DEVELOPMENT OF SOLAR DRYER SYSTEM FOR FOOD DRYING PURPOSES

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ABSTRACT

The objective of this work is to design, develop and evaluate performance of an indirect solar dryer prototype in a passive and active mode using thermal energy storage and without thermal energy storage for the drying of kiwifruits. Drying is one of the oldest methods using solar energy where the product such as vegetables, fruits, fish, and meat to be dried exposed directly to the sun. This method has many disadvantages such as spoilt products due to rain, wind, dust, insect infestation, animal attack and fungi. Foods should be dried rapidly, but the speed of drying will cause the outside becomes hard before the moisture inside has a chance to evaporate and it will affect the quality of dried product due to over drying. The design of a functional solar dryer system would minimize these disadvantages. This design of both modes was employed and has compared with the performance testing through parameters such as temperature, air velocity, collector efficiency and weight loss. It was shown that the use of this type of solar dryer reduced the drying time significantly and essentially provide better product quality compared with conventional drying method. The effect of temperature to moisture contents against time and rate of drying are studied in this research.

ABSTRAK

Objektif kerja ini adalah mereka bentuk, membina dan menilai prestasi prototaip pengering suria tidak langsung aktif dan pasif dengan mengunakan tenaga termal simpanan dan tidak mengunakan tenaga termal simpanan untuk pengeringan makanan seperti buah kiwi. Pengeringan adalah salah satu kaedah yang tertua yang menggunakan tenaga solar di mana produk seperti sayur-sayuran, buah-buahan, ikan dan daging serta sebagainya dikeringkan terdedah terus kepada matahari. Kaedah ini mempunyai banyak kelemahan seperti produk rosak disebabkan oleh hujan, angin, debu, serangga-serangga, serangan haiwan dan kulat. Makanan perlu cepat kering, tetapi kelajuan pengeringan akan menyebabkan luar produk menjadi keras sebelum kelembapan yang terdapat di dalamnya mempunyai peluang untuk menyejat dan ia akan memberi kesan kepada kualiti produk kering disebabkan oleh terlebih kering. Reka bentuk sistem pengering suria berfungsi akan meminimumkan kekurangan ini. Reka bentuk bagi kedua-dua jenis ini telah diambil kira dan di banding dengan ujian prestasi melalui parameter seperti suhu, kelajuan udara, kecekapan pemungut dan kehilangan berat. Ia telah menunjukkan bahawa penggunaan jenis pengering suria ini dapat mengurangkan masa pengeringan ketara dan pada asasnya menyediakan produk yang lebih bermutu setelah dibandingkan dengan kaedah pengeringan konvensional . Kesan suhu terhadap kandungan lembapan terhadap masa dan kadar pengeringan adalah bidang kajian dalam penyelidikan ini.

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LIST OF SYMBOLS

m_a	Air mass flow rate (kg/s)
C_p	Air specific heat capacity (J/kg.K)
T_0	Air temperature outlet from solar collector (°c)
T_1	Air temperature inlet to solar collector *(ambient air temperature)* (°c)
I	Solar radiation (W/m^2)
A_c	Area of solar collector (m^2)
M	Mass of the crop (kg)
L	Latent heat of evaporation of water at the dryer temperature (kj/kg)
t	Time of drying (s)
h_0	Abs humidity of air leaving the chamber (kg/kg)
h_i	Abs humidity of air entering the chamber (kg/kg)
h_{as}	Adiabatic saturation humidity of air entering the chamber (kg/kg)
M_0	Initial product mass (kg)
M_t	Product mass at time (kg)
A	Area (m^2)
ΔT	Difference in time reading (h)
ΔW	Weight loss in drying period per weight of food sample (kg/h/weight sample)

LIST OF ABBREVIATIONS

FYP 1	Final Year Project 1
FYP 2	Final Year Project 2
UMP	Universiti Malaysia Pahang
UV	Ultraviolet
HP	Heat Pump
DC	Direct Current

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Drying is one of the oldest methods using solar energy where the product such as vegetables, fruits, fish, and meat are to be dried by exposing directly to the sun. It is a simple process of removing the moisture contents from a natural or industrial product in order to reach the standard specification. This method is economical on a large scale drying because of cheaper operating costs compared to the drying machine.

However, this method has many disadvantages such as spoilt products due to rain, wind, dust, insect infestation, animal attack and fungi. Because of that, the solar dryer technology will become an alternative method which can process the products in clean, safe, hygienic and produce better quality and more nutritious foods. In general, this solar dryer has saved energy, labor intensive, time, less area for spreading the product to dry, makes the process more efficient and protects the environment.

Solar dryer can be classified by three types that is **direct**, **indirect** and **mixed mode** which it is according to the passive mode of drying, whether the product to be dried is exposed or not. The active solar dryer, auxiliary energy is necessary to operate the system. However, in the mixed mode solar dryer, it consists of both radiation with conduction of heat through the transparent cover and the convection of the heat from the solar air heater.

Food materials and crops are very sensitive to the drying conditions. Very short duration with high speed drying would caused a quality of dried product will be reduced due to over or under dry. Thus the selection of drying temperature is o ne ofthe most important thing to ensure the color, texture, flavor and value of the product will not degrade (Devahast, undated). Thereby, a new design of high efficiency solar dryer for small scale food was designed and tested for several products such as fruits and fish. Drying result obtained were compared with the result of the naturally direct sun-dried product.

1.2 PROBLEM STATEMENTS

Drying is one of the oldest methods using solar energy where the products such as vegetables, fruits, fish, and meat, etc to be dried exposed directly to the sun. This method has many disadvantages such as spoilt products due to rain, wind, dust, insect infestation, animal attack and fungi. The speed of drying especially in open sun drying which is solar radiation exposed directly to the products will cause the product's surface becomes hard before the moisture inside has a chance to evaporate and it will affect the quality of dried product due to over drying. Open sun drying also suffers from a high labor requirement and excessive crop handling particularly in periods of inclement weather which can result in high costs, crop damage and a loss in quality. In this study, the renewable solar dryer was designed to solve this problem and will adapt the ergonomics criteria and produce a better quality product.

1.3 PROJECT OBJECTIVES

There are two main objectives to achieve in this research which are:

i. To study a charateristics and performance of the solar dryer system.
ii. To develop a solar dryer system for food drying.

1.4 SCOPES OF THE PROJECT

In order to reach the project's objective, the following scopes are identified:

i. Designed a solar dryer according to the information obtained from the literature.
ii. Acquire materials needed is suitable for fabrication.
iii. Performance of solar dryer for collector efficiency, drying air temperature and weight loss will be compared with different types of drying method.

1.5 PROJECT PLANNING

Final Year Project has been divided in two parts, FYP 1 and FYP 2. FYP 1 was focused on research and literature review from journal, article and other resources that related to the project title. The literature review process took eight weeks to finish. The schedule management of the project was done by using Microsoft Excel Worksheet using the Gantt chart system.

After all of literature review done, the advantages and problems or weakness about the solar dyers product have been found out. After that I will sketch my ideas for making a new feature design. The sketching of the solar dryer takes about four weeks to be done. The sketching done using manual sketched hand at A4 size paper. After deciding the best ideas that have been chosen the sketching concept idea transfer into Auto CAD and SolidWork with actual dimension. The next task is preparation of progress presentation, both of these tasks take two weeks to be done. These FYP 1 presentations have been done at the end of this semester. For this week I have to prepare the slide presentation and speech for the presentation. After the presentation, I need to prepare the draft report and submit it.

Lastly, next 14 weeks for FYP 2 , it starts with fabrication process and followed by data analysis. The final report will be written and prepared for final presentation. This will take about a week to prepare and accomplish. A report is done using the UMP thesis format and also guidance from supervisor. All tasks scheduled takes around fourteen weeks to complete.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter discusses about the previous researches that have been done which related to this project. This project requires good understanding of the knowledge about drying method. Therefore, executing a research is necessary to obtain all the information available and related to this topic. The information or literature reviews obtained are essentially valuable to assist in the fabrication and specification of this final year project. With this ground established, the project can be accomplished with guidance and assertiveness in achieving the target mark. The sources of the review are extracted from journal, article, books and websites.

2.2 TYPES OF DRYING METHOD

Figure 2.1 show that solar dryers can be classified by two types, active and passive mode. Passive dryers can be further divided into direct and indirect models. A direct solar dryer is a system in which the food is directly exposed to the solar radiations only in which the material to be dried are placed in a transparent enclosure of glass or plastic or with reflected radiations such as box dryer. Reflected radiations are used to increase the temperature in the box dryer. In an indirect solar dryer, solar radiation do not falls directly onto the product being dried, but preheater or collecter is used to raise the hot air temperature in the dryer chamber. Passive dryers can be called natural convection in which the fluid motion is generated by density differences in fluid occurring due to temperature gradients. They can be constructed easily with inexpensive and locally available materials. This is a simple and economical method to preserve food for a long period of time storage (Chen, 2009).

Active dryers are required an external means such as fans or pumps. It is used for moving the heated air from the collector area to the drying chamber. The drying rate is higher compared with passive methods. However, for drying operation in mixed-mode solar dryer, the combination action process of solar radiation incident on the material to be dried and the air preheated in solar collector provide the heat required for the drying operation (Chen, 2009 and Bhattacharya, 2001)

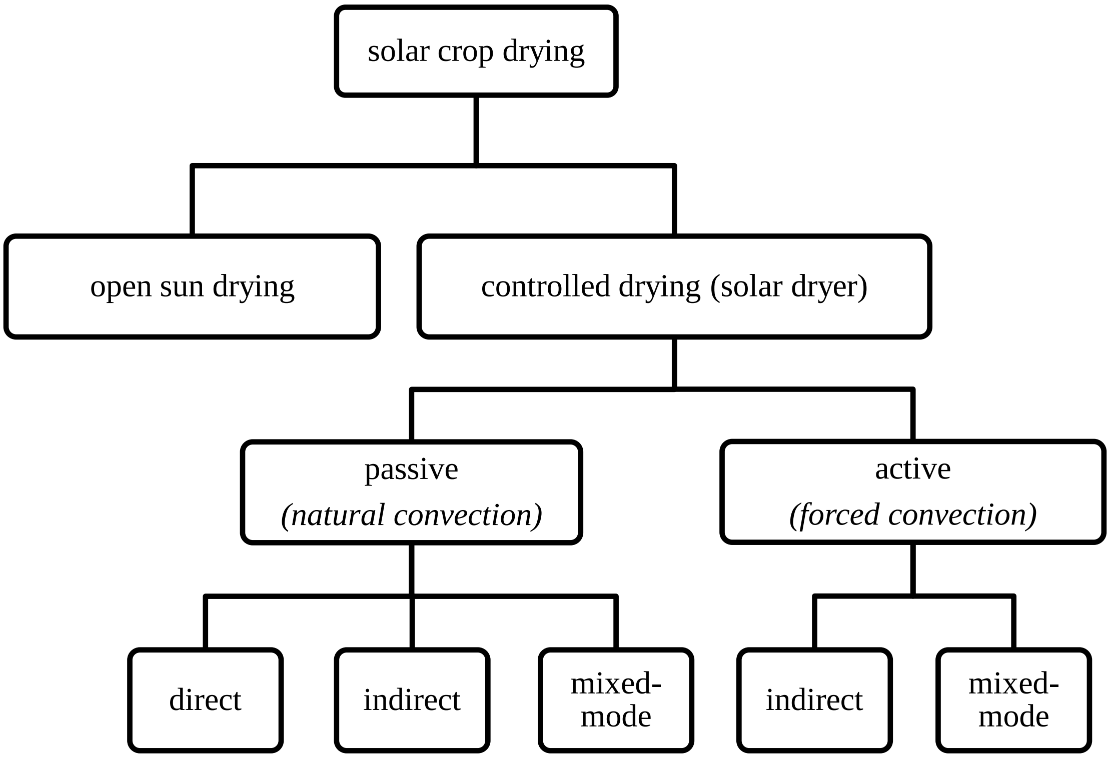
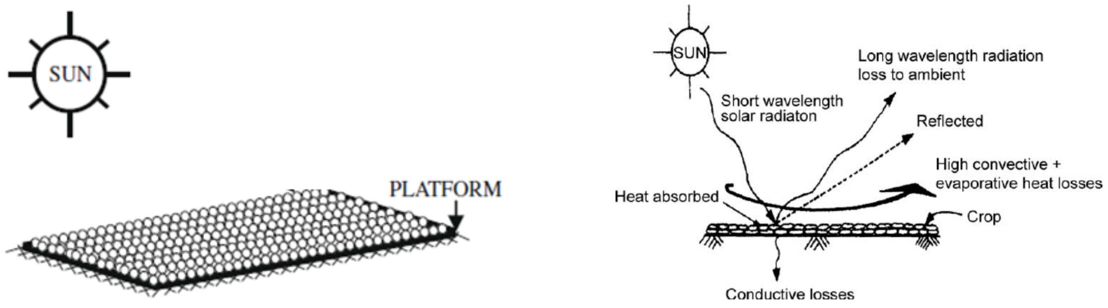


Figure 2.1: Classification of crop drying using solar energy

Source: Chen et al. (2009)

2.2.1 Open Sun Drying

Traditional drying methods use solar radiation to heat directly the products and to natural air currents. Hence, products drying using solar energy is a method that has been practiced for thousand of years. In traditional drying methods are also known as open sun drying, the products are spread on the ground or platform, where they are directly exposed to the sun and wind. Despite of using the solar radiation that is freely available in an ambient environment, a little capital cost and less labour are required. However, this method produces low quality products and also results in considerable losses due to various influences such as an animal attack, insect infestation and rain. Refer Figure 2.2 (a) as an open sun drying.



(a) (b)

Figure 2.2: (a) Open sun drying; (b) Working principle of open sun drying

Source: Chen et al. (2009)

Figure 2.2 (b) shows the working principle of open sun drying by using solar energy. Chen et al. (2009) has noted that the short wavelength solar radiation energy falling on the crop surface which is partly reflected and partly absorbed by depending the color of the crops. The absorbed radiation will increase the crop temperature and resulted the moisture of the crop surface to evaporate due to increase of air surrounding. This result is lost through long wavelength radiation to the atmosphere and through conduction to the ground surface.

2.2.2 Direct Solar Dryring in Passive Mode

This type of dryer typically consists of a drying chamber that is covered by transparent cover made of glass or plastic. Hence, the glass cover reduces direct convective losses to the surroundings and increases temperature inside the dryer. The drying chamber is a shallow, insulated box with holes in it to allow air to enter and leave the box. The food is placed on a perforated tray that allows the air to flow through it and the food as shown in Figure 2.3.

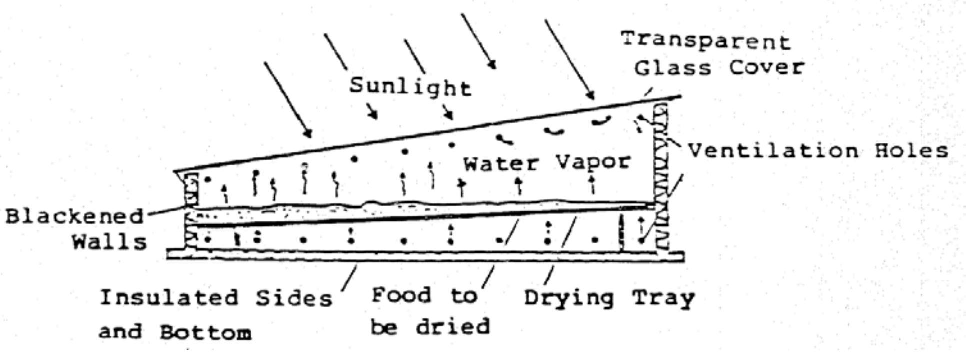


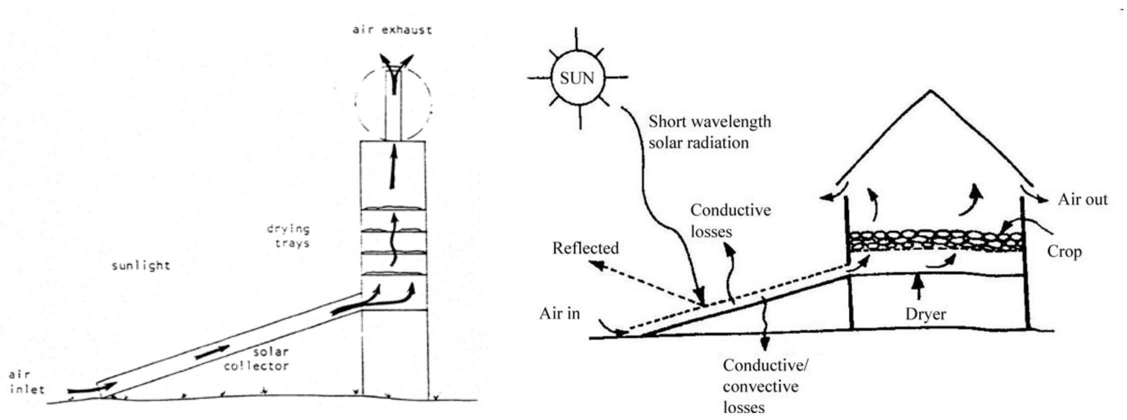
Figure 2.3: Cabinet dryer

Source: Gregoire (2009)

Sengar (2009) designed a low-cost and simple design that used for drying fish. It have been designed for dry commodities under hot and humid conditions prevailing in Konkan region of Maharashtra where most of the agricultural products need drying. The drying chamber was constructed by bamboo for a 92 cm x 75 cm frame and UV stabilized 200 micron plastic film was used for collection of solar energy. Drying chamber designed in such way that it consist 16 trays of 70 cm x 50 cm size. Mosquito net was used for trays as it betters performance in humid region. Bottom and topside of the dryer was provided with openings for air circulation which will carry away the moisture evaporated from the food.

2.2.3 Indirect solar drying in Passive mode

In indirect dryer typically consists of a drying chamber and collector chamber. A solar energy is collected in a separate equipment called as solar collector that is covered by transparent cover made of glass or plastic. A collector chamber is used for solar-energy collection for heating of entering air into the drying chamber that connected separately where the product is placed. The heated air is allowed to flow through wet products. Here, the heat from moisture evaporation is provided by convective heat transfer between the hot air and the wet crop. The drying is basically by the difference in moisture concentration between the drying air and the air in the vicinity of crop surface. The product is not directly exposed to solar radiation because to minimize discoloration and cracking on the surface of the products. Figure 2.4 shows the simple of the indirect solar dryer and working principles of indirect solar drying.



(a) (b)

Figure 2.4: (a) indirect solar dryer ; (b) Working principle of indirect solar drying

Source: Chen et.al (2009)

Scanlin (1997) has designed a several types of indirect solar dryer prototype. It was designed with locally available tools and materials and operated by natural convection. The basic design, a collector with a Sun Lite HP plastic glazing and black metal absorber was used in order to absorb the solar radiation and fully plywood painted with black color for frame and stainless steel for drying shelves . These dryer can produce temperature of 54 to 82° C , however it was possible to dry a foods in one day. In order to improve the performance of these solar dryers, additional reflector was built and analyzed. A single, vertical wall and side reflector was mounted at the solar dryer as shown in (Figure 2.5). A result shown that, using the reflector the temperature inside the dryer can be increased.

Figure 2.5: Passive Solar Dryer

Source: Scanlin (1997)

Gatea (2010) has tested a cylindrical section of solar dryer and found that from different flow rates tested, the maximum daily drying efficiency was 18.41 % and 14 % d.b at the flow rate of 0.0405 kg/s and the minimum was 16.27 % at a flow rate of 0.0675 kg/s. The experiment was designed for dried 70 kg of bean crop and it was conducted by the Department of Agricultural Mechanization, College of Agriculture, University of Baghdad, Iraq. Figure 2.6 shown the sectional view of cylindrical section solar drying system. From the experiment, it concluded that the efficiency of the solar drying system is affected by the properties of drying materials e.g. moisture content, size, shape and geometry as well as ambient conditions, which include solar radiation and temperature, relative humidity, velocity and atmospheric pressure of ambient air.

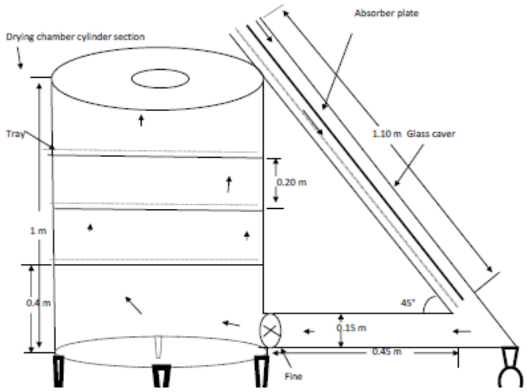


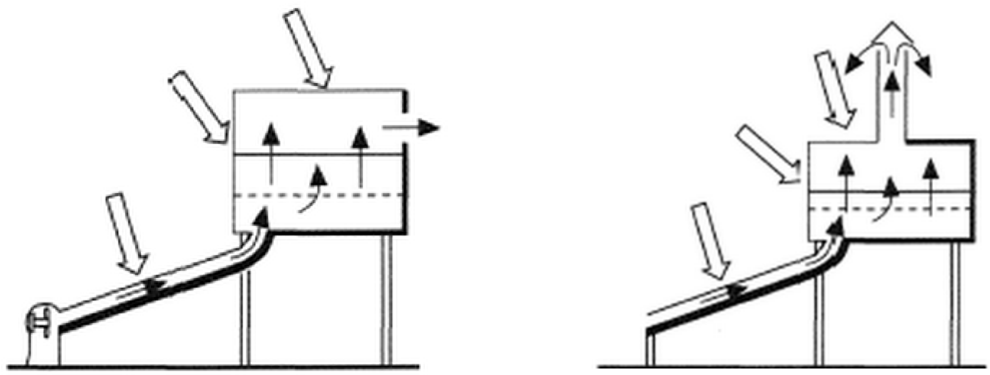
Figure 2.6: Sectional view of cylindrical section solar drying system

Source: Gatea (2010)

2.2.4 Mixed-mode Solar drying

In the mixed mode type of drying system, the heated air from the separate solar collector is passed through a drying chamber and the same time , the drying chamber will absorbs a solar energy directly through a transparent cover. The product is dried simultaneously by both radiation with conduction of heat through the transparent cover and the convection of the heat from the solar air heater . Moradi and Zomorodian (2009) have developed a solar dryer that suitable for drying the cuminum cyminum grains. Experiments have been carried out to evaluate the best drying method by using two drying states (mixed and indirect) from natural and forced convection. The dryer was operated with a load of 70-80 grams grains with 43 % average initial moisture content. They reported that the solar dryer is more efficient using natural convention method for mixed mode drying state compare to forced convection. After 90 min of drying, 43.5 % to 4.95 % of moisture contents was reduced using the passive mixed mode drying method.

On the other hand, mixed mode solar drying can be further classified into two types which is natural convection (passive) and forced convection (active). This type of solar dryer has less moisture content and drying rate compare with the others. Figure 2.7 shows the two modes of mixed-mode solar dryer.



(a) **(b)**

Figure 2.7: Mixed-mode solar dryer (a) active mode; (b) passive mode

Source: Norton (1992)

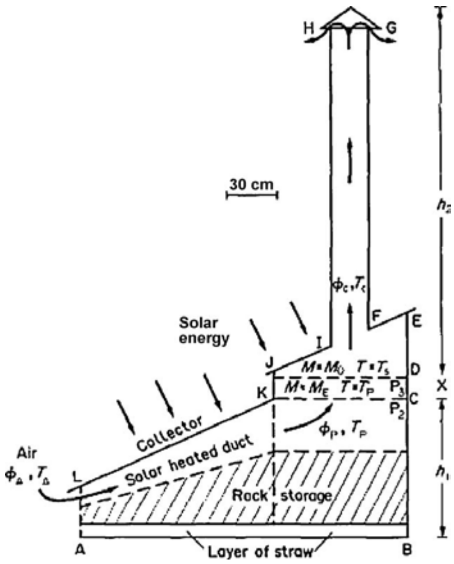
Azad (2008) has designed and developed an experimental study of natural convection solar dryer for rural area. The experimental result has shown that, in three to four days, the moisture contents of grapes were reduced from 81.7 % to 36.7 % by natural circulation. A prototype unit consists of a 25 mm wooden frame of collector chamber and to reduce the heat loss, it was covered with fiberglass sheet for . A black painted rocks were placed in the collector chamber in order to absorb solar radiation and to store thermal energy (Figure 2.8 a).

Khoshmanes (2006) have experimentally evaluated a solar dehydrator with a rock bed storage system for fish drying. Collector design with 100 m^2 in forced mode to produce a heated air at the average temperature of 50° C and air flow rate of 1 kg/s for 48 hours time drying. A 56 cube meter rock bed will be charged with 300 m^2 collector was used to continue the drying for 14 hours during the night.

According to Lalit et al. study (as cited in Ayensu and Asiedu-Bondzie, 1986), from an experimental simulation using a non mechanical solar dryer with energy storage, a drying characteristics test have investigated (Figure 2.8 b). The solar collector is capable of transferring $118Wm^2$ to the drying air at a temperature of 32° C. The following conclusion have been drawn:

1. The steady state condition for drying the wheat crop with and without thermal storage is reached after about 2 h for a given storage capacity and 1 kg of wheat grain (drying material.
2. The moisture content of the drying material decreases with increase in time for a given temperature.
3. The drying rate is reduced with the decrease of moisture content.
4. The steady state condition will take a larger time to achieve for high thermal capacity of the rock bed thermal storage.
5. By using thermal storage, the maximum temperature of the drying material is reduced within a safe range, thereby improving the quality of the agricultural procedure.

(a)



(b)

Figure 2.8: (a) Mixed Mode Solar Dryer; (b) Solar dryer with rock storage

Source: Khoshmanesh (2006)

2.2.5 Indirect solar drying in active mode

Active solar dryers or known as forced convection dryer is designed incorporating external means, like fans or pumps, for moving the solar energy in the form of heated air from the collector area to the drying beds. The external devices are used for air circulation. The heated air is forced onto the drying chamber where it will increase the drying rate as well as thermal efficiency and decreased of drying time. It's more effective dryer and suitable used for large scale in food processing industry. Figure 2.9 shows the active solar convective dryer.

Solar dryer using forced convection system integrated with gravel as heat storage material for chili drying that have been investigated by Mohanraj and Chandrasekar (2009) and tested at Pollachi, India. The system consist basically of a flat plate solar air heater connected to a drying chamber. The blower was connected on the one side of the collector and sand mixed with aluminum scrap was filled which is to store the heat. The experiment result shown that after 24 hours of drying , the systems were reduced 72.8 % moisture content to 9.1 % at the bottom tray and 9.8 % at the top tray. The heat storage material in the solar dryer was conducted for 8 hours during sunshine hours and continues to drying for 4 hours during sunset.

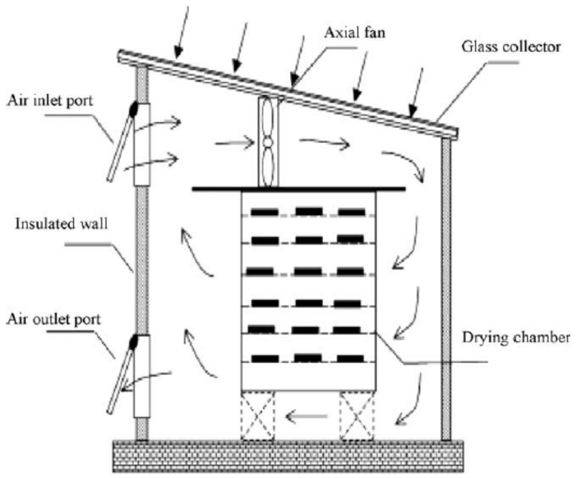


Figure 2.9: Active solar convective dryer

Source: Chen (2009)

A Double-Pass Solar Dryer is shown in Figure 2.10 has been studied (Azmi et al. (2007). This type of solar dryer could be employed to dry agricultural and marine product. The experiments of solar dryer have been carried out at the Green Energy Technology Innovation Park, Universiti Kebangsaan Malaysia. This solar dryes used forced convection drying system that consists of auxiliary heater and blower, 4.8 m x 1 m x 0.6 m size of drying chamber and 1.2 m x 4.8 m of the double pass solar collector array as a main component which is four collectors are set in a series. The collector consists of the glass cover, the insulated container and the black painted aluminum absorber. The upper channel depth is 3.5 cm and the lower depth is 7 cm. The bottom and sides of the collector have been insulated with 2.5cm thick fiberglass to minimize heat losses.

The experimental results of drying test with palm fronds has shown that the system was capable to dried 100kg of palm fronds and resulting of 38 kg of water content which is 60% (wet basis) and 10% (product basis) respectively in 22 hours at average solar radiation of about 557 W/m2 and air flow rate 0.1278 kg/s. The collector and drying system efficiencies were found to be 31 and 19% respectively. The pick-up efficiency of the solar drying system was estimated to be about 67% for 100 kg palm oil fronds.

Figure 2.10: Photograph of solar drying system

Source: Fudholi et al. (2011)