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# REVIEW ON PERFORMANCE OF INDIRECT TYPE SOLAR DRIERS

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**Abstract:** Poor processing techniques and shortage in storage facilities deteriorates the quality of food product. To solve the problem, drying has become one of the main processing techniques used to preserve food products in sunny areas. Drying with solar energy is an ancient food preservation technology. Solar food dryers are available in a range of size and design. Various types of driers are available to suit the needs of farmers therefore selection of dryers for a particular application is very important. In this paper, an attempt is made to review the development of different types of indirect solar dryer and their various designs, details of construction and performance result. A synthesis view of classification of solar energy dryers is presented. Some recent developments in indirect solar drying technology with thermal storage system are also discussed.

**Keywords:** Drying; Solar Drying; Indirect solar dryer; Passive solar energy dryers; Active solar energy dryer**.**

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## INTRODUCTION

To maintain the right balance between food supply and population growth, besides increasing food supply and limiting population growth, reducing food losses during production time harvest, post-harvest, and marketing seems to be a viable option is mandatory. The quality and quantity of food grains are deteriorating because of poor processing techniques and shortage in storage facilities. To solve the problem, drying has become one of the main processing techniques used to preserve food products in sunny areas [1]. The energy, for drying, supplied from various sources, namely, electricity, fossil fuel, and Natural gas, wood and solar. The Earth has abundant solar radiation. Thermal drying accounts for 10–20% of national industrial energy consumption in the developed economies of the world [2].

Removing water from food and thereby inhibiting bacterial growth in foods is the method of food preservation known as drying. Drying is a unit operation involving simultaneous heat and mass transfer processes to removal moisture or solute from a solid matrix [3].

In recent years, the use of solar energy has become more popular for drying Solar Drying Free, non-polluting, renewable, abundant energy source [4]. Drying offers an alternative which can process the vegetables and fruits in clean, hygienic and sanitary condition, it saves energy, time, occupies less area, improves product quality, makes the process more efficient and protects the environment. Also Fruits and vegetables are dried to enhance storage stability, minimize packaging requirement and reduce transport weight. Drying foods can be moved easily as less weight. [5, 6, 7]

## CLASSIFICATION OF SOLAR DRYING SYSTEM

### 2.1 Open sun drying-

Open sun - Spreading the Crop on ground or into thin layers on trays, covering the mats with shadow, concrete floor and exposing the product to wind and sun.

Rack type (shade type)

Advantages:

1) The process is independent of any other source of energy except sunlight.

2) The cheapest method.

3) Less skill labour required

Disadvantages: 1) Damage to the crop by rodents, birds, and animals.

2) Degradation through exposure to direct irradiation of the sun and to rain, storm, and dew.3) Contamination by dirt dust, wind-blown debris, and environmental pollution, 4) loss due to over drying.

5) Insect infestation Growth of microorganisms.6) Additional losses during storage due to insufficient or no uniform drying

Control Drying- Control drying using Solar Dryer

Direct type solar dryers- In the direct type of solar dryer, solar radiation passes through a transparent cover, usually glass, to be incident on the grapes placed for drying. The glass cover reduces direct convective losses to the surroundings and increases temperature inside the dryer

Box Type or Solar cabinet dryer

Staircase solar dryer

Glass roof solar dryer

Advantages: The advantages of solar drying over open sun drying are.

1) Contamination of product due to enclosure with transparent cover is less. 2) Offer protection from rains, dews, debris etc. 3) Product quality obtained is higher than open to the sun drying.

Disadvantages: The main disadvantages of the cabinet or direct solar dryers are:

1) Overheating of the crop may take place due to direct exposure to sunlight; consequently, the quality of the product may deteriorate, 2) the efficiency is low because part of the solar energy input is used to induce air flow. 3) Poor vapour removal rates leading to relatively slow overall drying rates.

2.2.2 Indirect solar drying

There are many drying systems which use the indirect means of solar drying. Two types of indirect solar drying systems, Natural circulation and Forced circulation.

Natural circulation type (Passive mode)

In these solar dryers, air movement is due to natural circulation. Food gets heated due to direct absorption of heat or due to high temperature in the enclosure and then moisture evaporated from the grapes escapes out of the chamber by natural circulation of air.

Indirect type conventional solar dryer- This type of solar dryer has a solar collector for heating air and a drying chamber.

Indirect natural convection solar dryer with chimney- a solar collector, drying chamber and a chimney

Multipurpose natural convection solar dryer- This solar dryer consists of a solar flat plate air heater, flexible connector, reducer with plenum chamber, drying chamber and chimney. The solar air heater consists of an absorber with fins, glass cover, insulation and frame. A chimney provided at the top of the drying chamber creates the required draft.

Indirect natural convection solar dryer with chimney and storage material. The solar dryer consists mainly of a flat plate solar air heater coupled to a drying chamber. It also consist of chimney to create draft and Storage Material to store the solar thermal energy of the sun which can be utilised during night time which reduced the drying time of material.

Forced circulation type

In these types of solar dryers air is forced into or out of the drying chamber using a blower or fan which is electrically or mechanically operated. So controlling the drying rate is possible in the case of Force circulation indirect type of dryer. It is also categories in same way like Natural circulation type with addition of fan or blower. Some other types of dryers are, Solar dryer with green house as collector, solar tunnel dryer with integral collector, Solar multiple layer batch dryer, indirect type solar fruit and vegetable dryer

Mixed mode solar dryer

This type of dryer is the combine feature of Direct Type and Indirect type of solar energy dryer. Heat from solar is observed by the product directly from sun as well as indirectly from the hot air which is heated in solar collector by the solar Energy.

Advantages of Indirect Type Solar Dryer In order to solve the open Drying and Direct type solar Drying problems, various design of indirect solar dryer had been developed and tested.

Advantages: 1) Better product quality exposed to lower temperatures.2) Quality levels are better retained as not exposed to ultraviolet radiation. 3)Better control over drying and better product quality than sun drying.4)Possibility of eliminating fan/blower using a heating media to heat the product being dried and passing drying air over it because moisture pickup per kg dry air is much higher. 5) Air circulation aided by draft due to the chimney multiple trays to hold the material being dried. 6) Better than other dryers in terms of solving various equation based on energy.

Disadvantages: Lack of skilled personnel for operation and maintenance, the intensity of incident radiation is a function of time so need Thermal storage, auxiliary energy source, the low energy density of solar radiation, which requires the use of large energy-collecting, surfaces (collectors), Expensive investment and high energy costs

WORKING PRINCIPLE OF INDIRECT TYPE SOLAR DRYER-

Indirect Type Solar dryer Consist of two part, one is drying cabinet where Materials is kept in trays or shelves inside drying cabinet and other unit termed as solar collector is used for heating of the air into the cabinet. Then heated air is allowed to flow over the wet material that provides the heat for moisture evaporation. The drying chamber is used for keeping the material in wire mesh tray. A downward facing or horizontal absorber is connected to the drying chamber at a sufficient distance. The absorber can be selectively coated with black colour to absorb maximum solar radiation. The inclination of the glass cover from horizontal to receive maximum radiation is depend on the location latitude. Solar radiation after incident on glass cover, part of the radiation reflected back to atmosphere and part of it pass through the glass cover. After transmission through glass cover, a part of this is lost to ambient through a glass cover, part of this is absorbed by the absorber and remaining is transferred to the flowing air above it by convection. The flowing air is thus heated and passes through in the drying chamber. Material is heated and moisture is removed through a vent provided at the top of drying chamber.

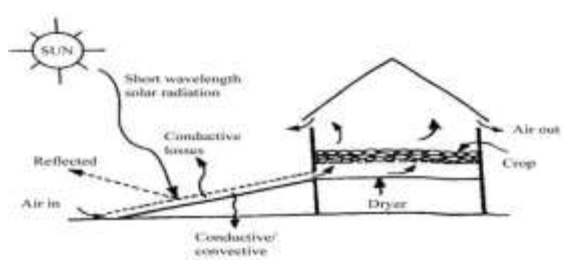


**Fig 1.Working Principle of Indirect Type Solar Dryer**

PREVIOUS WORK ON INDIRECT SOLAR DRYER

Mahopac et al. [8] developed a solar dryer consists of a flat plate collector, wire mesh absorber, glass cover, chimney and drying chamber. The heater was integrated to a drying chamber for food dehydration. The performance was evaluated by drying fresh samples of mango (Mangifera indica). The temperature rise of the drying air was up to 400C during noon hours. The thermal efficiency of the flat plate collector was 17% and wire mesh absorber was 21% at 0.0083 kg/s. The moisture content was observed to reduce from 85 to 13%.

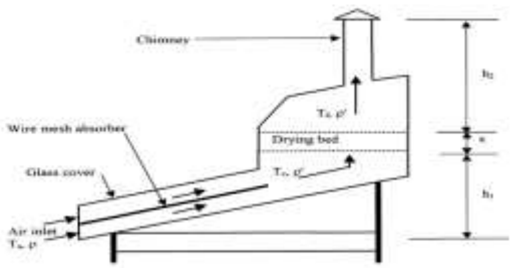


**Fig 2. Cross-section of solar dryer showing collector, drying chamber and chimney.**

Pangavhane et al. [9] designed and developed a multipurpose natural convection indirect solar dryer for drying various agricultural products like fruits and vegetables. Dryer consist of a solar air heater and drying chamber. The solar air heater consists of a finned absorber (painted matte black), glass cover, insulation and frame. The U-shaped corrugations were placed in the absorber plate parallel to the direction of airflow. Aluminum fins (a matrix foil 0.15 mm thick) were fitted to the back of the absorber. At the lower end of the collector (air inlet), shutter Plates 4 mm thick and 0.08 m × 0.4 m in size, were also provided to stop the air flowing during the night. The entire unit was placed in a rectangular box made from a galvanized iron sheet of 0.9 mm thick. The grapes were successfully dried in the developed solar dryer. After qualitative analysis it was concluded that the drying time of the grapes could be reduced by 43% compared to the open sun drying. The traditional shade drying and open sun drying dried the grapes in 15 and 7 days respectively, while the solar dryer took only 4 days with better quality raisins.

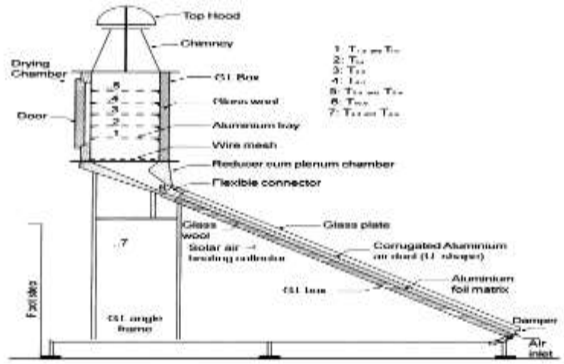


**Fig 3. Natural Convection Solar Dryer.**

Potdukhe and Thombre [10] designed, fabricated, tested and simulated solar dryer fitted with a novel design of absorber with inbuilt thermal storage capabilities. Experiment was performed on fenugreek leaves (Trigonella foenum-graecum) and chillies (Cap- sicum annuam). Thermic oil was used as a storage material. Drying and collector efficiency were found to be 21% and 34% respectively, so desired drying air temperature was achieved and maintained for a longer period. Also use thermic oil increased the total system cost by 10% but a significant saving of 40% in the drying period

Al-Juamily et al. [11] constructed and tested an indirect-mode forced convection dryer consists of a solar collector, a blower and Chamber. Two air solar collectors having V-groove absorption plates of two

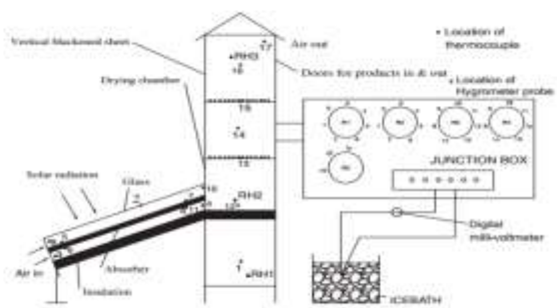


**Fig 4. Schematic of experimental set-up**

air passes and a single glass cover were used. One of vegetables (beans) and two fruits (grapes and apricots) were dried. The beans moisture content had been reduced from 65% to 18% in 1 day only. The moisture content of apricot had been reduced from 80% to 13% within one and a half day of drying and that of grapes had been reduced from 80% to 18% in two and a half days of drying. They concluded that the air temperature is the most effective factor on drying rate.

The effect of variation of the speed of air inside the drying cabinet was small and may be neglected. They also concluded that the relative humidity of air exits from the cabinet was small (between 25% and 30%) and therefore there is no need for high velocity of air inside the cabinet.

Aissa et al. [12] designed and studied the drying behaviour of sponge cotton (Gossypium spp.) by using an indirect solar dryer for different temperatures and air flow rates for five days of July 2008. The overall efficiency was observed to vary from 1.85 to 18.6% for an average temperature of 53.68 °C. Maximum overall efficiency of 18.6% was observed for air mass flow rate of 0.08 kg/s. The results indicated that drying air temperature is the main factor in controlling the drying process and air mass flow rate has remarkable influence on overall drying performance. It was concluded that higher drying air temperature produced higher drying rate and more temperature decay across the dryer chamber, Drying constant was nearly constant during the initial drying period and increases with the increase of dryer chamber inlet temperature, The overall efficiency and drying rate increase with the increase of drying air flow rate leading to subsequent decrease of the moisture ratio and drying time

Mohanraj and Chandrasekar [13] a forced convection solar drier was designed, fabricated and tested for the drying copra under Indian climatic condition. The moisture content of copra reduced from 51.8% to 7.8% and 9.7% in 82 h for trays at the bottom and top, respectively. The copra obtained was graded as 76% milling grade copra (MCG1), 18% (MCG2) and 6% (MCG3) according to Bureau of Indian standards (BIS: 6220-1971). The thermal efficiency of the solar drier was estimated to be about 24%.

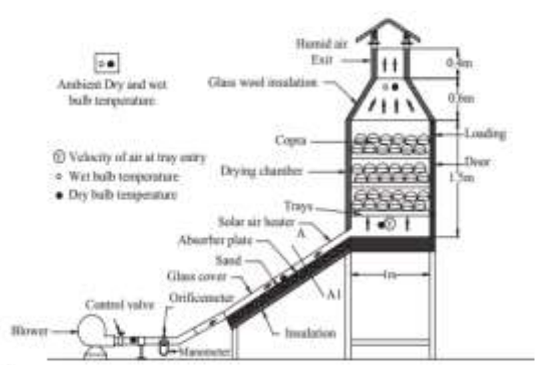


**Fig 5. Schematic view of the solar drier used for copra drying**

Boughali et al [14] constructed and investigated a new specific prototype of an indirect active hybrid solar–electrical dryer for agricultural products at LENREZA Laboratory, University of Ouargla (Algerian Sahara). Experimental tests were performed in winter season, with and without load, to study the thermal behaviour of the system and the effect of high air mass flow on the collector and drying efficiency was investigated. Also studied the fraction of electrical and solar energy contribution versus air mass flow rate.

Komilov et al. [16] designed a combined solar drying unit comprised of an air heater and a heat accumulator. The air coming out of the drying cell was recirculated through the solar collector by using air ducts which increased the overall drying efficiency of the unit.

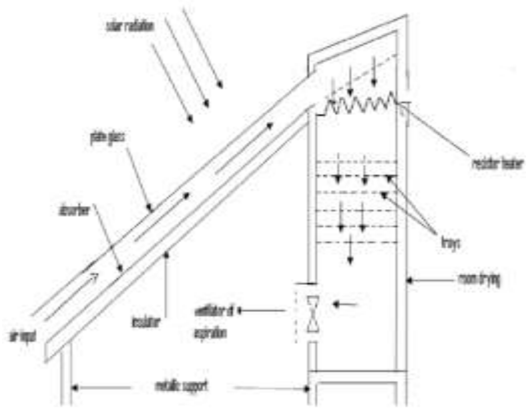

**Fig 6. Schematic diagram of an indirect active hybrid solar–electrical dryer**

It was concluded that experimental unit shortens the drying process by 4 to 5 times in comparison with air and sunshine drying, and the finished product is of high quality. Also concluded that, because of solar energy accumulation and circulation, productivity and efficiency of the unit increase by 1.5 to 2 times in comparison with the similar units.

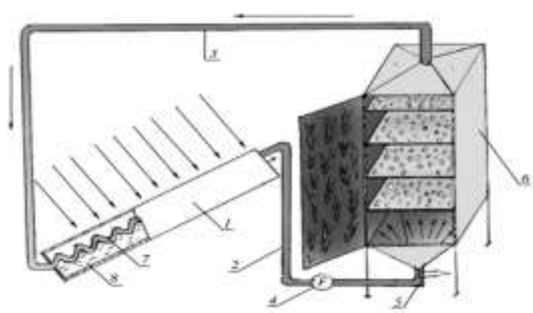

**Fig 7. Scheme of experimental unit: (1) air heater with heat-accumulating element; (2, 3) air ducts; (4) fan; (5) electric radiator; (6) drying cell; (7) heat exchanger; (8) heat accumulator.**

Akbulut and Durmus [17] studied the drying performance, both experimentally and theoretically, of mulberries (Morus) using convective solar dryer under seven different mass flow rates varying from 0.0015 to 0.0361 kg/s. It was reported that the drying time was decreased with the drying mass flow rate. The effective moisture diffusivity of mulberry was observed to vary between $3.47 \times 10^{-12}$ and $-1.46\times10^{-9}\ m^2\ s^{-1}$ within the mass flow rate range of 0.0015–0.036 kg/ s.

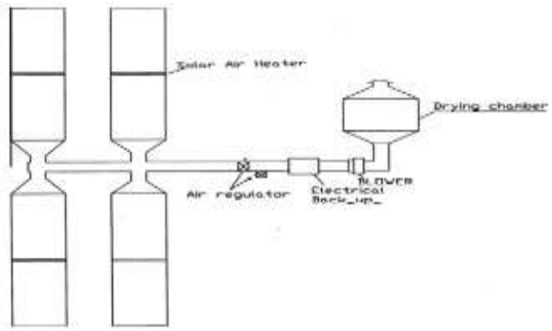


**Fig 8. Forced convection indirect solar dryer for thin layer silk cocoon drying**

Parikh and Aagrawal [19] designed design, develop and carry out detail experimentation and then analyze Double shelf cabinet dryer coupled with flat plate collector. Analysis was done for potato (S. tuberosum) chips and green chilly drying two spell of 12 days (in summer) and 35 days (in winter) at Mechanical Engineering Department, M. N. I. T., Jaipur, latitude (26.01° N). Various types of solar dryers, their principles and design methods, modeling, drying temperature, efficiency, utilization and payback period were reviewed. It was observed that observations that temperature of absorber plate during 1st spell in summer was lower as compared to winter. It was also observed that the use of glass and polycarbonate sheet as glazing cover improved dryer efficiency from 9 to 12% in case of simple dryer to 23.7% with glass glazing and 18.5% with polycarbonate sheet and drying time reduced.

Banout et al. [20] designed and developed a double pass indirect solar drier (DPSD) for drying of red chilli (C. annuam).System reduced its moisture content to 10% on wet basis. Double pass of ambient air improved the quality of dried product and its drying efficiency was reported 12.52% more than the cabinet drier. It was found that overall drying efficiencies of DSPD and Cabinet Dryer to reach the desired moisture content of 10% (on a wet basis) were 24.04% and 11.52% respectively. Also colour value of the solar dried products from the DSPD was higher than those from CD and open-air sun drying. The design and development of an indirect, natural convection batch-type solar dryer fitted with North–South reflectors. The collector efficiency using reflector was reported to increase from 40 to 58.5% without loading under peak solar irradiation conditions during a typical day in January in Bhavnagar, Gujarat, India.

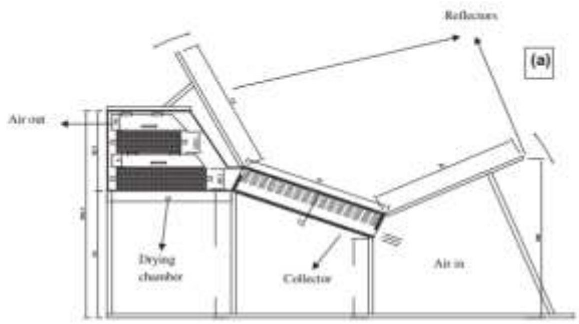


**Fig 9. Natural convection batch-type solar dryer**

Sundari et al. [23] designed and develop a forced convection solar dryer consists of a drying chamber, evacuated tube air collector, a blower and a chimney and studied its performance The moisture content of bitter gourd (Momordica charantia) was observed to reduce from 91 to 6.25% in 6 h compared to natural sun drying. Moisture ratio and drying rates, were calculated and compared with natural sun drying. It was found that the quality of the product using system was better than the natural sun-dried bitter gourd.

**Important Finding**

At low levels of relative humidity, the air had a high capacity to absorb moisture. The rate of water removal decreases with the decrease in moisture content of drying product during this period. [8,11,12]

The drying air flow rate increases with increase in ambient temperature by the thermal buoyancy in the collector. [9,11]

Efficiency of the collector increases and the air mass flow rate also increases with increasing temperature difference of the air in the collector.[9,12,16]

The mass flow rate of the drying air in the thermo syphon mode of the collector depends on the prevailing wind conditions, ambient air temperature, incident solar radiation and the collector design.[11]

Drying air temperature is the main factor in controlling the drying performance and that higher drying air temperature produced higher drying rate and more temperature decay across the dryer chamber.[12]

The overall efficiency and drying rate increase with the increase of drying air flow rate leading to subsequent decrease of the moisture ratio and drying time.[12,13,20]

Drying occurs in the falling rate period with a steep fall in the moisture content in the initial stages of drying which becomes very slow in the later stages. [13, 14].

The payback period is very small compared to the life of the dryer so the dryer will dry product free of cost for almost its entire life period. [14, 18]

**CONCLUSION**

Among the different types of solar dryers, the indirect mode forced convection solar dryer has been demonstrate to be superior in the speed and quality of drying. This paper is focused on review of indirect type solar dryers presenting their various designs, details of construction and performance Evaluation. Two broad groups of indirect solar-energy dryers can be identified, passive or natural circulation solar energy dryers and active or forced convection solar energy dryers. The natural convection solar dryers are easy to fabricate and are low cost as well as self-operated but no control over drying rate unlike forced convection dryers. The forced convection indirect dryer offers proper control over drying rate. Also through the use of enhancement techniques in the dryer like efficient system designs, heat storage units, the indirect type solar dryers are able to function even during the off-sunshine.

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