THE DEVELOPMENT OF DRYING SYSTEM BY USING PARABOLIC COLLECTOR FOR SMEs

PHATPISEY LIENG

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ENGINEERING PROGRAM IN AGRICULTURAL MACHINERY ENGINEERING

FACULTY OF ENGINEERING

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Thesis Title	The Development of Drying System by Using Parabolic Collector for SMEs
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Program	Agricultural Machinery Engineering
Thesis Advisor	Assistant Professor Kiattisak Sangpradit, Ph.D.
Academic Year	2018

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ABSTRACT

This research aimed to design, fabricate, and evaluate the mixed mode active solar dryer integrated with a gas burner and compare this with traditional open sun drying for drying agricultural products.

This drying system was divided into three main parts. The first part was a parabolic solar collector for solar collection. Second was a solar greenhouse chamber and temperature controller, and the last one was LPG energy used as a reserved heat source for the drying process. Two different experiments were carried out. The first one was solar drying test and the second one was solar hybrid test. The temperature set inside the dryer of the second experiment was at 60°C. When the temperature was lower than 60°C, the controller system automatically turned on the LPG energy source to reach the temperature set. Once the temperature reached the set point, the system automatically turned off the LPG energy source.

In the first experiment, the results indicated that the moisture content of Jinda Chili was reduced from 86.25% to 8.33% w.b, while in the second experiment this moisture was reduced from 87.40% to 16% w.b within three days. Both moisture contents of open sun drying were over 70% w.b in the same period. The second experiment was conducted during the rainy season so its moisture content decreased a bit slower than the first one. However, the final values of the moisture contents were still acceptable to the market demand. The expected payback periods of this system for drying Jinda Chili are about 0.45 years.

Keywords: solar dryer, parabolic collector, greenhouse chamber, moisture content

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CHAPTER 1

INTRODUCTION

At present the Thai government is attaching considerable importance to the promotion of small and medium-sized enterprises (SMEs) and startups. It has covered the promotion of SMEs in the national program. SMEs have been summoned as a vital driver and the foundation of the country's economy. 78 percent of the total employments and 99 percent of Thailand' enterprises were found in this country [1]. More than 90 percent of Thai exports come from SMEs. There are currently about 2.7 million SME operators in Thailand and they are the country's key income generators. The Government has, therefore, supported finance and technology for SMEs' productivity and innovation. It has set up a National Startup Committee and a fund to provide startups with greater access to financial sources.

The Government aims to encourage SMEs to adopt the concept of startups, or innovation-driven enterprises, for greater business opportunities. The promotion of startups is connected with efforts to convert Thailand into a digital economy and society and move the country toward Thailand 4.0. The startups are SMEs that adopt innovation and technology for the sustainability of their businesses. In order to guide the country toward Thailand 4.0, the Thai government aims to boost the number of startups. With innovation and technology, SMEs will be able to create high-value products and help develop Thailand into a digital economy and society. This will also contribute to developing Thai industry from a value-added to a high-value model, in response to the "Thailand 4.0" policy.

Nowadays, the world's population is remarkably increasing day by day. Food demand is also incredibly vital to provide people physical support for their daily living. Agriculture plays a crucial role in the life of an economy. It is the fundamental of economic system. It not only gives food and raw material but also employment opportunities to a extremely large proportion of population. Nowadays, marketing, processing, distribution of agricultural crops etc. are all recognized as a section of modern agriculture. Therefore, it may be set as the production, processing, marketing and distribution of crops and cattle products.

Thailand is an agricultural country; most of the products need some sort of preservation to enhance their shelf life since the production usually exceeds market demand at the harvest season. However, food production and long term food maintenance are limited if comparing to the need of consumption. To keeps agricultural products for long time period, preserved food is one of the popular methods. Many of these methods are like drying, salting, canning, pickling, and freezing etc. Among of these methods drying is one of the most techniques that farmers always used. The heat sources for drying products are like sunlight, wind, electric infrared, electric heater, gas burner, fuel diesel, fuel gasoil, and wood etc.

1.1 Background and Statement of the Problems

Drying is the process of removing moisture and in the case of drying of food, it is either to prevent the activities of microorganism for efficient storage or to reduce the bulk weight for easy transportation. It can sometimes be even a stage in the food preparation process. Thermal food drying using the sun's energy is a very simple and ancient skill which has been practiced for many years. Open sun drying is a form of drying where the food crops are directly exposed to the sun's radiation whereas a more advanced method, solar drying, houses the food in drying chambers and is directly or indirectly heated by the sun. Despite the numerous advantages of the solar drying over the open sun drying, the latter is the most preferred method in the rural areas particularly due to that fact that it is easy to execute and does not require great skill. Unfortunately this mode of drying has been wrought with many disadvantages one of which is the poor quality of food derived.

However, various researchers have found ways of improving upon this ancient method of drying in the form of the solar dryer. The solar dryer still harnesses the sun's energy but utilizes it more efficiently and subsequently results in better final products. Various forms of solar dryers exist and they vary from very simple direct dryers to more complex indirect designs.

Properly designed solar dryers have the advantage of giving faster drying rates by heating the air to about 10-15°C above room temperatures, which reduces the relative humidity and causes the air to move faster through the dryer. The faster drying time of the solar dryer reduces the risk of spoilage, improves quality of the product and gives a higher throughput. Improvement of the efficiencies of these solar dryers and developing cheaper dryers that are more easily adaptable by rural folks is still a working progress that can ultimately be achieved if research and development tend to focus more in that area. It has therefore become necessary to continue to find workable and adaptable designs which can easily be replicated and used in the rural areas without the need to procure expensive construction materials. These solar dryers should ultimately be able to cause a reduction in energy costs and also speed up drying, while still turning out good quality final dried produce. The aim of this thesis is therefore to introduce a new design of solar dryer which explores the possibility of incorporating the parabolic collector in a solar dryer [2].

Figure1-1: Traditional open sun drying

Food scientists have found that by reducing the moisture content of food to between 10 and 20%, bacteria, yeast, mold and enzymes are prevented from spoiling it. The flavor and most of the nutritional value is preserved and concentrated [3]. Given that most staple foods in South East Asia are seasonal and mostly perishable, it has become imperative to salvage some of these food crops which cannot all be consumed within the season they are produced. Most of the rural areas in South East Asia countries, sun drying of food crops is seen as the best method of food preservation because it has a low initial setup cost and requires very little skill. Unfortunately this very simple technique leaves the crop susceptible to rain, contamination by dirt and animals and also usually takes a much longer time to dry resulting in a final product with very poor quality.

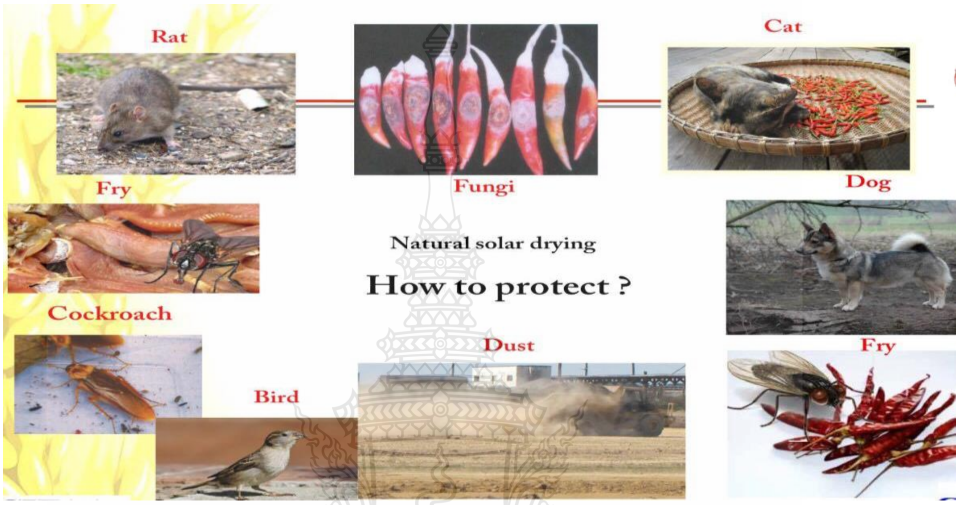

Figure 1-2: Issues of the open sun drying

In addition, ingenuity towards food preservation in South East Asia has been directed more towards food crop preservation. This has left a gap in the innovation of drying techniques for other types of food like major grain, most especially vegetables and fruits. Therefore, these problems have given rise to the need to design effective solar dryers which get more efficient and cost effective drying process and lastly promote the need to preserve more agriculture product during the glut season.

The parabolic collector has been fully adopted in the solar energy field because of its unique ability to focus high amount of energy to its focal point. This characteristic although explored in the design of solar thermal systems, has not been wholly explored as a means of increasing the efficiencies of solar dryers.

Therefore, this thesis seeks to create a new model and performance of a mixed-mode solar dryer for food preservation which combines the solar greenhouse, LPG energy and parabolic collector terms the ‘solar drying system’. It is the intention that the dryer becomes a more efficient method of drying agricultural products with reducing the drying time and cost of drying operations.

1.2 Purpose of the Study

In this thesis will aim to:

1.2.1 Create a new model of solar dryer system in hybrid mode.

1.2.2 Test the performance of the system using different parameters such drying time and temperature.

1.2.3 Compare the drying effectiveness between open sun drying, sun solar drying, and solar drying in hybrid test.

1.3 Research Questions and Hypothesis

We are interested in seeing to extend and bring a new model of the solar dryer which can reduce the drying time and cost of drying operations with high effectiveness if we make a comparison with another dryer, and most importantly it's suitable for the daily lives of farmers and consumers.

In this research, we introduce the drying system which is designed as the mixed-mode active solar dryer combining parabolic solar collector, solar greenhouse chamber, and LPG energy which are acceptable for SMEs.

1.4 Theoretical Perspective

1.4.1 In this thesis, we use many of the fundamental theories which is concerned the drying system in this project. By the concerned theories are:

1.4.2 The fundamental of the parabolic solar collector theories.

1.4.3 The fundamental of the psychrometric chart theory.

1.4.4 The basic of the drying system theory.

1.4.5 The air flow simulation theory.

1.5 Delimitations and Limitation of the Study

This thesis mainly focuses on bringing out a new design of solar dryer system in the size of 6m x 8m x 2.5m with operating in drying Jinda Chilli. Performance assessment of the dryer is also limited to the testing location in Rajamangala University of Technology Thanyaburi, Pathum Thani Province, Thailand, a couple of days in the month of February and June, 2018. The methodology which was adopted in carrying out the studies is as the following points:

1.5.1 Parabolic collector, greenhouse chamber has been designed and simulated by using Solidworks flow simulation.

1.5.2 The solar drying system is constructed based on the design concept.

1.5.3 The dryer is subsequently tested for drying Jinda Chili with different drying condition.

1.5.4 The ambient and internal temperature and humidity during operation of the dryer are measured by using different parameters.

1.5.5 Results are then compiled and analyzed.

1.6 Signification of the Study

The advantage of this studying in this project, we can improve and develop the previous concepts and knowledge in the drying system which can be used for the future development of the dryer.

CHAPTER 2

LIETERATURE REVIEW

The consumption of sun for drying of agricultural crop has been carried out since ancient times and to date it is still being used as the preferred method in developing countries like Thailand, Cambodia, Lao, Vietnam, and Myanmar…etc. because this source of energy is freely available and is very economical.

In a tropical like South East Asia, where sun solar energy is widely abundant it will be prudent to take advantage of this form of energy which is highly abundant and very environmentally friendly and does not pose adverse environmental impacts like other forms of non-renewable energy. There have been a lot of studies in the domain of harnessing the sun's energy in the drying process worldwide. However there seems to be more room for improvement so as to efficiently and effectively harness the maximum of the solar resource available. This will also help us avoid the need for non-conventional modes of drying which are not only costly but often cannot be replicated in the rural areas, where they are most needed.

This section aims to review the most important of fresh Jinda Chili and the different modes of drying using the sun's energy for both traditional and progressive methods and look at examples of some of the existing solar dryers and the working principles behind them. The review will also cover the principle behind the parabolic solar collector. When these are juxtaposed with the new solar dryer the design concept governing the parabolic solar dryer will be better appreciated.

2.1 Drying

2.1.1 Principle of Drying

There are various short of drying; however this thesis focuses on thermal drying using the sun's energy. The main function of the sun's energy is to heat the air surrounding the food and the food itself. As mentioned in the earlier chapter, drying is usually done for three main purposes; for easier transportation, storage and also as a food preparation process.

2.2 Solar Drying

This method is the drying of products in enclosed structures where the temperature of air surrounding the product is usually higher than the ambient temperature of the dryer. It is a better means of increasing the quality of final dried product, reducing post-harvest losses and often relieves the drying times as compared to open sun drying.

The energy desire for drying different products in solar dryers varies from the types of dryers, to the type of product being dried and also to the type of climate. It is usually set from the first and final moisture content of each product. Different types of agricultural crops have different drying rates and highest acceptable temperatures. In many cases, only a small temperature rise in the air is necessary to achieve proper drying conditions [6].

In dealing with solar dryers, it is always useful to investigate some two key characteristic of the dryer before use. These are the drying rate and the drying efficiency. These indicators give an overall assessment of the dryer in relation to their performance.

The drying efficiency of a dryer can be estimated from Equation 2-1. It can be used to effectively compare different kind of solar dryers to be selected for use. The factors which have said to influence the drying efficiency are basically [7]:

a) Factors pertaining to the crop like the size, type of crop, the moisture content etc.

b) Factors relating to the peculiar characteristics of the dryer in question and

c) Factors relating to the environmental conditions such as the climate.

The drying efficiency (de) is given by:

$$de = \frac{\text{Heat utilised for moisture removal}}{\text{Heat available for moisture removal}} \qquad \text{Equation} \quad (2\text{-}1)$$

The drying rate is set as the rate at which moisture is unstick from a material. The shorter the drying rate the better it is. The drying rate (dr) have also been said to have an effect on the quality of the final product .It is usually determined by the equation below:

$$dr = \frac{\text{Initial Weight} - \text{Final Weight}}{\text{Duration of drying}} \qquad \text{Equation (2-2)}$$

Seveda and Rathore [8] highlighted that the drying rate is essentially affected by some critical climatic factors such as the temperature, relative humidity, sunshine hours, available solar radiation, wind velocity, frequency and duration of drizzle during the drying period. However other factors which have also been identified to have some extent of influence on the drying process are the particle size of the product being dried, the type of solar dryer being used, the initial moisture content of the crop, air flow rate, crop absorptivity[9].

During the final decades, many developing countries have begun to change their energy policies in regard to further reduction of petroleum import and to alter their energy use toward the consumption of renewable energies. With very few exceptions, the developing countries are situated in climatic zones of the world where the insolation is considerably higher than the world average of 3.82 kWh/m^2 day. In Figure 2.3 daily average horizontal insolation data and sunshine hours of some developing countries are given. An alternative to traditional drying method and a contribution toward the solution of the open air drying problems is the use of solar dryers. Accordingly, the availability of solar energy and the operational marketing and economy reasons offer a good opportunity for using solar drying all over the world[10].

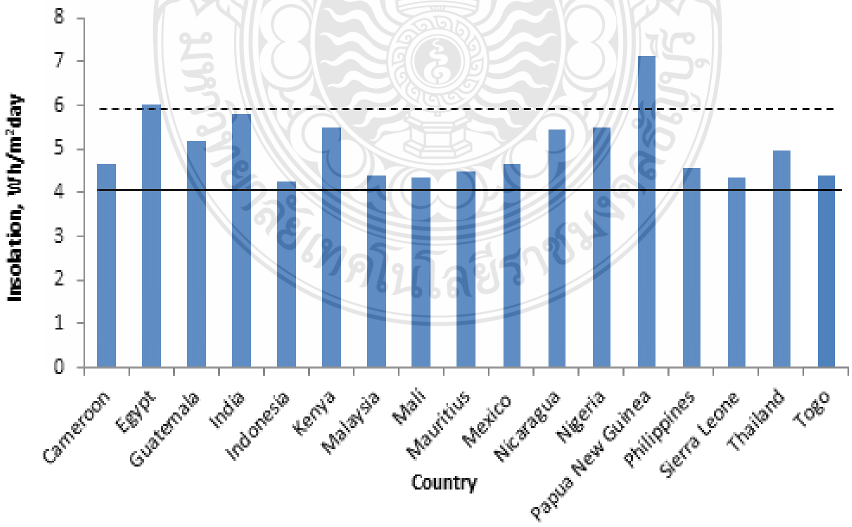

Figure2-3: Total horizontal solar insolation for some developing countries

2.3 Major Factors Affecting Solar Drying

2.3.1 Temperature

Temperature has been set as one of the main factors which affect the drying process most specifically the drying rate. Solar radiation absorbed by a solar dryer is converted to heat which increases the temperature of the air in the dryer. This increase in temperature of the air in turn heats up the crop surface which causes the moisture in the crop to migrate to the surface and is vaporized. It is then carried away through vents holes. Normally, the higher the temperatures in the drying chamber, the higher the drying rates. However, some crops have a maximum temperature under which they can be dried and if exceeded might lead to their deterioration. High temperatures in the drying chamber can only be effective, if it is relatively higher than the ambient temperature surrounding the dryer. Temperatures are often measured using a thermometer [4].

2.3.2 Solar Irradiation

Solar irradiance can be referred to as the "the rate at which solar energy reaches a unit area on the earth" [11]. It is composed of three components; the direct normal, indirect and reflected solar irradiance. The component that is directly incident and normal to a surface without its being diffused or changed in direction by the atmosphere is termed as the direct normal irradiance and is usually measured by a pyrheliometer. Indirect irradiance is the irradiance which is scattered by the atmosphere before being received on a surface. This component can only be practiced by flat plate collectors and some low type concentrators [11]. Some component of the irradiance which has been reflected off the earth's surface might be received for an inclined surface, and this part is called the reflected irradiance. However, for a horizontal surface the reflected irradiance is usually zero. These components of the worldwide solar irradiance in all determine the total amount of energy that will be received on a collector's surface and can be measured by a pyranometer. It varies depending on the geographic location, climatic conditions, the clearness of the sky, position of the sun, and the day of the year. Higher readings can be recorded on a clear and sunny day than on cloudy day or when the sun is low. The higher the available solar irradiance, the higher the temperature and therefore the higher the drying rate.

2.3.3 Humidity

The humidity is set as "the ratio of the amount of water vapor in the air at a given temperature to the maximum amount of air at the same temperature". The propensity for a crop to dry is dependent on the ratio of the amount of moisture in the crop to that of the immediate surrounding air. If the surrounding air has a lower relative humidity the drier surrounding air can accommodate moisture migrating from the crop. Therefore the lower the relative humidity (RH) entering the dryer, the higher the drying rate and vice versa. It is normally measured by a hygrometer [12].

2.3.4 Moisture Content

Most agricultural food products which require drying contain some amount of water in their fresh state. This water which is also called moisture, when present might render the products hazardous for storage as it might lead to deterioration. The moisture content of most food products can range from 20 to 90% [7] and depending on the type of product, the safe moisture content for storage might vary. The moisture content of any product being dried has the potential of directly affecting the drying time. The amount of moisture content in the product is likely to determine the type of solar dryer to be selected.

Two stages have been identified to characterize the drying process and they are the constant rate and the falling rate stage. The initial stage where water is evaporated directly from the produce surface is the constant rate. As the drying progresses it requires more energy to evaporate the water that is embedded in the produce. This stage is called the falling rate and the final moisture content of produce usually falls within this phase of the drying process.

The moisture content of food is determined by taking the initial mass before drying in an oven at about 105 °C for 24hours. The final mass of the oven dried product is acceptable if the mass after measuring over a period of time (when in the oven) continues to remains constant.

Moisture content can be set on the wet or dry basis as revealed in the Equation 2- 3 and Equation 2- 4 below [5]:

$$\text{Moisture Content(dry basis)}, MCd = \frac{(Wi-Wf)\times 100}{Wf} \qquad \text{Equation} \qquad (2\text{-}3)$$

$$\text{Moisture Content(wet basis)}, MCw = \frac{(Wi-Wf)\times 100}{Wi} \qquad \text{Equation} \qquad (2\text{-}4)$$

The final mass of water lost can then be determined by:

$$Mw = \frac{(MCwi-MCwf)\times Wix}{1-MCwf} \qquad \text{Equation} \qquad (2\text{-}5)$$

Where:

MCwi	Initial moisture content on a wet basis before drying (%)
MCwf	Final moisture content on a wet basis after drying (%)
MCd	Moisture content on dry basis (%)
MCw	Moisture content on wet basis (%)
Wi	Initial mass before drying (g)
Wf	Final mass after drying (g)

2.3.5 Air mass Flow rate

In as much as heat is important in the drying of produce, the characteristics of air flowing in and out of the drying chamber of a dryer is equally important. The air flow rate through a dryer is generally a measure of the quantity of air that has passed through a dryer within a specified time. The quantity which is usually measured is mass (kg). Therefore the air mass flow rate is the mass of air flowing through dyer in a unit time. Higher mass flow rates which denotes good ventilation, increases the drying efficiency of the dryer [5].

2.4 Sort of Solar Dryer

Solar dryers have been divided into two main groups based on the mode of air flow through the dryer (passive and active). However there are other sub categories under these main clusters which are defined based on whether the drying commodity is exposed to direct solar radiation or not (direct or indirect) or a constitution of both modes (mixed mode).

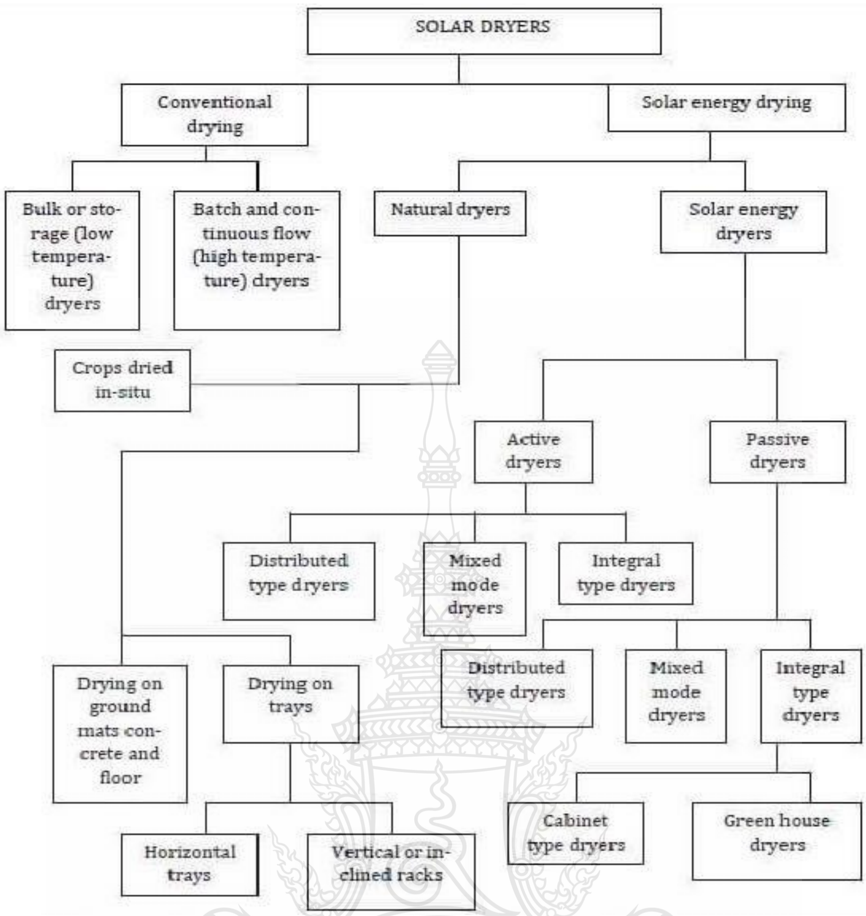

Figure 2-4: Classifications of dryers and drying modes [13]

2.4.1 Mixed Mode, Direct, and Indirect Model of Dryers

Three distinct sub-classes of either the active or passive solar drying systems can be identified namely:

a) Hybrid solar dryers
b) Indirect-type solar dryers
c) Direct-type solar dryers

Direct mode of drying generally consists of the drying chamber covered by a transparent material. This transparent material acting as the glazing, allows solar radiation into the chamber to heat up and increase the temperature of the air and the crop being dried. The main disadvantage of this type of dryer is its invalidity to control the crop temperature because of the direct absorption of radiation by the crop, which might cause some crops sensitive to sunlight to lose some of its nutrients e.g. Moringa.

With the indirect mode dryer, the crop is set in an opaque enclosed chamber and thus shielded from direct solar radiation and therefore the heat transfer mode for drying is by convection only. The incident radiation is absorbed by another surface and converted to heat which is transferred by convection into the drying chamber to heat the crop located within the opaque chamber. This mode of drying is usually good for some vegetable or herbs or other food species which are color sensitive or reduces in quality when exposed to direct sunlight especially food containing beta-carotene such as spinach, coriander etc. This is an advantage the indirect mode has over the direct mode dryer.

Even though the drying rates and final product quality are very dependent on the crop temperature in the direct mode, the setup is rather quite simple and relatively low cost making this type.

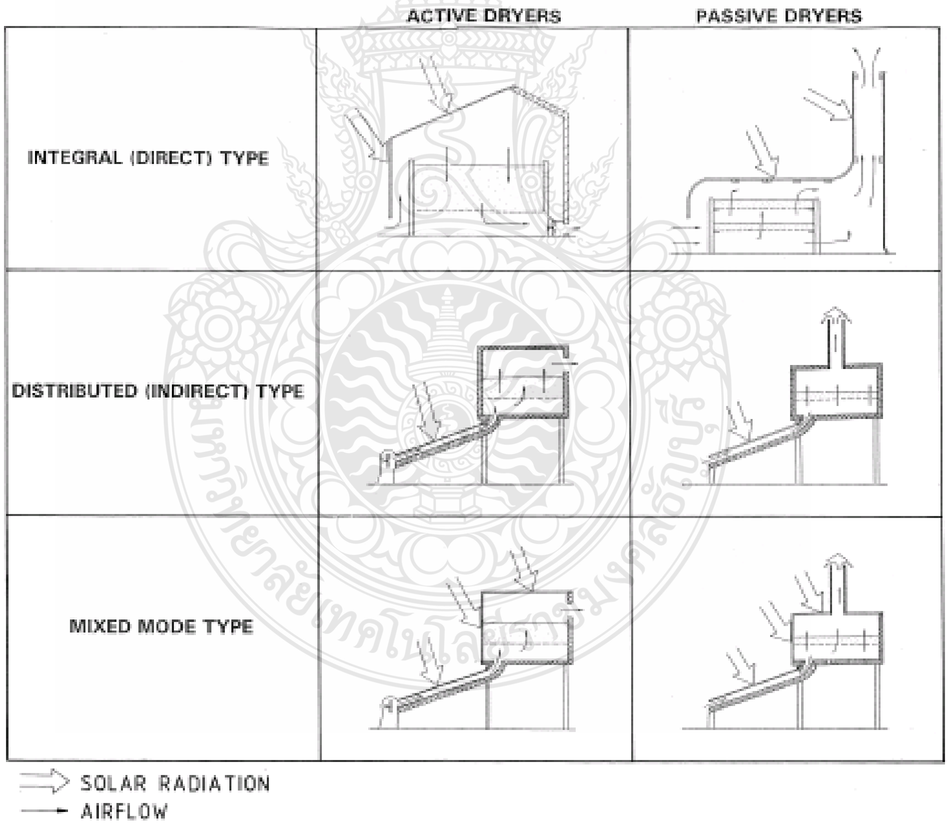

Figure 2-5: Typical solar energy dryer designs [14]

2.4.2 Natural-Circulation Dryers

These are also termed as tent dryers and are basically amended greenhouses. They are designed with vents of appropriate size and position to have a controlled air flow. They are featured by extensive glazing by the transparent roof of polyethylene panel. Figure 2.6 reveals the earliest shape of passive solar greenhouse dryer by the Brace Research Institute, with slanted glass roof, allowing direct solar radiation over the product. The length-wise north-south alignment of the dryer had black coated internals for improved absorption of solar radiation with the ridge-cap over the roof for exit vent [14].

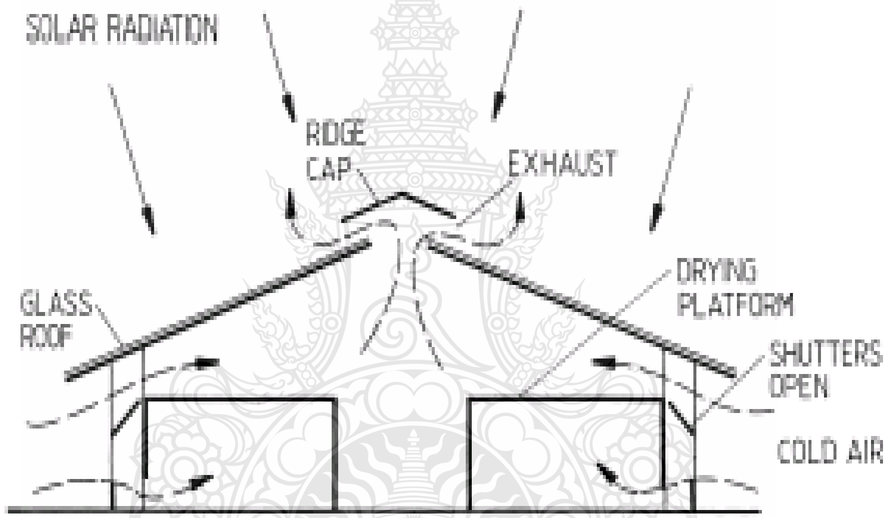

Figure 2-6 Model of glass roof solar energy dryer [14]

Tent dryers consist of a tent like casing that is normally cloaked with plastic sheet. Figure 2.7 display a sample of a tent dryer. In this system, a white plastic sheet is used to cover the ends and the sides facing the sun while black plastic sheet is used to cover the side in the shade and on the ground within the tent. The tray is located centrally along the length of the tent [15].

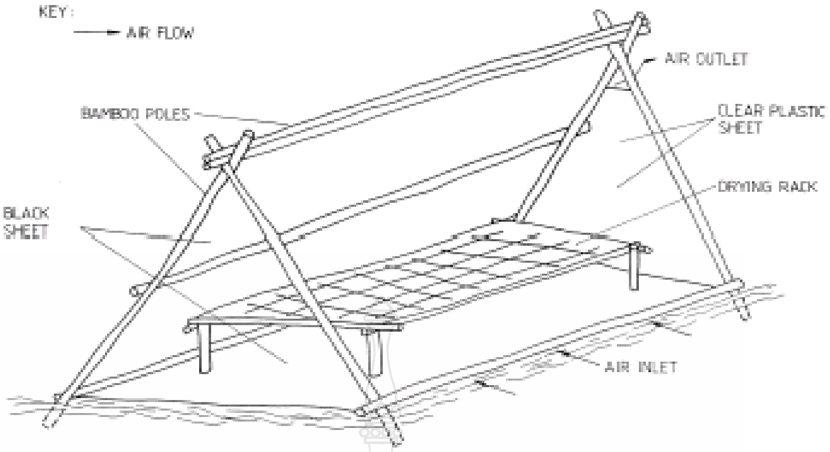

Figure 2-7: Natural-circulation polythene-tent dryer [13]

Brenndorfer et al. (1987) classifies direct solar dryers using natural convection with combined drying and collector chamber as cabinet dryer and tent dryer. Figure 2.8 reveals sample of cabinet dryer. It can be made from wooden case insulated at its base and side. The product to be dried is stored on a perforated tray. Air coming from the lower part of 9 the cabinet flows through the holes and leave through the upper ventilation holes maintaining a natural air circulation (Mujumdar, 2006) [16].

In order to dodge the effect of shading by the sides, the length of the case dryer should be three times its width. The roof should also be slanted to avoid the accumulation of water during rainy periods. Portable cabinet dryers can be constructed from wood or metal whereas for fixed structures stone, brick, mud or concrete could be used. For maximum internal temperatures, the base and sides of the cabinet should be insulated with a layer of at least 50 mm thick sawdust, dried grass or leaves, coconut fiber, bagasse or wood shavings. Plastic mesh or netting can be used to construct the drying trays (Brenndorfer et al., 1987).

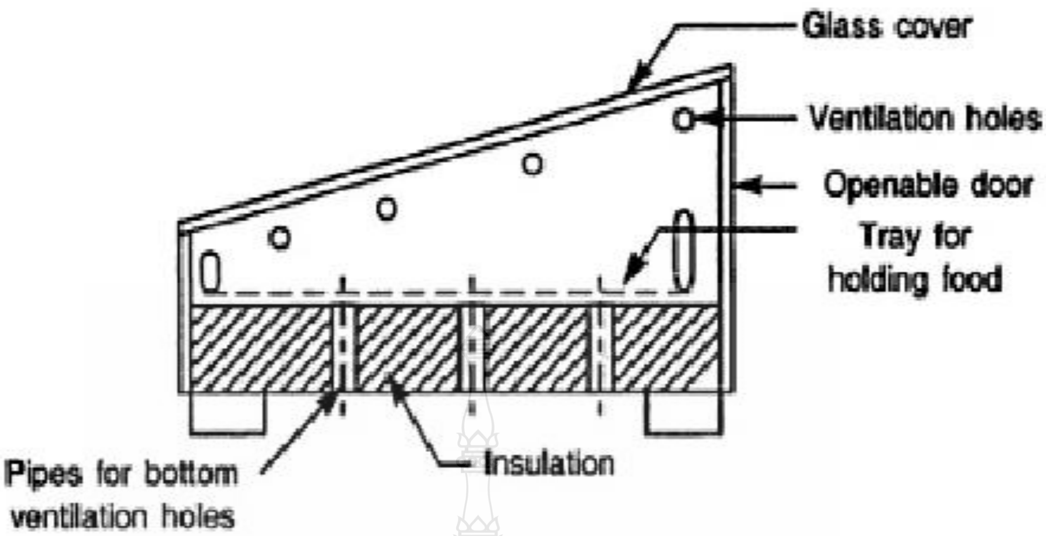

Figure 2-8: Cabinet dryer [16]

Fleming et al. [17] reported a typical greenhouse type solar dryer with a transparent semi-cylindrical chamber with a cylindrical solar chimney posted vertically at one end and a door for air inlet and access to the chamber at other end as shown in Figure 2.9 Rathore et al.[18] has conducted various experimental studies on a modified design of hemi-cylindrical solar tunnel dryer for drying of grapes also few researchers (Jaijai et al.,)[19] have used a polycarbonate cover for its construction. Afriyie et al. [20], has reported the study of simulation and optimization of a chimney ventilated solar crop dryer.

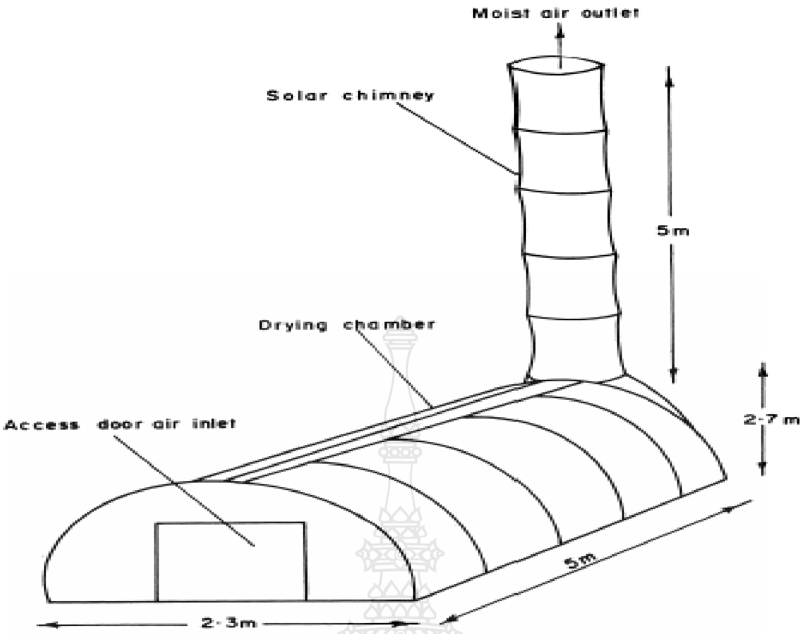

Figure 2-9 A greenhouse type natural-circulation solar–energy dryer [14]

2.4.3 Hybrid Solar Dryers

In addition to using only solar energy, hybrid systems amalgamate another means of heating the air for drying a produce (Brenndorfer et al., 1987). This enables the dryer to be operated during no sunlight periods and also at night time.

A solar-biomass hybrid case dryer was created in Philippines. It uses a solar collector for heating the drying air during daytime operation and a biomass stove is used for operations during night time and cloudy conditions. Slanted at 15o to the horizontal, the solar collector has an area of 2.12x0.9 m and is attached to the rear side of the drying chamber. The collector air gap is 0.05m.The drying chamber enclosed of 30 aluminum wire net trays for holding the materials. An exhaust fan, in which power is supplied by a 45 W electric motor, was fixed in the chimney to force ambient air to pass through the collector. The drying air temperature can archive up to 60 oC with 0.05 m^3/h airflow rate. The biomass stove uses coconut shell or charcoal as fuel input and the fuel consumption is about 2.0 kg/h. Moisture content of sliced pineapple was reduced from 85% to 20% wet basis in about 18 hours (IAE/UPLB, 2002).

In this system the blower is run by an electric motor. This limits its use in rural areas where there is no electric supply. Moreover, the total cost of the drying system (including the solar collector and gasifier stove), which is expected to be about US$ 1,120 (as of February 2002), is very expensive to be afforded by most farmers in developing countries.

Performance of a solar dryer with backup incinerator was evaluated by Barki et al. (2012) in Makurdi, Nigeria. The three main components of the hybrid solar dryer were flat plate collector, drying chamber and incinerator. The solar collector, made from a thick clear glass supported by a wooden casing, has an area of 0.82 m2 and the absorber plate has a depth of 0.14m. An incinerator of dimensions 49 cm x 124 cm x 40 cm is connected to 23 the drying chamber that can be used as an additional heat supplying source. Charcoal is the biomass that was burnt in the incinerator and water, which was allowed to flow by gravity, was used to convey the heat.

On load test was carried out using grated cassava with initial moisture content of 69.8%. It took 12 h to reduce the moisture content to 47.19 % using only the solar dryer whereas the combined solar-incinerator dryer took 16 h to dehydrate the grated cassava sample to moisture content of 47.48%. The incinerator dryer and open sun drying (control) both took 20 h to reach 47.99% and 47.01% of moisture content, respectively.

Barki et al. (2012) used the open sun drying as a control for evaluating the performance of the solar and solar-incinerator dryers. This implies that the comparison between the solar dryer with that of the combined solar-incinerator dryer was based on tests that were carried out at different times. The ambient temperature and humidity when testing the solar dryer alone and when testing the solar-incinerator dryer would be different, it might be more sunny or cloudy. A better comparison could have been made if an additional similar design was constructed which would have made it possible to run tests simultaneously.

Figure 2-10: Solar-Biomass Hybrid Cabinet Dryer [16]

2.4.4 Passive and Active Solar Dryers

These models of solar dryers can be divided into the indirect or mixed direct, mode type but the main difference between them is the model of air circulation. For the passive solar dryers, air circulation is by natural convection whilst the active type dryers are suited for big scale application where fans provide forced circulation of heated air. Active dryers are generally used for drying high moisture produce [4].

2.4.5 Typical Examples of Passive Solar Dryers

This section focuses on examples of passive solar dryers. There have been more designs of passive solar dryers, some more complex than others but one characteristic that stands out for the passive solar dryer is the low cost, the simplicity and low maintenance associated with it. Because they do not desire mechanical parts such as fans or blowers, the extra cost of sourcing for an alternative source of energy to power the mechanical parts are not required. However, most of them are used on a domestic scale as they have limited loading rate. As mentioned previously, the passive

Another one, reported on by Ogheneruona and Yusuf was the direct natural convection solar dryer. The dryer is a cabinet shaped mobile dryer sloped at 5^o to match the latitude of the testing location (Warri, Nigeria). Irradiation is incident on the dryer through a transparent cover which acts as glazing. Air vents are placed at the front and back of the dryer to facilitate air flow in the dryer. The major design considerations during the initial design of the dryer were, "harvesting period during which the drying is needed, daily sunlight hours for the selection of the total drying time, quantity of air needed for drying, daily solar radiation to set energy got by the dryer per day and wind speed for the calculation of air vent dimensions" [22].

2.5 Products Used for Creating Solar Dryers

As described in the previous topic on different kind of solar dryers, different designs used different product for building the driers. Many of the designs used the availability of the products as a main criterion. Other criteria for choosing the products were revealed as cost, ability and quality to resist harsh environmental conditions such as hard rain and hot weather. The subjected of the products used in the review are offered in Table 2.1.

In addition to the above materials used some dryers included thermocol sheet, glass wool, compacted glue, foam band and sawdust for offending the dryer and concrete floor was used as a heat storage gimmick [16].

Table 2.1 Material Usage for Dryer

Component		Material	Usage, %
Collector	Transparent	Glass	50
		Plexiglas	20
		Plastic	20
		Polycarbonate	10
	Absorber	Galvanized steel sheet	25
		Aluminum steel sheet	25
		Granite stone	12.5
		Galvanized iron sheet	25
		Polyethylene film	12.5
Drying Chamber	Structure	Wood	80
		Metal	20
	Cover	Glass	70
		Plastic	30
Tray	Net	Chicken wire	20
		Stainless steel	40
		Bamboo net	10
		Aluminum wire net	20
		Plastic screen	10
	Frame	Wood	50
		Angle bar	12.5
		No frame	37.5
Chimney		Plastic	25
		Metal sheet	50
		PVC pipe	25
Air Vent Cover		Mosquito net	20
		Aluminum mesh	10
		No cover	70

2.6 Parabolic Collector System

This section focuses on examples parabolic collector which is the main area of interest in this thesis. The general working principles behind solar dryers has been looked at; this section will highlight the vital areas of interest concerning principle behind parabolas and parabolic troughs. The key characteristic of the parabolic form is the ability to refocus any incident radiation that is parallel to its axis to a focal point. This is what makes it the ideal shape to be used in most concentrating collectors where large quantities of concentrated heat generated at the focus is converted into useful energy, like Concentrated Solar Power (CSP) plants do.

2.5.1 The Geometry of the Parabola

A parabola can be set as the locus of a point that shifts so that its distances from a fixed line termed the directrix and a point F termed the focus are equal (Figure 2-11). From the above definition, it can then be safely concluded from (Figure 2-11) that the length of the line FC is equal to the line CS. The axis of the parabola is also the line that passes through the focus line and is perpendicular to the directrix. The intersection of the parabola and its axis at a point V is called the vertex, which is exactly midway between the focus line and the directrix.

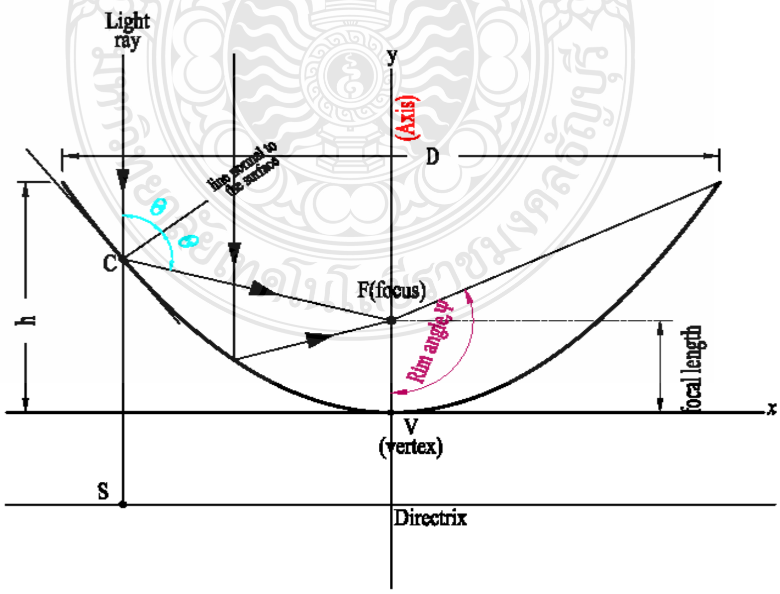

Figure 2-12: Geometry of a Parabola

For a typical parabola the depth of the curve, h, is the distance from the top of the curve to the bottom of the curve, V, as shown in (Figure 2-11) above. h is sometimes also termed the height of the parabola. The aperture width or the diameter, D, of the parabola is also the distance from one side of the top of the curve to the other side. The distance from the focus F, to the vertex, V, is termed the focal length and is calculated by the equation [5]:

$$f= \frac{D^2}{16h} \qquad \text{Equation} \quad (2\text{-}6)$$

And the arc length of the parabolic curve, s, is also given by

$$s = \left[\frac{D}{2} + \sqrt{(\frac{4h}{D})^2 + 1}\right] + 2f\ln\left[\frac{D}{2} + \sqrt{(\frac{4h}{D})^2 + 1}\right] \qquad \text{Equation} \quad (2\text{-}7)$$

2.5.2 Parabolic Cylinder

The result of the movement of the parabola along the axis normal to its plane is termed the parabolic cylinder which is sometimes referred to as the parabolic trough or the line focus trough when used in solar concentrators. The parabolic trough has been widely used in harnessing solar energy because of the peculiar ability of the concentrator to focus high amount of energy to a relatively small area (the absorber surface). This is possible when the sun rays are parallel to the axis of the parabola. In the case of the parabolic troughs, it forms a line perpendicular to the plane of the axis called the focal line. In view of this unique characteristic of the parabolic trough, the collector must be constantly aligned with the sun because of the constant relative movement between the sun and the earth. Stationary parabolas are therefore found to be less efficient than that of the tracking ones.

For any parabolic cylinder with the dimensions indicated in (Figure 2-11), the collector aperture area Aa, which gives an indication of the available area for radiation to be incident on the collector surface and the reflective area As are given by the equations:

$$Aa = I.D \quad (m^2) \qquad \text{Equation} \quad (2\text{-}8)$$

$$As = I.s \quad (m^2) \qquad \text{Equation} \quad (2\text{-}9)$$

Where l is the collector length and s is given in Equation 2- 7

Another parameter of interest with the parabola is the rim angle, Ψ which is the sole determiner of the form of a parabola. It is the angle subtended between the axis of the parabola and a line drawn from the top of the curve to the focal point as shown in (Figure 2-12). It has been stated that the rim angle can have some influence on the concentration ratio (ratio of the aperture width to absorber diameter) and the total irradiance per meter of the absorber. It is calculated by the equation:

$$\tan\varphi = \frac{(\frac{D}{f})}{2x\frac{1}{8}x(\frac{D}{f})^2} \qquad \text{Equation (2-10)}$$

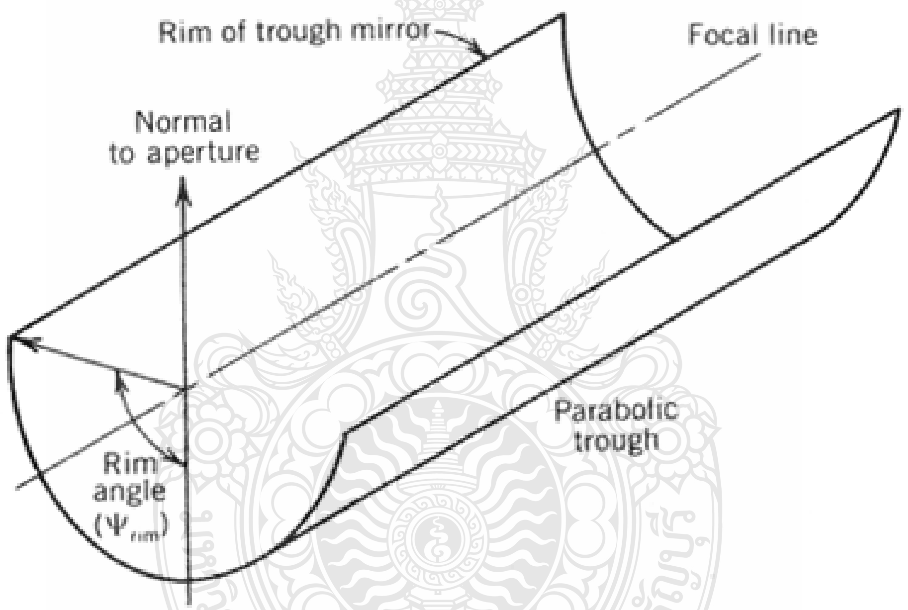

Figure 2-13: Geometry of a Parabolic Cylinder

2.5.3 Factors affecting the performance of a parabolic collector

For any system which utilizes the parabolic collector, the performance usually increases with increase in collector efficiency. The factors identified to affect the collector efficiency have been categorized into groups namely [23]:

a) Operating conditions such as the tracking mode, amount of Insolation etc.
b) Material properties such as the degree of reflectance of the collector, the absorptance of the absorber etc.

c) Geometric design of the receiver (absorber) such as the shape, the opening in the absorber, the absorber's surface etc.
d) Concentrator geometry such as the rim angle and the concentration ratio.

CHAPTER 3

METHODOLOGY

The dryer is essentially designed as a mixed mode active solar dryer. The dryer concept in this section is divided into three main systems:

1. Drying chamber
2. Parabolic solar collector
3. Gas burner

It mainly used sunlight as the source of energy. But in the case of hot air temperature from the solar collector is not adequate or not available during rainy season; the heat will be produced for the dryer process using biogas materials. This energy system will be worked as a reserve heat source for the dryer process. But due to the insufficient time in producing biogas, the kind of gas tank is used to replace the process of this experiment.

3.1 Materials for Construction of the Dryer

The mainly components for construct the dryer are as below:

3.1.1 Battery

3.1.2 Concrete floor

3.1.3 Polycarbonate sheets

3.1.4 Galvanized sheets

3.1.5 Pipe

3.1.6 Rectangular tube

3.1.7 Blower

3.1.8 Controller temperature box

3.1.9 Solar cell panels

3.2 Designing Procedure

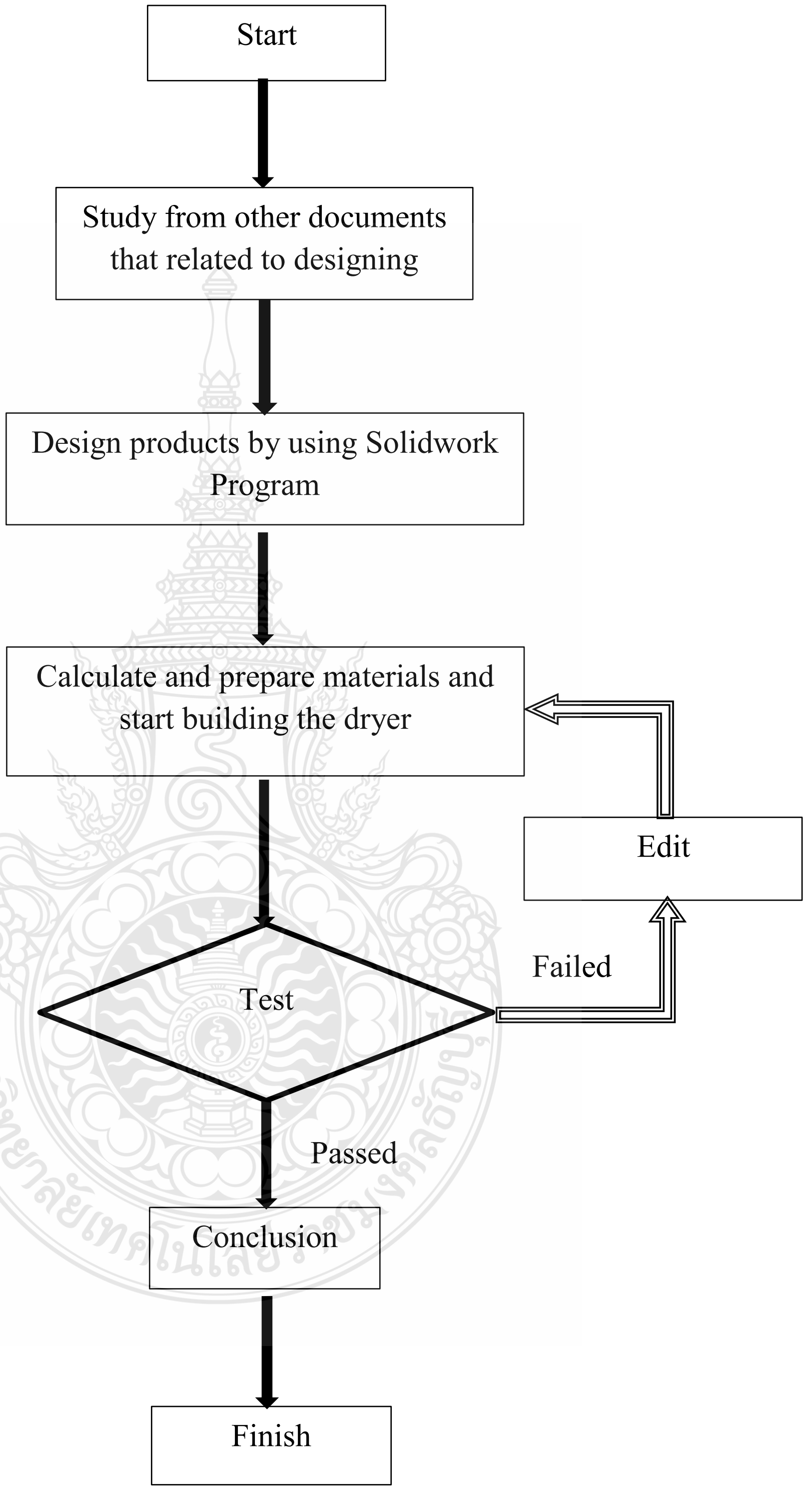

Figure 3-1: Experimental stages

The performance of the dryer was examined in Rajamangala University of Technology Thanyaburi, Pathumthani, Thailand. These design parameters included environmental conditions of the test location, volume of moisture to be removed, temperature of drying, resolution of airflow desire and heat energy requirement.

3.2.1 Greenhouse Chamber

The drying chamber was an enclosed structure where drying takes place. The model of the system took into consideration different form criteria and parameters. Some of these form criteria and parameters were from chapter two while others were defined using a series of mathematical method. The drying chamber is made up of rectangular tube with the polycarbonate sheets as cover. It is essentially designed as a parabolic form that can resist well the tropical rain and gale. It has a width of 6.0 meter, length of 8.0 meter and height 2.5 meter with a concrete floor with the area of 7m x 9m x 10 cm. The dryer consisted of two trays, each with size of 1.5m x 0.60 m x 0.9 m, for the produce to be dried.

3.2.2 Sketching of the Dryer

The dryer was designed by using software called Solidworks. The drawing of the design and the corresponding side views with dimensions are shown in (Figure 3-4).

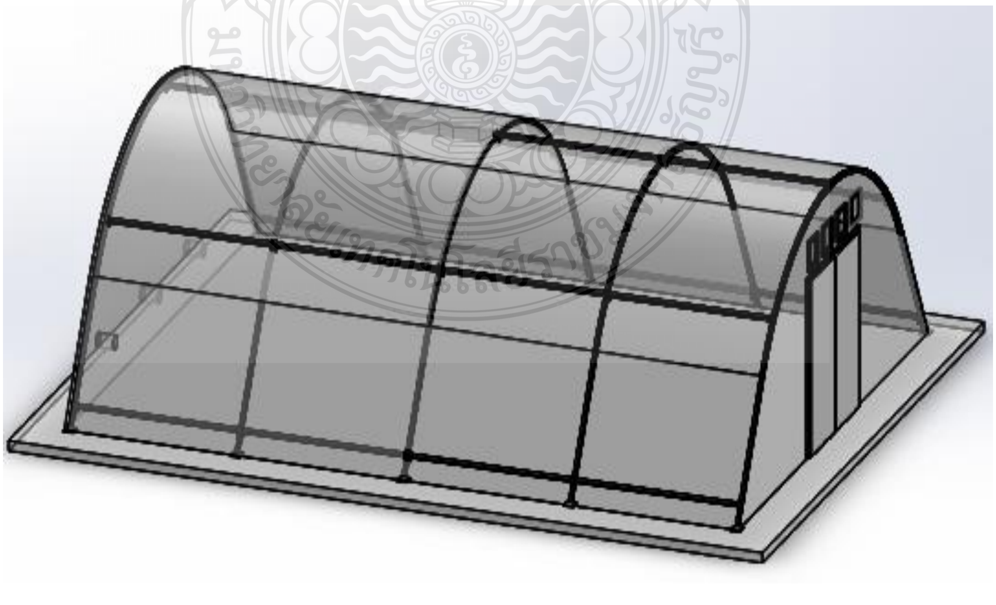

Figure 3-2: Designing of drying chamber by using Solidwork program

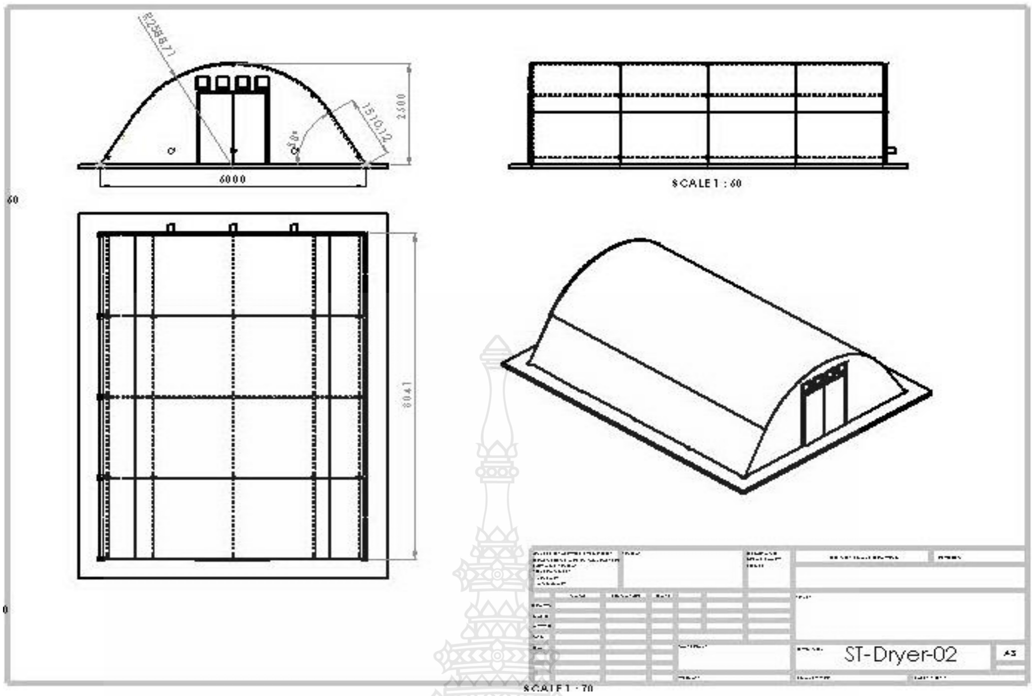

Figure 3-3: Side view of the dryer

3.2.3 Design Simulation

Airflow is designed and calculated by using Solidworks program flow simulation to determine the location of fan, blower and contributed ventilation. It is also calculated finding the size and capacity of the fan and blower. Four DC fans were found in this simulation and operated by one 80-Watt solar cell module. Three fans were installed on the door at the outlet side and other one on the bottom of the wall at the inlet side to ventilate the dryer well.

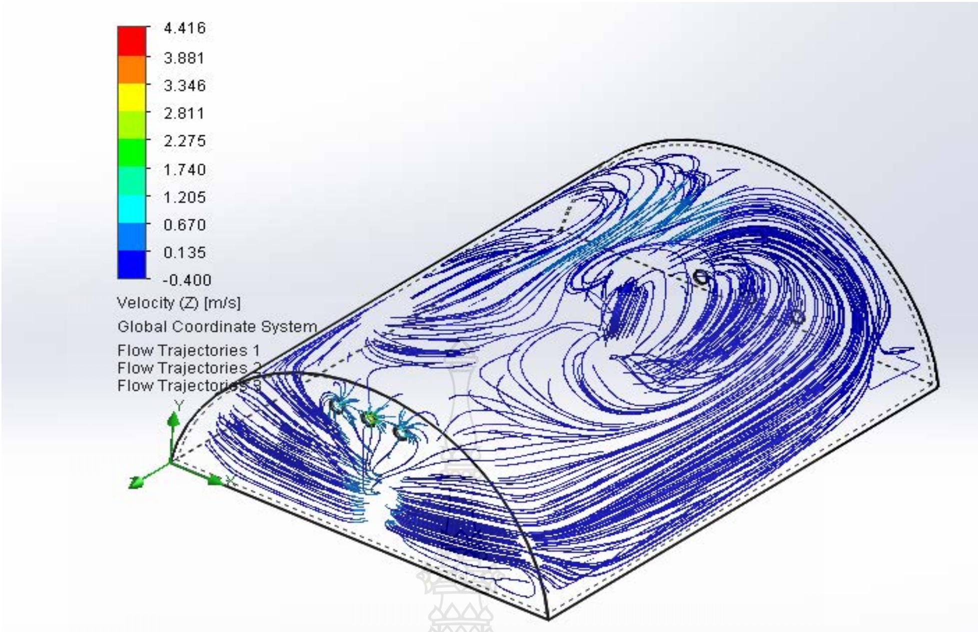

Figure 3-4: Simulation of airflow in the chamber by using Solidwork Simulation

3.2.4 Construction of the Dryer

When the model had designed, the main structure was bent and assembled as shown in (Figure 3-5).

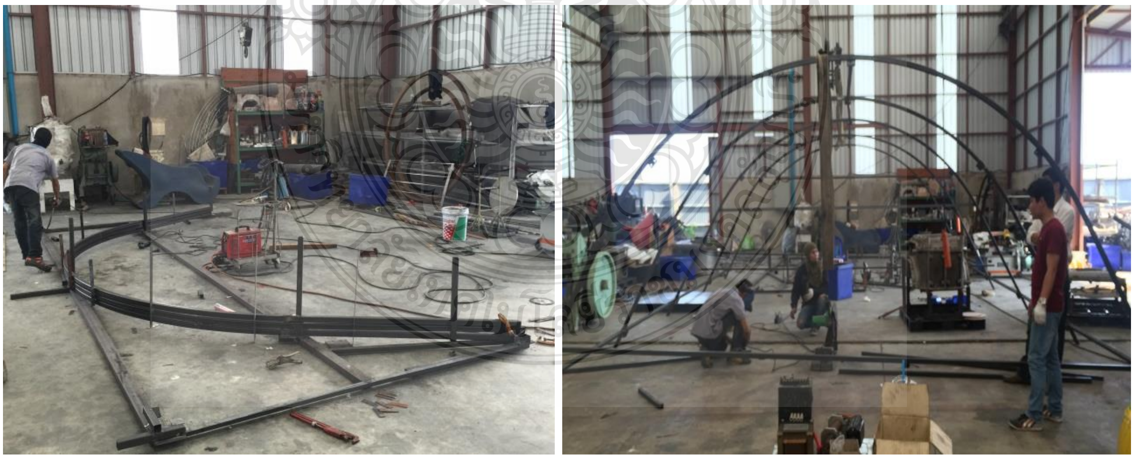

Figure 3-5: Photographs of fabrication structure of the dryer

After the structure had completed, it was installed at the prepared area on a concrete floor with the area of width 7m, length 9m, and thickness of 10 cm. The concrete floor was blend with black powder paint to serve as a modesty of the dryer as well as thermal absorber; it also functions as a heat storage system for the dryer.

Figure 3-6: Photograph of paving concrete floor of the dryer

When the paving of the concrete floor had completed, this was left for about 1-2 days, then the structure was prepared to install on the poured concrete floor as shown in (figure 3-7).

Figure 3-7: Photographs of installation structure of the dryer

While the structure had installed, polycarbonate sheets are used to cover the roof of the dryer. The plate was fastened to the frame by the aluminum lock sheets as shown in (Figure 3-8). Solar radiation passing through the polycarbonate sheets heats the air and concrete floor as well as the products inside the dryer.

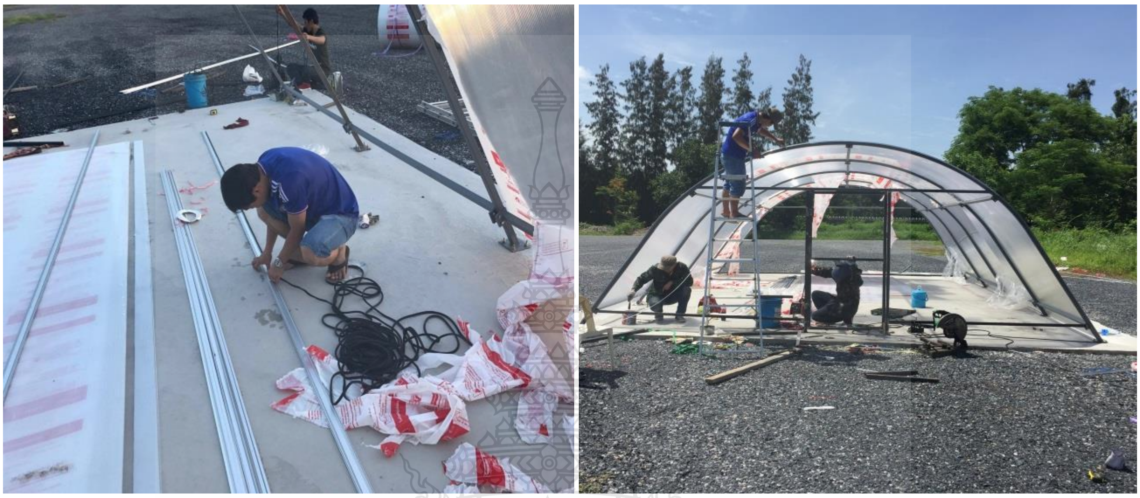

Figure 3-8: Photographs of installation of the roof

After the roof of the dryer had completed, Three DC fans powered by one 80-Watt solar cell modules were placed on the door at the outlet side and other one in the inlet side to ventilate the dryer.

Figure 3- 9: Photographs of Installation solar panel and fans of the dryer

3.2.5 Parabolic Solar Collector Panel

The basic concept behind the Parabolic Solar dryer is to explore the possibility of using the parabolic trough collector systems such as those used in the line focus plants and combining it with the glazing collector system to increase the efficiency of the solar system as shown in (Figure 3-10).

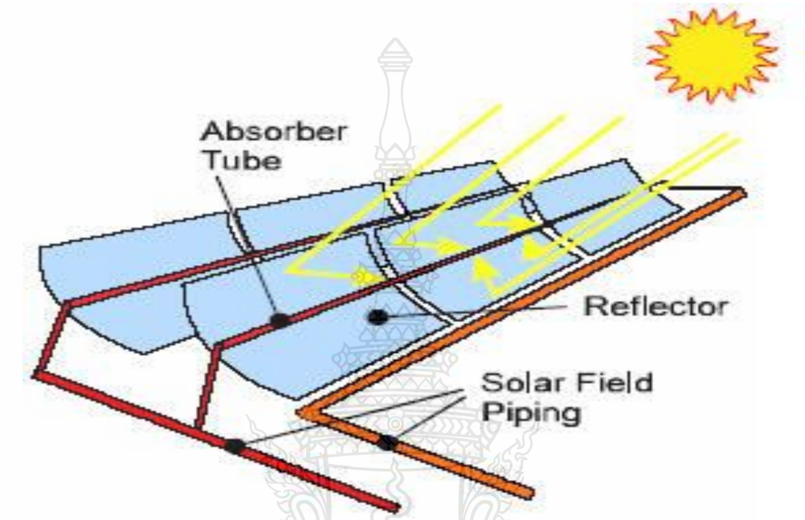

Figure 3- 10: Parabolic Collector System [24]

Focal point can be determined as indicated in the equations below:

x = 41.25 cm and y = 45 cm, using the equations below:

$$x^2 = 4cy \qquad \text{Equation} \qquad (3.1)$$

Substitute the values in the Equation (3.1)

$$c = \frac{x^2}{4y} = \frac{(41.25)^2}{4(45)} = 9.453 \text{ cm}$$

$$y = \frac{1}{4c}x^2 \qquad \text{Equation} \qquad (3.2)$$

Substitute the value in the equation 3.2 will get the parabolic curve as shown in (Figure 3- 11).

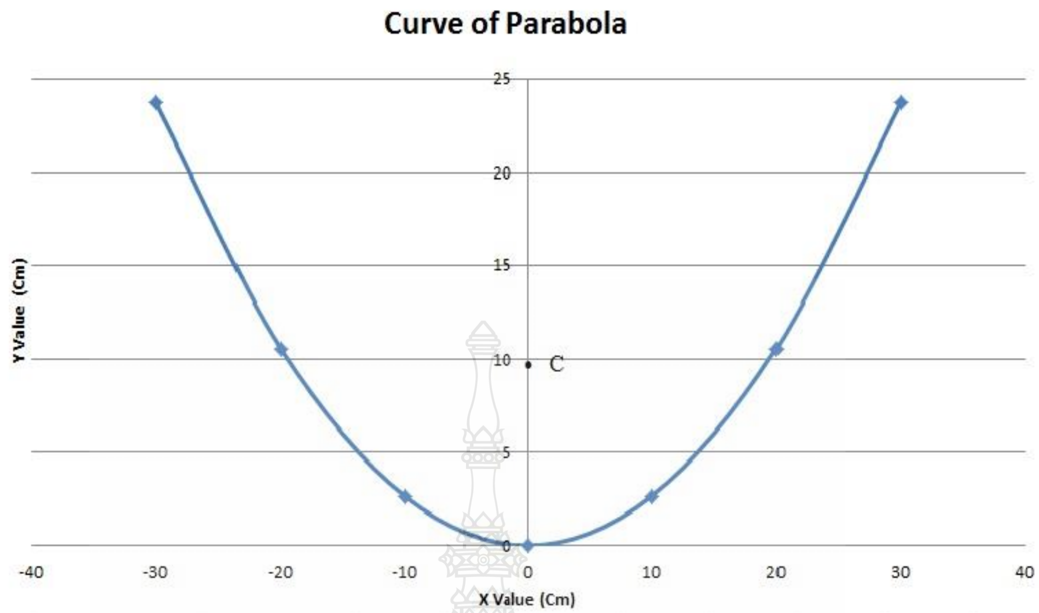

Figure 3-11: Pictorial view of parabolic curve

The hot air that used in this drying system is produced by this solar collector. The concentrating collectors were made up of galvanized sheets which had been molded into the shape of a parabola to have a width of 0.825 mater, a depth of 0.450 mater and a length of 2.40 mater with the pipe that stays as the focused point to get heater from the parabolic collector and brings the thermal to the chamber by blower. Eight panels of this solar collector were installed at the behind the chamber. When the sun's rays hit the surfaces of the parabolic panels the heat is reflected back to the absorber tube. Electric fan is used to lead the hot air from the absorber tube to the drying chamber. Parabolic collector was designed by using Solidworks program. The drawing of the design and the corresponding side views with dimensions are shown in (Figure 3-12).

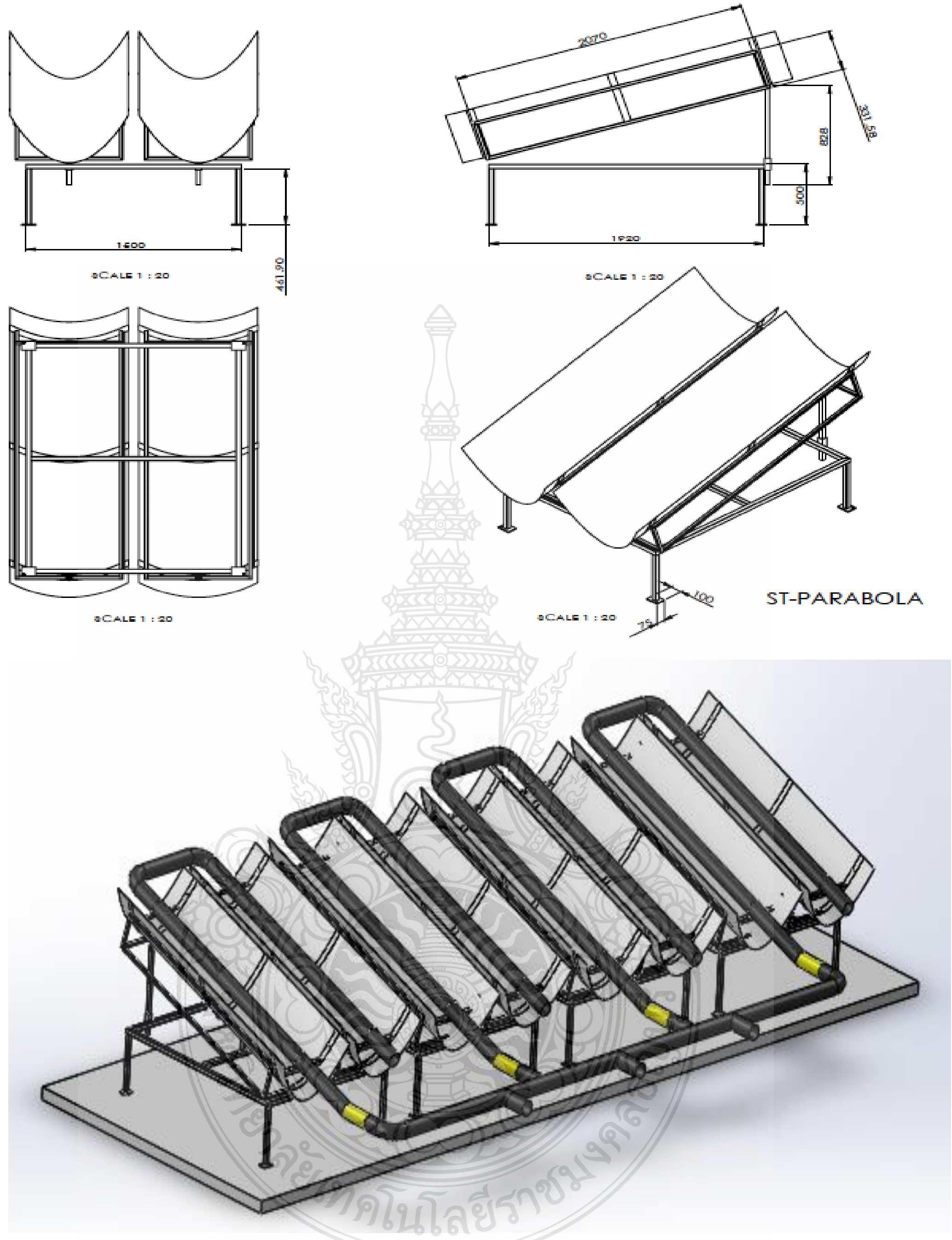

Figure 3-12: Designing of parabolic collector by using Solidwork program

3.2.6 Creation of the Parabolic Collector

To fabricate the parabolic collector, we can divide into the following steps as below:

Figure 3- 13: Photograph of fabrication structure of the parabolic collector

Figure 3-14: Photographs of the parabolic collector

3.2.7 Gas Burner

Stainless box was made to cover the gas burner to avoid rusting due to high moisture of the weather which had been molded into the shape of rectangle. At behind side of the chamber, a circular hole of 11 cm diameter was made. This hole was used to pass hot air through the chamber when the gas burner was used for drying. The concept in this section, LPG is used in this experiment as a reserve heat source for the dryer process.

Figure 3-15: Photograph of fabrication gas burner

Figure 3-16: Photograph of recording LPG’s weight before connect to the gas burner

One fan was installed with the gas burner system to lead the hot air from the iron pipe to the drying chamber as shown in (Figure 3-17).

Figure 3-17: Photograph of installation gas burner

Figure 3-18 Photographs of equipment installation automatic temperature controller

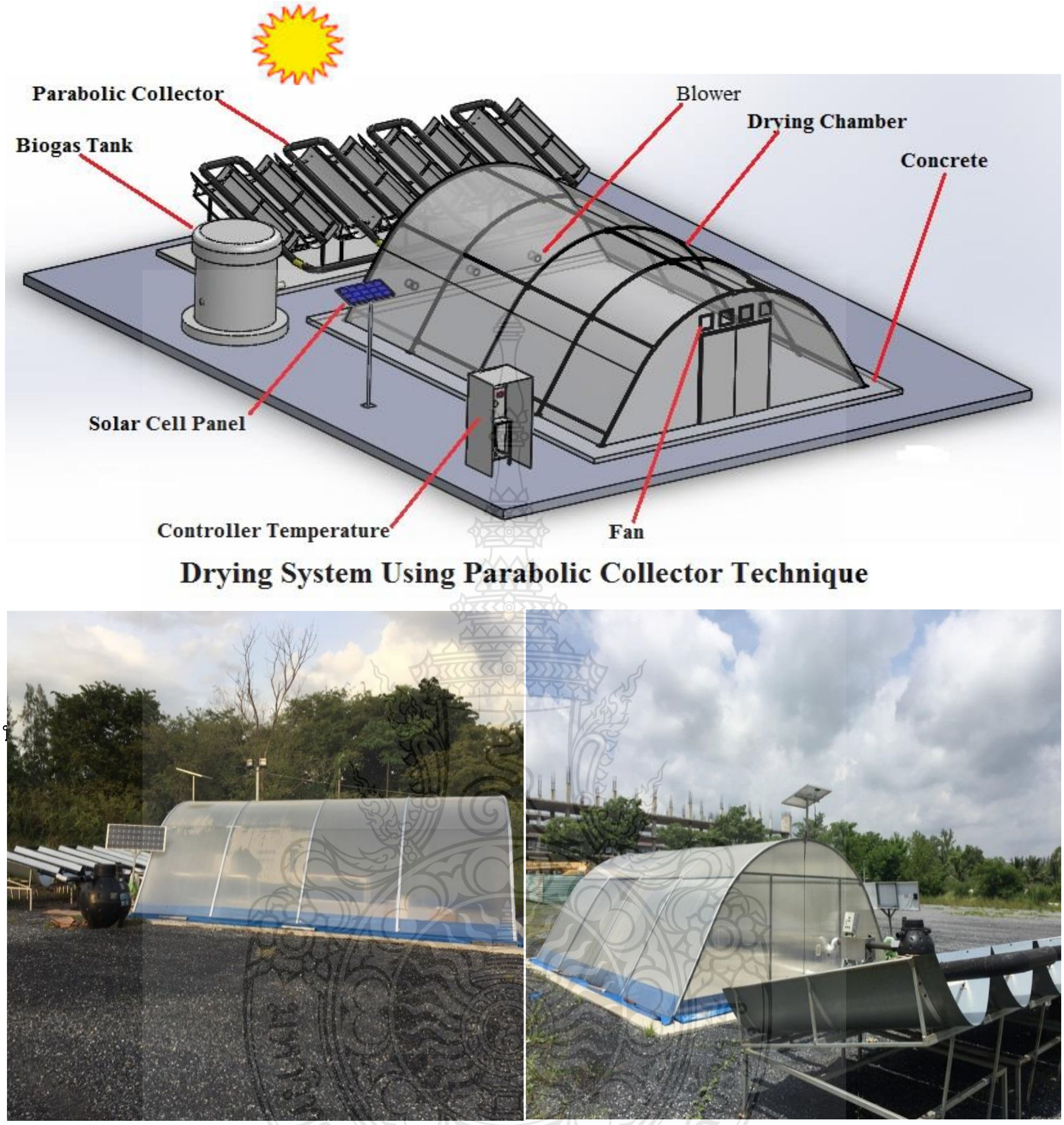

Figure 3-19: Photographs of assembling the drying system

3.3 Experimental Method

There are several ways to analyze the moisture content of the products. The most popular method is drying method, it is divided into 3 parts are as below:

1. Hot air oven method
2. Vacuum oven method
3. Desiccant method

Hot air oven method is the mode used in this experiment. The principle in this mode is to find the lost weight, because the evaporation of water contained in the sample is steam.

3.3.1 Materials Preparation and Instruments Use for Data Collection

Fresh Jinda Chilies were obtained from the local market in Thai market, Pathumthani province, where the place has the most of agricultural products. Solar radiation, temperature, humidity, air velocity, and included weight of the samples were recorded during the operation.

a) Inlet and outlet air temperature was measured by A K-type thermocouple (Daiichi-TH207).
b) A solar meter (Model G Taiwan Energy, G-22, Taiwan: accuracy ±1%) was used to measure the solar radiation.
c) Relative humidity and temperature of the ambient air were measured with a digital humidity/temperature meter (Model ThermoPro, TP 50, China: accuracy ±1%).
d) A vane type anemometer (Model CFM/CMM Thermo – Anemometer, DT-620, USA: accuracy ±.01 m/s) was used to record drying air.
e) Digital scales (Model Electric Kitchen Scale, SF-400, China: accuracy ±1g).

Figure 3- 20: Photographs of measurement tools

3.3.2 Experimental Procedure

The experimental were carried out 10 kg for Jinda Chili during the period of February, and June, 2018. The chilies was scaled and laid on the trays in the thin layer in the solar drying chamber. Seven control samples of Jinda Chili were placed on the trays inside the chamber at different position as shown in (Figure 3-21) and another one sample was also placed on a tray outside the chamber in the open sun drying.

Figure 3-21: Photographs of the Jinda Chili samples

Drying operation was began after completion of the loading, generally at 9:00 and finished at 17:00. About 20 g of each sample was weighed from the samples in the drying chamber. Both of weight loss of the samples in the operation and the control samples in the open sun drying were recorded during the drying period at 1 h interval. In the evening, after 17:00 Jinda chilies in the drying chamber were kept in the dryer and the all control samples were stored in a super lock box to keep the moisture. These control samples were put out again into the dryer next morning normally at 9:00 a.m. Both of the solar and sun drying samples were governed to dry under the same weather condition.

Figure 3-22: Photograph of recording sample's weight during at 1 hour interval

Figure 3-23: Photographs of recording inlet temperature and outlet airflow during at 1 hour interval

The moisture content of Jinda chili samples were noted at the beginning and end of each run of the experiment by drying the samples in an air ventilated oven at 105 °C for 24 h as shown in (Figure 3- 24). After done of drying, the dried chili was collected, cooled in a shade to the ambient temperature and then sealed it in the plastic bags.

Figure 3-24: Photographs of moisturizing method using air ventilates in the oven dryer

The ambient temperature, temperature inside the chamber, ambient humidity, humidity inside the chamber, air flow rate at the inlet, outlet of the dryer, solar radiation, were noted at 1h intervals during the solar drying operation.

3.3.3 Moisture Content

It can be defined on the wet or dry basis as indicated in the equations below:

$$\text{Moisture Content(dry basis)} = \frac{(Wi - Wf) \times 100}{Wf} \qquad \text{Equation} \quad (3.3)$$

$$\text{Moisture Content(wet basis)} = \frac{(Wi - Wf) \times 100}{Wi} \qquad \text{Equation} \quad (3.4)$$

Where:

MCd Moisture content on dry basis (%)

MCw Moisture content on wet basis (%)

Wi Initial mass before drying (g)

Wf Final mass after drying (g)

CHAPTER 4

RESULTS AND DISCUSSOIN

After completing the fabrication of the dryer, different tests were performed in order to evaluate its performance. Two different experiments were carried out as below:

1. Solar drying test
2. Solar drying in hybrid test

Jinda Chili was dried during the test period. Solar drying test operation was assumed on 13th -15th February, 2018 and solar drying in hybrid test was assumed on 23th -25th June, 2018. The results of different tests performed are presented below:

4.1 Solar Drying Test

The typical solar drying was used the solar greenhouse with parabolic collector for drying the products.

4.1.1 Solar Radiation

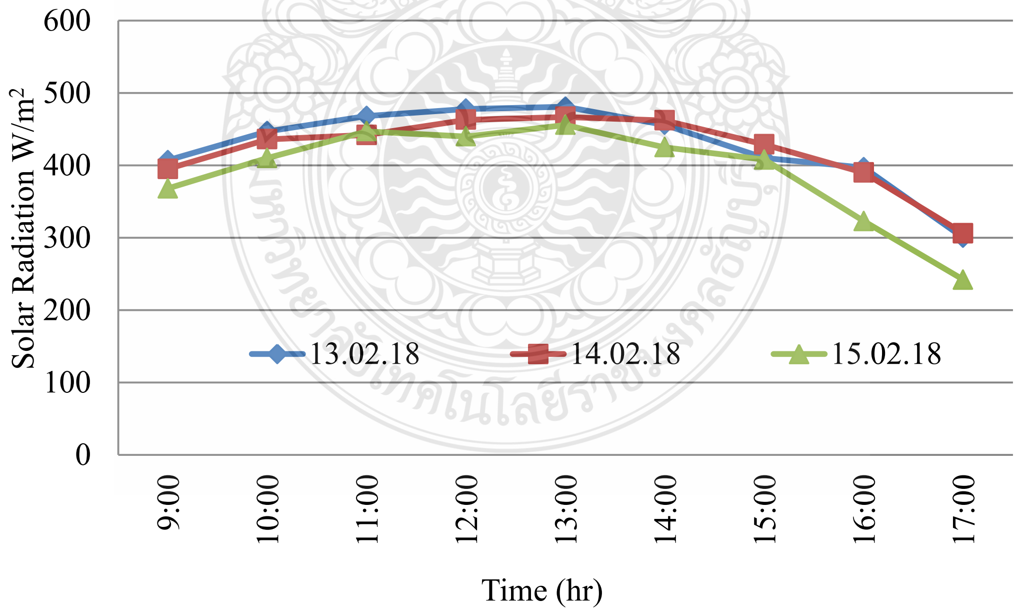

Figure 4-1: Differences of solar radiation with time of the days

Figure 4.1 shows the differences of solar radiation during the typical experimental runs of solar drying of Jinda Chili in the solar drying chamber. The experiment was carried out during 13^{th} -15^{th} February, 2018. In each experiments of drying the weather was sunshine day and windswept. The results of these three days of solar radiation are shown as below:

On February 13th, the results found that, at 9:00 solar radiation started at 407W/ m^2 and at 17:00 was 300 W/m^2 with a peak solar radiation value of 481 W/ m^2 at 13:00.

On February 14th, at 9:00 solar radiation started at 395 W/ m^2 and at 17:00 was 306 W/ m^2 with a peak solar radiation value of 467 W/ m^2 at 13:00.

On February 15th, at 9:00 solar radiation started at 368 W/ m^2 and at 17:00 was 242 W/ m^2 with a peak solar radiation value of 456 W/m2 at 13:00.

According to the above results, the maximum of solar radiation was 481 W/m^2 with the average of 413 W/m^2 during these three days and it reached its peak value when the sun was over head or at 13:00. During the drying of Jinda Chili, solar radiation was raised severely from 9 am to midday but it substantially decreased in the afternoon. There was also a slight random fluctuation in solar radiation. However, the overall cyclic patterns of the solar radiation were similar during these three days.

4.1.2 Temperature

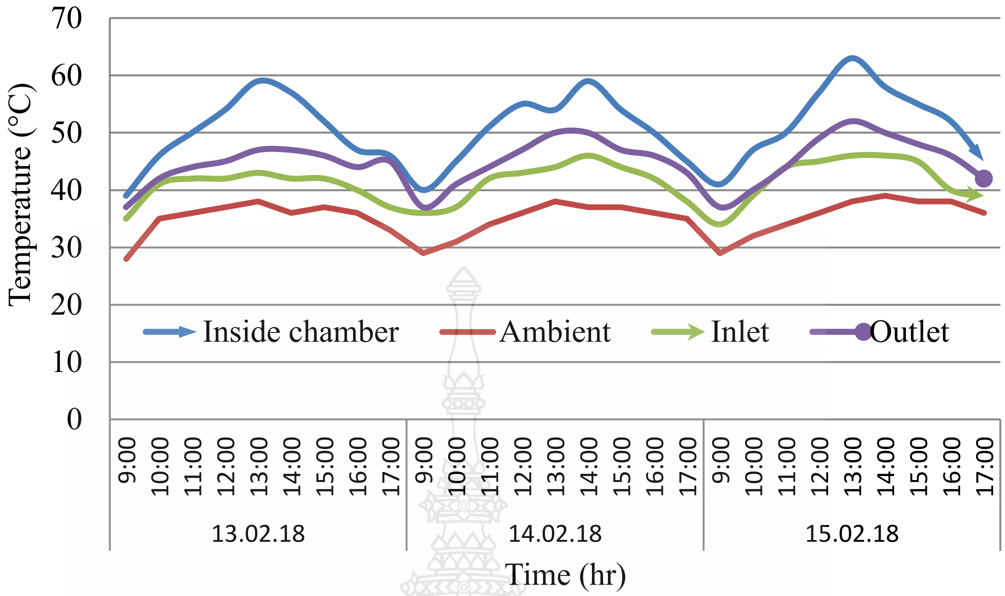

Figure 4-2: Differences of the temperature in the drying operation

Figure 4-2: Shows the differences of ambient temperature and temperature of the inlet air, outlet air and inside the chamber. The results of these three days of temperature are shown as below:

On February 13th, at 9:00 the ambient temperature started at 28 °C and inside the chamber was 39 °C while the ambient at 17:00 was 33 °C and inside the chamber was 46 °C. The dryer reached its peak temperature value of 59 °C at 13:00.

On February 14th, at 9:00 the ambient temperature stared at 29 °C and inside the chamber was 40 °C while the ambient at 17:00 was 35 °C and inside the chamber was 45 °C. The dryer reached its peak temperature value of 59 °C at 14:00.

On February 15th, at 9:00 the ambient temperature started at 29 °C and inside the chamber was 41 °C while the ambient at 17:00 was 36 °C and inside the chamber was 45 °C. The dryer reached its peak temperature value of 63 ° C at 13:00.

During the day time sunlight was the only source of heat supply, a highest temperature of 63 °C was gotten by the solar collector after five hours on the third day while the average temperature in the drying chamber at 09:00 to 17:00 was 51 °C. The dryer was hottest about noon when the sun was normally above head. The system reached its peak temperature value when the ambient temperature was 39 °C. The average temperature raise inside drying chamber was up to about 15 °C above the ambient temperature.

At the middle of the chamber, the drying air temperatures inside the chamber on the top of the tray were met to varied in the range of 39 - 63 °C from 9:00 - 17:00, which are the ambient temperature found to varied range of 28 °C - 39 °C, inlet temperature varied from 34 °C - 46 °C while the temperature at the outlet of the chamber varied from 37 °C - 52 °C during the same period in these three days. Inlet, outlet temperature and inside the chamber of solar system were compared with the ambient temperature as shown in (Figure 4.2).

4.1.3 Humidity

Figure 4-3 shows the humidity inside the drying chamber for typical experimental runs during solar drying of Jinda Chili. The results of these three days of temperature are shown as below:

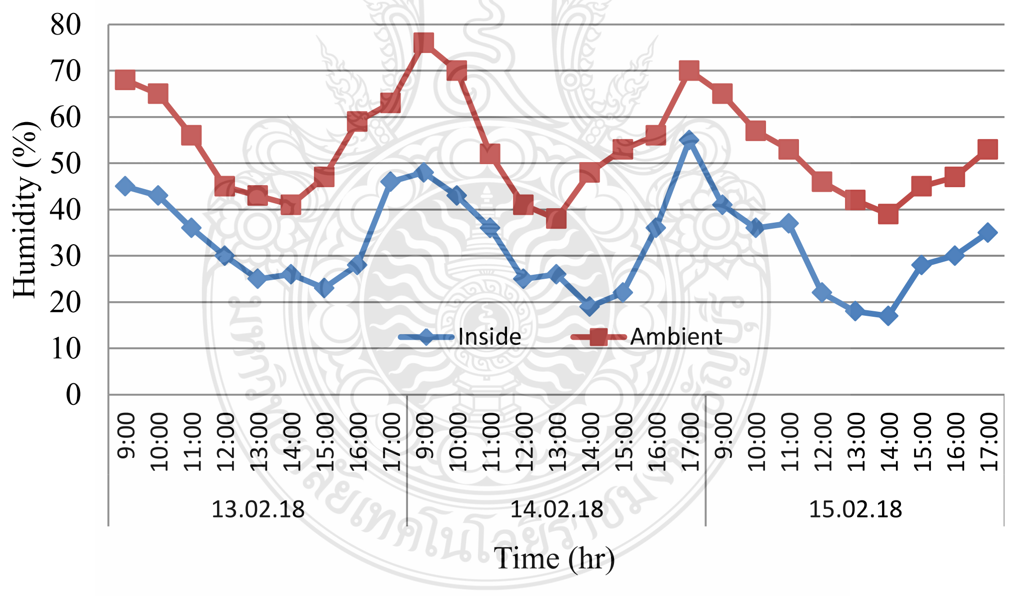

Figure 4-3: Differences of humidity in the drying operation

On February 13 th, at 9:00 the ambient humidity started at 68 % and at 17:00 was 63 % whereas inside the chamber was 45 % at 9:00 and at 17:00 was 46 %. The lowest humidity inside the chamber was 23 % at 15:00.

On February 14th, at 9:00 the ambient humidity started at 76 % and at 17:00 was 70 % whereas inside the chamber was 48 % at 9:00 and at 17:00 was 55 %. The lowest humidity inside the chamber was 19 % at 14:00.

On February 15th, at 9:00 the ambient humidity started at 65 % and at 17:00 was 53 % whereas inside the chamber was 41 % at 9:00 and at 17:00 was 35 %. The lowest humidity inside the chamber was 17 % at 14:00.

Through the above results, humidity was migrated with time inside the dryer during the first half of the day. It was caused by mitigating humidity of the ambient air and raised water holding capacity of the drying air due to temperature increase, whereas the opposite was true for the latter half of the day. The humidity of the air inside the dryer was always lower than the ambient air and the lowest humidity was in the middle of the day which persists for about 5 hours. Thus, the time of day with the most potential for solar dying was from 9:00 - 16:00.

4.1.4 Moisture Content

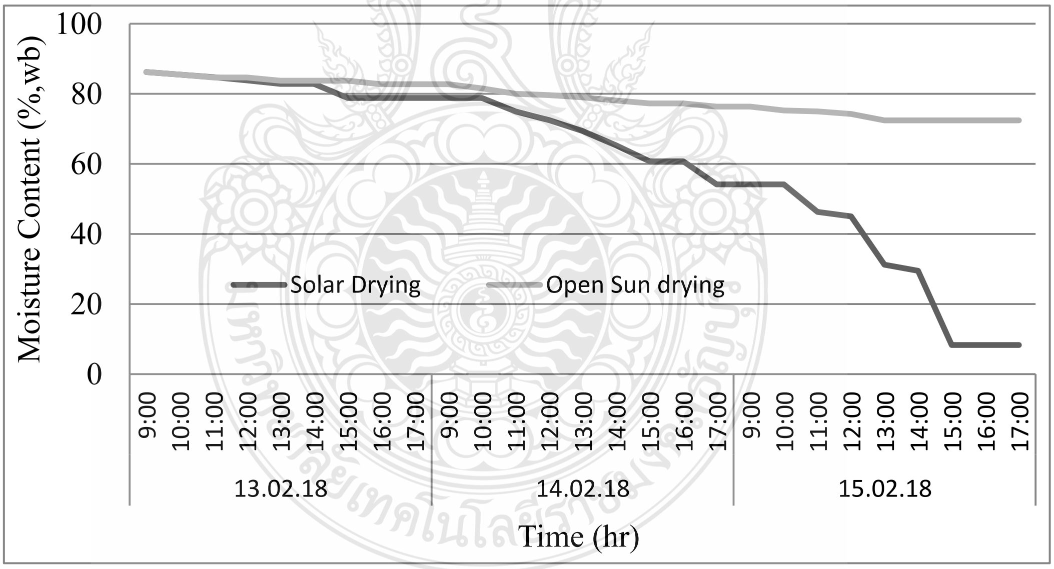

Figure 4-4: Differences of the moisture contents (w.b.) of Jinda Chili inside the drying chamber with the open sun drying method

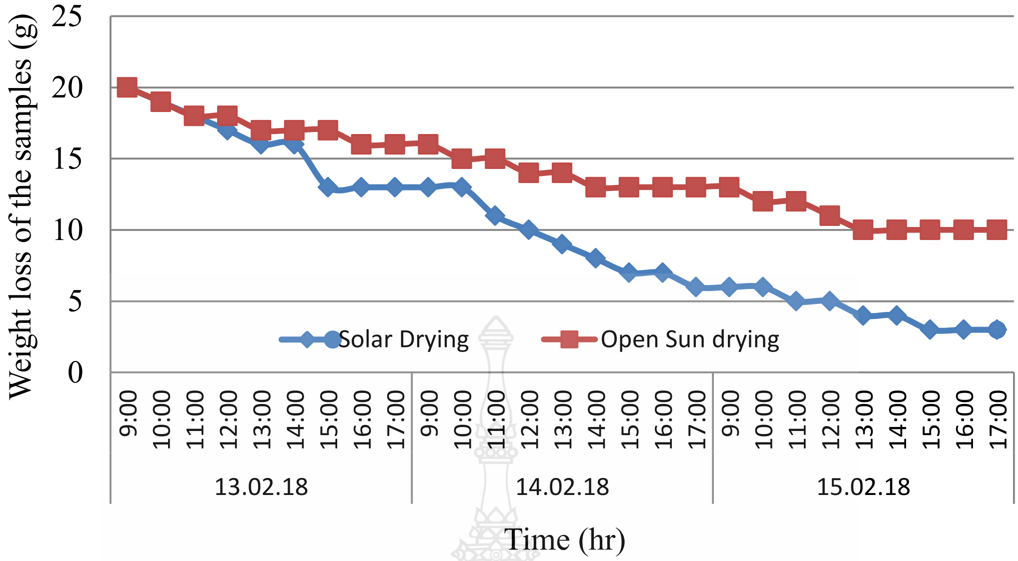

Figure 4-5: Differences of the weight loss of Jinda Chili inside the drying chamber with the open sun drying method

Figure 4.4 and Figure 4.5 shows the differences of the weight loss of Jinda Chili in the drying chamber for typical experimental runs compared to the control samples dried in the open sun drying. The results of these three days of temperature are shown as below:

On February 13th, the moisture content of sample inside the chamber was decreased from the first value of 86.25 % (w.b.) to 78.85 % (w.b.) or 20 g H_2O /g solids to 13 g H_2O /g solids and the moisture content of the open sun drying sample was decreased from the first value of 86.20 % (w.b.) to 82.75 % (w.b.) or 20 g H_2O /g solids to 16 g H_2O /g solids.

On February 14th, the moisture content of sample inside the chamber was decreased from 78.85 % (w.b.) to 54.17 % (w.b.) or 13 g H_2O /g solids to 6 g H_2O /g solids and the moisture content of the open sun drying sample was decreased from 82.75 % (w.b.) to 76.36 % (w.b.) or 16 g H_2O /g solids to 13 g H_2O /g solids.

On February 15th, the moisture content of sample inside the dryer was decreased from 54.17 % (w.b.) to 8.33 % (w.b.) or 6 g H_2O /g solids to 3 g H_2O /g solids and the moisture content of the open sun drying sample was decreased from 76.36 % (w.b.) to 72.40% (w.b.) or 13 g H_2O /g solids to 10 g H_2O /g solids.

During in these three days the moisture content of Jinda Chili inside the solar dryer was decreased from the first value of 86.25 % (w.b.) to 8.33 % (w.b.) or 20 g H_2O/g solids to 3 g H_2O/g solids whereas the moisture content of the open sun drying sample was decreased from the first value of 86.20 % (w.b.) to 72.40 % (w.b.) or 20 g H_2O/g solids to 10 g H_2O/g solids within the same period. If we look at the moisture content on wet basis of sample on the third day, moisture content was decreased faster than that on the first day and second day, whereas the weight loss of the samples was decreased faster on the first day than that on the second and third day of the experiment. The abatement differences of moisture content on wet basis and weight loss of the samples were caused by using digital scale to weigh the samples with accuracy level of ±1g. Thus, the drying in the solar dryer results was reduced the drying time. About 5 kg of fresh Jinda Chilies in this experiment were dried to about 0.8 kg.

4.2 Solar Drying in Hybrid Test

The typical hybrid test was used the solar greenhouse combined with parabolic collector and biogas for drying the products. But due to the insufficient time in producing biogas, the kind of gas tank was used to replace the process of this experiment. In this stage the experiment was set the temperature in the drying chamber at 60 °C to dry Jinda Chili. The dryer system was automatically controlled the temperature inside the chamber, which was remain as no lower than 60 °C. When the temperature was below 60 °C, the controller system was automatically turned on the gas parts to raise the temperature up to 60 °C. After that the system would be automatically turned off the gas part when the temperature reached the setting point.

4.2.1 Solar Radiation

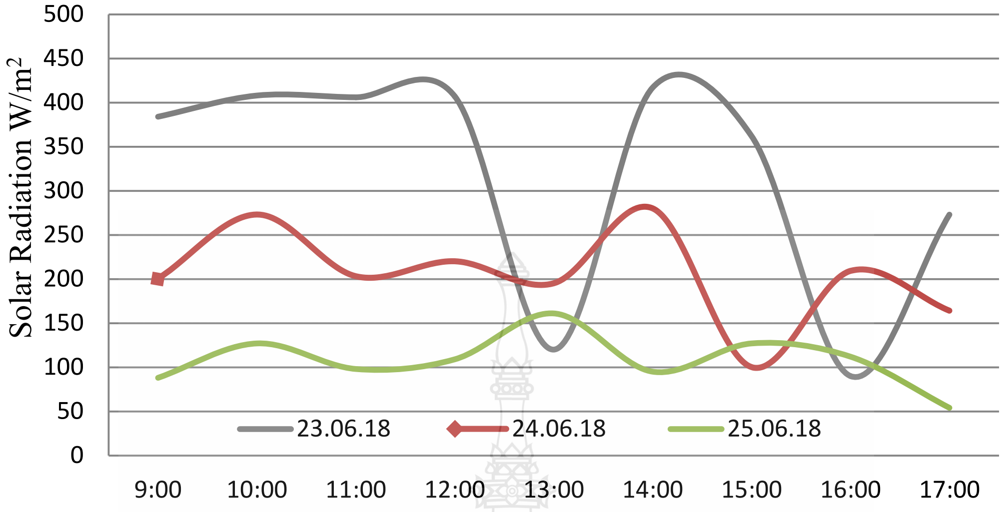

Figure 4-6: Differences of solar radiation with time of the days (hybrid test)

Figure 4-6 shows the differences of solar radiation with time of the days of drying operation of Jinda Chili in the solar drying chamber. The experiment was carried out during 23th - 25th June, 2018. The results of these three days of solar radiation are shown as below:

On June 23th, the results found that, at 9:00 solar radiation started at 384 W/m^2 and at 17:00 was 273 W/ m^2 with a peak solar radiation value of 417 W/ m^2 at 14:00.

On June 24th, at 9:00 solar radiation started at 200 W/m2 and at 17:00 was 164 W/m^2 with a peak solar radiation value of 280 W/ m^2 at 14:00.

On June 25th, at 9:00 solar radiation started at 88 W/m^2 and at 17:00 was 54 W/m^2 with a peak solar radiation value of 161 W/m^2 at 13:00.

Since, June is the rainy season, so that solar radiation was very low during the experiment. On the first experimental day the weather was sunshine day with little cloudy with the highest solar radiation of 417 W/m^2, while the second and third experimental day the weather was cloudy and drizzle in the afternoon of the third day. Solar radiations were too low with maximum 280 W/m^2 on second day and 161 W/m^2 on third day where the average solar radiation during these three days was 210 W/m^2.

4.2.2 Temperature

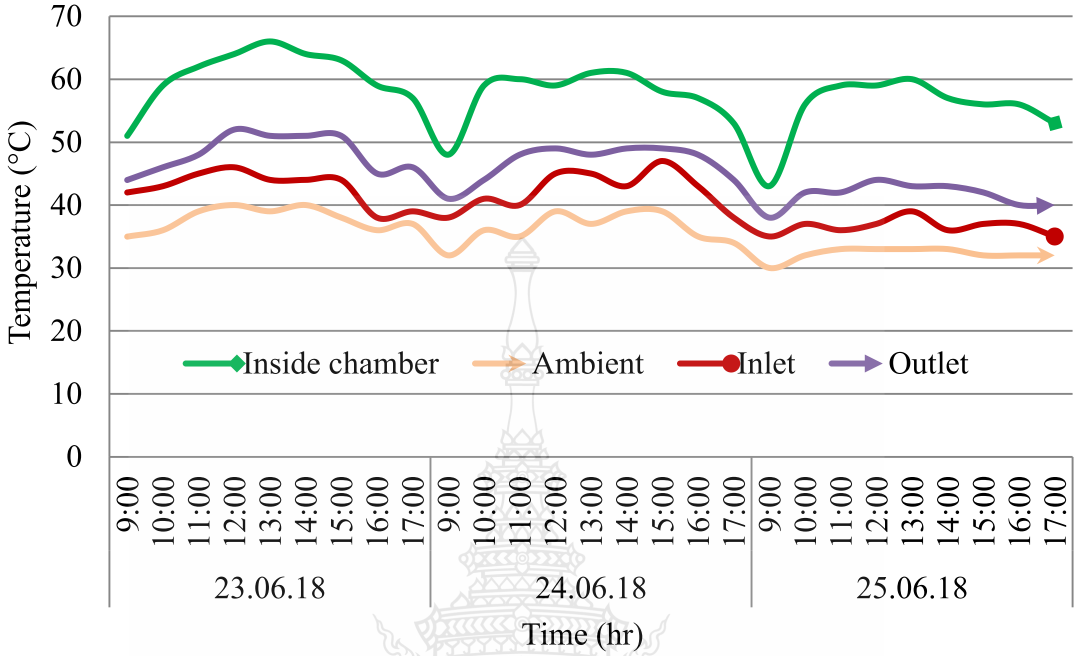

Figure 4-7: Differences of the temperature in the drying operation (hybrid test)

Figure 4-7: shows a different day results of the hourly variation of the temperatures in the drying chamber and the inlet air, outlet air were compared to the ambient temperature. The results of these three days of temperature are shown as below:

On June 23th, at 9:00 the ambient temperature started at 35 °C and inside the dryer was 51 °C while the ambient temperature at 17:00 was 37 °C and inside the dryer was 57 °C. The system obtained its top temperature value of 66 °C at 13:00.

On June 24th, at 9:00 the ambient temperature started at 32 °C and inside the dryer was 48 °C while the ambient temperature at 17:00 was 34 °C and inside the dryer was 53 °C. The system obtained its top temperature value of 61 °C at 13:00.

On June 25th, at 9:00 the ambient temperature started at 30 °C and inside the dryer was 43 °C while the ambient temperature at 17:00 was 32 °C and inside the dryer was 53 °C. The system obtained its top temperature value of 60 °C at 13:00.

In this experiment LPG was used to burn the iron pipe with gas burner to produce hot air to lead the thermal into the chamber. The temperatures inside the chamber were much higher than the ambient temperature during most hours of the daylight. As the fans were operate by a solar cell module, the air flow varied with solar radiation. This flow rate help to control the drying air temperature in the dryer. The average temperature rise inside drying chamber was up to about 22 °C above the ambient temperature and it was virtually constant in dryer. This shows prospect for better performance than traditional open sun drying.

According to Figure 4-7 showed that, the highest temperature inside the chamber were found to vary in the range of 43 °C - 66 °C from 9:00 – 17:00, and the ambient temperature found to vary in the range of 30 °C - 40 °C. This step the experiment was set the temperature inside the chamber at 60 °C. LPG was used as an aid in this experiment to increase the temperature inside the chamber to reach the setting point. For this study, it took 24 sunshine hours for a solar dryer with LPG energy to dry Jinda Chili at an average drying temperature of 57 °C. As a result, the heat from the gas burner was found to vary in the range of 80 °C - 92 °C. Temperature air inlet, air outlet and inside the chamber of solar dryer were compared with the ambient temperature as shown in (Figure 4.7).

4.2.3 Gas Consumption

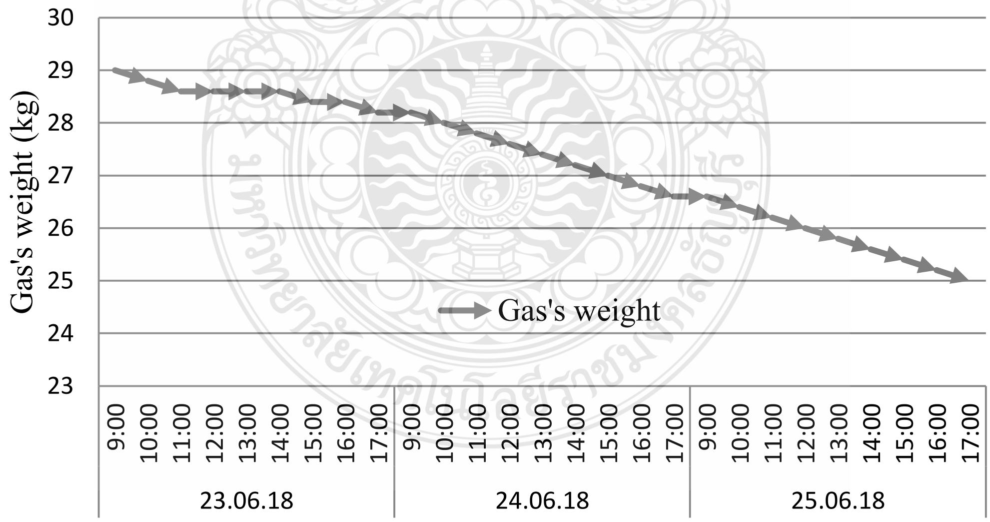

Figure 4-8: Variation of gas consumption in (hybrid test)

On the first day of this experiment, 500g of LPG was consumed while the second day and third day gas was loaded full day due to the weather was cloudy and drizzle. About 200 g of LPG was provided every 1hour or 1.8 kg per day in the experimental set up. Approximately 4 kg of LPG was supplied to this operation, which cost at THB 25 per kilogram. Thus, it was spent about THB 100 on this operation.

4.2.4 Humidity

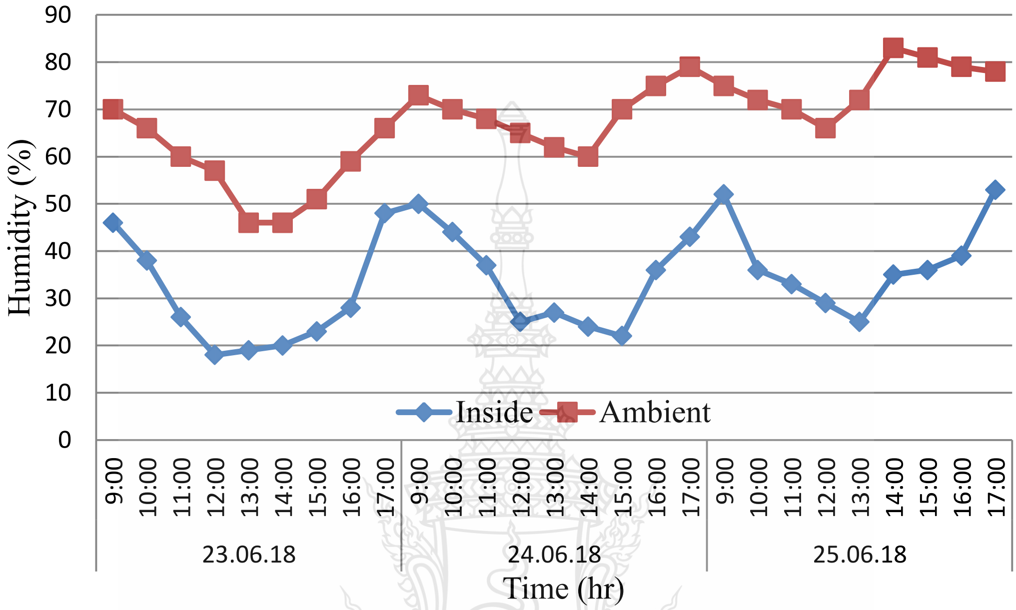

Figure 4-9: Differences of humidity in drying operation (hybrid test)

On June 23th, at 9:00 the ambient humidity started at 70 % and at 17:00 was 66 % whereas inside the chamber was 46 % at 9:00 and at 17:00 was 48 %. The lowest humidity inside the chamber was 18 % at 12:00.

On June 24th, at 9:00 the ambient humidity started at 73 % and at 17:00 was 79 % whereas inside the chamber was 50 % at 9:00 and at 17:00 was 55 %. The lowest humidity inside the chamber was 22 % at 15:00.

On June 25th, at 9:00 the ambient humidity started at 75 % and at 17:00 was 78 % whereas inside the chamber was 52 % at 9:00 and at 17:00 was 53 %. The lowest humidity inside the chamber was 25 % at 13:00.

Depend on Figure 4-9 showed that, the ambient humidity on second day and third day were much higher than the ambient humidity on first day because of the weather on that day mostly cloudy. Although the sky in this running was less of sun light, the humidity and temperature inside the dryer were still suitable for drying the products because of gas burner was loaded to burn the iron pipe and brought the hot air into the drying chamber.

4.2.5 Moisture Content

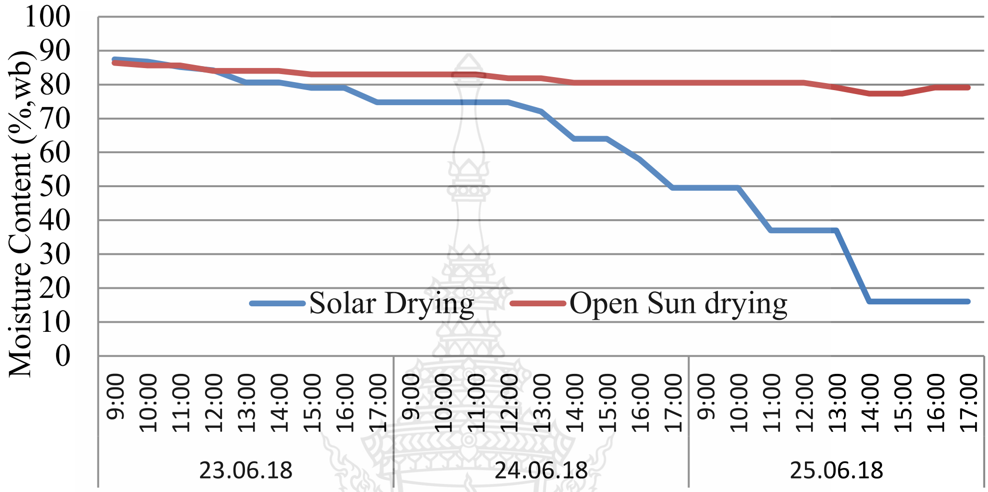

Figure 4-10: Differences of the moisture contents of Jinda Chili (hybrid test)

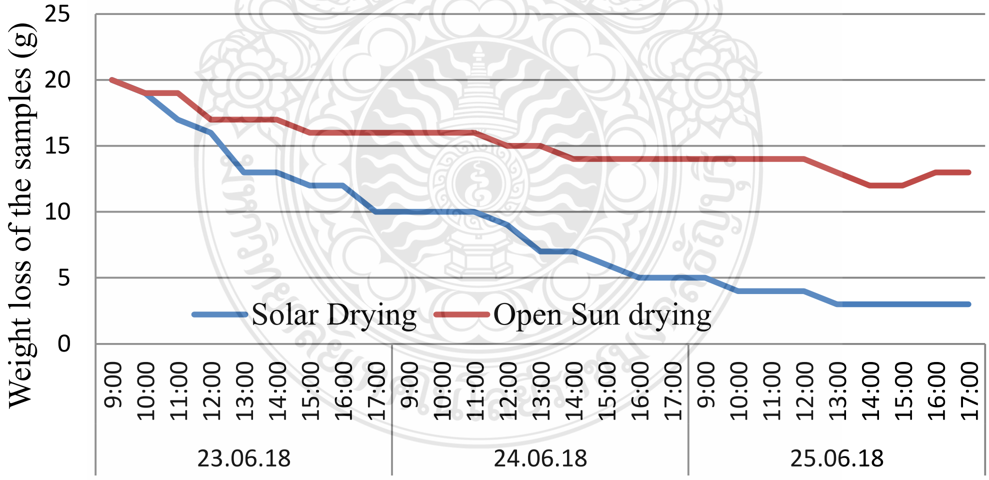

Figure 4-11: Differences of the weight loss of Jinda Chili (hybrid test)

Figure 4-10 and Figure 4-11 shows the different moisture content and weight loss of Jinda Chili samples in the drying chamber for typical experimental runs compared to the control samples dried in the open sun drying in (hybrid test). The results of these three days of temperature are shown as below:

On June 23th, the moisture content of sample inside the dryer was decreased from the first value of 87.40 % (w.b.) to 74.80 % (w.b.) or 20 g H_2O/g solids to 10 g H_2O /g solids and the moisture content of the open sun drying sample was decreased from the first value of 86.40 % (w.b.) to 83.00 % (w.b.) or 20 g H_2O /g solids to 16 g H_2O /g solids.

On June 24th, the moisture content of sample inside the dryer was decreased from 74.80 % (w.b.) to 49.60 % (w.b.) or 10 g H_2O /g solids to 5 g H_2O /g solids (d.b) and the moisture content of the open sun drying sample was decreased from 83.00 % (w.b.) to 80.57 % (w.b.) or 16 g H_2O /g solids to 14 g H_2O /g solids.

On June 25th, the moisture content of sample inside the dryer was decreased from 49.60 % (w.b.) to 16.00 % (w.b.) or 5 g H_2O /g solids (d.b) to 3 g H_2O /g solids (d.b) and the moisture content of the open sun drying sample was decreased from 80.57 % (w.b.) to 79.08 % (w.b.) or 14 g H_2O /g solids to 13 g H_2O /g solids.

The moisture content of Jinda Chili in the chamber was decreased from the first value of 87.40 % (w.b.) to 16 % (w.b.) or 20 g H_2O/g solids to 3 g H_2O/g solids within 3 days whereas the moisture content of the open sun drying sample was decreased from 86.40 % (w.b.) to 79.08 % or 20 g H_2O/g solids to 13 g H_2O/g solids within the same period. Due to the third experimental day at about 14:00 was drizzled; the samples of the open sun drying were stored in a super lock box to keep the moisture. These control samples were put out again at 15:00. The moisture content of the open sun drying sample was increased from 77.33 % to 79.08 % or 12 g H_2O/g solids (d.b) to 13 g H_2O/g solids (d.b) due to much humidity of the atmosphere during drizzle as shown in (Figure 4-10) and (Figure 4-11).

4.3 Comparison of the Moisture Contents: Solar Drying Test and Hybrid Test

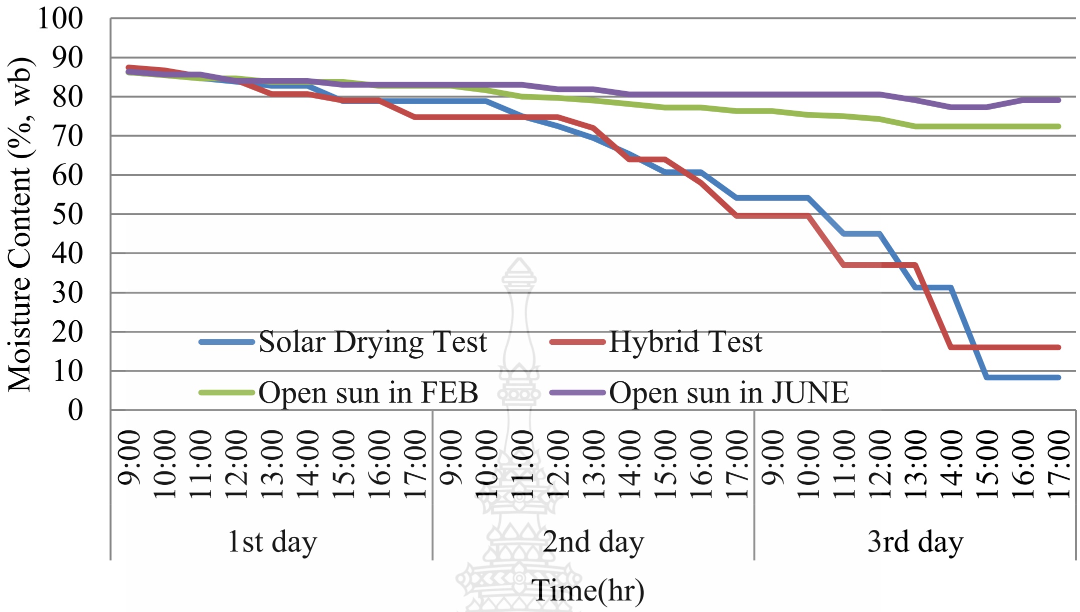

Figure 4-12: Differences of the moisture contents on wet bases of Jinda Chili between solar drying test and hybrid test

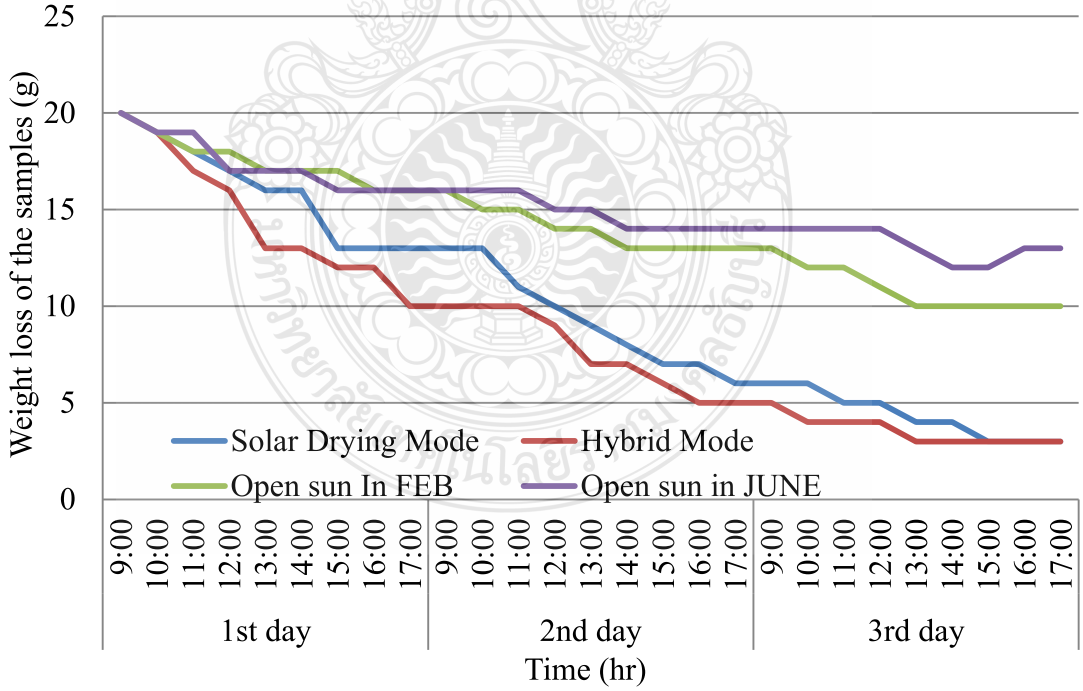

Figure 4-13: Differences of the weight loss of Jinda Chili between solar drying test and solar drying in hybrid test

Figure 4-12 shows the comparison of the moisture contents on wet bases of Jinda Chili between solar drying test and hybrid test for a typical experimental run. The initial value of solar drying test sample was reduced from 86.25 % (w.b.) to 8.33 % (w.b.) and solar drying in hybrid test sample was reduced 87.4 % (w.b.) to 16 % (w.b.) within 3 days or with an effective drying time of approximately 24 solar hours whereas the moisture contents of open sun drying sample in February was reduced from 86.20 % (w.b.) to 72.4 % (w.b.) and the initial value of open sun drying sample in June was reduced from 86.40 % (w.b.) to 79.08 % (w.b.) within 3 days.

Because June is the rainy season, solar radiation were much shorter than in February and humidity in June also higher than too. In addition, the fans were operated by a solar cell module, the air flow varied with solar radiation. As the airflow increases the locomotion of humidity from the chamber also increases. This caused the moisture contents sample in June decreased a bit slower than the moisture contents sample in February even though the gas energy was used to assist this operation. However, the final value of moisture content sample of solar drying in hybrid test of 16 % (w.b.) was still acceptable to the market demand.

Figure 4-13 shows the comparison of the weight loss of Jinda Chili between solar drying test and solar drying in hybrid test. The initial value of solar drying test sample was reduced from 20 g H_2O/g solids (d.b) to 3 g H_2O/g solids and solar drying in hybrid test sample was reduced from 20 g H_2O/g solids to 3 g H_2O/g solids within 3 days at day time whereas the weight loss of open sun drying sample in February was reduced from 20 g H_2O/g solids to 10 g H_2O/g solids and the initial value of open sun drying sample in June was reduced from 20 g H_2O/g solids to 13 g H_2O/g solids within three days the same.

The reduction of samples' weight of solar drying in hybrid test inside the chamber in June was abated faster than that the samples' weight in solar drying test in February, it was caused of the temperature inside the chamber was higher than that in February but however from 15:00 onward of the third experimental day both samples were the same in weight about 3 g H_2O/g solids up to the end of the both operations. And samples' weight of open sun drying test in June was abated slower than that the samples' weight in open sun drying test in February. At this point, let's take a look at the weight loss as to why there was a fair value; while the moisture content on wet basis had the different one, this reason was due to using digital scale to weigh the samples with accuracy level of ±1g.

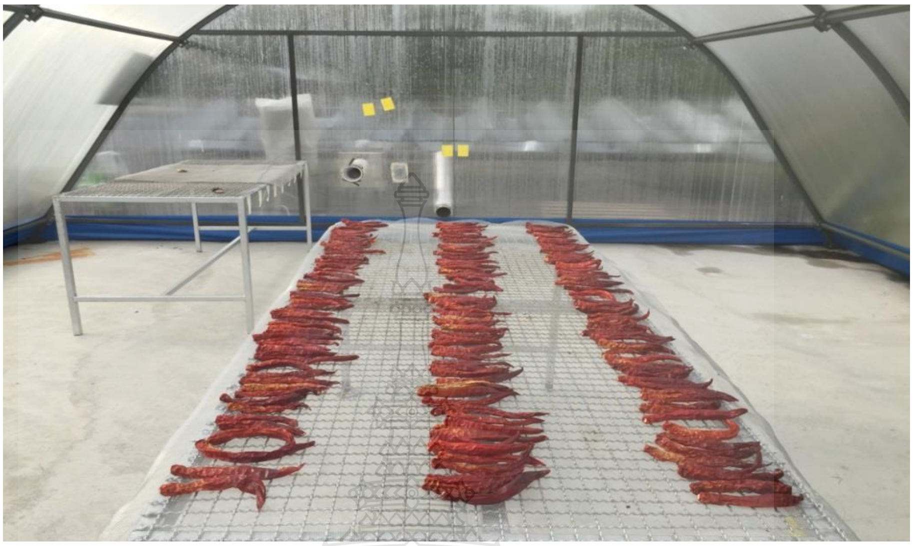

Figure 4-14: Photograph of Jinda Chili samples on solar drying in hybrid Mode

Figure 4-15: Photograph of Jinda Chili samples on solar drying mode

4.4 Economic Analysis

Table 4.1 Price of the drying system

Materials with specifications	Price (Baht)
1. Concrete floor 7m x 9m x 0.1m	15,000.00
2. Polycarbonate sheets 2800 x 10	28,000.00
3. Solar cell panel 80 watt 12v	2,600.00
4. Temperature controller + Solar panel + Battery	30,000.00
5. DC fan 12v x 5	300.00
6. Parabolic panels 8 x 10000	80,000.00
7. Fabrication charge 150000	100,000.00
8. Rectangular tube	50,000.00
9. Other…	20,000.00
Total:	BHT 325,900.00

Exchange rate 1 USD = 32.98 Baht

4.4.1 The total capital cost for the system (C_T) is given by the following equation:

$$C_T = C_m + C_l \quad \text{Equation (4.1)}$$

Where

C_m material cost of the dryer

C_l labor cost for the construction

From the above Table 4.1 C_T = 325,900.00 Baht

4.4.2 The annual cost calculation method proposed by Audsley and Wheeler [25] yields:

$$\text{Cannual}= [C_T + \sum_{i=1}^{N} (C_{maint,i} + C_{op,i})\omega^i] [\frac{(\omega-1)}{\omega(\omega^N-1)}] \quad \text{Equation (4.2)}$$

Where

C_{annual} annual cost of the system

N expected life of the dryer (about 15 years)

$C_{maint,i}$ maintenance cost

$C_{op,i}$ operating cost at the year i respectively. ω is expressed as:

$$\omega = \frac{100+i_{in}}{100+i_f} \qquad \text{Equation (4.3)}$$

Where

i_{in} 10% (interest rate)

i_f 3.5% (inflation rate)

Substitute the values in the Equation (4.3)

$$\omega = \frac{100+0.1}{100+0.035} = 1.0006$$

4.4.3 The operating cost consists Cop of the gas consumption cost, and the labor cost for operating the dryer. The maintenance cost of the first year was assumed to be 1% of the capital cost. This cost can be written as follows:

Cmaint = 325,900.00 Baht x 0.01 = 3,259 Baht

Cop = Cgas + Clabour,op

Where

Cgas = 25 Baht/kg x 648kg = 16,200 Baht/year

Clabour,op = 300 Baht/day x 365 = 109,500 Baht/year

Cop = 16,200 + 109500 = 125,700 Baht/year

Substitute the values in the Equation (4.2)

$$C_{annual} = [325900 + \sum_{i=1}^{15}(3259 + 125700)1.0006^{1}]\ [\frac{(1.0006-1)}{1.0006(1.0006^{15}-1)}]$$

$$C_{annual} = 150{,}040 \text{ Baht}$$

4.4.4 The annual cost per unit of dried product is called the drying cost (Z, Baht/kg). It can be written as:

$$Z = \frac{C_{annual}}{M_{dry}} = \frac{150040baht}{7200kg} = 20.83 \text{ Baht/kg}$$

Where M_{dry} is the dried product obtained from this dryer per year

4.4.5 Payback Period (PBP)

$$PBP = \frac{C_T}{M_{dry}P_d - M_f P_f - M_{dry}Z} \qquad \text{Equation (4.4)}$$

Where

M_{dry} is annual production of dry product (kg)

M_f is the amount of fresh product per year (kg)

P_d is the price of the dry product (Baht/kg)

P_f is the price of the fresh product (Baht/kg)

Substitute the values in the Equation (4.4)

$$Payback\ Period = \frac{325900}{(7200x150) - (42000x50) - (7200x20.83)} = 0.45\ years$$

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

In this research, a solar greenhouse chamber combine heat with a parabolic collector and LPG energy as a reserved heat source has been experimentally examined. This system has an area 63m^2 with a concrete floor. Parabolic collector plays as an assistance heater in this operation. Solar drying test and solar drying in hybrid test were carried out in this operation. Solar drying test operation was assumed on 13th -15th February and solar drying in hybrid test was assumed on 23th -25th June, 2018. From the tests carried out, the following conclusions were made. The system can raise the ambient air temperature to a considerable high value for increasing the drying rate of agricultural crops. The average temperature of solar drying test rise inside drying chamber was up to about 15 °C above the ambient temperature whereas the solar drying in hybrid test was up to about 22 °C. The product inside the dryer requires less attentions, like attack of the product by rain, dust or insect (both human and animals), compared with those in the open sun drying. Even though the dryer was used to dry Jinda Chili, it can be used to dry other crops like banana, tomato, corn, grape and durian etc. There is no trouble in monitoring when compared to the natural sun drying method.

The experimental results of proposed dryer system are compared to the ancient models of open sun drying. The results indicated that, the experimental solar drying test can be reduced the initial value moisture content of Jinda Chili from 86.25 % to 8.33 % w.b within 3 days, while using open drying meet the moisture content of 72.40 % w.b within the same period. And the other one is the experimental solar drying in hybrid test can be reduced the initial value moisture content of Jinda Chili from 87.40% to 16 % w.b, while the open sun drying sample in hybrid test meet the moisture content of 79.08 % w.b within the same 3 days. Because the experiment on solar dying in hybrid test was conducted on rainy season, solar radiations were much shorter than the experiment on solar drying test, ambient humidity and humidity inside the dryer were much higher than the experiment on solar drying test, on the other hand, because the fans were operated with a solar cell module, the air flow varied with solar radiation. This caused the moisture contents sample on solar drying in hybrid test decreased a bit slower than the moisture contents sample on solar drying test even though the gas energy was used to assist this operation. However, the final value of moisture content sample of solar drying in hybrid test of 16 % (w.b.) was still acceptable to the market demand. Only approximately 4 kg of LPG was supplied to this operation, which costs at BHT 25 per kilogram. Thus, it was spent about BHT 100 on this operation. The expected payback periods of this system for drying Jinda Chili are about 0.45 years and estimated life of the system are about 15 years. Base on the above results reveals that, the dryer exhibit sufficient ability to dry food items reasonably quickly to a safe moisture level and simultaneously it ensures a superior quality of the dried product, which are farmer and agro-industry has the potential to compete the market. It also gives the farmers a higher cost price compared to open sun drying method, while the moisture content of open sun drying method is still high up to 79.08%, which will increase the risk of mold and contamination. Moreover it loses income and market opportunities.

Thus, this research is presented an effective of used such as natural energy for the drying process. It can improve the quality of products and reduce drying time and costs drying operations for farmers.

5.2 Recommendation

Even though this study can lead us to the conclusion, the size of the experiment is still limited. Therefore the next researcher and agricultural engineering experts who figure out the above topic is incredibly important should conduct additional research on some sections as follows:

5.2.1 Apply biogas in the experiment to reduce the capital on drying operation.

5.2.2 Design gas burner to more standard and effective.

5.2.3 Extra studies on air flow of the dryer.

5.2.4 Introduce the digital scale with the accuracy level of ± 0.01 g for weighing sample to obtain more specific data.

5.2.5 Introduce the next study to dry other agricultural products such as banana, tomato, durian, and mushroom…etc. for receiving experimental data which will be used in the future.

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APPENDICES

APPENDIX A

Typical Temperature, Humidity, Air Flow, Gas Consumption, and Solar Radiation Variation with Time during Experiments

Table 1: Solar Radiation on February and June

Time/Date	Solar Radiation, W/m2					
	13.02.18	14.02.18	15.02.18	23.06.18	24.06.18	25.06.18
9:00	407	395	368	384	200	368
10:00	447	436	410	408	273	410
11:00	468	442	447	406	203	447
12:00	478	463	440	407	220	440
13:00	481	467	456	120	195	456
14:00	456	462	425	417	280	425
15:00	410	429	408	362	100	408
16:00	397	390	323	90	209	323
17:00	300	306	242	273	164	242

Table 2: Relative Humidity of the ambient and inside the dryer in February

Time/Date	Humidity (%)					
	13.02.18		14.02.18		15.02.18	
	Inside	Ambient	Inside	Ambient	Inside	Ambient
9:00	45	68	48	76	41	65
10:00	43	65	43	70	36	57
11:00	36	56	36	52	37	53
12:00	30	45	25	41	22	46
13:00	25	43	26	38	18	42
14:00	26	41	19	48	17	39
15:00	23	47	22	53	28	45
16:00	28	59	36	56	30	47
17:00	46	63	55	70	35	53

Table 3: Relative Humidity of the ambient and inside the dryer on in June

Time/Date	Humidity (%)					
	23.06.18		24.06.18		25.06.18	
	Inside	Ambient	Inside	Ambient	Inside	Ambient
9:00	46	70	50	73	52	75
10:00	38	66	44	70	36	72
11:00	26	60	37	68	33	70
12:00	18	57	25	65	29	66
13:00	19	46	27	62	25	72
14:00	20	46	24	60	35	83
15:00	23	51	22	70	36	81
16:00	28	59	36	75	39	79
17:00	48	66	43	79	53	78

Table 4: Temperature of the ambient and inside the dryer in February

Time/Date	Temperature (°C)					
	13.02.18		14.02.18		15.02.18	
	Inside	Ambient	Inside	Ambient	Inside	Ambient
9:00	39	28	40	29	41	29
10:00	46	35	45	31	47	32
11:00	50	36	51	34	50	34
12:00	54	37	55	36	57	36
13:00	59	38	54	38	63	38
14:00	57	36	59	37	58	39
15:00	52	37	54	37	55	38
16:00	47	36	50	36	52	38
17:00	46	33	45	35	45	36

Table 5: Temperature of the ambient and inside the dryer in June

Time/Date	Temperature (°C)					
	23.06.18		24.06.18		15.06.18	
	Inside	Ambient	Inside	Ambient	Inside	Ambient
9:00	51	35	48	32	43	30
10:00	59	36	59	36	56	32
11:00	62	39	60	35	59	33
12:00	64	40	59	39	59	33
13:00	66	39	61	37	60	33
14:00	64	40	61	39	57	33
15:00	63	38	58	39	56	32
16:00	59	36	57	35	56	32
17:00	57	37	53	34	53	32

Table 6: Gas Consumption in Hybrid Test

Time/Date	Gas Consumption (Kg)		
	23.06.18	24.06.18	25.06.18
9:00	29	28.2	26.6
10:00	28.8	28	26.4
11:00	28.6	27.8	26.2
12:00	28.6	27.6	26
13:00	28.6	27.4	25.8
14:00	28.6	27.2	25.6
15:00	28.4	27	25.4
16:00	28.4	26.8	25.2
17:00	28.2	26.6	25

Table 7: Inlet and Outlet air velocity on 13.02.2018

Time	Inlet air velocity m/s	Outlet air velocity m/s		
		1st Blower	2nd Blower	3rd Blower
9:00	2.94	8.87	8.73	8.35
10:00	3.54	10.31	9.86	10.04
11:00	3.61	10.02	10.40	10.44
12:00	3.72	10.49	10.87	10.78
13:00	3.57	11.41	11.34	11.09
14:00	3.5	11.30	10.58	10.80
15:00	3.57	10.24	9.75	9.50
16:00	2.92	8.31	8.38	7.88
17:00	2.2	6.02	6.04	6.26

Table 8: Inlet and Outlet air velocity on 14.02.2018

Time	Inlet air velocity m/s	Outlet air velocity m/s		
		1st Blower	2nd Blower	3rd Blower
9:00	2.9	8.04	8.33	8.02
10:00	2.23	9.00	10.13	9.25
11:00	3.54	10.73	9.57	9.72
12:00	3.7	10.78	10.78	10.67
13:00	3.59	10.60	11.25	12.06
14:00	3.59	11.07	11.07	11.14
15:00	3.21	10.26	10.15	10.33
16:00	2.69	8.51	8.20	8.87
17:00	1.55	5.21	4.92	5.07

Table 9: Inlet and Outlet air velocity on 15.02.2018

Time	Inlet air velocity m/s	Outlet air velocity m/s		
		1st Blower	2nd Blower	3rd Blower
9:00	2.62	8.04	8.02	8.06
10:00	3.12	9.52	9.99	9.41
11:00	3.45	11.16	10.15	10.96
12:00	3.79	10.76	11.03	11.48
13:00	3.72	11.46	11.43	11.41
14:00	3.32	10.40	10.53	11.36
15:00	3.16	9.61	10.11	10.11
16:00	2.47	7.25	7.05	7.45
17:00	1.59	5.09	4.76	4.83

Table 10: Inlet and Outlet air velocity on 23.06.2018

Time	Inlet air velocity m/s	Outlet air velocity m/s		
		1st Blower	2nd Blower	3rd Blower
9:00	3.37	7.12	7.61	7.43
10:00	3.9	9.63	9.81	9.77
11:00	3.93	10.37	10.63	10.90
12:00	4.11	11.43	10.85	11.50
13:00	3.75	11.10	11.23	11.21
14:00	3.4	5.95	5.70	5.81
15:00	1.46	6.35	6.67	6.44
16:00	2.62	4.33	4.60	4.53
17:00	2.15	3.70	3.68	3.52

Table 11: Inlet and Outlet air velocity on 24.06.2018

Time	Inlet air velocity m/s	Outlet air velocity m/s		
		1st Blower	2nd Blower	3rd Blower
9:00	2.96	4.80	5.10	4.90
10:00	3.03	9.40	9.57	9.55
11:00	3.48	11.41	10.73	10.91
12:00	3.25	11.05	10.25	10.48
13:00	3.91	8.94	9.84	10.37
14:00	3.05	8.40	9.18	8.80
15:00	2.11	8.06	7.90	8.40
16:00	2.56	9.10	8.90	9.21
17:00	2.08	5.36	5.23	5.48

Table 12: Inlet and Outlet air velocity on 25.06.2018

Time	Inlet air velocity m/s	Outlet air velocity m/s		
		1st Blower	2nd Blower	3rd Blower
9:00	2.56	6.44	6.06	6.15
10:00	2.48	7.54	8.02	8.06
11:00	3.01	7.61	7.25	7.36
12:00	3.1	8.35	7.88	8.08
13:00	2.98	9.03	8.83	8.96
14:00	2.62	7.66	7.39	7.30
15:00	2.49	6.67	7.30	7.32
16:00	2.24	7.20	6.90	6.84
17:00	2.15	5.12	4.95	5.23

APPENDIX B

Sample Analysis of Moisture Content and Cost of Dryer

Table 13: Moisture contents on wet basis in February

Time/Date	Moisture contents on wet basis (%)					
	13.02.18		14.02.18		15.02.18	
	Solar drying	Open sun	Solar drying	Open sun	Solar drying	Open sun
9:00	86.25	86.2	78.85	82.75	54.17	76.36
10:00	85.53	85.47	78.85	81.6	54.17	75.3
11:00	84.72	84.67	75	80	46.3	75
12:00	83.82	84.67	72.5	79.66	45	74.26
13:00	82.81	83.76	69.44	79	31.25	72.4
14:00	82.81	83.76	65.33	78.1	29.5	72.4
15:00	78.85	83.76	60.71	77.23	8.33	72.4
16:00	78.85	82.75	60.71	77.23	8.33	72.4
17:00	78.85	82.75	54.17	76.36	8.33	72.4

Table 14: Moisture contents on dry basis in February

Time/Date	Moisture contents on dry basis (g)					
	13.02.18		14.02.18		15.02.18	
	Solar drying	Open sun	Solar drying	Open sun	Solar drying	Open sun
9:00	20	20	13	16	6	13
10:00	19	19	13	15	6	12
11:00	18	18	11	15	5	12
12:00	17	18	10	14	5	11
13:00	16	17	9	14	4	10
14:00	16	17	8	13	4	10
15:00	13	17	7	13	3	10
16:00	13	16	7	13	3	10
17:00	13	16	6	13	3	10

Table 15: Moisture contents on wet basis in June

Time/Date	Moisture contents on wet basis (%)					
	23.06.18		24.06.18		25.06.28	
	Solar drying	Open sun	Solar drying	Open sun	Solar drying	Open sun
9:00	87.4	86.4	74.8	83	49.6	80.57
10:00	86.74	85.68	74.8	83	49.6	80.57
11:00	85.18	85.68	74.8	83	37	80.57
12:00	84.25	84	74.8	81.87	37	80.57
13:00	80.62	84	72	81.87	37	79.08
14:00	80.62	84	64	80.57	16	77.33
15:00	79	83	64	80.57	16	77.33
16:00	79	83	58	80.57	16	79.08
17:00	74.8	83	49.6	80.57	16	79.08

Table 16: Moisture contents on dry basis in June

Time/Date	Moisture contents on dry basis (g)					
	23.06.18		24.06.18		25.06.18	
	Solar drying	Open sun	Solar drying	Open sun	Solar drying	Open sun
9:00	20	20	10	16	5	14
10:00	19	19	10	16	4	14
11:00	17	19	10	16	4	14
12:00	16	17	9	15	4	14
13:00	13	17	7	15	3	13
14:00	13	17	7	14	3	12
15:00	12	16	6	14	3	12
16:00	12	16	5	14	3	13
17:00	10	16	5	14	3	13

Table 17: Moisture content samples on dry bases: Solar Drying Test and Hybrid Test

Moisture content samples on dry basis on 13.02.18 (g)								
Time	T1	T2	T3	T4	T5	T6	T7	Open sun
9:00	20	20	20	20	20	20	20	20
10:00	19	18	19	19	19	20	19	19
11:00	19	17	18	18	18	19	18	18
12:00	18	17	17	17	17	18	18	18
13:00	17	16	16	15	16	17	16	17
14:00	16	16	16	15	16	16	16	17
15:00	15	14	14	14	13	15	14	17
16:00	14	14	14	13	13	14	14	16
17:00	14	13	14	13	13	14	13	16
Moisture content samples on dry basis on 14.02.18 (g)								
Time	T1	T2	T3	T4	T5	T6	T7	Open sun
9:00	14	13	14	13	13	14	13	16
10:00	14	13	14	13	13	13	13	15
11:00	13	12	12	11	11	12	12	15
12:00	11	11	12	10	10	11	11	14
13:00	9	9	10	9	9	10	10	14
14:00	9	9	9	8	8	9	9	13
15:00	8	7	9	7	7	8	8	13
16:00	7	7	8	6	7	7	7	13
17:00	7	6	8	6	6	6	7	13
Moisture content samples on dry basis on 15.02.18 (g)								
Time	T1	T2	T3	T4	T5	T6	T7	Open sun
9:00	7	6	8	6	6	6	7	13
10:00	6	6	7	6	6	6	7	12

Time	T1	T2	T3	T4	T5	T6	T7	Open sun
11:00	6	5	6	5	5	6	6	12
12:00	5	5	6	4	5	5	5	11
13:00	5	4	5	4	4	5	5	10
14:00	4	4	4	3	4	4	4	10
15:00	4	4	4	3	3	3	4	10
16:00	4	4	3	3	3	3	3	10
17:00	3	4	3	3	3	3	3	10

Moisture content samples on dry basis 23.06.18 (g)

Time	T1	T2	T3	T4	T5	T6	T7	Open sun
9:00	20	20	20	20	20	20	20	20
10:00	19	19	20	19	19	18	19	19
11:00	18	19	19	17	18	17	17	19
12:00	16	17	18	16	17	16	16	17
13:00	14	16	15	13	15	13	14	17
14:00	13	15	15	13	14	13	14	17
15:00	13	14	14	12	14	12	13	16
16:00	12	13	14	12	13	11	12	16
17:00	11	12	13	10	12	10	11	16

Moisture content samples on dry basis 24.06.18 (g)

Time	T1	T2	T3	T4	T5	T6	T7	Open sun
9:00	11	12	13	10	12	10	11	16
10:00	11	12	13	10	12	10	11	16
11:00	9	11	12	10	11	10	11	16
12:00	9	10	10	9	10	8	6	15
13:00	8	9	10	7	9	7	8	15
14:00	7	8	9	7	9	6	8	14

Time	T1	T2	T3	T4	T5	T6	T7	Open sun
15:00	6	7	8	6	8	5	7	14
16:00	6	6	7	5	7	5	6	14
17:00	6	6	7	5	7	5	6	14

Moisture content samples on dry basis 25.02.18 (g)								
Time	T1	T2	T3	T4	T5	T6	T7	Open sun
9:00	6	6	7	5	7	5	6	14
10:00	5	5	6	4	6	5	5	14
11:00	5	5	6	4	6	4	5	14
12:00	5	5	6	4	6	3	5	14
13:00	4	5	6	3	6	3	4	13
14:00	4	4	5	3	5	3	4	12
15:00	3	4	4	3	5	3	4	12
16:00	3	4	4	3	5	2	4	13
17:00	3	4	4	3	5	2	4	13

Table 18: Moisture content samples on wet bases: Solar Drying Test and Hybrid Test

Moisture content samples on wet basis 13.02.18 (%)								
Time	T1	T2	T3	T4	T5	T6	T7	Open sun
9:00	86.50	83.90	87.85	86.90	86.25	88.90	86.55	86.20
10:00	85.79	82.11	87.21	86.21	85.53	88.90	85.84	85.47
11:00	85.79	81.06	86.50	85.44	84.72	88.32	85.06	84.67
12:00	85.00	81.06	85.71	84.59	83.82	87.67	85.06	84.67
13:00	84.12	79.88	84.81	82.53	82.81	86.94	83.19	83.76
14:00	83.13	79.88	84.81	82.53	82.81	86.13	83.19	83.76
15:00	82.00	77.00	82.64	81.29	78.85	85.20	80.79	83.76
16:00	80.71	77.00	82.64	79.85	78.85	84.14	80.79	82.75

Time	T1	T2	T3	T4	T5	T6	T7	Open sun
17:00	80.71	75.23	82.64	79.85	78.85	84.14	79.31	82.75

Moisture content samples on wet basis on 14.02.18 (%)

Time	T1	T2	T3	T4	T5	T6	T7	Open sun
9:00	80.71	75.23	82.64	79.85	78.85	83.21	79.31	82.75
10:00	80.71	75.23	82.64	79.85	78.85	81.92	79.31	81.60
11:00	79.23	73.17	79.75	76.18	75.00	80.42	77.58	81.60
12:00	75.45	70.73	79.75	73.80	72.50	78.64	75.55	80.29
13:00	70.00	64.22	75.70	70.89	69.44	76.50	73.10	80.29
14:00	70.00	64.22	73.00	67.25	65.63	73.89	70.11	78.77
15:00	66.25	54.00	73.00	62.57	60.71	70.63	66.38	78.77
16:00	61.43	54.00	69.63	56.33	60.71	66.43	61.57	78.77
17:00	61.43	46.33	69.63	56.33	54.17	60.83	61.57	78.77

Moisture content samples on wet basis on 15.02.18 (%)

Time	T1	T2	T3	T4	T5	T6	T7	Open sun
9:00	61.43	46.33	69.63	56.33	54.17	60.83	61.57	78.77
10:00	55.00	46.33	65.29	56.33	54.17	60.83	61.57	77.00
11:00	55.00	35.60	59.50	47.60	45.00	60.83	55.17	77.00
12:00	46.00	35.60	59.50	34.50	45.00	53.00	46.20	74.91
13:00	46.00	19.50	51.40	34.50	31.25	53.00	46.20	72.40
14:00	32.50	19.50	39.25	12.67	31.25	41.25	32.75	72.40
15:00	32.50	19.50	39.25	12.67	8.33	21.67	32.75	72.40
16:00	32.50	19.50	19.00	12.67	8.33	21.67	10.33	72.40
17:00	10.00	19.50	19.00	12.67	8.33	21.67	10.33	72.40

Moisture content samples on wet basis on 23.06.18 (%)

Time	T1	T2	T3	T4	T5	T6	T7	Open sun
9:00	88.05	88.00	86.90	87.40	87.55	91.60	85.30	86.40
10:00	87.42	87.37	86.90	86.74	86.89	90.67	84.53	85.68
11:00	86.72	87.37	86.21	85.18	86.17	90.12	82.71	85.68
12:00	85.06	85.88	85.44	84.25	85.35	89.50	81.63	84.00
13:00	82.93	85.00	82.53	80.62	83.40	87.08	79.00	84.00
14:00	81.62	84.00	82.53	80.62	82.21	87.08	79.00	84.00
15:00	81.62	82.86	81.29	79.00	82.21	86.00	77.38	83.00
16:00	80.08	81.54	81.29	79.00	80.85	84.73	75.50	83.00
17:00	78.27	80.00	79.85	74.80	79.25	83.20	73.27	83.00

Moisture content samples on wet basis on 24.06.18 (%)

Time	T1	T2	T3	T4	T5	T6	T7	Open sun
9:00	78.27	80.00	79.85	74.80	79.25	83.20	73.27	83.00
10:00	78.27	80.00	79.85	74.80	79.25	83.20	73.27	83.00
11:00	73.44	78.18	78.17	74.80	77.36	83.20	73.27	83.00
12:00	73.44	76.00	73.80	72.00	75.10	79.00	63.25	81.87
13:00	70.13	73.33	73.80	64.00	72.33	76.00	63.25	81.87
14:00	65.86	70.00	70.89	64.00	72.33	72.00	63.25	80.57
15:00	60.17	65.71	67.25	58.00	68.88	66.40	58.00	80.57
16:00	60.17	60.00	62.57	49.60	64.43	66.40	51.00	80.57
17:00	60.17	60.00	62.57	49.60	64.43	66.40	51.00	80.57

Moisture content samples on wet basis on 25.06.18 (%)

Time	T1	T2	T3	T4	T5	T6	T7	Open sun
9:00	60.17	60.00	62.57	49.60	64.43	66.40	51.00	80.57
10:00	52.20	52.00	56.33	37.00	58.50	66.40	41.20	80.57
11:00	52.20	52.00	56.33	37.00	58.50	58.00	41.20	80.57

Time	T	T2	T3	T4	T5	T6	T7	Open sun
12:00	52.20	52.00	56.33	37.00	58.50	44.00	41.20	80.57
13:00	40.25	52.00	56.33	16.00	58.50	44.00	26.50	79.08
14:00	40.25	40.00	47.60	16.00	50.20	44.00	26.50	77.33
15:00	20.33	40.00	34.50	16.00	50.20	44.00	26.50	77.33
16:00	20.33	40.00	34.50	16.00	50.20	16.00	26.50	79.08
17:00	20.33	40.00	34.50	16.00	50.20	16.00	26.50	79.08

APPENDIX C

Public Paper


METAL WORK
PEA
KU
KASETSART UNIVERSITY
2018
TSAE
THAILAND
The 11 th TSAE International Conference
การประชุมวิชาการสมาคมวิศวกรรมเกษตรแห่งประเทศไทยระดับชาติ ครั้งที่ 19
26-27 APRIL 2018
Chulabhorn International Convention Center
(Wora Wana Hua Hin Hotel & Convention)
Hua Hin, Prachuap Khiri Khan, Thailand
Thai Society of Agricultural Engineering
TSAE 2018
วิศวกรรมเกษตร
เปิดแนวคิดวิศวกรรมสู่การเกษตรแนวใหม่
AGRICULTURAL ENGINEERING
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Topics of Oral and Poster Presentation
Power and machinery
Soil and water engineering
Post-harvest and food engineering
Structures and buildings
Agricultural systems
Electronics and information technology
Energy and environment

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The Development of Drying System by Using Parabolic Collector Technique for SMEs

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Abstract

Drying is one of the most methods used to preserve food products for longer periods. The majority of farmers nowadays used the open sun drying method for drying agricultural products. It is the oldest preservation technique of agricultural products and sun drying is widely practiced in the tropics and subtropics. It usually takes long time periods and will not be completed on time when the lack of sunlight or on the raining season. Moreover, by using an ancient model such as open sun drying, this very simple technique leaves the crop susceptible to rain, contamination by dirt and animals and also usually takes a much longer time to dry resulting in a final produce with very poor quality. Thus, this research has been used the application of solar energy for a dryer to solve the problems. The dryer concept is divided into two main parts; first is a solar collector for sun solar collection using parabolic technique. The heat produced from solar energy on this system is used to provide 50 % of heat source for the dryer process. Second system is a solar greenhouse chamber and the temperature controller; the parabolic panels can be adjusted from 1-50 degrees. The dryer system can produce heat up to 80° C in the greatest sunny days [1]. However, this season the drying system can produce the temperature up to 63°C in the chamber dryer to dry fresh chilli.

The experimental results of proposed dryer system are compared to the ancient model of open sun drying, the result shown that by using the applied of parabolic collector technique and solar greenhouse chamber can reduced the moisture content of Jinda chili from 86 % wb (wet basic) to 8% wb within 3 days, while using open sun drying meet the moisture content of 67 % wb (wet basic) within the same period. The Development of Drying System by Using Parabolic Collector Technique for SMEs is presented an effective of used such as natural energy for the drying process. It can improve the quality of products and reduce drying time and costs drying operations for farmers.

Keywords: Solar energy, Parabolic, Hot air, Dryer

1 Introduction

Thailand is an agricultural country, and its products range from world famous jasmine rice to various vegetables, fruits and herbs. Most of the products need some kind of preservation to enhance their shelf life since the production usually exceeds market demand at the harvest season. Drying is one of the most used methods for product preservation, and as a result, it adds higher value to the products. A dryer can achieve this purpose by supplying more heat which in turn increases the vapor pressure of the moisture in the product, reduces relative humidity of the air, then increases its moisture loading capacity and ensures sufficiently low equilibrium moisture content. Solar energy can be used as an important and environmental compatible source of renewable energy. The use of solar energy for drying effectively reduces the problems arising from generating energy by convention method. This is because the use of the conventional energy source for drying purposes is costly and hazardous to environment [2]. "Clean, economical and unlimited use" all of these are the definition of solar energy. In general, it is well known for its use in the production of electricity through the solar cell panel. In the past majority of famers mostly used open sun drying method for drying agricultural products to preserve or keep the quality of products. It usually takes long time and will not be done by time when the lack of sunlight or on the raining season. Moreover, by using an old fashion such as open sun drying, it will cause the products not achieved the demand target; contaminated of the dust and this would be reduced the quality of the products. Nowadays even though there are increasing in development of dryers such as Microwave, electric infrared, electric heater, gas burner, fuel diesel, fuel gasoline, etc. Those methods mentioned above use high capital, high power consumption and also affects the environment. Nowadays, solar energy is widely used in the world [1].

Therefore, this research has been used the application of parabolic solar collector technique for a dryer to make benefit. This energy is clean energy and no capital and it can be used as tha main heat source.

2 Materials, Methods and Theories

2.1 *Experimental Setup*

The drying system type of parabolic collector technique was installed at Rajamangala University of Technology Thanyaburi, Pathum Thani Province, Thailand. The dryer consists of a parabolic roof structure made from polycarbonate sheets on a concrete floor. The system has a width of 6.0 m, length of 8.0 m and height 2.5 m. Four DC fans operated by one 50-Watt solar cell modules were installed in the wall outlet side and other one in the inlet side to ventilate the dryer. Parabolic solar collector has a width of 0.825 m, length of 2.40 m. depth of 0.45m with eight panels were installed at the rear side of the dryer. The basic concept behind the parabolic solar dryer is to explore the possibility of using the parabolic trough collector systems such as those used in the line focus point and combining it with the glazing collector system to increase the efficiency of the solar dryer. It is made of zinc which transforms the heat through the reflection to the tube absorbing the heat to the drying chamber properly. The pictorial view of the whole designs of the solar drying system in this study is shown in Fig.1.

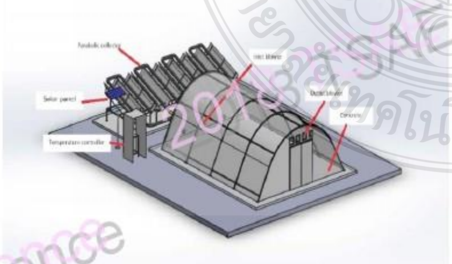

Fig.1. Whole designs of the solar drying system

Solar radiation passing through the polycarbonate roof heats the air and the products inside the dryer as well as the concrete floor. The hot air from the parabolic collector is ventilated through a small hole at the bottom of the behind side of the dryer was absorbed by one DC fan, which the air inside the chamber heated by the concret floor and the products exposed to solar radiation. The heated air while passing through and over the products absorbs moisture from the products. Direct exposure to solar radiation of the products and the heated drying air enhance the drying rate of the products. Most air is sucked from the dryer by three PV-fans at the top of the outlet side of the dryer. The pictorial view of the solar drying system with parabolic collector technique is shown in Fig.2.

Fig.2. The pictorial view of the solar drying system with parabolic collector technique

2.2 *Experimental procedure*

The experimental were carried out 50kg for Jinda Chilli during the period of February, 2018. The chilli was weighed and spread out over the tray in a thin layer in the solar chamber dryer. Seven control samples of Jinda Chilli were placed on the tray inside the chamber at different position as shown in Fig.3 and another one sample was also placed on a tray outside the chamber in the open sun drying. Drying was started after completion of the loading, usually at 9:00 and discontinued at 17:00. About 20g of each sample was weighed from the samples in the chamber dryer. Weight loss of both the samples in the solar chamber dryer and the control samples in the open sun drying were measured during the drying period at 1 h interval with digital scales (Model SF-400, accuracy ±1g). In the afternoon, after 17:00, the samples in the solar chamber dryer were kept in the dryer and the control samples were kept in a room at ambient conditions. These control samples were again put out in the sun next morning usually at 9:00 a.m. Then both the solar and sun drying samples were subjected to dry under the same weather conditions.

A K-type thermocouple (Daiichi-TH207) was used to measure the drying air temperature inside the chamber, inlet and outlet. A solar meter (Model IR G-22, accuracy ±1.5%) was used to measure the solar radiation at the position of the PV module. Relative humidity and temperature of the ambient air were measured with a digital humidity/temperature meter (Model ThermoPro TP 50: accuracy ±1%). Velocity of drying air was measured with a vane type anemometer (Model CFM/CMM Thermo - Anemometer: accuracy ±.01 m/s) at the inlet and outlet of the dryer. The ambient temperature, ambient relative humidity, temperature inside the chamber dryer, relative humidity at the inlet and outlet of the dryer, air flow rate at the inlet, outlet of the dryer, solar radiation, were recorded at 1h intervals during the solar drying of chilli. The moisture content of the chilli samples were measured at the starting and end of each run of the experiment by drying the samples in an air ventilated oven at 105 °C for 24 h as shown in Fig.4 [3]. After completion of drying, the dried chilli was collected, cooled in a shade to the ambient temperature and then sealed it in the plastic bags.

Fig.3. Pictorial view of the Jinda Chilli inside the chamber dryer

Fig.4. Pictorial view of the moisture content experiments using air ventilates the oven dryer

2.3 *Experimental theories*

The focus point of the parabolic collector system can be determined as the equation below [4]:

$$f = \frac{D^2}{16h} \qquad (1)$$

Where:

F focus point of the parabolic collector
D width of the product
H depth of product

Moisture content can be determined on the wet or dry basis as indicated in the equations below [4]:

$$\text{Moisture Content(dry basis)} = \frac{(Wi-Wf)\times 100}{Wf} \qquad (2)$$

$$\text{Moisture Content(wet basis)} = \frac{(Wi-Wf)\times 100}{Wi} \qquad (3)$$

The final mass of water lost can then be determined by:

$$Mw = \frac{(MCwi-MCwf)\times Wi}{1-MCwf} \qquad (4)$$

Where:

MCwi	Initial moisture content on a wet basis before drying (%)
MCwf	Final moisture content on a wet basis after drying (%)
MCd	Moisture content on dry basis (%)
MCw	Moisture content on wet basis (%)
Wi	Initial mass before drying (g)
Wf	Final mass after drying (g)

3 Results and discussion

Fig.5 shows the variations of solar radiation during the typical experimental runs of solar drying of Jinda Chili in the solar chamber dryer.The three experiments were carried out during 13th-15th Febraury, 2018. In each experiment of drying the weather was clear sky day with the maximum solar radiation of 481W/m^2. During the drying of Jinda Chili, solar radiation increased sharply from 9 am to noon but it considerably decreased in the afternoon. There was also a slight random fluctuation in solar radiation. However, the overall cyclic patterns of the solar radiation were similar during these three days.

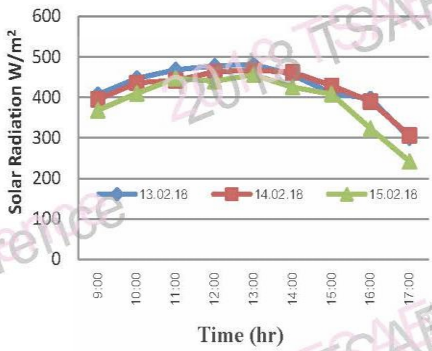

Fig.5. Variations of solar radiation with time of the days for a typical experimental run during drying of Jinda Chilli

At the middle of the dryer, the drying air temperatures inside the chamber on the top of the tray were found to varried in the range of 39 - 63 °C during 9:00 .– 17:00. Temperature air inlet, air outlet and inside the chmaber of solar collector were compared with the ambient temperature and shown in Fig. 6.

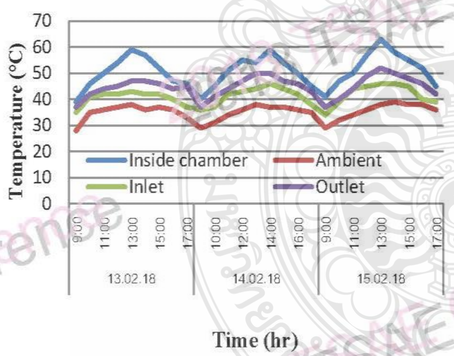

Fig.6. Variations of the ambient temperature and temperature of the inlet air, outlet air and inside the chamber dryer

Fig.7. shows relative humidity inside the chamber dryer for typical experimental runs during solar drying of Jinda Chili. Relative humidity decreases with time inside the dryer during the first half of the day. This is caused by decreasing relative humidity of the ambient air and increased water holding capacity of the drying air due to temperature increase, whereas the opposite is true for the latter half of the day. The relative humidity of the air inside the dryer is always lower than the ambient air and the lowest humidity is in the middle of the day which persists for about 5 hours. Thus, the time of day with the most potential for solar dying is between 9:00 and 16:00.

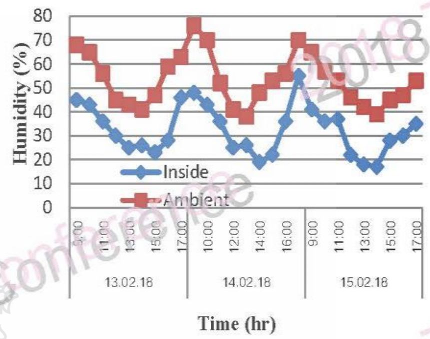

Fig.7. Variations of ambient relative humidity and relative humidity inside the chamber dryer with time of the day for a typical experimental run during drying of Jinda Chili

Fig.8. shows the variations moisture content of Jinda Chili samples in the chamber dryer for typical experimental runs compared to the control samples dried in the open sun drying. The moisture content of Jinda Chili in the solar dryer was reduced from the initial value of 86 % (wb) to a final value of 8 % (wb) within 3 days whereas the moisture content of the open sun drying sample was reduced to 67 % (wb) within the same period.Thus, drying in the solar chamber dryer results in a reduced drying time. About 5 kg of fresh Jinda chillies were dried to about 0.8kg as shown in Fig.9.

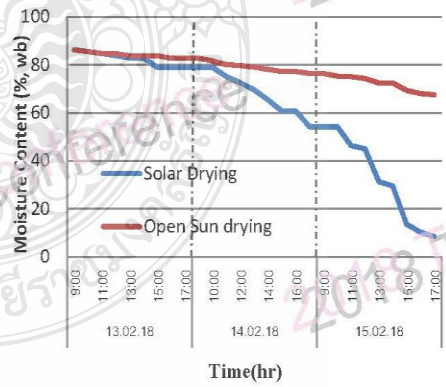

Fig.8. Comparison of the moisture contents of Jinda Chili inside the chamber dryer with the open sun drying method

Fig.9. Remains weight of Jinda Chilli from 5kg to about 0.8kg after 3 days of the drying process


Fig.10. Pictorial view of the Jinda Chili after 3 days of drying process

4 Conclusions

This research is applied parabolic collector technique with heat from solar energy inside the chamber greenhouse for drying agricultural products. Solar energy is based on the principle of the parabola in lighting. The dryer system can produced heat up to 63 °C and a daily average was 51 °C the results presented that; it can reduced the moisture content of Jinda Chilli from 86% wb (wet basic) to 8% wb within 3days, while using open sun drying meet the moisture content of 67% wb (wet basic) within the same period, which is not suitable for market moisture requirement. The Development of Drying System by Using Parabolic Collector Technique for SMEs is presented an effective of used such as natural energy for the drying process. It can improve the quality of products and reduce drying time and costs drying operations for farmers.

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ประกาศมหาวิทยาลัยเกษตรศาสตร์

เรื่อง แต่งตั้งคณะกรรมการจัดประชุมวิชาการสมาคมวิศวกรรมเกษตรแห่งประเทศไทยระดับชาติ ครั้งที่ ๑๙ และระดับนานาชาติ ครั้งที่ ๑๑ ประจำปี ๒๕๖๑

เพื่อให้การดำเนินการโครงการประชุมวิชาการสมาคมวิศวกรรมเกษตรแห่งประเทศไทยระดับชาติ ครั้งที่ ๑๙ และระดับนานาชาติ ครั้งที่ ๑๑ ประจำปี ๒๕๖๑ ในระหว่างวันที่ ๒๖ – ๒๗ เมษายน ๒๕๖๑ ดำเนินการไปด้วยความเรียบร้อย มีประสิทธิภาพและบรรลุผลตามวัตถุประสงค์

มหาวิทยาลัยเกษตรศาสตร์จึงแต่งตั้งคณะกรรมการจัดประชุมวิชาการสมาคมวิศวกรรมเกษตรแห่งประเทศไทยระดับชาติครั้งที่ ๑๙ และระดับนานาชาติ ครั้งที่ ๑๑ ประจำปี ๒๕๖๑ ดังนี้

คณะกรรมการอำนวยการ

๑. รองอธิการบดีวิทยาเขตกำแพงแสน	ที่ปรึกษา
๒. นายกสมาคมวิศวกรรมเกษตรแห่งประเทศไทย	ที่ปรึกษา
๓. ผู้อำนวยการสถาบันวิจัยเกษตรวิศวกรรม	ที่ปรึกษา
๔. หัวหน้าฝ่ายเครื่องจักรกลการเกษตรแห่งชาติ	ที่ปรึกษา
๕. ศาสตราจารย์สมชาติ โสภณรณฤทธิ์	ที่ปรึกษา
๖. ศาสตราจารย์สักกมน เทพหัสดิน ณ อยุธยา	ที่ปรึกษา
๗. รองศาสตราจารย์ปานมนัส ศิริสมบูรณ์	ที่ปรึกษา
๘. รองศาสตราจารย์สมชาย ชวนอุดม	ที่ปรึกษา
๙. คณบดีคณะวิศวกรรมศาสตร์ กำแพงแสน	ประธานกรรมการ
๑๐. รองคณบดีฝ่ายบริหาร คณะวิศวกรรมศาสตร์ กำแพงแสน	รองประธานกรรมการ
๑๑. รองคณบดีฝ่ายวิจัย คณะวิศวกรรมศาสตร์ กำแพงแสน	กรรมการ
๑๒. หัวหน้าภาควิชาวิศวกรรมการอาหาร	กรรมการ
๑๓. หัวหน้าภาควิชาวิศวกรรมชลประทาน	กรรมการ
๑๔. หัวหน้าภาควิชาวิศวกรรมคอมพิวเตอร์	กรรมการ
๑๕. หัวหน้าภาควิชาวิศวกรรมเครื่องกล	กรรมการ
๑๖. หัวหน้าศูนย์ปฏิบัติการวิศวกรรมพลังงานและสิ่งแวดล้อม	กรรมการ
๑๗. หัวหน้าภาควิชาวิศวกรรมเกษตร	กรรมการและเลขานุการ

คณะกรรมการดำเนินงาน

๑. นายชีรวรรธก์ มั่นกิจ	ที่ปรึกษา
๒. ผู้ช่วยศาสตราจารย์ศิวลักษณ์ ปฐวีรัตน์	ที่ปรึกษา
๓. หัวหน้าภาควิชาวิศวกรรมเกษตร	ประธานกรรมการ
๔. รองหัวหน้าภาควิชาวิศวกรรมเกษตร	รองประธานกรรมการ
๕. นางสาวสิรินาฏ น้อยพิทักษ์	กรรมการและเลขานุการ
๖. นางสาวอรุณรัตน์ บุญปองหา	กรรมการและผู้ช่วยเลขานุการ
๗. นางสาวพีรดา แจ้งศรี	กรรมการและผู้ช่วยเลขานุการ

โดยให้คณะกรรมการมีหน้าที่ ดังนี้

๑. ขออนุมัติโครงการประชุมวิชาการสมาคมวิศวกรรมเกษตรแห่งประเทศไทยระดับชาติครั้งที่ ๑๙ และระดับนานาชาติ ครั้งที่ ๑๑ ประจำปี ๒๕๖๑ ให้สำเร็จเรียบร้อยตามวัตถุประสงค์ที่ตั้งไว้
๒. กำหนดสถานที่และระยะเวลาการประชุม
๓. จัดเตรียมเงินจ่ายค่าใช้จ่ายในการจัดงาน/ค่าสถานที่ ค่าอาหาร ค่าตอบแทน
๔. ติดต่อ ดูแล ประสานงานกับคณะกรรมการฝ่ายต่างๆ เพื่อให้การจัดประชุม ดำเนินการตามวัตถุประสงค์
๕. สรุปเอกสารการเบิกเงิน และจัดทำสรุปโครงการ

คณะกรรมการฝ่ายวิชาการ

๑. รองศาสตราจารย์อนุพันธ์ เทอดวงศ์วรกุล	ประธานกรรมการ
๒. รองศาสตราจารย์ประเทือง อุษาบริสุทธิ์	รองประธานกรรมการ
๓. Prof. Dr. Satoru Tsuchikawa	กรรมการ
๔. Asst. Prof. Dr. Tetsuya Inagaki	กรรมการ
๕. Assoc. Prof. Dr. Tofael Ahamed	กรรมการ
๖. Assoc. Prof. Dr. Pomin Li	กรรมการ
๗. Prof. Dr. Masami Ueno	กรรมการ
๘. Assoc. Prof. Dr. Taira Eizo	กรรมการ
๙. Prof. Dr. Jong-Whan Rhim	กรรมการ
๑๐. Dr. Maria Bernardita Perez Gago	กรรมการ
๑๑. Prof. Dr. Nobutaka Ito	กรรมการ
๑๒. รองศาสตราจารย์รังสินี โสธรวิทย์	กรรมการ
๑๓. รองศาสตราจารย์เอกสิทธิ์ โฆสิตสกุลชัย	กรรมการ
๑๔. ผู้ช่วยศาสตราจารย์ประสันต์ ชุ่มใจหาญ	กรรมการ
๑๕. ผู้ช่วยศาสตราจารย์ขวัญตรี แสงประชาธนารักษ์	กรรมการ

๑๖. ผู้ช่วยศาสตราจารย์เทวรัตน์ ตรีอำนรรค	กรรมการ
๑๗. ผู้ช่วยศาสตราจารย์กระวี ตรีอำนรรค	กรรมการ
๑๘. ผู้ช่วยศาสตราจารย์ณัฐพงศ์ รัตนเดช	กรรมการ
๑๙. ผู้ช่วยศาสตราจารย์อมรฤทธิ์ พุทธิพิพัฒน์ขจร	กรรมการ
๒๐. ผู้ช่วยศาสตราจารย์วันรัฐ อับดุลลากาซิม	กรรมการ
๒๑. ผู้ช่วยศาสตราจารย์วัชรพล ชยประเสริฐ	กรรมการ
๒๒. ผู้ช่วยศาสตราจารย์ปนัดดา กสิกิจวิวัฒน์	กรรมการ
๒๓. ผู้ช่วยศาสตราจารย์ปรีดา ปรากฏมาก	กรรมการ
๒๔. นายศิริศักดิ์ เชิดเกียรติพล	กรรมการ
๒๕. นายอนุชิต ฉ่ำสิงห์	กรรมการ
๒๖. นายณัฐวุฒิ เนียมสอน	กรรมการ
๒๗. นางสาวนารถระพี นาคะวัจนะ	กรรมการ
๒๘. นายอาทิตย์ พวงสมบัติ	กรรมการและเลขานุการ
๒๙. นางสาวแก้วกานต์ พวงสมบัติ	กรรมการและผู้ช่วยเลขานุการ

โดยให้คณะกรรมการมีหน้าที่ ดังนี้

๑. กำหนดหัวข้อและเนื้อหาการประชุม
๒. กำหนดรูปแบบบทคัดย่อ และรูปแบบบทความฉบับสมบูรณ์
๓. กำหนดกำหนดการประชุม ประสานงานวิทยากรพิเศษ และดำเนินการในขั้นตอนต่างๆ
๔. ประสานงานเชิญผู้ทรงคุณวุฒิและร่วมเป็นผู้ทรงคุณวุฒิพิจารณาผลงานวิจัย
๕. จัดทำประวัติผู้ทรงคุณวุฒิ และประสานงานกับฝ่ายพิธีการ
๖. พิจารณากลั่นกรองผลงานวิจัย จำแนกประเภทการนำเสนอ พร้อมจัดลำดับการนำเสนอ
๗. ทำหน้าที่กองบรรณาธิการ เพื่อจัดทำรายงานสืบเนื่องจากการประชุม (Proceedings)
๘. พิจารณาตัดสินผลงานวิจัยดีเด่น การนำเสนอดีเด่น

คณะกรรมการฝ่ายพิธีการ ปฏิคม และประชาสัมพันธ์

๑. ผู้ช่วยศาสตราจารย์วันรัฐ อับดุลลากาซิม	ประธานกรรมการ
๒. รองศาสตราจารย์ประเทือง อุษาบริสุทธิ์	รองประธานกรรมการ
๓. นายศิริศักดิ์ เชิดเกียรติพล	กรรมการ
๔. นางสาวแก้วกานต์ พวงสมบัติ	กรรมการ
๕. นายอาทิตย์ พวงสมบัติ	กรรมการ
๖. นายภวินท์ ธัญภัทรานนท์	กรรมการ
๗. นายวชิรศิริ ทวีเดช	กรรมการ
๘. นายสุขชัย ยั่งยืน	กรรมการ
๙. นางสาวปฐมาภรณ์ อุ่นเรือน	กรรมการและเลขานุการ

๑๐. นางสาวอรุณรัตน์ บุญปองหา กรรมการและผู้ช่วยเลขานุการ

๑๑. นางสาวพีรดา แจ้งศรี กรรมการและผู้ช่วยเลขานุการ

โดยให้คณะกรรมการมีหน้าที่ ดังนี้

๑. จัดทำเอกสารประชาสัมพันธ์งานประชุมวิชาการ
๒. ประชาสัมพันธ์การจัดประชุมโดยใช้สื่อรูปแบบต่างๆ
๓. ติดต่อเรียนเชิญ ประธานในการเปิดงาน
๔. ดำเนินการด้านพิธีการในการเปิด-ปิด จัดหาพิธีกร ผู้ดำเนินรายการตลอดงานประชุม เชิญและต้อนรับ ประธาน วิทยากร และผู้เข้าร่วมงานประชุม
๕. ร่างคำกล่าวเปิดงาน และปิดงาน
๖. จัดเตรียมคอมพิวเตอร์ เครื่องฉาย และอุปกรณ์ต่างๆ
๗. อำนวยความสะดวกในการลงข้อมูลเพื่อเตรียมนำเสนอผลงาน
๘. ดูแล ต้อนรับ ประธานในการเปิดงาน
๙. จัดเตรียมเจ้าหน้าที่ รวบรวมคะแนน การบรรยาย สรุปคะแนน จัดทำประกาศนียบัตรรางวัล
๑๐. บันทึกภาพกิจกรรมต่างๆ ทั้งภาพนิ่ง และภาพเคลื่อนไหว
๑๑. จัดทำแบบสอบถาม

คณะกรรมการฝ่ายลงทะเบียน และการเงิน

๑. นางสาวสิรินาฏ น้อยพิทักษ์ ประธานกรรมการ
๒. นายภวินท์ ธัญภัทรานนท์ กรรมการ
๓. นางส้มแก้ว อยู่สำราญ กรรมการ
๔. นางสาวอรุณรัตน์ บุญปองหา กรรมการและเลขานุการ
๕. นางสาวพีรดา แจ้งศรี กรรมการและผู้ช่วยเลขานุการ

โดยให้คณะกรรมการมีหน้าที่ ดังนี้

๑. จัดเตรียมเอกสารแจกผู้เข้าร่วมประชุม (กระเป๋า หนังสือ ของที่ระลึก อื่นๆ)
๒. จัดเตรียมประกาศนียบัตรรางวัลการประกวดบทความ โดยประสานงานกับฝ่ายวิชาการและฝ่ายพิธีการ
๓. จัดเตรียมใบเสร็จรับเงินสำหรับผู้ลงทะเบียน
๔. จัดทำป้ายชื่อ ป้ายห้อง สถานที่ต่างๆ ในงาน
๕. เตรียมเอกสารด้านการเงินต่างๆ
๖. จัดเก็บและทำบัญชีการเงินของผู้เข้าร่วมสัมมนาและภาคเอกชน
๗. ดำเนินการด้านการเงิน งบประมาณค่าใช้จ่าย โดยประสานงานกับคณะกรรมการทุกฝ่าย

คณะกรรมการฝ่ายสถานที่ นิทรรศการ และพาหนะ

๑. นางสาวพิมพ์พรรณ ปรีองาม	ประธานกรรมการ
๒. นายภวินท์ ธัญภัทรานนท์	กรรมการ
๓. นางนงลักษณ์ เล็กรุ่งเรืองกิจ	กรรมการ
๔. นางสาวง่ายงาม ประจวบวัน	กรรมการ
๕. นายศุภชัย กุลมุติวัต	กรรมการ
๖. นางสาวอรุณรัตน์ บุญปองหา	กรรมการและเลขานุการ
๗. นางสาวพีรดา แจ้งศรี	กรรมการและผู้ช่วยเลขานุการ

โดยให้คณะกรรมการมีหน้าที่ ดังนี้

๑. กำหนดสถานที่/ดูสถานที่/สืบราคาสถานที่จัดงาน
๒. จัดเตรียมห้องประชุม/สัมมนา พร้อมอุปกรณ์
๓. จัดหาอุปกรณ์การจัดนิทรรศการ และประสานงานการติดโปสเตอร์ผลงานจากฝ่ายวิชาการ
๔. จัดหารถเพื่อพาคณะทำงานไปสถานที่จัดงาน
๕. จัดเตรียมที่พักสำหรับคณะทำงาน/ผู้ทรงคุณวุฒิ
๖. จัดเตรียมอาหาร สำหรับผู้เข้าร่วมงาน/คณะทำงาน
๗. อำนวยความสะดวกในเรื่องการเดินทาง ไปยังสถานที่จัดงาน
๘. ดูแลความเรียบร้อยด้านสถานที่ให้พร้อมในการประชุมวิชาการ
๙. ดูแลเรื่องอาหารผู้เข้าร่วมประชุม/คณะทำงาน
๑๐. สรุปค่าใช้จ่ายจากสถานที่จัดงาน แล้วประสานค่าใช้จ่ายกับฝ่ายการเงิน

ทั้งนี้ตั้งแต่บัดนี้เป็นต้นไป จนกว่าจะเสร็จสิ้นการดำเนินงาน

ประกาศ ณ วันที่ ๒๗ พฤศจิกายน พ.ศ. ๒๕๖๐

(นายจงรัก วัชรินทร์รัตน์)
รักษาการแทนอธิการบดีมหาวิทยาลัยเกษตรศาสตร์

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KASETSART
UNIVERSITY

CERTIFICATE OF PRESENTATION

Faculty of Engineering at Kamphaeng Saen, Kasetsart University, and
Thai Society of Agricultural Engineering hereby confirm that

Phatpisey Lieng*, Kiattisak Sangpradit

gave the oral presentation entitled

The Development of Drying System by Using Parabolic Collector Technique for SMEs

at 11th TSAE International Conference: TSAE 2018
26 – 27 April 2018, Chulabhorn International Convention Center
(Wora Wana Hua Hin Hotel & Convention) Hua Hin, Prachuap Khiri Khan, THAILAND

(Dares Kittiyopas)
President
Thai Society of Agricultural Engineering

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Dean
Faculty of Engineering at Kamphaeng Saen
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Experiences Work	Senior official technician in Ministry of Agriculture, Forestry and Fishery, Cambodia (2012-Present)
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