramesh et al. (2001)** suggested that the optimum temperature for drying of red chilli should be 60°C.Thus maintaining 65°C became a benchmark for chilli drying.Various process of chilli drying is illustrated as under.

2. OPEN SUN DRYING

Sun drying remains the most commonly used method for preserving agricultural products in tropical and subtropical countries. Due to lack of sufficient preservation methods, farmers have to spread the fruits and vegetables to be dried in thin layers on paved grounds or on mats where they are exposed to sun and wind. Considerable losses may occur during natural sun drying due to various influences such as rodents, birds, insects, rain, etc. The quality of dried products may also be lowered significantly. Over drying and contamination by dust and insect infestation are typical for natural sun drying. The resulting decrease in product quality may cause the products not to be marketable, although many fruits, and vegetables are produced for domestic and international markets with natural sun drying **(Tiris Cigdem et al.,1994)**. This is a traditional method of drying agricultural products in all countries. In this method, crops are spread in open sun-light on the ground, floors or on roofs of houses and stirred once or twice dailyas shown in **Fig-1** .The thickness of such a spread may vary from 10 to 15 cm. The crops are heaped in the evening and covered with tarpaulin or gunny bags and are spread again the next day morning till they are completely dried up. Agricultural products like chillies take 10–15 days to dry up and lose 65–75% of weight during the drying. **(P. A. Potdukhe et al., 2008)** In Bangladesh chillies are traditionally sun dried. The farmers expose their chillies to the open sun on a mat, earthen floor, and cemented floor or on a tin shed. In this method, drying cannot be controlled and a relatively low quality dried product is obtained. Drying rate is very slow and takes 7–15 days, depending on the weather conditions **(Hossain, 2003).**

3. SOLAR DRYER FOR CILLLI DRYING

Solar dryers have been introduced for drying chilli in order to decrease the drying time and improve the quality of dried chilli. With solar air dryer, the drying capability of air is significantly improved with increase in the temperature of air by the use of a dryer. Various types of solar dryers are used for drying chillies. In the direct type of solar dryer the chillies are exposed directly to the solar radiation or a combination of direct solar radiation as well as reflected radiation.

- In the indirect type of solar dryer the chillies are not exposed directly to the solar radiation but air heated by the solar radiation is made to flow through them.
- In the natural circulation mode, air is heated and circulated through the chillies naturally by buoyant force or a result of wind pressure or a combination of both.
- In the forced circulation mode, heated air is circulated through the chillies with the help of motorized fans or pumps.

4. DIRECT MODE SOLAR DYER

In the direct type of solar dryer, incident solar radiation passes through a glass / plastic to be on the chillies placed for drying. The glass / plastic cover reduces direct convective losses to the surroundings and increases temperature inside the dryer.

5. SOLAR CABINET DRYER

Natural Circulation Solar Cabinet dryer are basically used for drying low quantity of vegetables & fruits. Solar cabinet dryers was developed by the Brace Research Institute, Canada illustrates in **Fig. 1** the fundamental features of the standard Brace Institute solar cabinet dryer. The dryer consists of a container, insulated at both its base and sides and

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covered with a double-layered transparent roof. Drying temperatures in excess of about 80^0C were reported for the dryer. **(Ekechukwu O.V, 1999).**

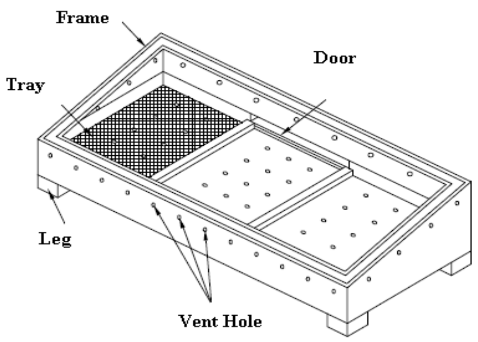

Fig. 1 Solar Cabinet Dryer Developed by Brace Institute

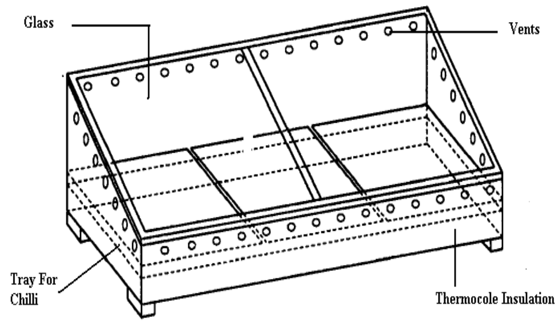

Fig. 2 Natural Convection Solar Cabinet Dryer

6. SOLAR CABINET DRYER

Solar cabinet dryer shown in **Fig 2** developed at ENEA C.R.E. Trisaia, Dipartimento Energia, Divisione Ingegneria Sperimentale, Italy by **(Vinod Kumar Sharma, et al.,1994)** is essentially a wooden rectangular box divided lengthwise into parallel channels of equal width. Solar radiation is transmitted through the single-layered transparent glass at the top and is absorbed on the blackened interior surfaces. The bottom of the dryer is insulated with thermocole sandwiched between an underside commercial board sheet and an inner side blackened metallic sheet. Owing to the trapped energy, the internal temperature increases. Holes are drilled through the base to permit fresh ventilating air to enter the cabinet. As the temperature rises, warm air passes out from the upper aperture by natural convection, creating a partial vacuum and drawing fresh air up through the base. The cabinet has a bed area of 1.4 m^2. The trays have wooden sides of equal height (0.04 m) and a plastic mesh at the base. The cabinet-type natural convection solar dryer is very well suited for drying 7-10 kg of chillies.

7. LOW COST SOLAR DRYER

The dryer consists of a rectangular box, made of mild steel sheet. A 10-cm portion of the box is fixed in the ground and bajra husk insulation (10 cm thick) is provided at the base. Four hollow bamboos are fixed in the walls of the dryer above the insulation and a number of holes are drilled in the bamboo to introduce fresh air into the base. Two wood-and-wire-mesh frames are fitted above the bamboo for placement of the produce to be dried. The dryer is provided with a double-sloped 0.3-mm PVC roof. Three aluminium chimneys painted black are provided at the top of the inclined roof as exits for hot air. Regulating valves are provided in the chimneys to change the passage area of circulating air. The moisture content was reduced from 86.3% to 4.1% within 9 days by the solar drying method; in contrast, it took 18 days to dehydrate the same quantity of chillies by open drying for 12kg of chillies. **(Thanvi et al., 1987)**

8. FOLDABLE DRYER

Bhabha Atomic Research Centre India had developed foldable type of the dryer **Fig 3** having drying capacity of 25 kg in 1998. The foldable solar dryer receives direct solar radiation on the product. Hence, the drying rate in the foldable solar dryer is higher. It takes five days to dry 2kgs of chilli in foldable dryer.

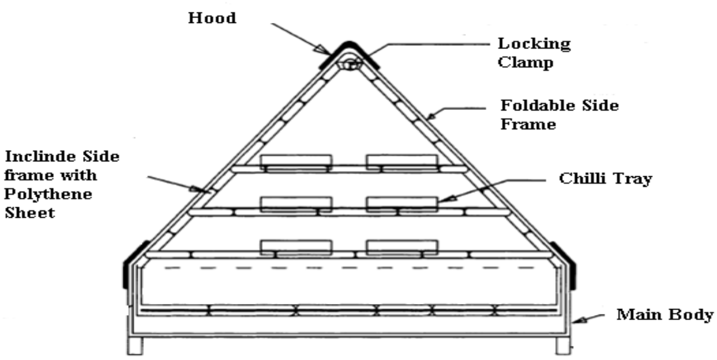

Fig. 3 Foldable solar dryer

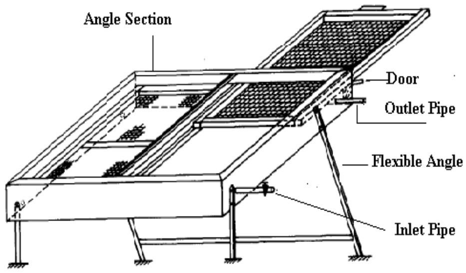

Fig. 4 Solar Dryer cum water heater

9. Solar dryer cum water heater

The solar dryer cum water heater is comprised of two rectangular G.I. tanks the details are shown in **Fig 4.** In this gadget, four G.I. nipples are provided across the depth on both sides of the G.I. tank for inducing fresh air during drying. These G.I. nipples also prevent bulging of the G.I. tanks when filled with water. Two G.I. nipples are provided at the bottom and top of the sides of each G.I. tank which act as the inlet and outlet for water. An opening wooden door is provided at the top side of the tray. Two wooden trays with G.I. wire mesh are made to keep the material inside the dryer. A partition is provided in the tray so that agricultural produce can be stacked on the inclined surface easily. An adjustable iron angle stand is provided to keep the system at an optimum tilt in accordance with the season of operation. The performance of this unit as a solar dryer was studied for drying chillies in the winter months. Both the GI tanks were filled with water and the drying trays were loaded with 5 kg of red chillies. The maximum air temperatures that were reached inside the new unit varied from 64 to 67°C on different drying days. The interesting point was that the water inside the tanks beneath the drying tray got heated above 40°C. It took 3 days to reduce the moisture content of the fresh chillies from 80 to 9.1%.**(Pande et al., 1991)**

10. MULTISTACKED NATURAL CONVECTION SOLAR DRYER

Multistacked natural convection solar dryer is a simple solar-air-collector/solar-dryer
housed in a single cubic wooden box. The box has been divided into two halves. The first half is a single glazed solar air collector, whereas the drying unit is in the second half of the complete unit. As shown in **Fig-5,** a glazed solar air heater located at the base of the drying chamber provides supplementary heat. Preheated air in the solar collector rises through the second half of the system. An additional chimney is provided at the top of the drying unit. The hot air dehydrates the product and gets exhausted through the chimney. The product to be dried is placed on the moveable trays kept on the metallic frames attached to the drying unit. The system can be operated both in natural as well as in forced convection. **(Vinod Kumar Sharma, et al., 1994)**.

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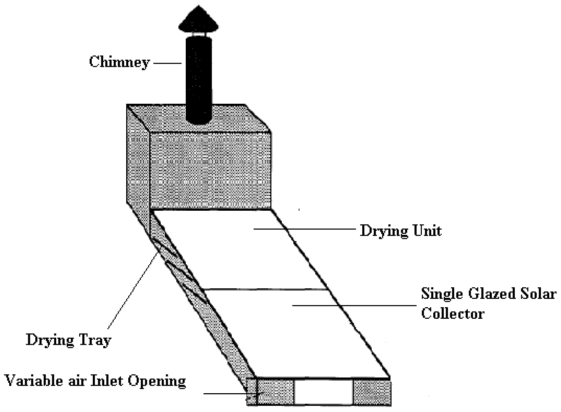

Fig. 5 Multistacked natural convection solar dryer

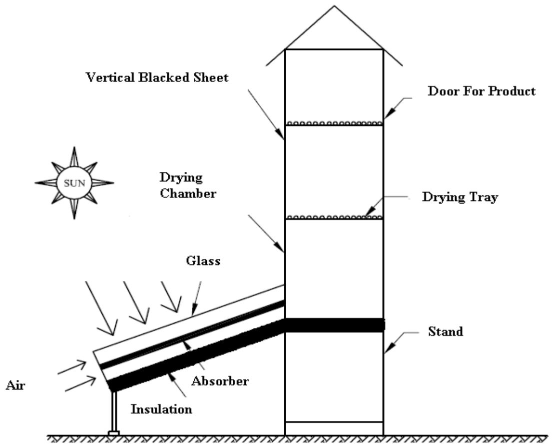

Fig. 6 Natural convection solar dryer

11. NATURAL CONVECTION SOLAR DYER

The schematic of experimental set-up for a new type of solar dryer is shown in **Fig 6.** The absorber plate of the solar air heater consists of a thin box made of corrugated galvanized iron sheet on one side and plain galvanized iron sheet on the other. The box was filled with thermic oil-forming inbuilt thermal storage absorber. The upper surface of the absorber was blackened for maximum heat gain. It was provided with a single cover glass glazing at the top and rice husk insulation at the bottom. The sides were insulated by polyethylene sheet of thickness 15 mm. Drying chamber is the vertical box attached to the solar air heater and houses two agro product trays. The bottom of the drying chamber is elevated to 500mm from the ground level and is insulated with rice husk for reducing bottom loss. The trays can be kept at different elevations through the doors provided at the rear side of the drying chamber. The vertical side of the drying chamber facing south is blackened for maximizing solar heat gain. The hood bolted to the drying chamber at the top can be lowered or elevated for controlling the airflow rate through the drying chamber. The drying period in the solar dryer was reduced by 75 and 40% compared with open Sun drying and using conventional dryer. It takes 4 days to dry 2 kg of chillies with a new type of solar dryer compared to 15 days in case of open sun drying.(**P. A. Potdukhe et al., 2008)**

12. FORCED CONVECTION SOLAR DRYER WITH ELECTRIC AIR HEATER

Solar dryer shown in **Fig 7** was designed and installed on the Pilot Plant of the Solar Energy Institute, Ege University for use in arid zones, consists of two main parts: namely, a solar air-heater and a drying chamber. The solar air-heater were completely painted with a black colour and used as an absorbent surface. During experiments, the solar air-heater combined with the collector was orientated in a southerly direction with a collector angle of 30°C. The roof and other sides of the drying chamber was designed using polyester containing glass wool as the covering material. Eight metal racks were placed inside the chamber and the distance between each rack was 12 cm. An open able lid was connected to the north side of the chamber, in order to put the products inside the chamber for drying purpose. A fan controlled by a manual valve was used to force the drying air through the collector and to the air outlet of the drying chamber . An electrical heater was used to test the solar air-heater due to selection of proper inlet temperatures of the working fluid (air). An analog device provided the temperature control. The flow rate of the air was measured via a digital flow meter which was placed at the entrance of the solar air-heater. The total solar radiation intensities were measured with a star-type pyrometer which had the same slope as the solar air-heater. In the experiments chilli peppers were halved and spread out uniformly on the racks inside the dryer. The samples were dried both in the dryer (solar drying) and on paved grounds (traditional sun drying). The drying periods of the natural sun-dried products ranged between 8 and 14 days compared to the drying times for solar-dried chilli peppers were 2.8 times shorter, respectively. **(Cigdem Tiris, et al., 1995).**

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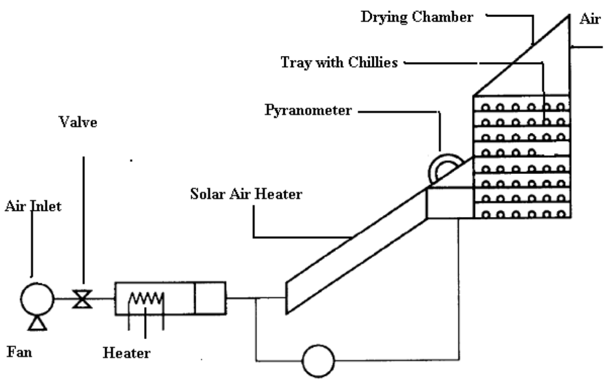

Fig. 7 Forced convection solar dryer with electric air heater

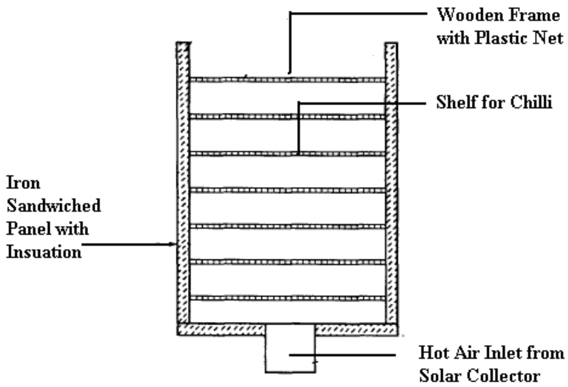

Fig. 8 Multi Self Solar Drying Box

13. INDIRECT-TYPE MULTI-SHELF FORCED CONVECTION SOLAR DRYER

The design of an indirect-type solar dryer shown in **Fig 8** is to heat a body of air using a solar air collector and then let this air pass through a bed of material placed on trays kept inside an opaque drying chamber connected in series with the solar air collector. The system is based on the principle of forced convection. Outlet from the solar air collector is made to pass through thermally and acoustically well-insulated rectangular air ducts. The drying cabinet houses a single column of seven product shelves. The shelves are placed 15 cm apart from each other so as to ensure a uniform air circulation under and around the product. The material holding capacity of the drying box depends mainly on the bulk density of the product to be dried and ranges from 75 to 100 kg **(Vinod Kumar Sharma, et al., 1994)**. The schematic diagrams for the solar air collector and the drying box are presented in Fig 8.

14. SOLAR TUNNEL DRYER (MODIFIED HOHENHEIM TYPES)

A Hohenheim type solar tunnel drier was redesigned, fabricated and installed at the Department of Farm Power and Machinery, Bangladesh Agricultural University, Mymensingh, Bangladesh. The drier basically consisted of a plastic sheet covered flat plate solar air heating collector, a drying tunnel unit, two dc fans and a 40 W photovoltaic module. The drier was 20 m long and 1.80 m wide. The solar collector unit was connected in series with the drying tunnel as shown in **Fig 9.** The collector and drying chamber were made of plain metal sheets and wooden frames in a number of small sections and were joined together in series. Glass wool was used between the two metal sheets at the bottom of the drier as an insulation material to reduce the heat loss from the bottom of drier. The collector was painted black to facilitate absorption of solar radiation. The drying area of the drier unit was same as that of the collector. Both the collector and the drying units were covered by 0.2 mm thick transparent UV stabilized plastic sheet. A 40 W solar module was installed at the inlet of the solar collector as a power source to operate the fans, which supplied air over the product. The whole system was placed horizontally on tables made of iron angle frame 0.8 m above the ground floor for ease of loading and unloading of the products. Plastic net of 2 mm · 2 mm size was used as a tray and the tray was placed 75 mm above the floor of the drier. The drier had a loading capacity of 80 kg of fresh chillies .It takes 20 h in solar tunnel drier compared to 32 h in case of improved and conventional sun drying method **(M. A. Hossain,et al., 2007)**

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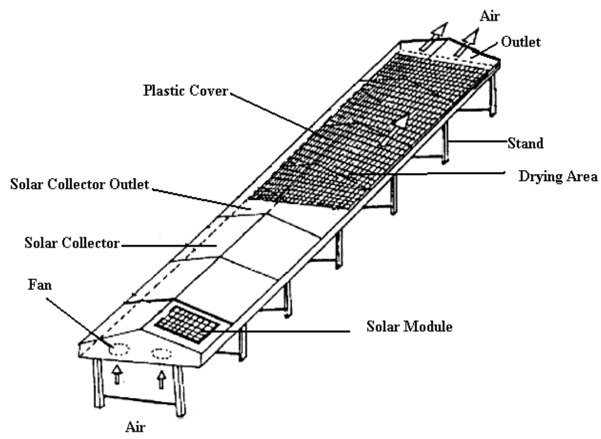

Fig. 9 Solar tunnel dryer (Modified Hohenheim)

Fig.10. solar tunnel drier (Developed at AIT)

15. SOLAR TUNNEL DRYER

The solar tunnel drier developed at AIT shown in **Fig 10** consists of a solar collector, drying tunnel, and five radial flow fans to drive the moist air out of the drier .The product to be dried is placed as a single layer inside the drying tunnel. Air entering the solar collector is heated and is forced on the products placed in the drying tunnel using five fans at the air inlet of the solar collector. The fans, with a rating of 14W, have an air handling capacity of $130m^3$/hour each. For experiments with DC power, three solar PV panels could be used. Glass wool insulation provided at the back side of the collector and drying chamber minimizes heat losses. The drier stands on a 75 cm high brick plinth. Both the collector and tunnel are covered with a 0.2 mm thick, UV-stabilized polythene sheet. The collector is painted matt black to act as an absorber. Products to be dried are placed in perforated aluminum trays and loaded inside the drier. Easy loading and unloading of the materials is facilitated by rolling one side of the plastic cover up or down using a hand-operated pipe and crank arrangement. The dryer was loaded with 19.5kg of chillies as ripe fruits, by spreading the chillies inside in a single layer. It takes 3 days for AC operated fan & 2 days for DC/PV operated fan to achieve the required moisture content**.(Gauhar A et al., 1998)**

16. SOLAR PV WINNOWER- CUM- DRYER

The solar PV winnower- cum- dryer is unique system, which was designed and developed for dehydrating fruit and vegetables with forced circulation of air. The composite photovoltaic thermal unit comprises a PV module- mirror booster assembly, a compatible winnower, a pre air heating tunnel, an especially designed solar drying cabinet for utilizing solar energy effectively and having interfacing arrangements to use the fan of the winnower for enhanced air circulation while dehydrating the produce. The dryer comprises a cabinet, especially designed to take the advantage of the sun’s position in different months for getting the required energy gain and simultaneously to load the drying material conveniently on twelve trays stacked one above another in two parallel compartments. The cabinet is made of iron angle with a top cover of two glass windows fixed on wooden frame and inclined at an angle of 23 degree from horizontal. Two vertical glass windows are provided in the front side and another glass window is fixed on east side of the cabinet. The base of the cabinet is above the ground and provisions are made to insert the PV run fan of the winnower on the west opening. Two doors are provided at the rear side for loading and unloading of the material. Four ventilation holes are provided at the base with detachable caps. This facilitates the operation of the dryer both in natural and forced circulation modes. The openings on the east side above the window and on the rear side above the doors are provided with GI wire mesh to prevent the entry of insects and to facilitate the air circulation. In the beginning two PV modules (35 Wp each) were used to have sufficient out put to operate the winnower for more than six hours a day. The PV system as winnower and dryer are shown in the **Fig 11. (P.C. Pande, 2009)**

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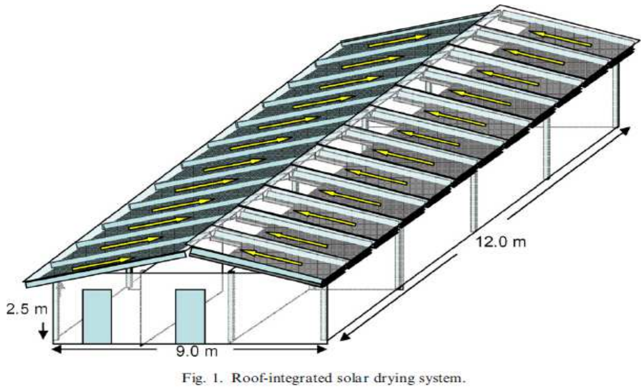

Fig. 11 Solar PV winnower- cum- dryer)

Fig.12. Roof-Integrated Solar Drying Sysyetm

17. ROOF-INTEGRATED SOLAR DRYING SYSTEM

The dryer shown in **Fig 12** consists of a roof-integrated solar collector and a drying bin with an electric motor operated axial flow fan to provide the required airflow. The bin is connected to the middle of the collector through a T-type air duct. The roof-integrated collector consists of two arrays of collector: one facing the south and other facing the north with a total area of $108m^2$. These arrays of the collectors also serve as the roof of the building. The roof-integrated collector is essentially an insulated black-painted roof serving as an absorber, which is covered with a polycarbonate plate. The drying bin is essentially a deep bed batch dryer. The dryer is located inside the building. The building was partitioned into one space for the drying bin and another two additional rooms. The first room was used for the preparation of the product to be dried and the second for the storage of dried products. Solar radiation passing through the polycarbonate cover heats the absorber. Ambient air is sucked through the collectors and while passing it through the collectors gains heat from the absorber. This heated air is passed through the drying bin. The roof-integrated solar dryer results in reduction in drying time and production of quality dried product. The color of the dried chili was comparable to that of a high-quality dried chili in markets when the color was tested. It takes 14 hour to dry chilli to required level of moisture content .Approximately 3040 kg of dry chili are annually produced.**(S. Janjai et al., 2006)**

18. FLUIDIZED BED DRUM DRYER (COMMERCIAL SCALE SOLAR DRYER)

The products to be dried have different characteristics and require different drying procedures. Dryers can be a batch type or continuous**. Fig 13** illustrates commercial scale solar dryers currently in use for dyring chilli. ChiIlies have a higher moisture content to be removed and can be dried at a higher temperature. A collector flow rate of will produce a higher temperature rise of up to 30°C which would give a total temperature of 60°C. Chilles require more energy for drying and each square meter of solar panel will dry approximately 3 kg of chillies a day assuming a 50% drying efficiency. A higher air flow with lower temperature rise could be used with a longer time in the drier. Solar panel efficiency would increase and each square meter of solar panel would be able to dry 4 kg of chillies a day from 80 % moisture content to 5%.**(J.C.Hollick, 1999)**

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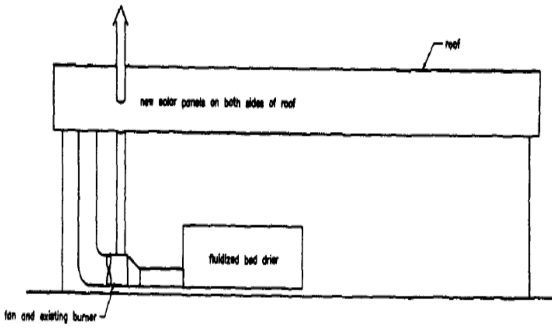

Fig. 13 Fluidized Bed Drum Dryer

Fig.14 PV-Ventilated Greenhouse Solar Dryer

19. PV-VENTILATED GREENHOUSE SOLAR DRYER

A PV-ventilated greenhouse solar dryer was developed at Silpakorn University **(Janjai, 2004)**. The dryer shown in **Fig 14** essentially consists of a parabolic shape greenhouse with a black concrete floor. As concrete has relatively high heat capacity, it also functions as a heat storage system for the dryer. The dryer is shown is of parabolic shape can withstand well the tropical rain and storm. The roof of the dryer is covered with polycarbonate plates. In addition, its thermal inertia helps to reduce the variation of the drying air temperature due to the fluctuation of incident solar radiation. Three fans powered by a solar cell module are used to ventilate the dryer during day. The loading capacity of the PV ventilated greenhouse solar dryer is 100-150 kg of fresh chillies. Drying in the PV ventilated greenhouse results in considerable reduction in drying time (50%) and the quality of the dry products is high quality dried products in terms of color and texture.

20. THIN LAYER DRYING APPARATUS

The thin layer drying apparatus was developed at the University of Newcastle. The drying chamber consists of an inner cylinder of diameter of 230 mm suspended in an oil bath from an electric balance and supporting the tray containing the sample to be dried. The insulated outer cylinder causes the air leaving the sample to flow down through an annular space between the two cylinders. The inner cylinder and the tray frame were made of aluminium to make the system lighter and suitable for high temperature drying. The base of the drying tray consists of fine nylon mesh supported by a honeycomb. The dryers is shown in **Fig 15** Humidified air is delivered via a plenum chamber (A), through an insulated vertical chamber (B) to a circular drying tray (C) of area of 0.135 m2, which is supported by a collar (D) suspended by a frame from a digital balance (E). An oil seal at the base of the support collar ensures that all air passes through the drying tray**.(M. A. Hossain,et al., 2003)**

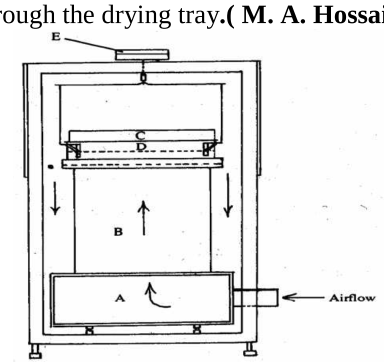

Fig.15 Thin layer Solar Dryer

21. CONCLUSION

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It has been established that solar drying of chilli is technically feasible and economically viable. Blanching of chilli prior to drying improves the quality of final product to reach the safe moisture content for storage. Also drying temperature retains its colour & texture which is acceptable in the market. An indirect type of solar dryer with forced air circulation not only enhances the production of final product but also produce superior quality chilli acceptable in the international market. Normally farmers not capable of investments for drying chilli which increases losses. Researcher must strive to develop new generation solar dryer which are effective and economically viable.

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