UNIVERSITI MALAYSIA PAHANG

BORANG PENGESAHAN STATUS TESIS ◆

JUDUL: **DEVELOPMENT OF SOLAR DRYER SYSTEM FOR FOOD DRYING PUPOSES**

SESI PENGAJIAN: 2011/2012

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DEVELOPMENT OF SOLAR DRYER SYSTEM FOR FOOD DRYING PURPOSES

NABILAH BINTI HARMAIN

Report submitted in partial fulfillment of the requirements
for the award of Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

JUNE 2012

UNIVERSITI MALAYSIA PAHANG

FACULTY OF MECHANICAL ENGINEERING

I certify that the project entitled Development of Solar Dryer System for Food Drying Purposes is written by Nabilah Binti Harmain.I have examined the final copy of this project and in my opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. I herewith recommend that it be accepted in partial fulfilment of the requirements for the degree of Bachelor of Mechanical Engineering.

MDM. NORHAIDA AB RAZAK

Examiner Signature

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project and in my opinion, this project is adequate in terms of scope and quality of the award of the degree of Bachelor of Mechanical Engineering.

Signature

Name of Supervisor: MR. AMIR BIN ABDUL RAZAK

Position: LECTURER OF UNIVERSITI MALAYSIA PAHANG

Date: 22nd JUNE 2012

STUDENT'S DECLARATION

I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature

Name: NABILAH BINTI HARMAIN

ID Number: MA 09013

Date: 22th JUNE 2012

Dedicated to my parents, lecturers and friends

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ABSTRACT

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

ABSTRAK

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

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

LIST OF ABBREVIATIONS

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

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF THE STUDY

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

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

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

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

1.2 PROBLEM STATEMENTS

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

1.3 PROJECT OBJECTIVES

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

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

1.4 SCOPES OF THE PROJECT

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

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

1.5 PROJECT PLANNING

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

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

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

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

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

2.2 TYPES OF DRYING METHOD

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

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

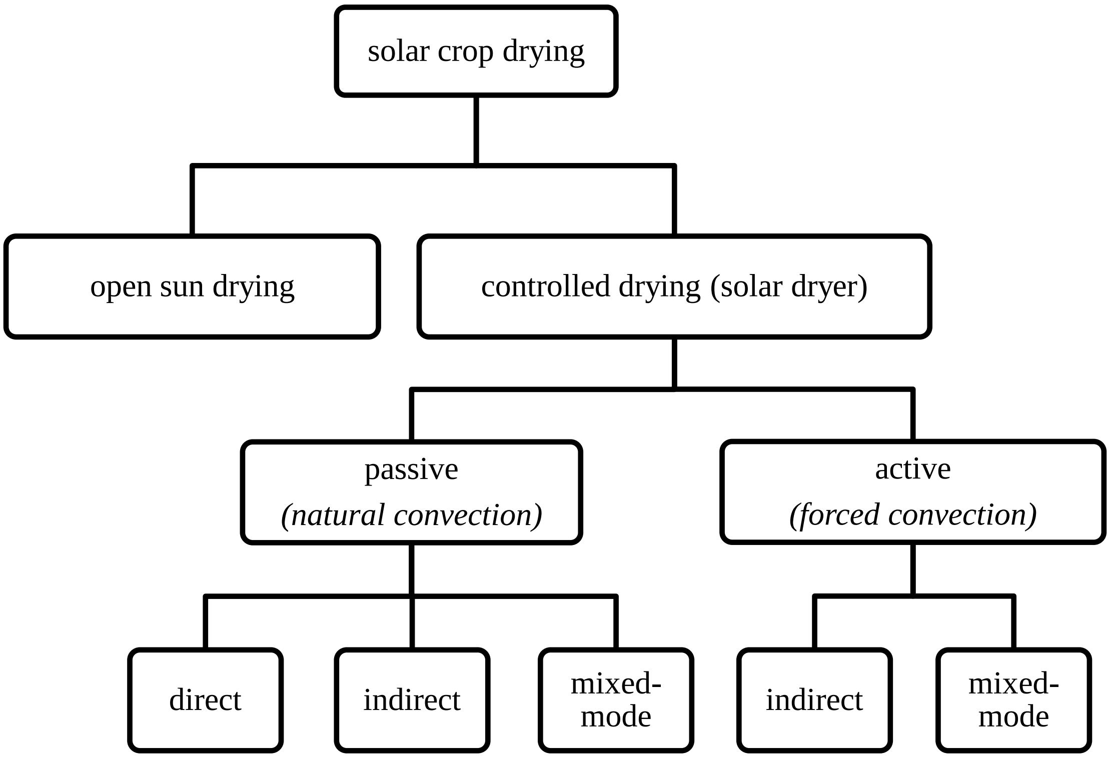
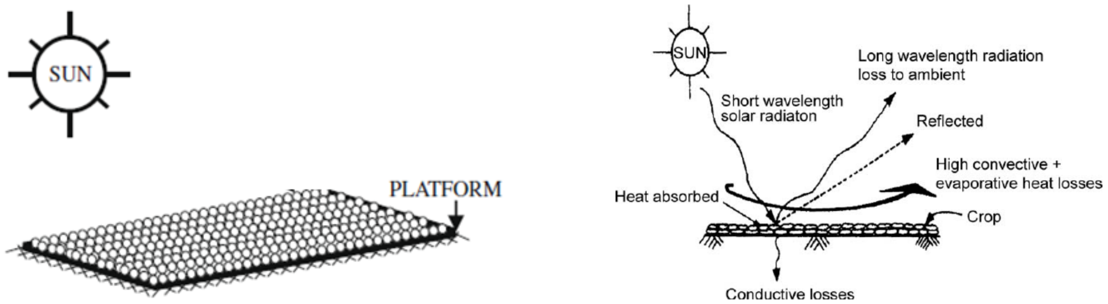


Figure 2.1: Classification of crop drying using solar energy

Source: Chen et al. (2009)

2.2.1 Open Sun Drying

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



(a) (b)

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

Source: Chen et al. (2009)

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

2.2.2 Direct Solar Dryring in Passive Mode

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

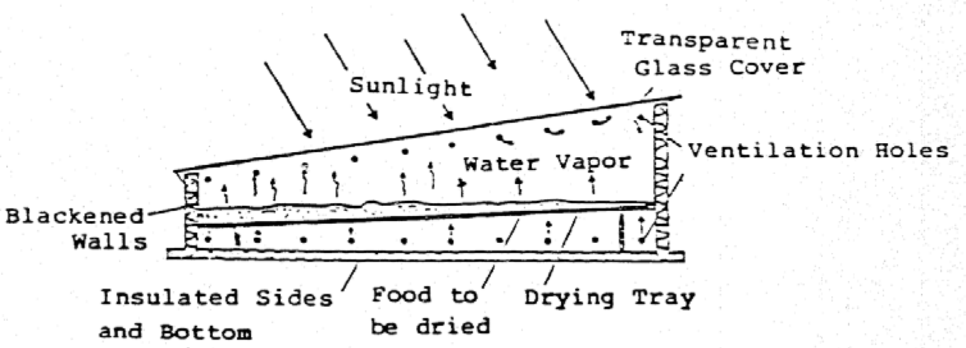


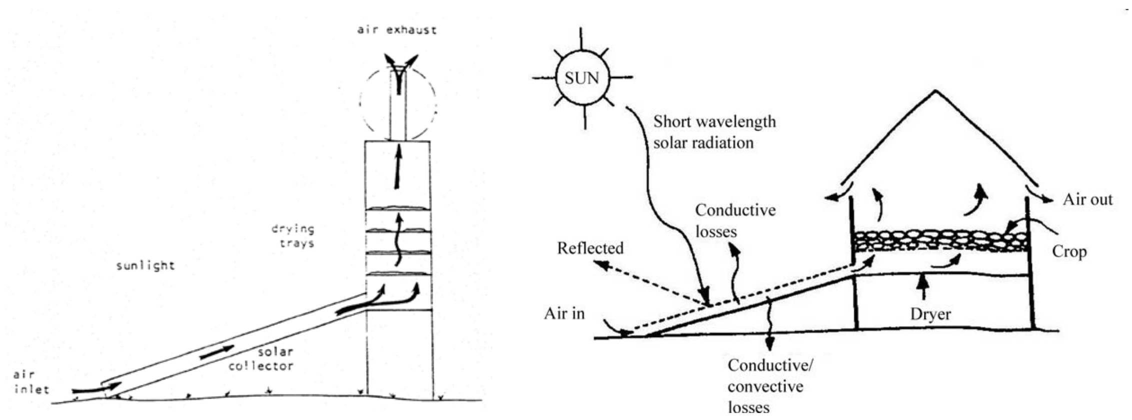
Figure 2.3: Cabinet dryer

Source: Gregoire (2009)

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

2.2.3 Indirect solar drying in Passive mode

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



(a) (b)

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

Source: Chen et.al (2009)

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

Figure 2.5: Passive Solar Dryer

Source: Scanlin (1997)

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

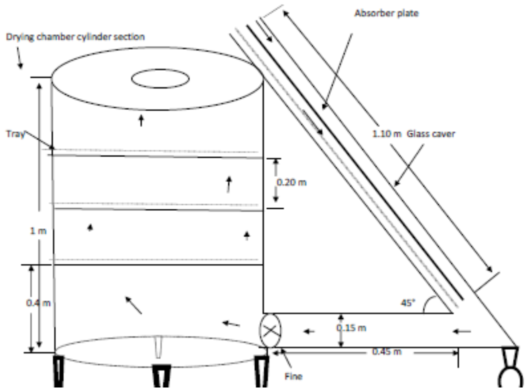


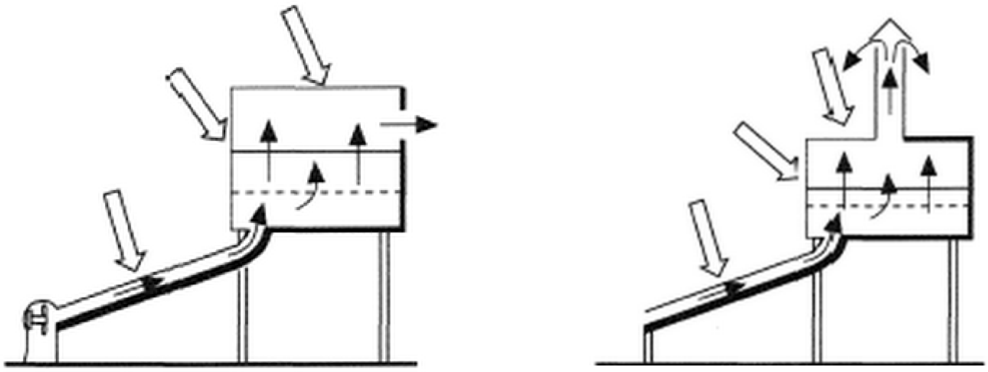
Figure 2.6: Sectional view of cylindrical section solar drying system

Source: Gatea (2010)

2.2.4 Mixed-mode Solar drying

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

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



(a) **(b)**

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

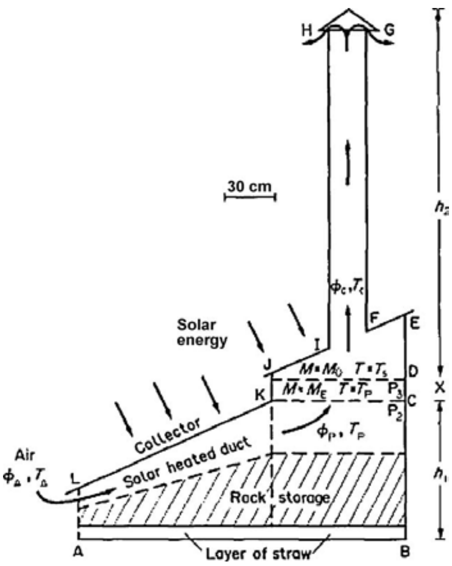
Source: Norton (1992)

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

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

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

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



(a) (b)

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

Source: Khoshmanesh (2006)

2.2.5 Indirect solar drying in active mode

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

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

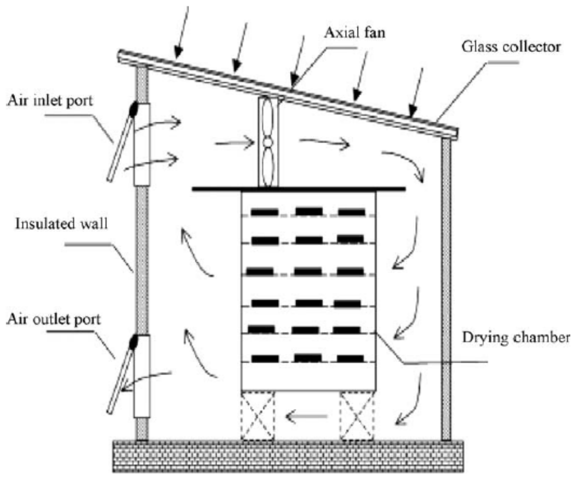


Figure 2.9: Active solar convective dryer

Source: Chen (2009)

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

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

Figure 2.10: Photograph of solar drying system

Source: Fudholi et al. (2011)

Later Fudholi et al. (2011) developed experimental study of marine product for seaweeds and techno – economic study using a same drying system . The experimental result shown that 40kg seaweed can be dried down to 4.01kg, 10% of water contents without auxiliary heater in 15 hours (2 days drying). During the two days, the daily average of air temperature at the drying chamber are 57 and 64^{o}C and for solar radiations 453 and 562 W/m2 for mass flow rate 0.0536 kg/s. The efficiency of collector varies from 26 to 80%. The average efficiency of the collector is 35%.

Mohanraj and Chandrasekar (2008) was designed, fabricated and tested a forced convection solar dryer for drying the copra. This study was tested under Indian climatic conditions. This solar dryer was consisted of (1m x 2m) flat plate air heater, (1m x 1m x 1.5m) sizes of drying chamber that made from 2mm thick mild steel sheet and 1HP centrifugal fan. 2mm thick copper absorber plated that painted with black color was used to absorb the incident solar radiation in the solar air heater. Sand was used as a thermal energy storage in between the 100mm gap the absorber plate and insulator inside of solar air heater. From the result, about 24 % average thermal efficiency of the solar air heater has been estimated.

The system pickup efficiency, specific moisture extraction rate, dimensionless mass loss, mass shrinkage ratio and drying rate for green peas drying are was discussed by Shanmugam and Natarajan (2005). The experiment was conducted to investigate the performance of indirect forced convection and desiccant integrated solar dryer under the hot and humid climatic conditions at Chennai, India. The design system was consists of a flat plate solar air collector, drying chamber and desiccant unit. Desiccant integrated solar dryer show the best result in producing the quality dried product and ability to continue the drying process in the off-sunshine hours.

2.3 THEORETICAL ANALYSIS OF DRYING

2.3.1 Collector Efficiency

The collector efficiency was calculated using the heat gained by air flowing through the collector with respect to the actual solar energy received by the collector. Drying rate as well as thermal efficiency of solar collector (η) can calculated from the useful heat (q_u) divided by the total solar radiation (q_r) in the following form (Montero, 2010)

$$\eta_c = q_u / q_r \qquad (1)$$

The useful heat passed to the air and the total solar radiation are defined as;

$$q_u = m_a\, c_p\, (T_0 - T_1) \qquad (2)$$

and

$$q_r = I_c\, A_c \qquad (3)$$

Thus, the collector efficiency of the dryer is;

$$\eta = \frac{m_a\, C_p\, (T_0 - T_1)}{I\, A_c} \qquad (4)$$

2.3.2 Dryer Efficiency

The dryer efficiency (ηd) is the ratio of the energy required to evaporate the moisture of the commodity to the heat supplied to the dryer with the time (Ezekoya, 2006). Therefore,

$$\eta_d = ML / I_c\, A_c\, t \qquad (5)$$

2.3.3 Pick – up efficiency

Pick –up efficiency can be used to measure of how efficiently the capacity of the heated air to absorb moisture is utilized which is by evaluating the actual evaporation of moisture from the food inside the drying chamber (Montero, 2010; Ezekoye, 2006).

$$\eta_p = [(h_0 - h_i) / (h_{as} - h_i)] \quad (6)$$

Or

$$\eta_p = [(M_0 - M_t) / m_a A_t (h_{as} - h_i)]$$

2.3.4 Drying rate

A very important quantity is the drying rate, determined by the temperature and moisture content of the product as well as the temperature, relative humidity and velocity of the drying air. The drying rate was determined from change in mass with time. (Sengar, 2009).

$$\mathbf{D.R} = \frac{\Delta \mathbf{W}}{\Delta T} \quad (7)$$

2.3.5 Moisture content

During drying, the moisture content of the product is decreased and water loss during drying is usually accompanied by shrinkage. The quantity of moisture present in a material can be expressed either on the wet basis or dry basis, where is content in wet basis (Wb) is the weight of moisture present in a product per unit weight of the undried material:

$$\mathbf{M.C\ (Wb)} = \frac{\mathbf{Wo-Wd}}{Wo} \quad (8)$$

while the moisture content on the dry basis (Wd) is the weight of moisture present in the product per unit weight of dry matter in the product:

$$\mathbf{M.C\ (Wd)} = \frac{\mathbf{Wo-Wd}}{\boldsymbol{Wd}} \tag{9}$$

and the percentage of moisture content in wet and dry basis can be represented as:

$$\textbf{Percentage}\quad \boldsymbol{M.C\ (Wb) = Wb\ \times 100} \tag{10}$$

$$\textbf{Percentage}\quad \boldsymbol{M.C\ (Wd) = Wd\ \times 100} \tag{11}$$

The most convenient way to express moisture for mathematical calculations is on dry basis but for agricultural products moisture content normally is expressed in wet basis.

2.4 SOLAR RADIATION

Total solar irradiance is about 1373 W/m^2 or we can called that as a solar radiation reaching the earth's atmosphere. This is known as the Solar constant that represent the rate at which solar energy is incident on a surface normal to the sun's rays at the outer edge of the atmosphere when the earth is at its mean distance from the sun (Cengal, 2007). At the clear day at noon, solar radiation will be approximately at 1000 W/m^2.

Table 2.1: Monthly average daily global solar radiation and solar hours for Kuala Lumpur, Malaysia

Source: Ahmad (2004)

Month	**Solar radiation (Wh/m^2)**	**Solar Hours**
January	10146	13.0
Febuary	8821	13.0
Mac	6690	12.0
April	6287	11.0
May	6072	10.5
June	4353	10.0
July	5499	10.8
August	6231	11.0
September	7233	11.5
October	8240	12.3
November	8487	13.9
December	8242	13.7
Average	7191.8	11.9

Ahmad (2004) has investigated on the impacts of solar radiation towards high-rise building form, orientation and building envelope. It shows that from monthly average daily solar radiation, Malaysia have an average of 605 W/m^2 which is October to November has high solar radiation compared with May to June. Table 2.1 shows the Monthly average daily global solar radiation and solar hours for Kuala Lumpur, Malaysia. From the result of study by Muzathik (2010) at April 5, 2004 Terengganu has daily maximum solar radiation of 1139 W/m^2.

The hourly average of solar irradiance for Subang during 1993 to 2002 periods was compared in table 1. Clearly, the highest hourly average solar radiance among 10 years is 1998 with 0.69 $kW/m^2/day$ was recorded and the lowest is 0.02 $kW/m^2/day^1$ (Leon and Kumar, 2007).

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter presents a description of the research methodology employed in this study. The methodology can be described as a framework where it contains the elements of the work based on the objectives and a scope of the project were to make sure the project can run successfully and get expected result. The purpose of this study focuses mainly on parameters that affects the temperature in the solar dryer which would result in reducing the food's moisture contents and produce the good quality product. The purpose of the study would be to compare the performance analysis of different types of parameters indirect solar dryer that consist of temperature, air velocity and weight loss. To develop a functional solar dryer system for food, the product quality produced by these types of indirect solar dryer was compared with conventional drying method.

3.2 FLOWCHART

Figure 3.1 shown the process of flowchart. It consists of seven steps which are problem statements, literature study, introduction to the literature study, design and fabricate the model, analysis and conclusion.

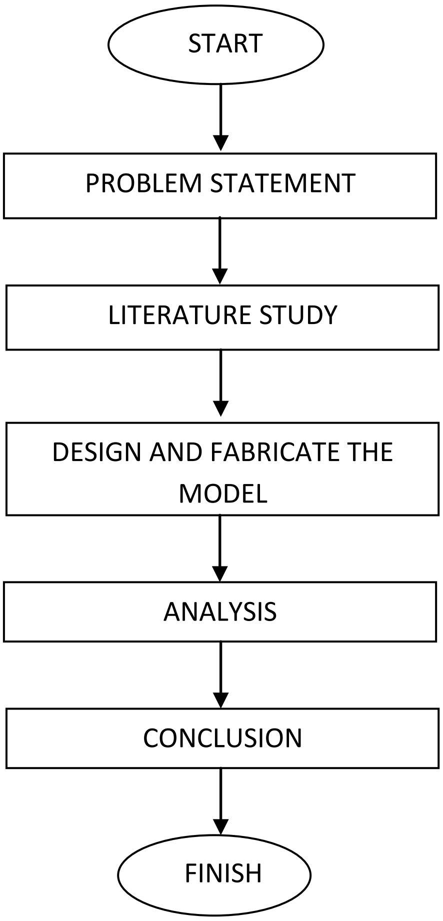


Figure 3.1: Process flowchart

3.2.1 EXPLANATION ON THE FLOW CHART

i. Problem Statement

To understand the problem, it is required to research the working principles for each type of solar dryer and list down the advantages and disadvantages of product dried. As for the result, the best solution is to develop the indirect solar dryer (passive mode) that is suitable for small drying industry.

ii. **Literature Study**

Literature review was done on the comparison of drying working principles between the active and passive solar dryer. It also consists of how to determine the collector efficiency, moisture contents and drying rate.

iii. **Design and fabricate the model**

The design and fabrication of solar dryer system was done for passive and active mode. It includes the material that is suitable to absorb the heat for a collector and insulator to reduce the heat losses. This design is more focused on collector chamber because it is the important part to supply heat for dryer chamber. The selected design has been proven to be able to decrease the moisture ratio of the product effectively.

iv. **Analysis**

The examination of data experiment. The analysis will consist of collector efficiency, moisture ratio, drying rate and comparison between the conventional drying system.

v. **Conclusion**

The summary of the project and recommendation for future project.

3.3 DESIGN AND CONSTRUCTION OF THE SYSTEM

The basic operation of this solar dryer is started from the collector chamber where is the energy caught from the solar radiation will heating of entering air into the drying chamber. It is become a natural convection process and fundamentally to reduce relative humidity. This heated air will circulate from the collector chamber to the drying chamber and causing the moisture reduction of products. Finally the heated air will leave through the chimney with low temperature and higher relative humidity. The design of the solar dryer prototype was consist of drying chamber and collector chamber. A view of the dryer is given in Figure 3.2.

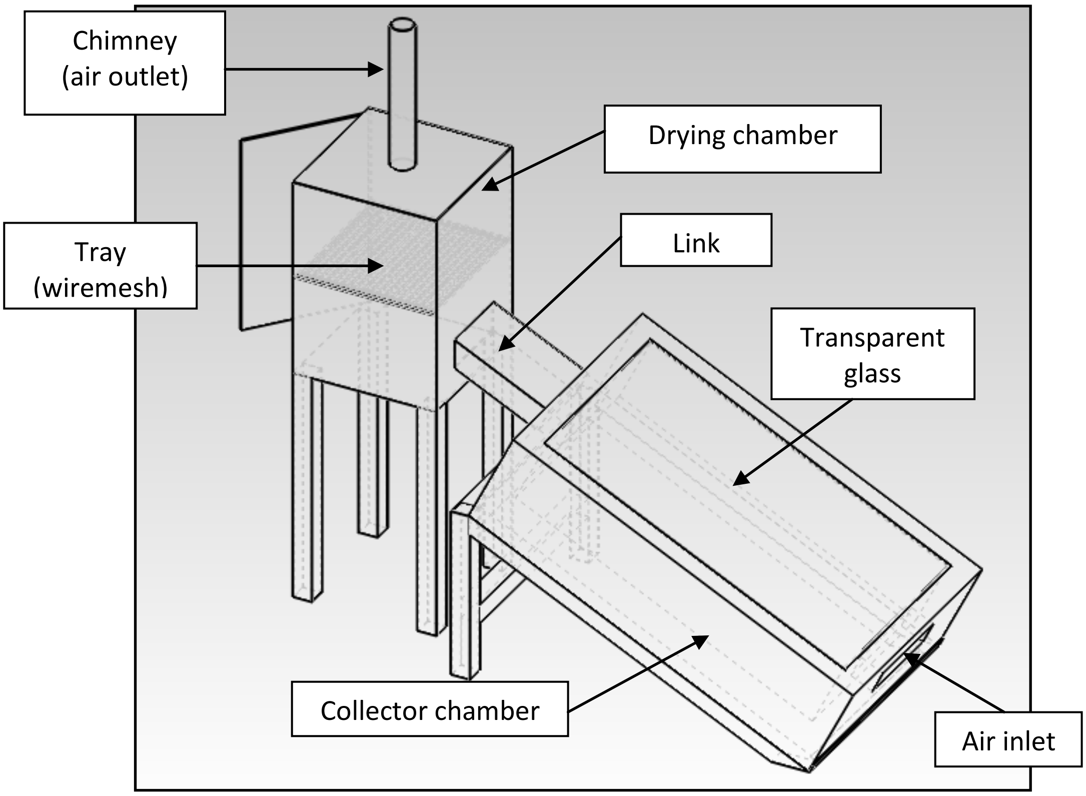


Figure 3.2: View of solar dryer prototype

Aluminum steel sheet is used for the construction of the drying chamber body and chimney. Rectangular wood is used for making the dryer chamber frame and rectangular hollow for dryer and collector chamber stands. For this prototype, only one tray that was made from wire mesh were placed in the drying chamber. The outer of drying chamber with dimension of 30 cm x 30 cm x 41 cm is painted with black color in order to increase absorptivity. Trays are inserted and removed through the door provided at the back of the drying chamber. By increasing air circulation rates, chimney is placed on the top of the drying chamber. A 30 cm height of the chimney was designed to allow the air flow caused by chimney effect which creates pressure difference to the system. Air flow is desired to remove water around the product.

For collector chamber, this part has an air inlet vent, transparent glass and black painted rock as an additional source to absorb solar radiation and to store thermal energy (Azad, 2008). Polyethylene foam as an insulator in reducing heat losses and woods for making the collector chamber frame. The cross section of the collector used in this study is shown in Figure 3.3.

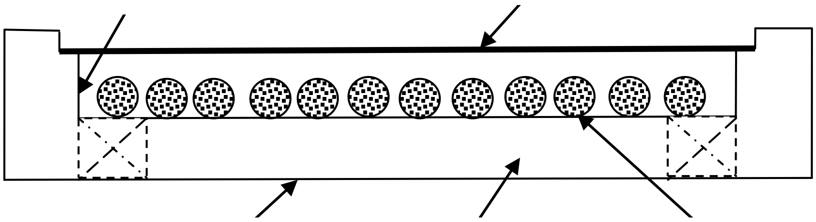


Figure 3.3: Cross section of solar dryer collector

The collector chamber has external sizes of 79 cm x 52 cm x 21 cm and internal sizes of 69 cm x 42 cm x 15 cm for placed the gravel stones. The 69 cm x 42 cm transparent glass will placed at the top of collector chamber. Besides that, the insulator of polyethylene foam will be placed between the gap of 5 cm at the collector sides and bottoms. Polyethylene foam will reduce the heat losses across the wall during the heat collecting process from solar radiation. The surface inside of the collector chamber was placed with aluminum sheet that become a reflector that would reflect the solar radiation and increased the temperature inside the dryer chamber. The whole body of the collector chamber will be painted with black color and be placed in an inclined position. Lastly, the link that made from aluminum sheet will be connected between drying chamber and collector chamber.

3.4 DESIGN SPECIFICATIONS

The design of the functional solar dryer must be compliance with several aspects. The design consideration must be done carefully so the design can be fabricated and the parts are all functioning. The aspects that must be considered in designing the solar dryer are included:

i. Ergonomics

- Increase the production time because foods can be dried in a shorter period of time and easy to handle.
- Low cost saving and save the energy because used freely solar energy during the drying process.

ii. Food quality

- Produce the better quality products and can stored longer.
- Safer and hygienic which are less to be contaminated by pests, animals and dust.

3.5 MATERIAL PROPERTIES

i. Aluminum sheet

Aluminum is a good reflector material that has 0.904 J/g.° c specific heat capacity which is able to absorb heat from the solar energy. It is also very light metal with a specific weight of 2.7g/cm3 and corrosion resistant from rain and hot air.

ii. Polyethylene foam

Polyethylene foam has a structure of small regular cells that makes it good for heat insulator and sound insulator capacity and excellent in shock absorbing capability. Polyethylene foam also can be used for cushion packaging in order to protect the products from damage. It also can be a material insulation for maximum temperature rating around be 60°C or 80°C.

iii. Rocks

Rocks were placed in the collector chamber in purpose to absorb solar radiation and as a storage medium. It also becomes an additional heating sources in this system.

iv. Transparent glass

Transparent glass was placed on the collector chamber and used a main material to absorb solar radiation for this system.

3.6 INSTRUMENTS

i. Digital Meter

It is used to measure the temperature in the drying chamber and collector chamber. Six of digital meter was used with the thermocouple.

ii. Digital Balance

It is used to determine the weight loss of the dried product or to find the initial and final moisture contents of the material to be dried.

iii. Anemometer

The anemometer is a wind speed indicator which can be used to measure the accurate visual reading of wind speed. It measures flow velocities in the interval 0 to 250 m/s .

iv. Radiometer

Radiometer is used to measure heat and gives the instantaneous solar irradiance (W/m^2).

3.7 EXPERIMENTAL SET-UP

Drying experiments were conducted at the HVAC laboratory for drying the kiwifruit slices in purposes to study the dryer performance under differences modes: (a) natural convection without thermal energy storage, (b) indirect forced convection with thermal energy storage for velocity of 0.8 m/s and 2.4 m/s , (c) natural convection with thermal energy storage, (d) indirect forced convection without thermal energy storage for velocity of 0.8 m/s and 2.4 m/s and (e) direct sun drying was shown in Figure 3.4. The experiments were carried out at room temperature of 29 ^{o}C and 1180 W/m^{2} incident radiations from four halogen floodlight 1000 Watt.

Figure 3.4: Experimental set-up

Figure 3.5 shows the experimental set-up for indirect forced convection consists of 2.4 m/s drying air velocity by using a DC 12 Volt fan and 0.8 m/s drying air velocity by using a two DC 5 Volt fan for circulating the drying air inside the drying chamber and gravel stones as a thermal energy storage.

Figure 3.5: DC 12 Volt fan

Digital meter with six thermocouples is used to measure the temperatures at different locations in the solar dryer system. The temperature for each point in the solar dryer was measured on an interval of 10 minutes and after 20 minutes the collector is heated. The location of thermocouples position was shown in Figure 3.6. The weight losses of the drying samples were measured using an electronic balance with minimum weight of 5 g.

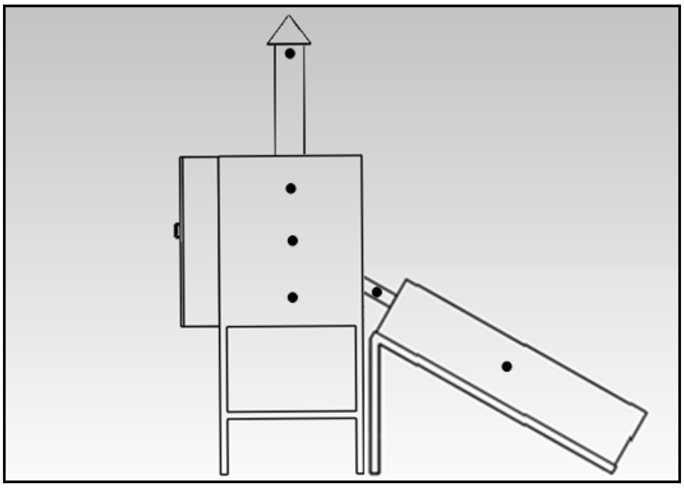


Figure 3.6: Sensors positioning

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

Six experiment tests were conducted to analyze the performance of solar dryer using two types of solar dryer method which is Indirect Natural Convection and Indirect Force Convection. Each type of solar dryer was compared using different air velocity with thermal energy storage and without thermal energy storage. The quality samples for each experiment was compared with the samples that produced by direct sun drying. The experiments were carried out at room temperature of 29 ^{o}C , 2.4 m/s drying air velocity by using a DC 12 V fan and 0.8 m/s drying air velocity by using a two DC 5 V fans and 1180 W/m^2 incident radiations from four halogen spotlights 1000 W. The test raw data from the experiment is tabulated in the Table 4.2, 4.3, 4.4, 4.5, 4.6 and 4.7.

4.2 RESULT AND DISCUSSION

Table 4.1 shows the initial and the final weight of samples during the experiments. The experiment was started with an initial moisture content ranged from 76.2 g to 82.2 g kiwifruit and three hours of drying with solar sources is switched on until a final moisture content of the samples ranged from 16.2 g to 43.9 g was reached.

4.2.1 QUALITY OF DRIED PRODUCT

Table 4.1 The result of weight samples

Method of drying	Initial weight (g)	Final weight (g)	Weight loss (g)
Indirect natural convection with thermal energy storage	78.8	16.9	61.9
Indirect natural convection without thermal energy storage	76.2	42.2	34
Indirect forced convection with thermal energy storage at (V=2.4 m/s)	82.2	22.4	59.8
Indirect forced convection without thermal energy storage at (V=2.4m/s)	77.9	43.9	34
Indirect Forced convection with thermal energy storage at (V=0.8m/s)	80.1	19.3	60.8
Indirect forced convection without thermal energy storage at (V=0.8m/s)	76.7	34.1	42.6
Direct sun drying	78.7	16.2	62.5

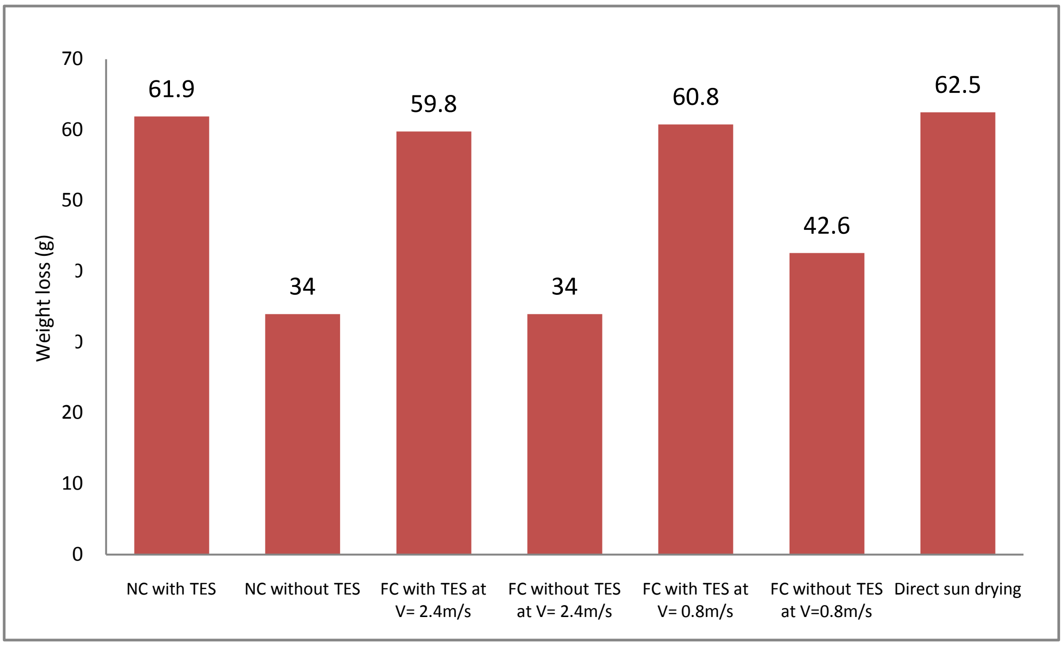


Figure 4.1: Comparison of the weight loss for each types drying experiments

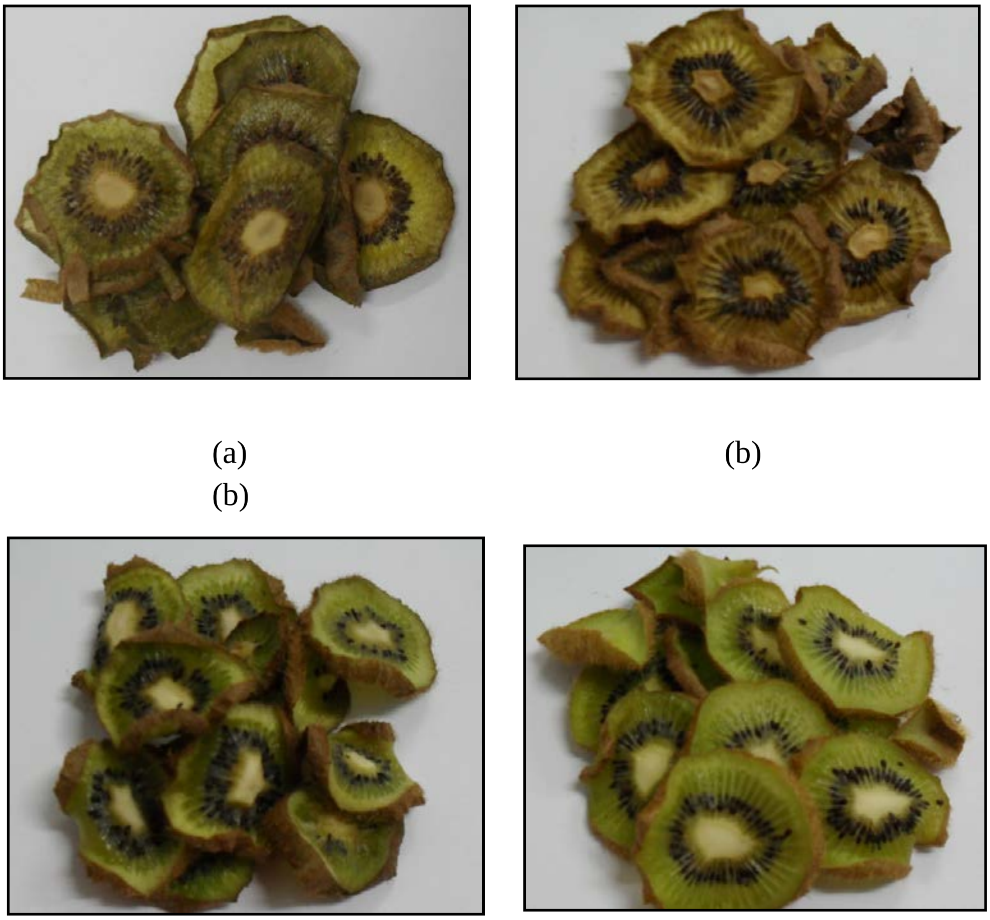
(a)

(b)

(c)

Figure 4.2: Product quality for (a) Indirect natural convection with thermal energy storage; (b) Indirect natural convection without thermal energy storage; (c) Direct sun drying

However, direct sun drying experiments was causing a texture of dried samples shrink, hard and becomes darker due to over drying. Quality of samples product was presented in Figure 4.2 and 4.3. By comparing the seven samples, indirect forced convection with thermal energy storage with a velocity of 0.8 m/s and natural convection with thermal energy storage shows the light green color of dried products compared with samples for other dryers. Diamante (2010) also reported that higher drying temperature lighten the color of green kiwifruit while resulted darkening for gold kiwifruit. Due to not properly dried and low temperature received inside the dryer chamber, the dried samples product that using indirect natural convection without thermal energy storage has become rotten and moldy after two days. The surface of product samples that dried with high air velocity at 2.4 m/s and without thermal energy storage still look moist and still with the original green kiwifruit color. Diamante (2010) found that at 80 ^{o}C for dried green kiwifruit resulted less total color change.



(a) (b)

(b)

(c) (d)

Figure 4.3: Samples quality using the Indirect Forced Convection method; (a) drying with thermal energy storage at V=2. 4 m/s; (b) drying with thermal energy storage at V=0.8m/s; (c) drying without thermal energy storage at V=0. 8 m/s and (d) drying without thermal energy storage at V=2. 4 m/s.

4.2.2 DRYING AIR TEMPERATURE

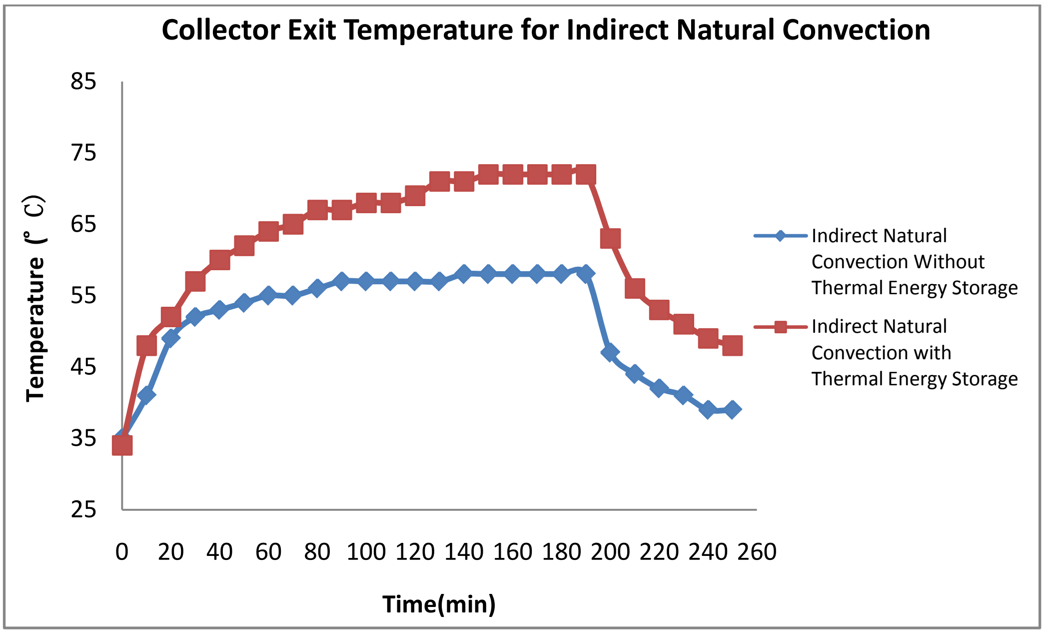


Figure 4.4: Collector exit temperature for indirect natural convection

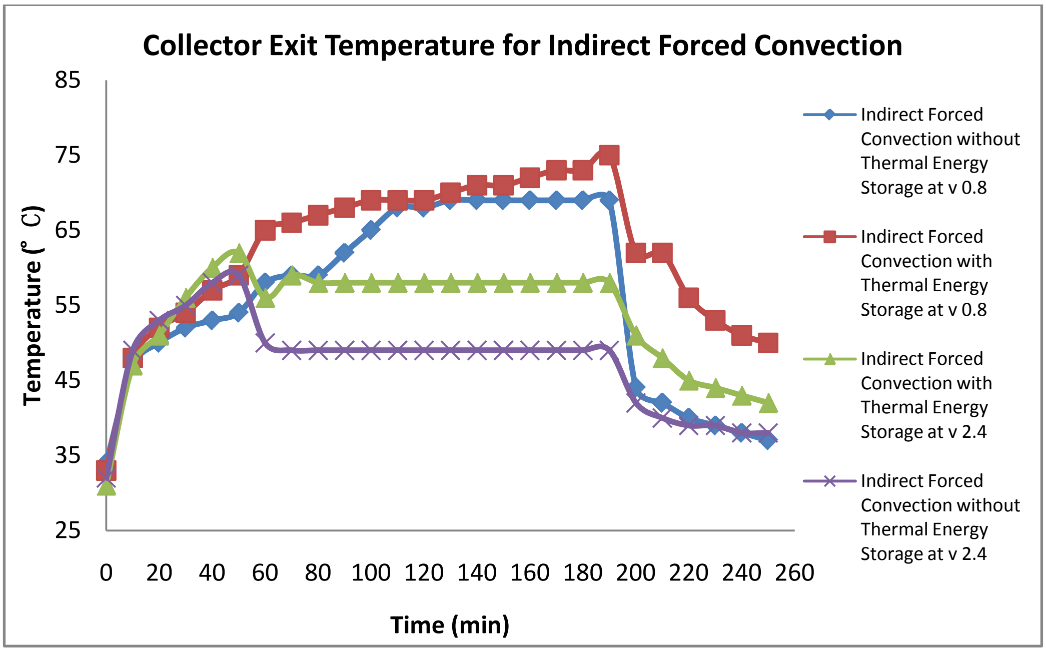


Figure 4.5: Collector exit temperature for indirect forced convection

For solar dryer system, it is important to know the quantity of energy received from the collector and its distribution in the time. Figure 4.4 and 4.5 presents collector exit temperature for two types of drying method. Analysis of this figure reveals that the temperature increased with low velocity and thermal energy storage and dropped down after the solar source was turned off. Besides that, the graph show that the temperature becomes constant after the dryer received the maximum heat.

From the Figure 4.4, the graph shows that after one hour the solar sources turn off, the indirect natural convection with thermal energy storage was provided the ability to continuous drying with high temperature differences of 10^{o}C compare with indirect natural convection without thermal energy storage . The ability of indirect forced convection with thermal energy storage at 0.8 m/s air velocity to increase the temperature inside the dryer chamber is same as by using the indirect natural convection with thermal energy storage. The temperature increased in steady state with 1^{o}C for every 10 minutes and becomes constant after 140 minutes and the temperature decreased rapidly without solar sources and it back to the initial temperature after 60 minutes.

From the Figure 4.5, by using the high velocity of 2.4 m/s, each type of drying method shows that temperature decreased and become constant after the collector was heated for 60 minutes and the fan is switched on. Temperature received in the dryer chamber for indirect forced convection without thermal energy storage with 2.4 m/s velocity has the lowest performance compared to others.

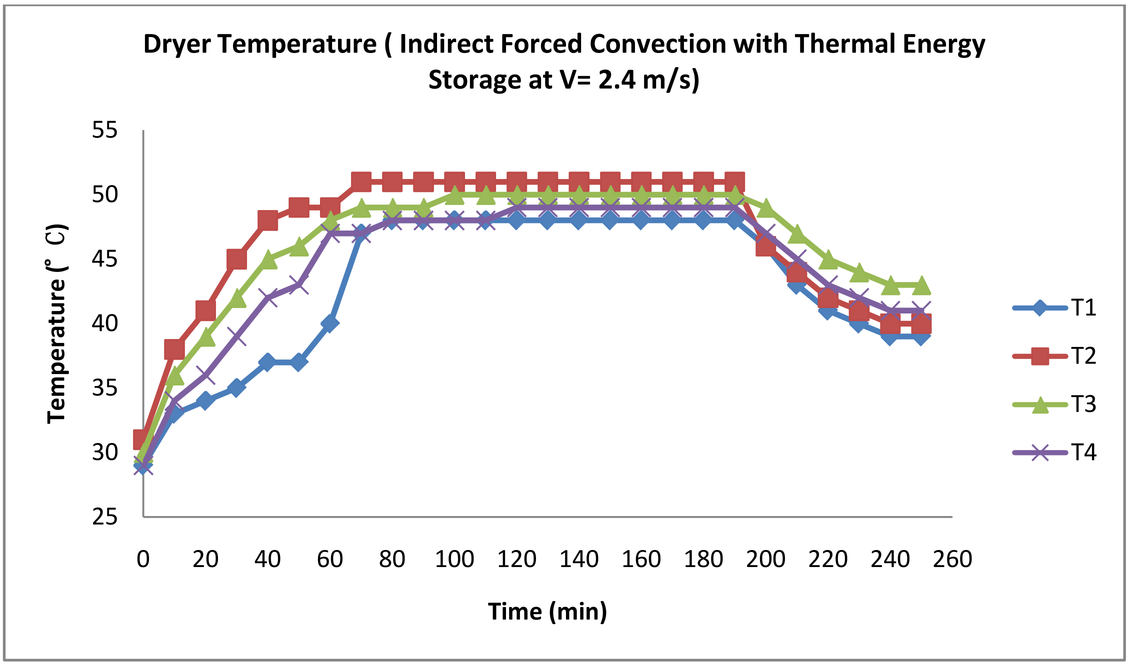


Figure 4.6: Dryer temperature for indirect forced convection with thermal energy storage at v=2.4 m/s

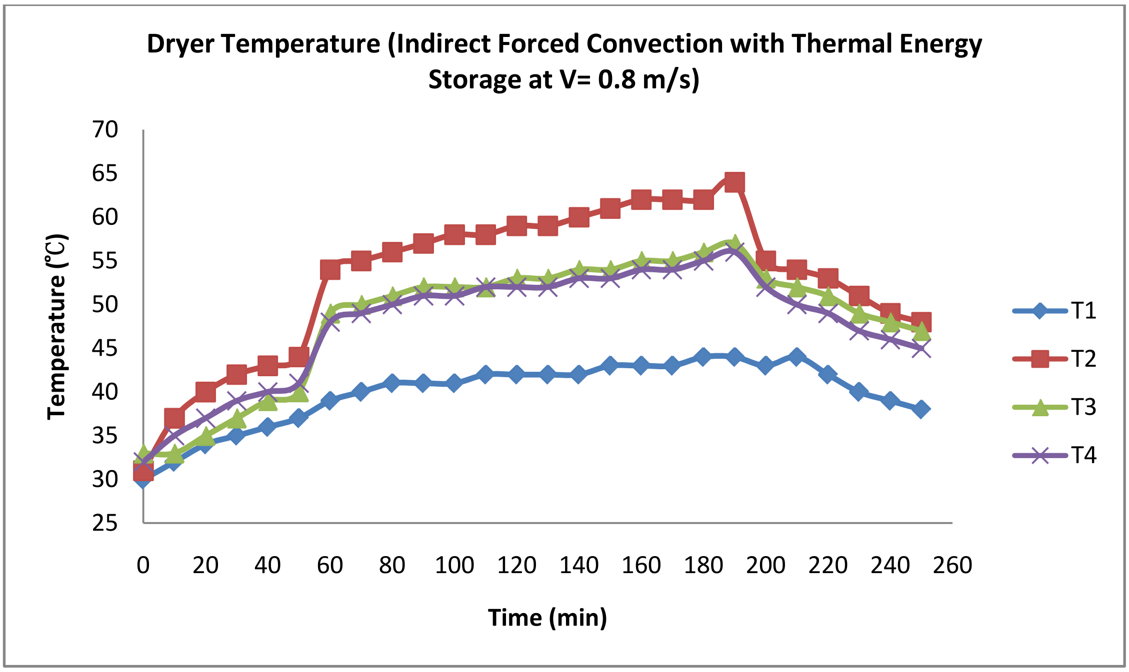


Figure 4.7: Dryer temperature for indirect forced convection with thermal energy storage at v=0.8m/s

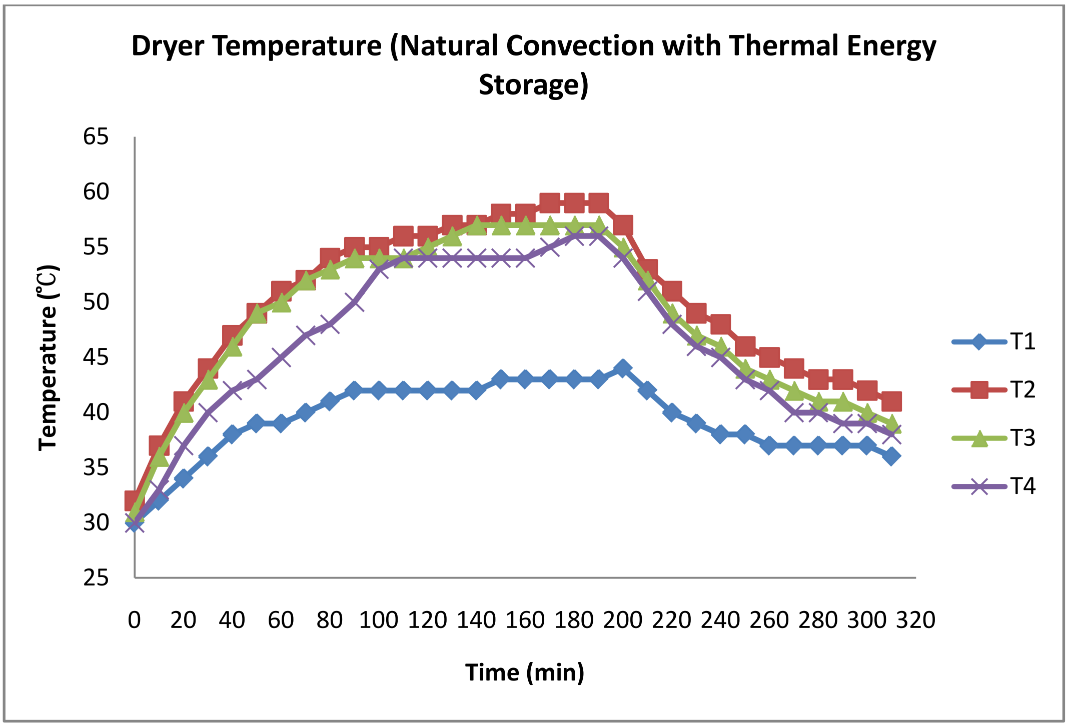


Figure 4.8: Dryer temperature for indirect natural convection with thermal energy storage

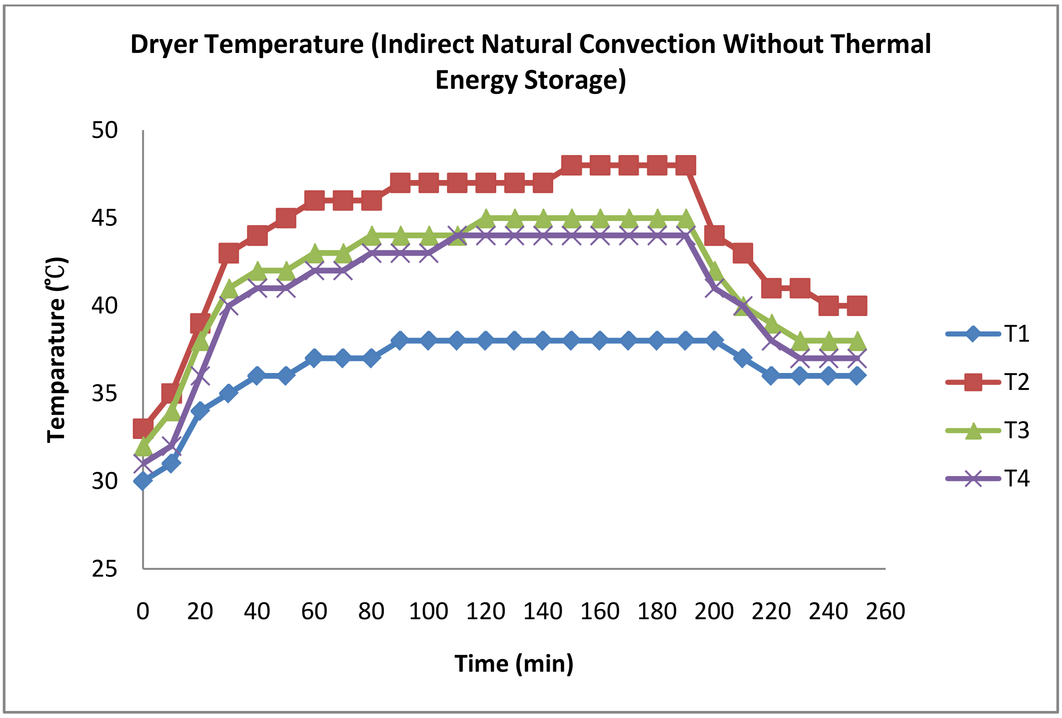


Figure 4.9: Dryer temperature for indirect natural convection without thermal energy storage

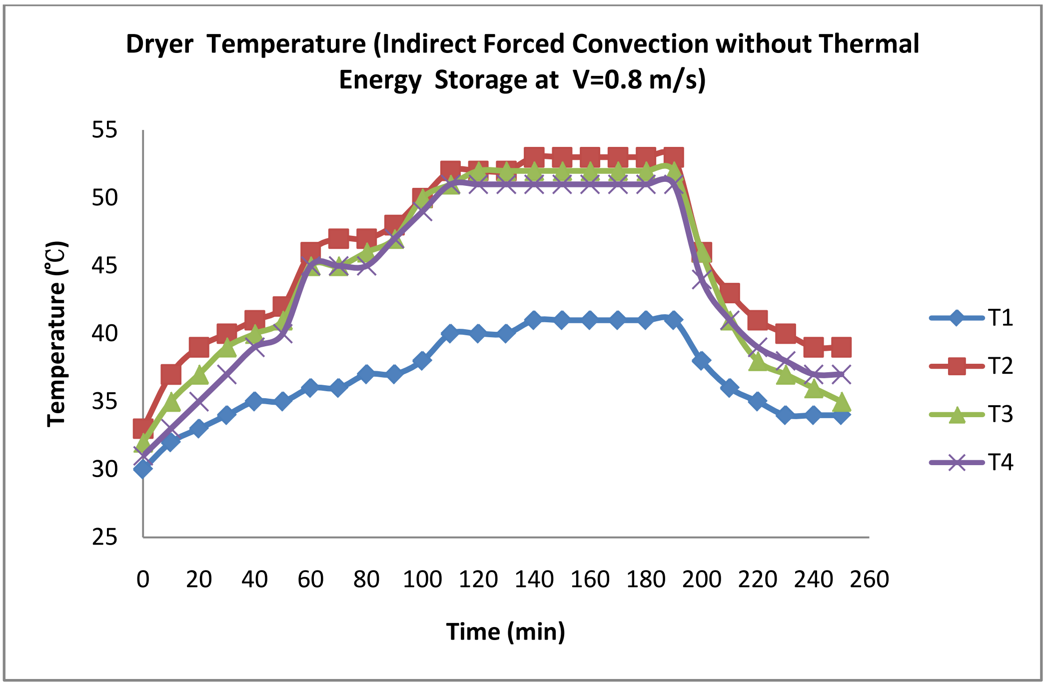


Figure 4.10: Dryer temperature for indirect forced convection without thermal energy storage at v= 0.8 m/s

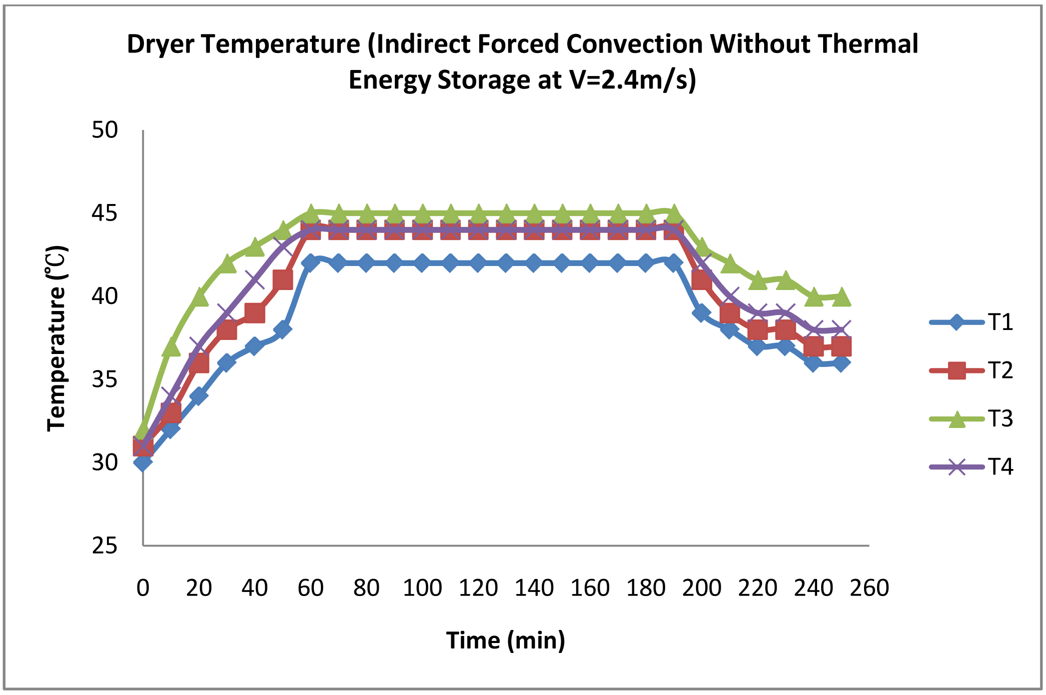


Figure 4.11: Dryer temperature for indirect forced convection without thermal energy storage at v=2.4m/s

Thermal energy storage absorb and emit heat which resulted the temperature rises and maintaining a nearly constant temperature. The results are presented in Figure 4.8 and 4.9. The analysis of the curve in Figure 4.8 shows that after the solar sources was turned off, the final temperature inside of indirect forced convection with thermal energy storage had reached at 41°C after two hours compare with a solar dryer without thermal energy storage in Figure 4.9 which is 40 °C for only one hour.

Figure 4.6, 4.7, 4.8, 4.9, 4.10 and 4.11 shows the temperature differences for three levels of thermocouples placed in the dryer chamber. During the experiments, T1 was placed below the exit collector and T2 was placed nearer to the tray position and above the hot air, T3 at above the T2 and T4 at the exit chimney (dryer exit). Buoyancy occur due to a difference inside and outside air density of dryer that resulting from temperature differences. The result show that, T2 exhibits higher temperature than T4, T3 and T1 because of buoyancy force.

4.2.3 AIR VELOCITY

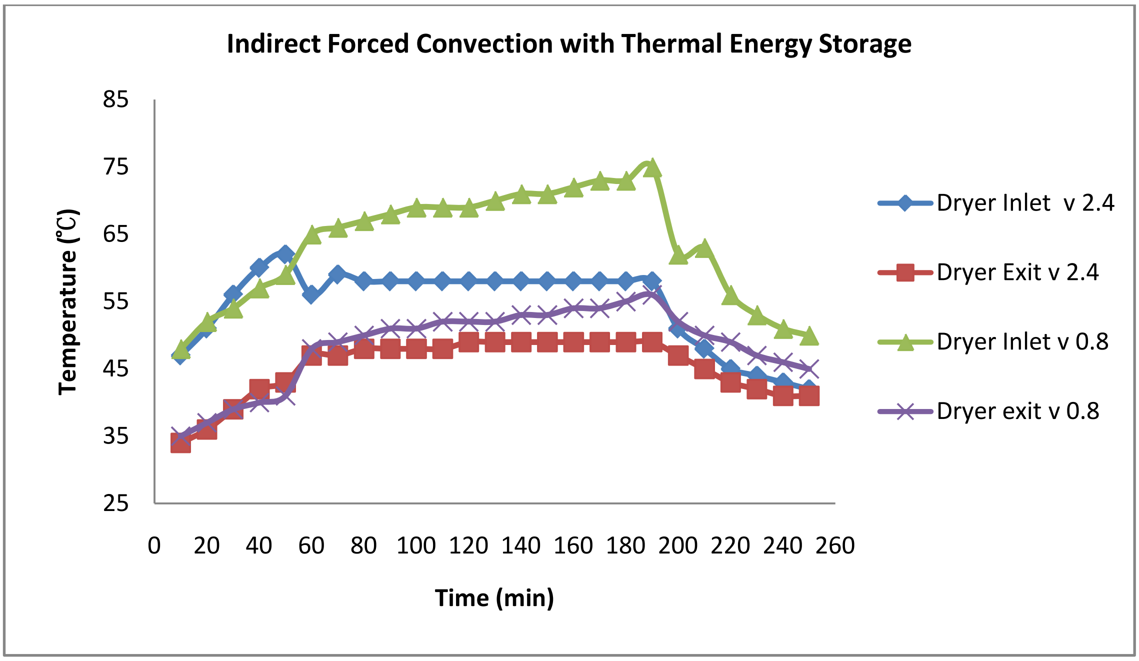


Figure 4.12: Comparison of air velocity with thermal energy storage

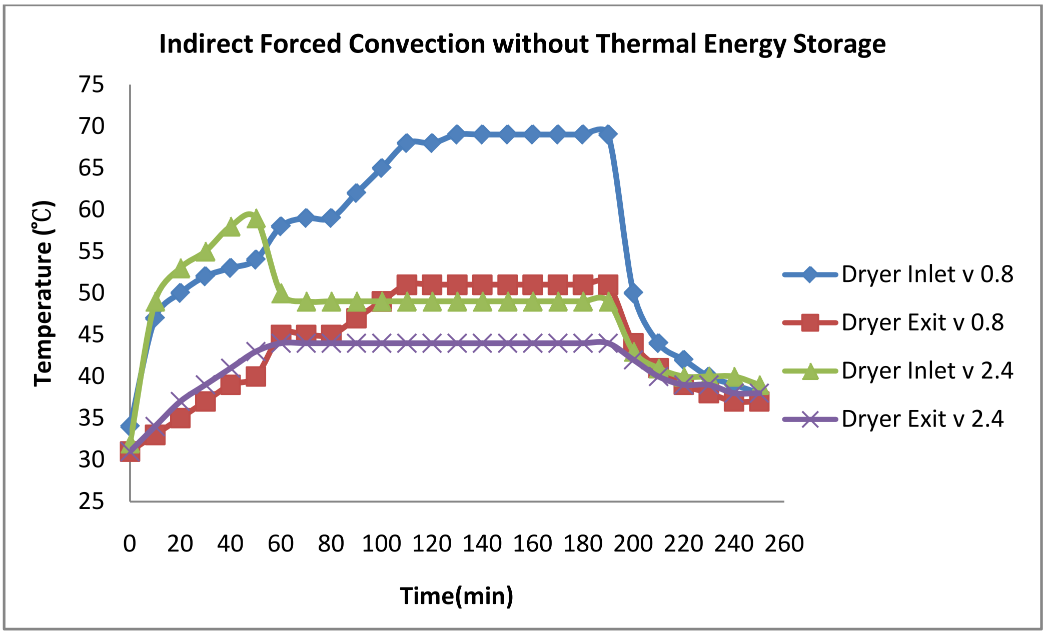


Figure 4.13: Comparison of air velocity without thermal energy storage

Lamb (2002) has noted that , air velocity can be an alternative way to control the drying rate at required and appropriate level which is temperature and relative humidity inside of solar dryer. Figure 4.12 and 4.13 shows that the effect of air velocity on drying air temperature. Drying with thermal energy storage was resulted in increased the temperature inside of dryer chamber. By comparing the graph that using the same velocity 0.8 m/s, a small difference of temperature received in the dryer chamber which is around 69 ^{o}C and 71^{o}C at 140 minutes. However, after 140 minutes, dryer with thermal energy storage still increased until it reaches at the 75 ^{o}C maximum temperature.

Besides that, drying with the 2.4 m/s air velocity was increased the drying time of the product to be dried. Because of the high air velocity received, both methods of drying shows that the temperature inlet decreased after the fan was switched on and it become constant after 80 minutes. By comparing the temperature inside the dryer chamber at Figure 4.6 and 4.7 , the temperature increased rapidly from 44 ^{o}C to 54 ^{o}C at T2 when the fan with the velocity of 0.8 m/s is switched on and it decreased at 47 oC when the fan is switched off. However, increased the velocity at 2.4 m/s, from 49 ^{o}C the temperature becomes constant at 51 ^{o}C after 10 minutes the fan is switched on.

Generally, the drying rate increased with the drying temperature and air velocity but decreased the drying time. (Garavand, 2011and Chinenye, 2009)

4.2.4 COLLECTOR EFFICIENCY

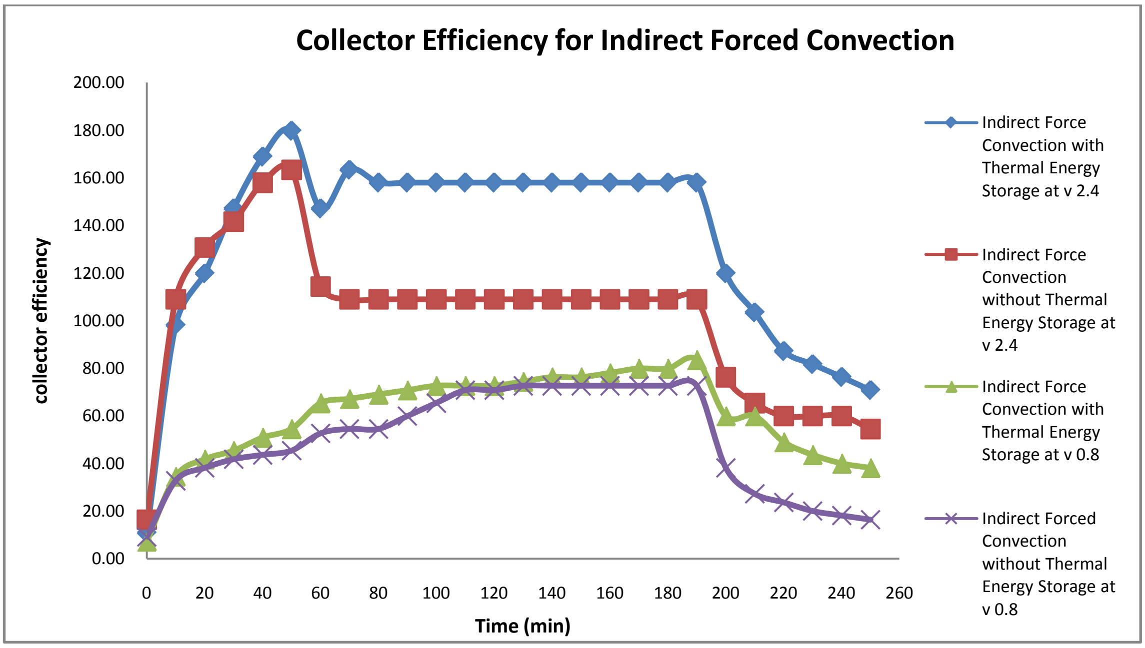


Figure 4.14: Influence of the air velocity on the collector efficiency

Figure 4.14 illustrates the effect of the approach velocity on collector efficiency for dryer used thermal energy storage and without thermal energy storage. Because of the air velocity for indirect natural convection is too low, so temperature cannot be measured and collector efficiency calculation cannot be done, but Leon, M.A. et al. (2007) have studied the effect of air velocity on the collector efficiency which is the velocity at 0.009m/s resulted to low collector efficiency than 0.033 m/s. Montero, I. et al. (2010) also have investigated the influence of air mass flow on the collector efficiency, the collector efficiency increased with the increased air mass flow.

The graph shows that increased in air velocity at 2.4 m/s means a proportional increase the collector efficiency than 0.8 m/s, however at high velocity the efficiency was constant during the experiment, but only slightly efficiency rises at 0.8 m/s. Increasing the velocity in the collector with thermal energy storage, resulted in increased the collector efficiency, since higher velocities resulted to operate the collector at lower temperature levels, which results in lower heat losses from the collector. The efficiency is nearly constant for velocities greater than 0.05 m/s. (Leon, A. et al. 2007)

Table 4.2: Data for indirect forced convection with thermal energy storage experiment (v= 2.4 m/s)

Time (min)	Collector Temperature (° C)	Collector Exit Temperature (° C)	T1 (° C)	T2 (° C)	T3 (° C)	Dryer Exit Temperature (° C)	Fan Velocity (m/s)
8.05	29	31	29	31	30	29	0
8.15	51	47	33	38	36	34	0
8.25	57	51	34	41	39	36	0
8.35	60	56	35	45	42	39	0
8.45	64	60	37	48	45	42	0
8.55	67	62	37	49	46	43	0
9.05	64	56	40	49	48	47	2.4
9.15	63	59	47	51	49	47	2.4
9.25	61	58	48	51	49	48	2.4
9.35	62	58	48	51	49	48	2.4
9.45	62	58	48	51	50	48	2.4
9.55	62	58	48	51	50	48	2.4
10.05	62	58	48	51	50	49	2.4
10.15	62	58	48	51	50	49	2.4
10.25	63	58	48	51	50	49	2.4
10.35	63	58	48	51	50	49	2.4
10.45	63	58	48	51	50	49	2.4
10.55	63	58	48	51	50	49	2.4
11.05	63	58	48	51	50	49	2.4
11.15	63	58	48	51	50	49	2.4
11.25	52	51	46	46	49	47	2.4
11.35	47	48	43	44	47	45	2.4
11.45	45	45	41	42	45	43	2.4
11.55	43	44	40	41	44	42	2.4
12.05	42	43	39	40	43	41	2.4
12.15	41	42	39	40	43	41	2.4

Table 4.3: Data for indirect forced convection with thermal energy storage experiment (v= 0.8 m/s)

Time (min)	Collector Temperature (°C)	Collector Exit Temperature (°C)	T1 (°C)	T2 (°C)	T3 (°C)	Dryer Exit Temperature (°C)	Fan Velocity (m/s)
2.30	31	33	30	31	33	32	0
2.40	53	48	32	33	37	35	0
2.50	62	52	34	35	40	37	0
3.00	69	54	35	37	42	39	0
3.10	74	57	36	39	43	40	0
3.20	78	59	37	40	44	41	0
3.30	70	65	39	54	49	48	0.8
3.40	70	66	40	55	50	49	0.8
3.50	71	67	41	56	51	50	0.8
4.00	72	68	41	57	52	51	0.8
4.10	72	69	41	58	52	51	0.8
4.20	73	69	42	58	52	52	0.8
4.30	73	69	42	59	53	52	0.8
4.40	74	70	42	59	53	52	0.8
4.50	74	71	42	60	54	53	0.8
5.00	75	71	43	61	54	53	0.8
5.10	76	72	43	62	55	54	0.8
5.20	76	73	43	62	55	54	0.8
5.30	77	73	44	62	56	55	0.8
5.40	78	75	44	64	57	56	0.8
5.50	62	62	43	55	53	52	0.8
6.00	60	63	44	54	52	50	0.8
6.10	58	56	42	53	51	49	0.8
6.20	55	53	40	51	49	47	0.8
6.30	53	51	39	49	48	46	0.8
6.40	52	50	38	48	47	45	0.8

Table 4.4: Data for Natural convection without thermal energy storage experiment

Time (min)	Collector Temperature (°C)	Collector Exit Temperature (°C)	T1 (°C)	T2 (°C)	T3 (°C)	Dryer Exit Temperature (°C)
10.45	34	35	30	33	32	31
10.55	47	41	31	35	34	32
11.05	56	49	34	39	38	36
11.15	58	52	35	43	41	40
11.25	59	53	36	44	42	41
11.35	61	54	36	45	42	41
11.45	62	55	37	46	43	42
11.55	63	55	37	46	43	42
12.05	63	56	37	46	44	43
12.15	64	57	38	47	44	43
12.25	64	57	38	47	44	43
12.35	64	57	38	47	44	44
12.45	64	57	38	47	45	44
12.55	64	57	38	47	45	44
1.05	65	58	38	47	45	44
1.15	65	58	38	48	45	44
1.25	65	58	38	48	45	44
1.35	65	58	38	48	45	44
1.45	65	58	38	48	45	44
1.55	65	58	38	48	45	44
2.15	47	47	38	44	42	41
2.25	43	44	37	43	40	40
2.35	40	42	36	41	39	38
2.45	39	41	36	41	38	37
2.55	38	39	36	40	38	37
3.05	38	39	36	40	38	37

Table 4.5: data for natural convection with thermal energy storage experiment

Time (min)	**Collector Temperature (˚ C)**	**Collector Exit Temperature (˚ C)**	**T1 (˚ C)**	**T2 (˚ C)**	**T3 (˚ C)**	**Dryer Exit Temperature (˚ C)**
12.25	31	34	30	32	31	30
12.35	50	48	32	37	36	33
12.45	56	52	34	41	40	37
12.55	61	57	36	44	43	40
1.05	64	60	38	47	46	42
1.15	67	62	39	49	49	43
1.25	69	64	39	51	50	45
1.35	70	65	40	52	52	47
1.45	72	67	41	54	53	48
1.55	73	67	42	55	54	50
2.05	73	68	42	55	54	53
2.15	74	68	42	56	54	54
2.25	77	69	42	56	55	54
2.35	77	71	42	57	56	54
2.45	77	71	42	57	57	54
2.55	77	72	43	58	57	54
3.05	77	72	43	58	57	54
3.15	77	72	43	59	57	55
3.25	77	72	43	59	57	56
3.35	77	72	43	59	57	56
3.55	69	63	44	57	55	54
4.05	58	56	42	53	52	51
4.15	53	53	40	51	49	48
4.25	50	51	39	49	47	46
4.35	49	49	38	48	46	45
4.45	47	48	38	46	44	43
4.55	45	46	37	45	43	42
5.05	45	45	37	44	42	40
5.15	44	44	37	43	41	40
5.25	44	43	37	43	41	39
5.35	42	42	37	42	40	39
5.45	42	41	36	41	39	38

Table 4.6: Data for indirect forced convection without thermal energy storage experiment (v= 0.8 m/s)

Time (min)	Collector Temperature (° C)	Collector Exit Temperature (° C)	T1 (° C)	T2 (° C)	T3 (° C)	Dryer Exit Temperature (° C)	Fan Velocity (m/s)
8.10	32	34	30	33	32	31	0
8.20	58	47	32	37	35	33	0
8.30	65	50	33	39	37	35	0
8.40	69	52	34	40	39	37	0
8.50	72	53	35	41	40	39	0
9.00	74	54	35	42	41	40	0
9.10	68	58	36	46	45	45	0.8
9.20	68	59	36	47	45	45	0.8
9.30	68	59	37	47	46	45	0.8
9.40	68	62	37	48	47	47	0.8
9.50	69	65	38	50	50	49	0.8
10.00	71	68	40	52	51	51	0.8
10.10	72	68	40	52	52	51	0.8
10.20	73	69	40	52	52	51	0.8
10.30	73	69	41	53	52	51	0.8
10.40	73	69	41	53	52	51	0.8
10.50	73	69	41	53	52	51	0.8
11.00	73	69	41	53	52	51	0.8
11.10	73	69	41	53	52	51	0.8
11.20	73	69	41	53	52	51	0.8
11.30	48	50	38	46	46	44	0.8
11.40	41	44	36	43	41	41	0.8
11.50	38	42	35	41	38	39	0.8
12.00	36	40	34	40	37	38	0.8
12.10	35	39	34	39	36	37	0.8
12.20	34	38	34	39	35	37	0.8

Table 4.7: Data for indirect forced convection without thermal energy storage experiment (v= 2.4 m/s)

Time (min)	**Collector Temperature (˚C)**	**Collector Exit Temperature (˚C)**	**T1 (˚C)**	**T2 (˚C)**	**T3 (˚C)**	**Dryer Exit Temperature (˚C)**	**Fan Velocity (m/s)**
12.05	28	32	30	31	32	31	0
12.15	59	49	32	33	37	34	0
12.25	68	53	34	36	40	37	0
12.35	73	55	36	38	42	39	0
12.45	75	58	37	39	43	41	0
12.55	77	59	38	41	44	43	0
1.05	58	50	42	44	45	44	2.4
1.15	57	49	42	44	45	44	2.4
1.25	57	49	42	44	45	44	2.4
1.35	57	49	42	44	45	44	2.4
1.45	57	49	42	44	45	44	2.4
1.55	57	49	42	44	45	44	2.4
2.05	57	49	42	44	45	44	2.4
2.15	57	49	42	44	45	44	2.4
2.25	57	49	42	44	45	44	2.4
2.35	57	49	42	44	45	44	2.4
2.45	57	49	42	44	45	44	2.4
2.55	57	49	42	44	45	44	2.4
3.05	57	49	42	44	45	44	2.4
3.15	57	49	42	44	45	44	2.4
3.25	42	43	39	41	43	42	2.4
3.35	38	41	38	39	42	40	2.4
3.45	37	40	37	38	41	39	2.4
3.55	36	40	37	38	41	39	2.4
4.05	36	40	36	37	40	38	2.4
4.15	35	39	36	37	40	38	2.4

CHAPTER 5

CONCLUSSION AND RECOMMENDATION

5.1 CONCLUSSION

The performance of two types of solar drying method which is indirect forced convection and indirect natural convection was designed, fabricated and investigated for kiwifruits drying. The performance of each solar dryer was compared with two different velocities (2.4 m/s and 0.8 m/s) by using thermal energy storage and without thermal energy storage. The kiwifruits samples from this experiment was compared with samples from direct sun drying.

The dryer with thermal energy storage enables to increase the temperature inside of dryer chamber and increased the drying time. Low velocity 0.8 m/s was resulted to increased the temperature in the dryer chamber compared with 2.4 m/s of air velocity that resulted a constant temperature in the dryer chamber and increased the time for products to dry.

Increasing the velocity in the collector, resulted in increased the collector efficiency, since higher velocities resulted to operate the collector at lower temperature levels, which results in lower heat losses from the collector. Although the velocity decreased the dryer temperature, but it can be used to control the drying temperature in the solar dryer and drying time for a different kind of food.

The kiwifruits samples were dried from with an initial moisture content ranged from 76.2 g to 82.2 g kiwifruit and three hours of drying with solar sources is switched on until a final moisture content of the samples ranged from 16.2 g to 43.9 g was reached. It could be concluded that, forced convection with thermal energy storage with a velocity of 0.8 m/s and natural convection with thermal energy storage shows the good color and texture of dried products.

5.2 RECOMMENDATION

Several recommendations are listed below:

i. Simulation using Computational Fluid Dynamic (CFD) or Solidwork Flow Simulation software to investigate the design and optimization of the solar dryer and hot air distribution in the dryer chamber.

ii. Increase the amount of heat received in the collector and the dryer chamber by using side reflector or mirror.

iii. Study the effect of number of trays used and weight loss at every location of tray for another design of dryer system.

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APPENDICES A

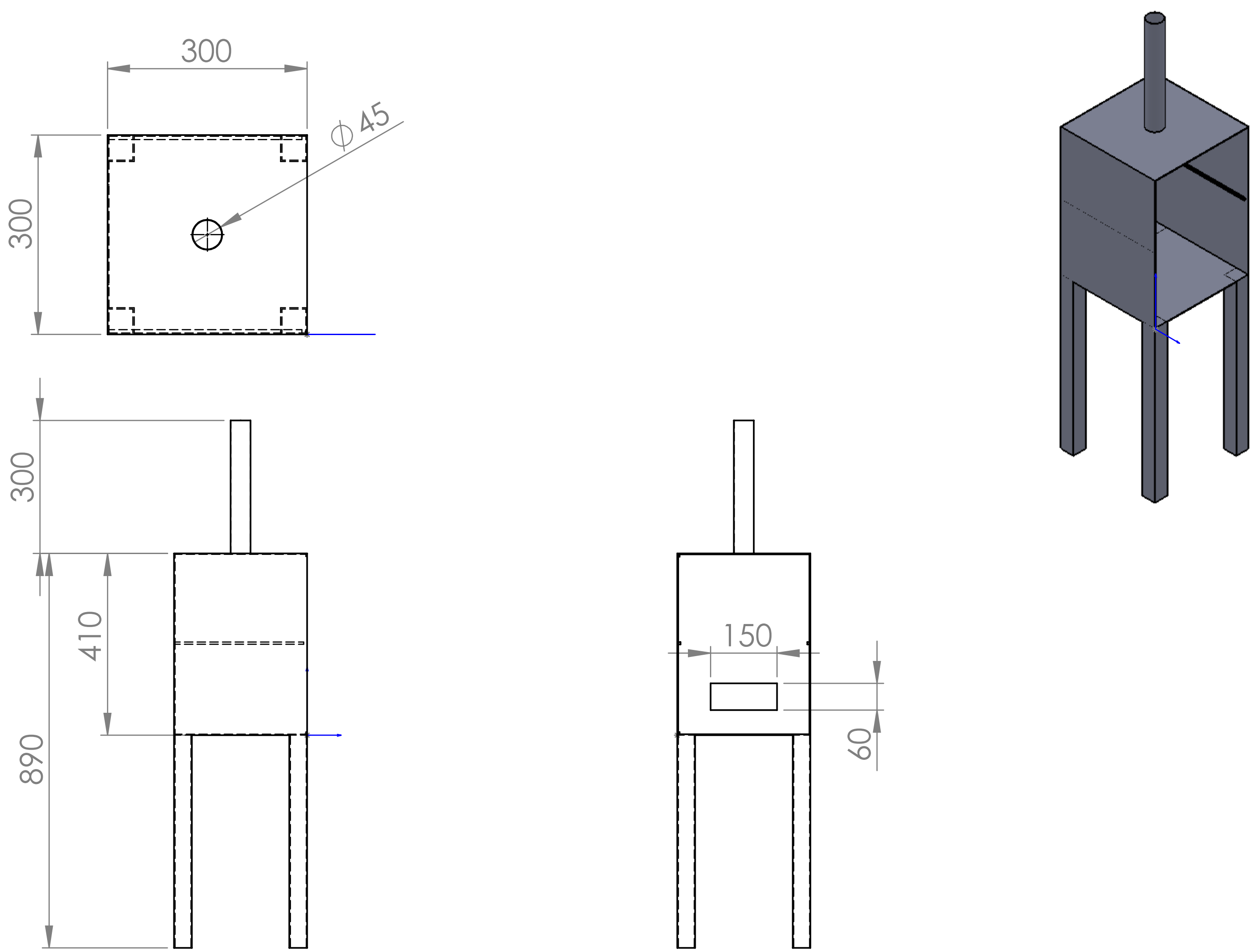
(Parts of Solar Dryer)

.

APPENDICES B

GANTT CHART

PROJECT ACTIVITIES	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Meeting with supervisor		■	■	■	■	■	■	■	■	■	■	■	■	■																
Research & gathering data																														
a) Find the problems statements,objectives, scopes of project.		■	■	■	■	■																								
b) Literature study	■	■	■	■	■	■	■	■	■	■	■	■	■																	
Design the prototype																														
a) Sketching the ideas							■	■																						
b) Sketching using the Solidwork software									■	■	■	■																		
Making the draf report																														
a) Chapter 1: Introduction						■	■	■																						
b) Chapter 2: Literature review						■	■	■	■	■																				
c) Chapter 3: Methodology											■	■	■	■																
FYP 1 presentation															■															
Submission of draft report															■															
Fabrication process																■	■	■	■											
Experiment & Analysis																				■	■	■	■	■	■	■	■	■		
FYP 2 presentation																													■	
Submission of final report																													■	■



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CHECKED	AMIR	12/11/11
APPROVED	AMIR	12/11/11

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MATERIAL
ALUMINIUM

FACULTY OF MECHANICAL ENGINEERING

DO NOT SCALE DRAWING

Universiti Malaysia PAHANG

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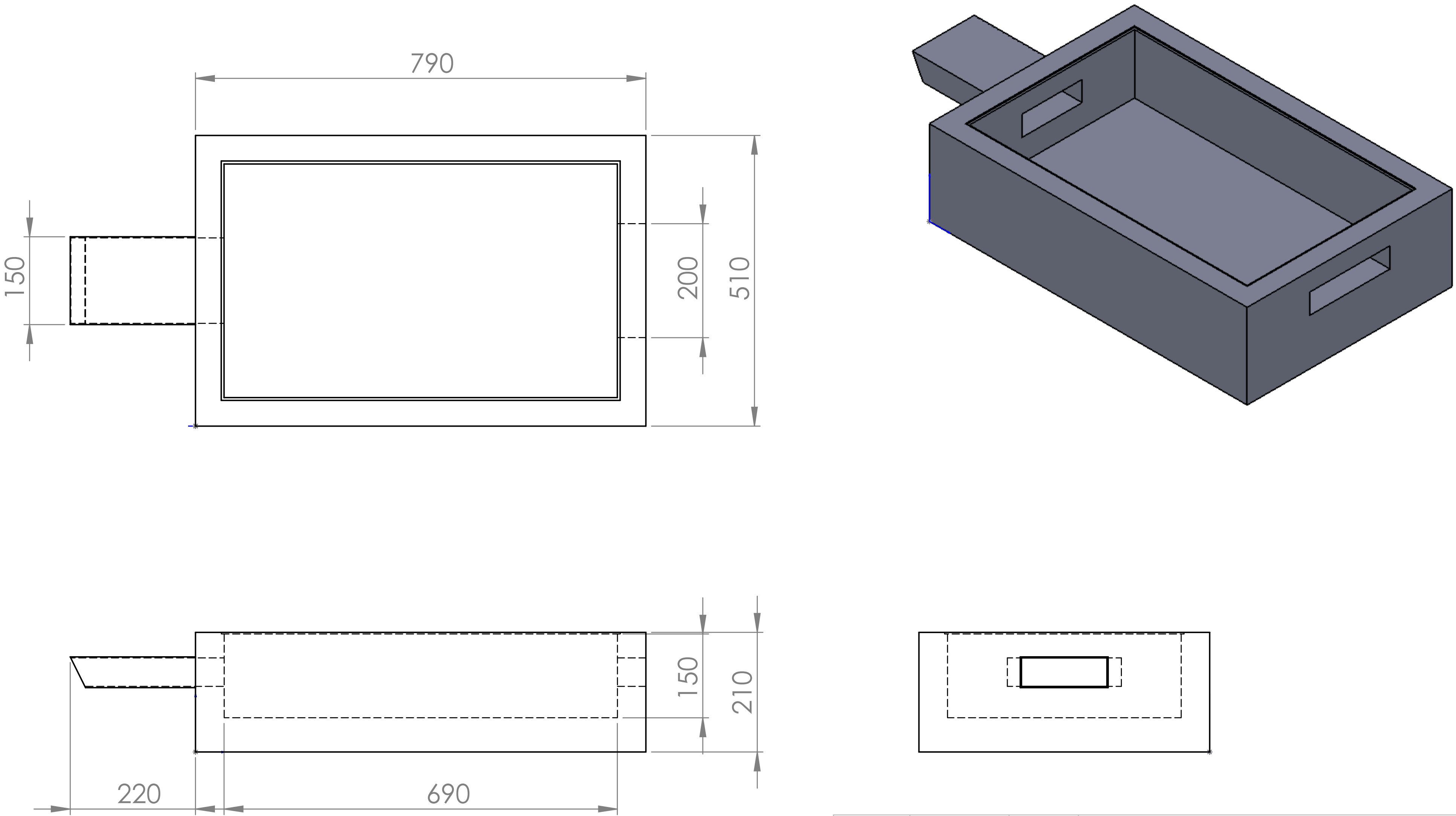

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FACULTY OF MECHANICAL ENGINEERING

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Universiti Malaysia PAHANG

TITLE:

COLLECTOR CHAMBER

SIZE A

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Collector Chamber

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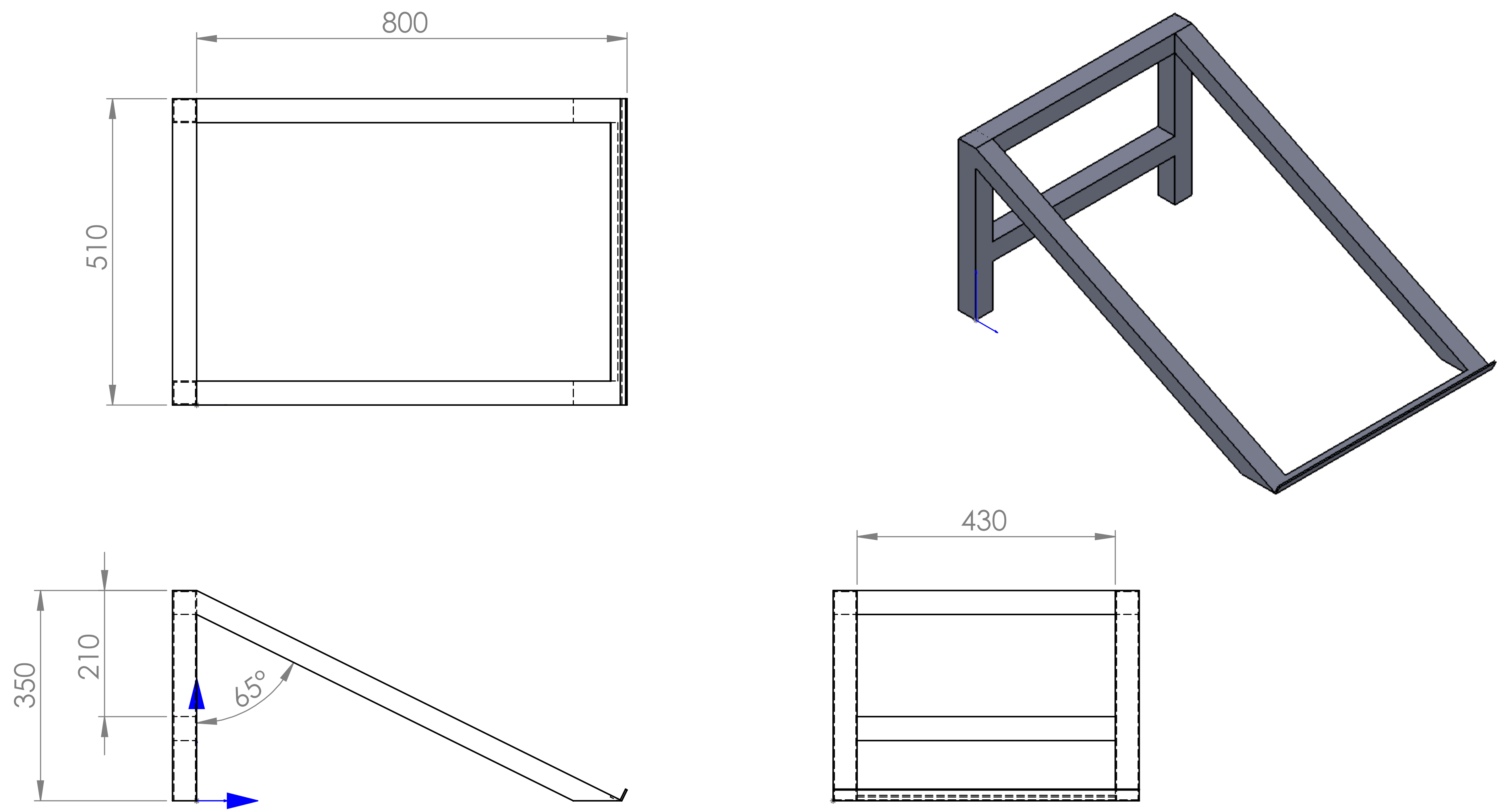

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APPROVED	AMIR	12/11/11

DIMENSIONS ARE IN MILIMETRES (mm) UNLESS OTHERWISE SPECIFIED

MATERIAL
STEEL

FACULTY OF MECHANICAL ENGINEERING

DO NOT SCALE DRAWING

Universiti Malaysia PAHANG

TITLE:

COLLECTOR STAND

SIZE: A

DWG. NO. Collector Stand

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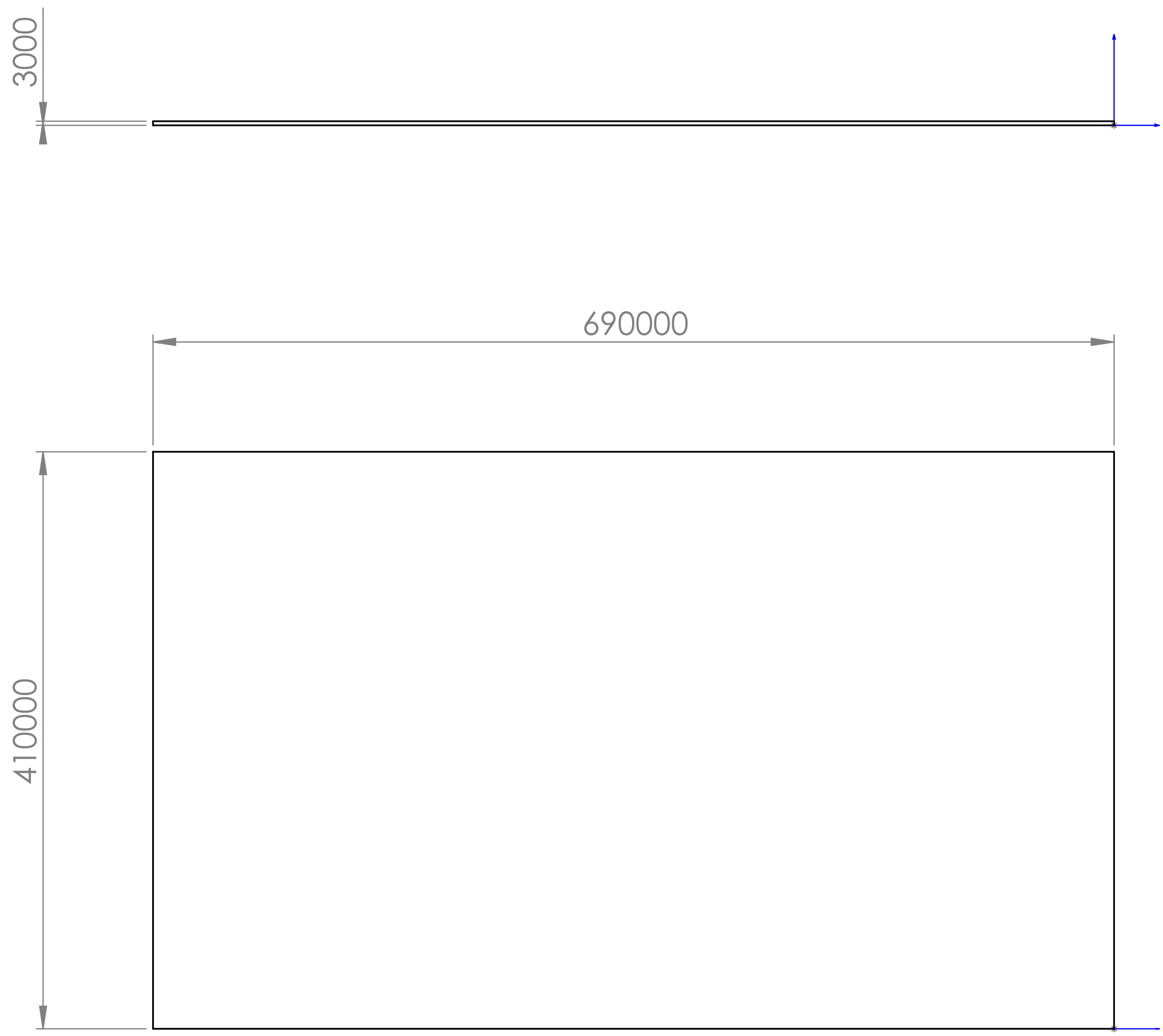

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MATERIAL GLASS	APPROVED	AMIR	12/11/11	
FACULTY OF MECHANICAL ENGINEERING	Universiti Malaysia PAHANG			SIZE A — DWG. NO. Transparent glass
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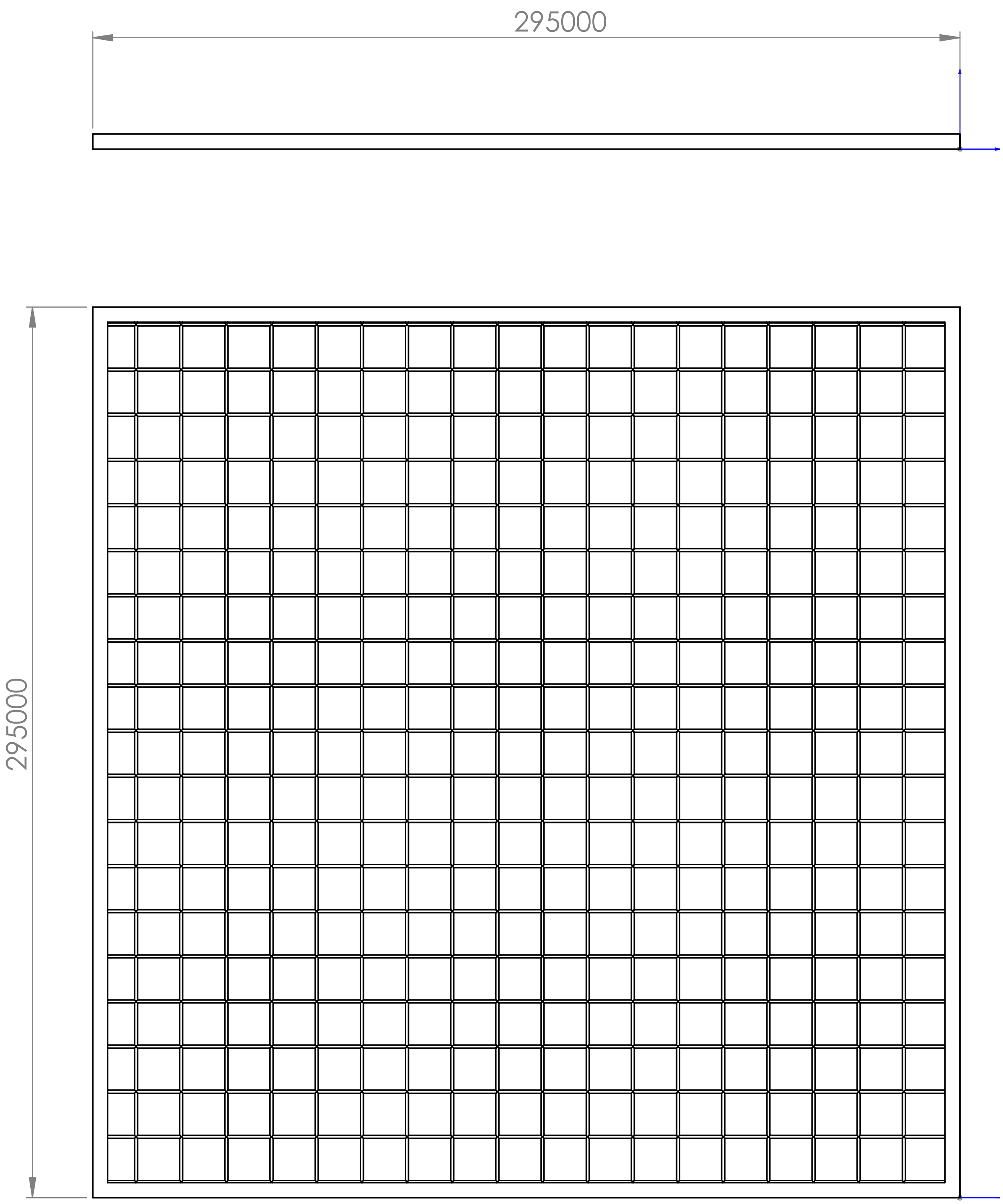

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MATERIAL
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TRAY

SIZE A | DWG. NO. Tray

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