Design and Fabrication of Hybrid Solar-Biomass System for Crops Drying

By

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Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
(Mechanical Engineering)

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Universiti Teknologi PETRONAS
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CERTIFICATION OF APPROVAL

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December 2008

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

(IRWAN SYAH BIN MOHD YASIN)

ABSTRACT

One of the applications of solar energy in agriculture industry is the drying of the agricultural crops. The limited source of solar energy becomes a problem in drying process that is slowing the drying process. With the additional source of energy, the problem can be solved. From here on, the project is focused on the designing, fabrication, and testing the solar-biomass hybrid system for drying the crops and also analysing its performance. Calculation of heating energy used for drying process of 80% of crop's moisture content and its thermal efficiency, incident of solar radiation, speed and mass flowrate of air are included in designing process besides the dimension of the hybrid drier unit and the material used. As the complement for the designing process, the mechanical drawings are been produces in 2D with AutoCAD and 3D with Catia. The fabrication is done as per mention in the report. Continued from it, the testing also be done by using the potato as a crop in this drying process for 24 hours and the result is gained with the drying process using this hybrid drier is actually successful to get the desired value of moisture content for crops to be stored for long period in less than 24 hours. In conjunction with the result, the analysis is done to see its performance together with the discussions. As the completion in this project, the recommendation on this hybrid drier is provided to be the reference for the future works and the conclusion is done.

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NOMENCLATURE

C_p	-	Specific Heat for Air, kJ/kg.K
E"	-	Energy, W
G_s	-	Solar Radiation, W/m^2
h_{ai}	-	Enthalpy of Inlet Air, kJ/kg
h_{ao}	-	Enthalpy of Outlet Air, kJ/kg
h_{si}	-	Enthalpy of Initial Water in Food, kJ/kg
h_{so}	-	Enthalpy of Final Water in Food, kJ/kg
h	-	Convective Heat Transfer Coefficient, W/m^2.K
L	-	Latent Heat of Vaporization for free water, J/kg
M	-	Moisture Content
M_{ai}	-	Moisture Content of Inlet Air
M_{ao}	-	Moisture Content of Outlet Air
M_e	-	Equilibrium Moisture Content
M_i	-	Moisture Content of Initial food/crops
M_o	-	Moisture Content of Final food/crops
m	-	Mass, kg
m_a	-	Mass of Air, kg
m_w	-	Mass of Water, kg
P	-	Atmospheric Pressure, 1.01 x 10^5 Pa
q"u	-	Useful Energy, W
$q"_{conv}$	-	Energy Loss due to Convection, W
$q"_{rad}$	-	Energy Loss due to Radiation, W

R - Gas Constant per Unit Mass of Dry Air, 2.9×10^2 J/kg.K

T_{ai} - Temperature of Inlet Air, K

T_{ao} - Temperature of Outlet Air, K

T_{pi} - Temperature of Initial Food/Crop, K

T_{po} - Temperature of Final Food/Crop, K

T_{ap} - Temperature of Solar Collector Absorber Plate, K

T_g - Temperature of Solar Collector Glass, K

T_∞ - Temperature of Ambient Air, K

T_{sky} - Temperature of Sky, K

V_a - Volume of Air, m^3

$\alpha_{ap,s}$ - Absorbtivity of Absorber Plate

$\alpha_{g,s}$ - Absorbtivity of Glass

ε_{ap} - Emissivity of Absorber Plate

ε_g - Emissivity of Absorber Plate

$\tau_{g,s}$ - Transitivity of Glass

ΔT - Temperature Different

ρ - Density, kg/m^3

σ - Stefan-Boltzman Constant, 5.67×10^{-8} $W/m^2.K^4$

CHAPTER 1
INTRODUCTION

1.1 Background of study

Crop drying is the one of the main event in agricultural world. The moisture content of the crops must be dried for properly store to prevent the spoilage and mold that some of which is toxic to humans and livestock [9]. In beginning of crops drying system, direct solar heat is used. In this method, the crops is scattered on the opened area under the sun as per shown in figure 1.1. The direct sun drying method is taking so much time and affected by the weather change.

Figure 1.1: Direct solar drying method.

In solving the direct sun drying problem, using the fuel-burning method is used. Therefore, the drying process can be done anytime. The organic materials such as grass, leaves and woods are usually used as the fuel. This energy is called biomass energy. Biomass can be defined as all types of animal and plant material which can be converted into energy. It includes trees and shrubs, grasses, algae, aquatic plants, agricultural and forest residues, energy crops and all forms of wastes [1]. The quantities of biomass produced throughout the world are very large. The annual net production of organic matter has an energy content of about 3 x 10^{21} J, some eight times the world's annual energy use in the early 1990s. In forests alone the biomass productivity was estimated to be about three times the world's annual energy use at the end of the 1970s [2]. At that time the biomass is the largest and most familiar resource renewable energy in the world.

Through the process of photosynthesis, the biomass energy is come from the sun. The chlorophyll on the plants will absorb the energy from the sun. The carbon dioxide from the air and water will be change into the carbohydrates, complex compounds composed of carbon, hydrogen, and oxygen. This carbohydrate produce, when it is burn, it is simply produce the carbon dioxide and release the energy.

Biomass is funtioning like an battery charge from the sun. Biomass energy brings numerous environmental benefits—reducing air and water pollution, increasing soil quality and reducing erosion, and improving wildlife habitat [10].

When the thermal solar energy technology is raised up, many people go to solar energy method. The crops drying process by using the solar drier is saving in energy usage as the example in figure 1.2.

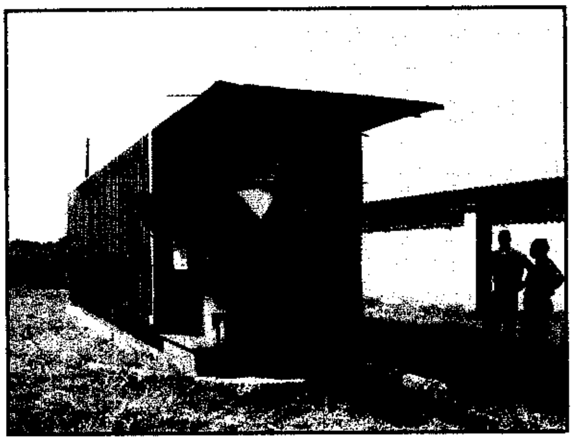


Figure 1.2: The solar wall crops drying method.

The solar energy is combination of thermal and light. In drying process, the thermal energy from solar is used. With the technology, this thermal energy can be collected more efficient by using the solar collector. In the crops drying method, the thermal energy of solar is used in heating the air. By the breeze of hot air to crops, the drying process is happened. With this method, the crops are drying more efficiently, saving the energy and also cost.

1.2 Problem Statement

The solar thermal system cannot be used without the energy from the sun. With the rotation of the world and changing of weather, the solar energy cannot be the same every time at one point. With the limitation of the energy, the solar drier cannot be used in the night or in the dull day.

Therefore, it is needed to introduce the other source of energy and combine it with the solar drier to solve the problem. With this integration system, the hybrid drier then can be used in any time.

1.3 Significance of the Project

Explicitly, the concern of this project is on the designing and fabrication or the new hybrid solar-biomass system for crops drying that can be used for any time.

1.4 Objectives

1. To design the hybrid solar-biomass system for crops drying.
2. To fabricate the designation hybrid solar-biomass drier.
3. To test the hybrid solar-biomass drier unit and analysis the result to see its performance.

1.5 Scope of Study

This project is focused on the designing the hybrid of solar-biomass drier that is used for drying 5 kg of crops per day. The crops will be under 80% of moisture content and the potato has been used as a selected crop in the process. In gaining the design parameter, the study of the basic requirement for the design process is done. This hybrid drier is fabricated and then is tested for 24 hours non-stop in gaining the result. The analysis of the result is conducted and the recommendation on this project is also being provided for the future reference.

CHAPTER 2

LITERATURE REVIEW

Drying or dehydration is the application of heat under a controlled environment to remove moisture from food. Drying has pronounce effects on the textural quality and nutritive value of food, but it results in reducing water activity to such levels that product is relatively shelf-stable for prolonged periods, provided it is enclose in an inert atmosphere in moisture-barrier container.

2.1 Drying fundamental

In drying process, the latent heat of vaporization is supply to the water in the food. As a result the water vapor is removed from the food. So, the process involves the application of heat and the removal of the moisture to yield a solid dry product. Drying is carried out the passing of hot air that provides the latent heat for water to having the evaporation process. The moisture form then is transferred from the food to the air by the movement of the air.

The drying process can be subdivided into two processes occurring simultaneously; the transfer of energy (mostly heat) from the surrounding environment to evaporate the surface moisture characterized as the active drying; the transfer of the internal moisture to the surface of solid and it subsequence evaporation according to the process; it is named restrictive/resistive drying [3].

In a drying operation, either one of limiting factor could affect the governing rate of drying, although it is occur simultaneously throughout the drying cycle [4]. When the dry hot air is having a contact with the food, the vapor pressure in the food will be higher than in the air. This will cause the evaporation of water from the food surface until it reach an equilibrium state. In order the for the food lose the moisture as water vapor, the equilibrium latent heat must be apply to the liquid of water. In the absent of an external heat source, this latent heat is normally absorbed from the food itself, resulting in the lowering of its temperature. This is called evaporative cooling [3]. Also goes on in the dry hot air, the latent heat is provided to water existence in the food, and also lowering the air temperature.

The supplied heat by the air and the food is being used to evaporate the water. Until a saturated condition is achieved, the evaporation process overrides, as long as there is an abundant reserve of moisture to meet evaporation needs. This will cause the temperature of the food to be lower than that of the air stream. As the air gets saturated, the food temperature reaches the saturation air temperature. This condition will represent the wet bulb condition of the incoming air. During this period, the food material has an abundant supply of free moisture on the product surface that can be easily picked up by the air. The lost moisture is quickly replenished by the internal moisture diffusion. This stage of drying is usually named the active drying period and usually lasts for only a short period of time.

As moisture content in the product diminishes, the internal moisture will not migrate as easily as before, and the drying outer surfaces start to offer resistance to the moisture transfer. The temperature of the leaving air will begin to increase above the wet bulb temperature, and the leaving air will not be saturated. The inlet air temperature is still greater than the outlet air temperature. Properties of the product especially the moisture diffusivity will play a major role, in addition to air properties. This condition represents restrictive or resistive drying conditions. Eventually, equilibrium conditions are reached when no further drying takes place. At this stage, the moisture content in the air will be in equilibrium with that in the food. There will not be any heat and mass transfer under these conditions. The food temperature is equal to the outlet air temperature, which is also equal to the inlet air temperature.

2.1.1 Drying Curve

A drying curve will give the information on time of necessary for a product to be dried under certain condition [3]. A drying curve is normally obtained by plotting some form of moisture change with the time. The drying curve for the typical solid food is can be shown on figure 2.1 below.

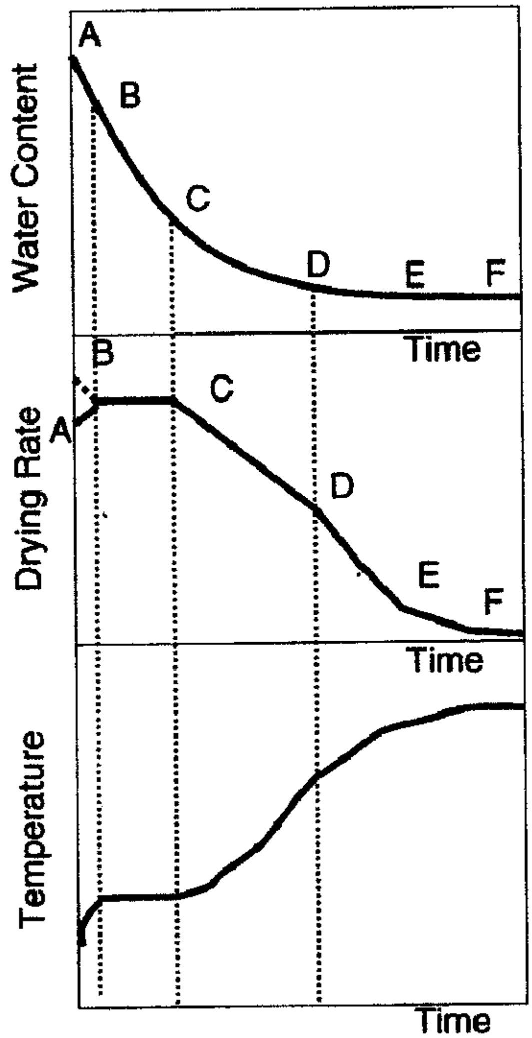


Figure 2.1: Drying curve using water content, drying rate and temperature of the typical solid food [4]

2.1.2 Moisture Content

There are two ways in expressing the moisture content of the food that is can be reported as a percentage or fraction either on a wet basis (% wb) or on a dry basis (% db). In calculating the moisture content on wet basis, the equation below is used.

$$\text{Moisture Content (\% wb)}, M_{wet} = \frac{m_{water}}{m_{water} + m_{Solid}} \times 10 \tag{2.1}$$

Where M is moisture content and m is the weight. While the calculation for moisture on dry basis, the equation is followed,

$$\text{Moisture Content (\% db)}, M_{dry} = \frac{m_{water}}{m_{Solid}} \times 100 \tag{2.2}$$

The wet and dry basis moisture content can be related using the following equation,

$$M_{dry} = \frac{M_{wet}}{100 - M_{wet}} \tag{2.3}$$

2.1.3 Equilibrium Moisture Content (M_e)

In final stage of drying, the initial value of moisture content (M_i) in the air will reach the constant value. No moisture from the food will lost thereafter. Under this condition, the drying air is equilibrium with the product. The mass transfer will not happen between food and air. Therefore, the moisture content on the food under this situation is called equilibrium moisture content.

2.1.4 Mass and Energy Balance of Air Drying

Considering the drying process is on continuous basis and the food and air is entering the dryer then leaving with the opposite condition as in figure 2.2 below,

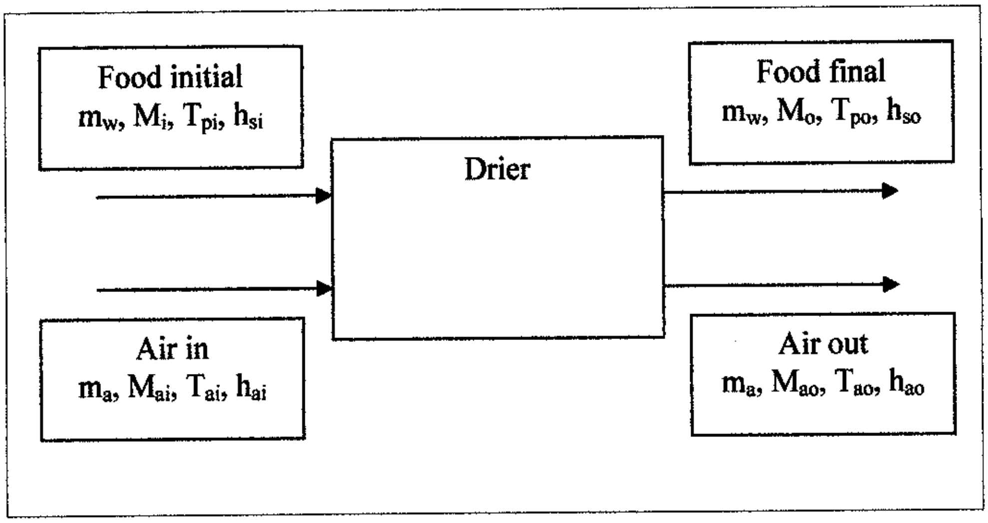


Figure 2.2: Schematic diagram of a drying process

Where the m_w is weight of food, m_a is a weight of air entering and leaving the dryer. M_i and M_o are the product moisture contents (db). T_{pi} and T_{po} are product temperature. h_{is} and h_{so} are product enthalpy. M_{ai} and M_{ao} are air moisture content. T_{ai} and T_{ao} are temperature of air. h_{ai} and h_{ao} are enthalpy of the air.

The mass balance indicates that the moisture coming in must equal to moisture going out. Therefore:

$$m_w M_i + m_a M_{ai} = m_w M_o + m_a M_{ao} \tag{2.4}$$

By rearranging the equation showing the moisture lost by the product is equal to moisture gained by air,

$$m_w(M_i - M_o) = m_a(M_{ao} - M_{ai}) \tag{2.5}$$

The energy balance of the dryer, assuming the ideal idebatic unit working at stady-state condition, is expressed by:

$$M_w h_{si} + m_a h_{ai} = m_w h_{so} + m_a h_{ao} \tag{2.6}$$

Rearrangingthe equation indicates that the heat gained by the product is lost by the supply air:

$$m_w(h_i - h_o) = m_a(h_{ao} - h_{ai}) \quad (2.7)$$

In other term, the energy balance for drying process can be expressed as

$$m_w L = m_a C(T_{ai} - T_{ao}) \quad (2.8)$$

where L is the latent heat of the water at respective temperature and C is the specific heat of the air.

2.2 Hot Air Volume

In dehydration process, the hot air used in order to remove the moisture content. The volume of air required for dehydration process can be calculate from the equation,

$$V_a = m_a R T_{ao}/P \quad (2.9)$$

where V_a is the volume of air required, R is gas constant per unit mass of dry air which is $2.9x10^2$ $Jkg^{-1}K^{-1}$. P is atmospheric pressure which is $1.01x10^5$ Pa.

Alternatively, by using the equation 2.8, V_a is

$$V_a = m_w LRT_{ao}/C_p(T_{ai} - T_{ao}) \quad (2.10)$$

There are many ways in getting the hot air for the drying process. Hot air basically exists by heating process which can use the burning of fuel and solar radiation.

2.3 Solar Collector

Solar collector has been used in many applications such as, water heater for household, produce stem in order to generate the electricity by using steam turbine and also in drying purpose.

There are many type of solar collector, for example unglazed EPDM collector, flat plate collector, parabolic and evacuate tube that is used for producing different outlet fluid temperature.

2.3.1 Solar flat plate collector.

Solar flat plate collector is normally used for producing medium temperature. It is consist of cover plate, absorber plate and insulation.

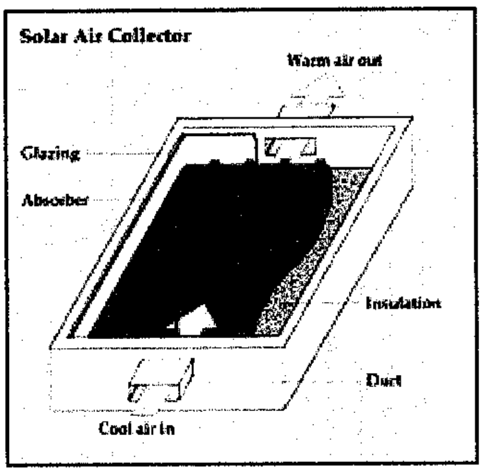


Figure 2.3: Single glazing solar air collector.

2.3.2 Energy Balance.

The energy balance for the solar flat plate collector can be expressed as the energy gain is equal to energy loss,

$$E''_{in} = E''_{out} \tag{2.11}$$

From the figure 2.4 below, the energy balance equation can be determine.

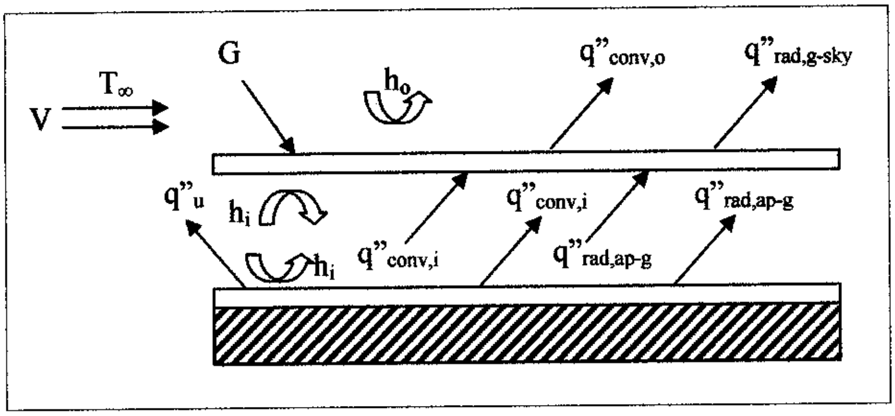


Figure 2.4: Energy balance on solar collector.

At absorption plate, the solar energy absorbed is equal to useful energy + energy loss due to convection + energy loss due to convection.

Solar $Energy_{absorbed,absorberplate} = Energy_{useful} + Energy_{Loss(convection)} + Energy_{Loss(conduction)}$

$$\alpha_{ap,s} (\tau_{g,s})\, G_s = q"_u + q"_{conv,i} + q"_{rad,ap\text{-}g} \qquad (2.11)$$

So,

$$q"_u = \alpha_{ap,s} (\tau_{g,s})\, G_s - h_i (T_{ap} - T_g) - (\sigma\, [T_{ap}^{\ 4} - T_{cp}^{\ 4}] / [(1/\varepsilon_{ap}) + (1/\varepsilon_g) - 1]) \qquad (2.12)$$

At cover plate, sum of the solar energy absorbed by glass, energy loss due to convection from absorber plate and energy loss due to radiation from absorber plate is equal to sum of energy loss due to convection from glass and energy loss due to radiation from glass.

Solar $Energy_{absorbed,glass} + Energy_{Loss(convection,absorber\_plate)} + Energy_{Loss(radiation,absorber\_plate)} = Energy_{Loss(Convection,glass)} + Energy_{Loss(radiation,glass)}$

$$\alpha_{g,s} (G_s) + q"_{conv,i} + q"_{rad,ap\text{-}g} = q"_{conv,o} + q"_{rad,g\text{-}sky} \qquad (2.13)$$

so,

$$\alpha_{gs} (G_{gs}) + h_i(T_{ap} - T_g) + (\sigma [T_{ap}^4 - T_g^4] / [(1/\varepsilon_{ap}) + (1/\varepsilon_g) - 1]) = h_o(T_g - T_\infty) + \varepsilon_g\sigma(T_g^4 - T_{sky}^4) \qquad (2.14)$$

At fluid flow, the seful energy is equal to energy absorbed to the fluid,

$$q''_u = \dot{m}_a C_p \Delta T \qquad (2.15)$$

2.3.3 Material Properties

2.3.3.1 Cover

Solar energy from the sun is formed of short radiation. After the energy reached to the earth's surface, it will re-radiate into surrounding or deep space as long wave radiation. So the power of solar energy source which is short wave radiation has to capture to prevent it from being re-radiated directly to the atmosphere. The selection of the cover is based on cost, non-degradability, durability, specific heat. So, glass is used for glazing because the ability to allow the passage of short radiation and retain them in solar collector because the wave becomes long wave radiation and energy to dissipate is less.

Table 2.1: Absorptivity, emissivity and transmittance for different types of glass [5]

Type of Glass	Absorptivity, α	Emissivity, ε	Transmitance, τ	Effective transmittance-absorptance, τ α	Long-wave infrared transmittance
Crystal Glass	0.13	0.83	0.91	0.1183	0.02
Window Glass	0.13	0.83	0.85	0.1105	0.02
Perspex polymethylmethacrylate (PMMA).	-	-	0.84	-	0.02

2.3.3.2 Absorber Plate

Absorber plate is used to absorb heat from the incoming solar radiation. The more thermal specific heat, the more heat will absorb.

Table 2.2: Properties of selected materials for absorber [6]

Materials	Density, ρ (kg/m^3)	Specific Heat, C (J/kg.K)	Thermal conductivity, k (W/m.K)
Aluminum 1100	2379	903	237
Copper	8933	385	401
Carbon Steel	7832	434	60.5
Tin	7310	227	66.6

2.3.3.3 Insulation

Selection of the insulation is based on the lowest thermal conductivity and the material cost of different types of materials. Selected materials that can be use for the solar collector as stated in Table 2.3.

Table 2.3: Thermal conductivity of selected materials for insulation

Materials	Thermal conductivity, k (W/m.K)
Rigid foam	0.026
Glass Fiber	0.043
Blanket	0.038
Cotton	0.06
Sawdust	0.06
Straw	0.09
Paper	0.18
Plaster / gypsum	0.48

2.3.3.4 Selective Coatings

The characteristic of coating that should select for absorber plate is determined by solar absorptance,α and emittance,ε of the material. According to Gilani, 2007, the objective to select coating for absorber plate is to achieve maximum absorptance,α and minimum re-emittance,ε so that the ratio of performance factor,α/ε is a maximum. The flat black paint is selected for coating because it is locally available and cheap compare to Black Nickel or Black Chrome plating.

Table 2.4: Performance ratio for selected coatings

Material	Absorptivity, α	Emissivity, ε	Performance Factor, α/ε
Black chrome on copper	0.95	0.12	7.92
Nonmetallic black surfaces: carbon	0.92	0.94	0.98
Flat black paint	0.97	0.86	1.13
Gray paint	0.75	0.95	0.79

2.4 Biomass Incinerator

Open fire is often giving 90% efficiency in work of turning wood into the energy. But only a small proportion, from 10% to 40%, of the release energy make into pot [7]. It is not appreciably help the stove to use less fuel by improving the burning efficiency. But, by improving the heat transfer efficiency can make a large different.

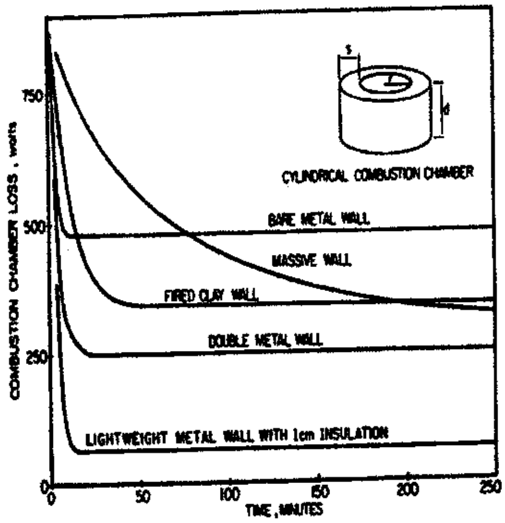
In improving the fuel efficiency of a stove thus requires attention to a number of different factors that are:

1. Combustion Efficiency: so that as much of the energy stored in the combustible as possible is released as heat.
2. Heat Transfer Efficiency: so that as much of the heat generated as possible is actually transferred to the contents of the pot. This includes conductive, convective, and radiative heat transfer processes.
3. Control Efficiency: so that only as much heat as is needed.

2.4.1 Heat loss thru Wall

When heating begins, the walls of the stove are cold. With time they warm up at a rate determined by their mass and specific heat as discussed above. Lightweight walls have a low thermal inertia and warm quickly. Thick, heavy walls warm more slowly. Heat loss from the combustion chamber is determined by how quickly these walls warm and subsequently how much heat the wall loses from its outside surface. This is shown clearly in figure 2.5 below.

The thicker the wall the more slowly it warms. Although a thick wall of dense high specific heat material may have slightly lower heat loss than a thinner wall after several hours, it takes many hours more for the eventual lower heat loss of the thick wall to compensate for its much greater absorption of heat to warm up to this state. Thus, it is always preferable to make the solid (non-insulator) portion of the wall as thin and light as possible. Additionally, the use of lightweight insulates such as fiberglass or double wall construction can dramatically lower heat loss.



Source: BIOMASS STOVES: ENGINEERING DESIGN, DEVELOPMENT, AND DISSEMMINATION, Samuel F. Baldwin, Princeton University

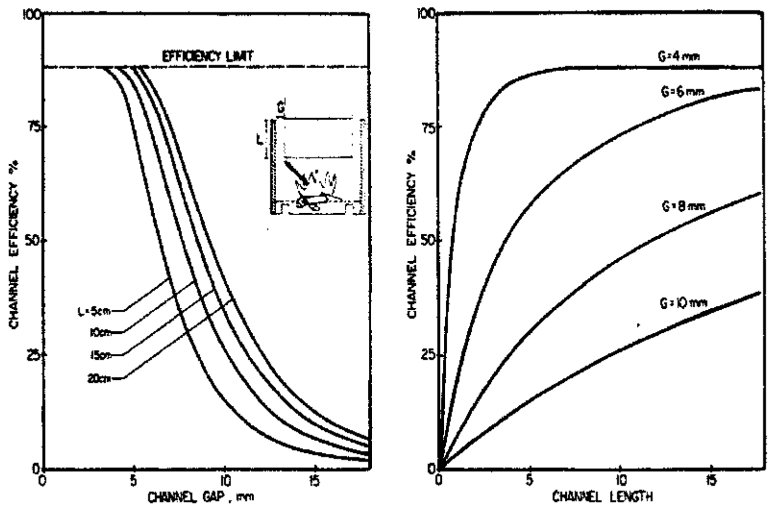
Figure 2.5: Heat loss into and through combustion chamber of varying material as a function of the time elapsed.

2.4.2 Channel Size and Channel Length

Sam Baldwin in his Biomass Stove: Engineering Design, Development, and Dissemination (1987) figure out on how the channel size between pot and pot skirt, firepower and efficiency are related. Here are few examples:

1. A 1.7 kW fire with a channel gap of 6mm that forces hot flue gases to scrape against the pot for 15 cm will be about 47% efficient.
2. A 4kW fire with channel gap of 10 mm that force heat to scrape against the pot for 15 cm will be about 35% efficient.
3. A 6kW fire with a channel gap of 12mm that force heat to scrape against the pot for 15 cm will be about 30% efficient.
4. A 8kW fire with a channel gap of 14 mm that force heat to scrape against the pot for 15 cm will be about 26% efficient.

From the example above, it is clearly that decreasing the gap channel will increasing the heating efficiency. The efficiency of heating of pot with the various gap and length of pot skirt and pot is clearly shown in figure 2.6 below.



Source: BIOMASS STOVES: ENGINEERING DESIGN, DEVELOPMENT, AND DISSEMMINATION,
Samuel F. Baldwin, Princeton University

Figure 2.6: Channel efficiency with various channel gap and channel length.

CHAPTER 3
METHODOLOGY

3.1 Procedure Identification

Initially, the project is about designing and fabrication of the hybrid solar-biomass drier for crops. The flow chart of the project is shown in figure 3.1 below.

The project will started with some research in solar energy and biomass basic. The research then is going deeper in finding the design of the system by having the theoretical calculation. Then the design process started with the sketch of the system. After having and material selection, the 2D drawing will be done by using AutoCAD Software and then it followed the 3D drawing by using CATIA software.

The project then is continued by fabrication process where the real hybrid solar-biomass drier for small amount of crops is fabricated by using the selected material as per design.

The model of hybrid drier then is tested to see the performance on three types of crops. The analysis is done to get more picture of the overall performance of this hybrid solar-biomass drier system.

3.2 Tool/Equipment Required

Tool and equipment that being considered for this project are as follows:

- AutoCAD and CATIA Software
- Mechanical tool for fabrication
- Mechanical laboratory
- Testing equipments

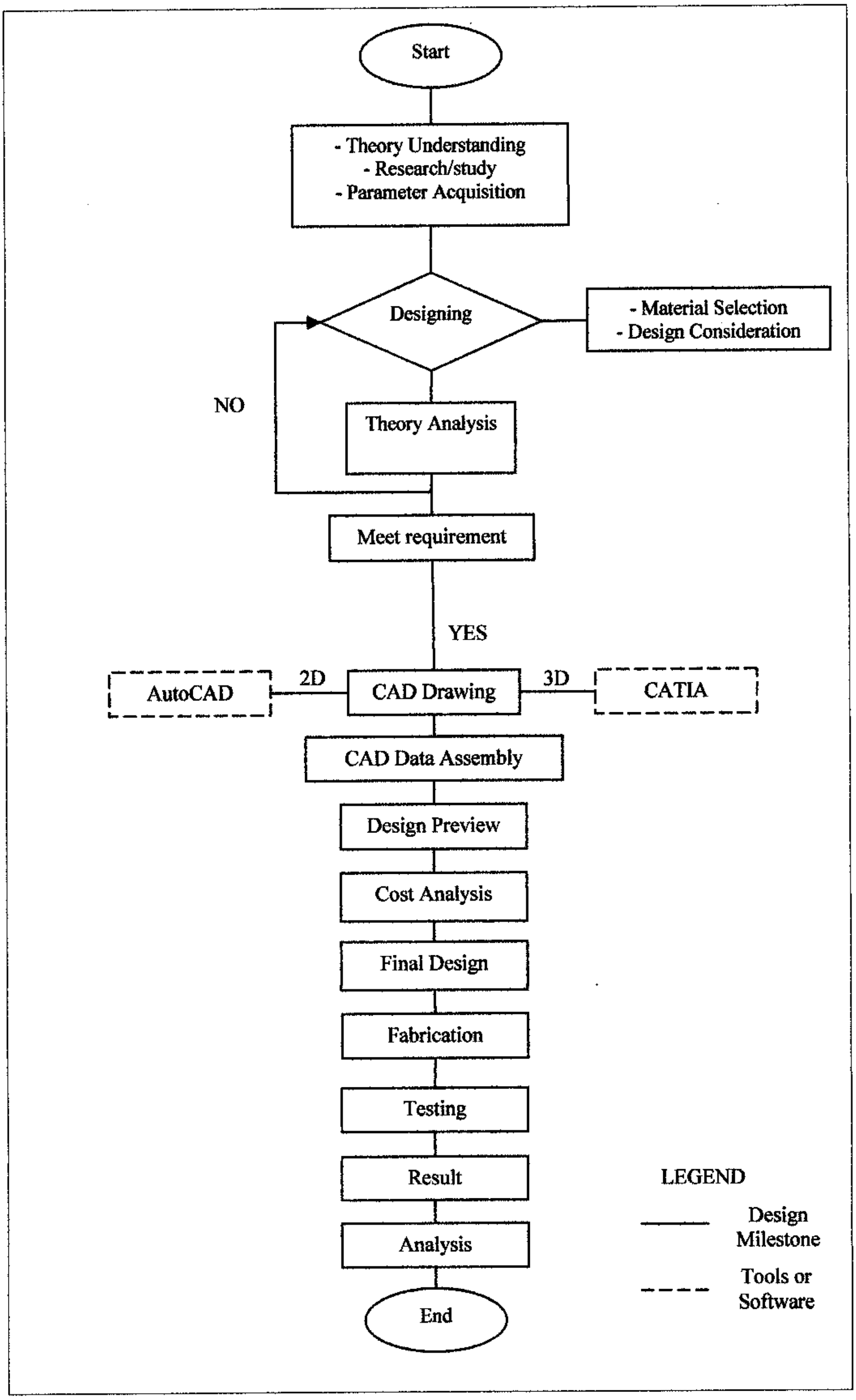


Figure 3.1: Project Flowchart

3.3 Designation of Hybrid Drier

The project is continued with the designing phase the hybrid solar-biomass drier to be used in solving the problem of drying. It also will show the design parameter that is need for the crops drying process.

3.3.1 Concept Idea

This hybrid system will be used solar energy and biomass energy separately. In this system, the solar energy is used when available and biomass is used in vise versa conditions that are in early morning, late evening, cloudy day and at night.

In this solar-biomass designation, the medium that is used in drying process is air. The air will be heated rather by solar collector or biomass incinerator. The heat from the biomass incinerator is getting from the direct burning of biomass that is wood shaver.

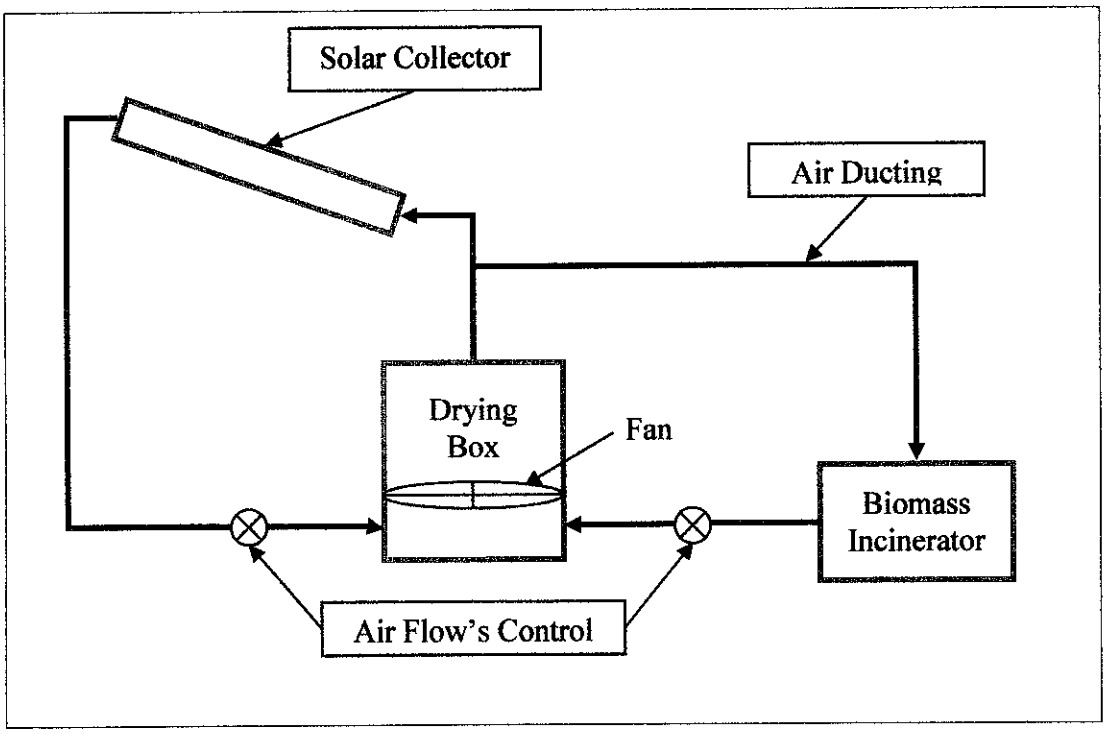


Figure 3.2: Schematic diagram of solar biomass hybrid dryer.

The hybrid design is using three major components that will be used that are solar panel for collecting the solar heat energy, biomass incinerator, and lastly is the crops drier box. This schematic diagram of the hybrid drier system design is shown in figure 3.2 above.

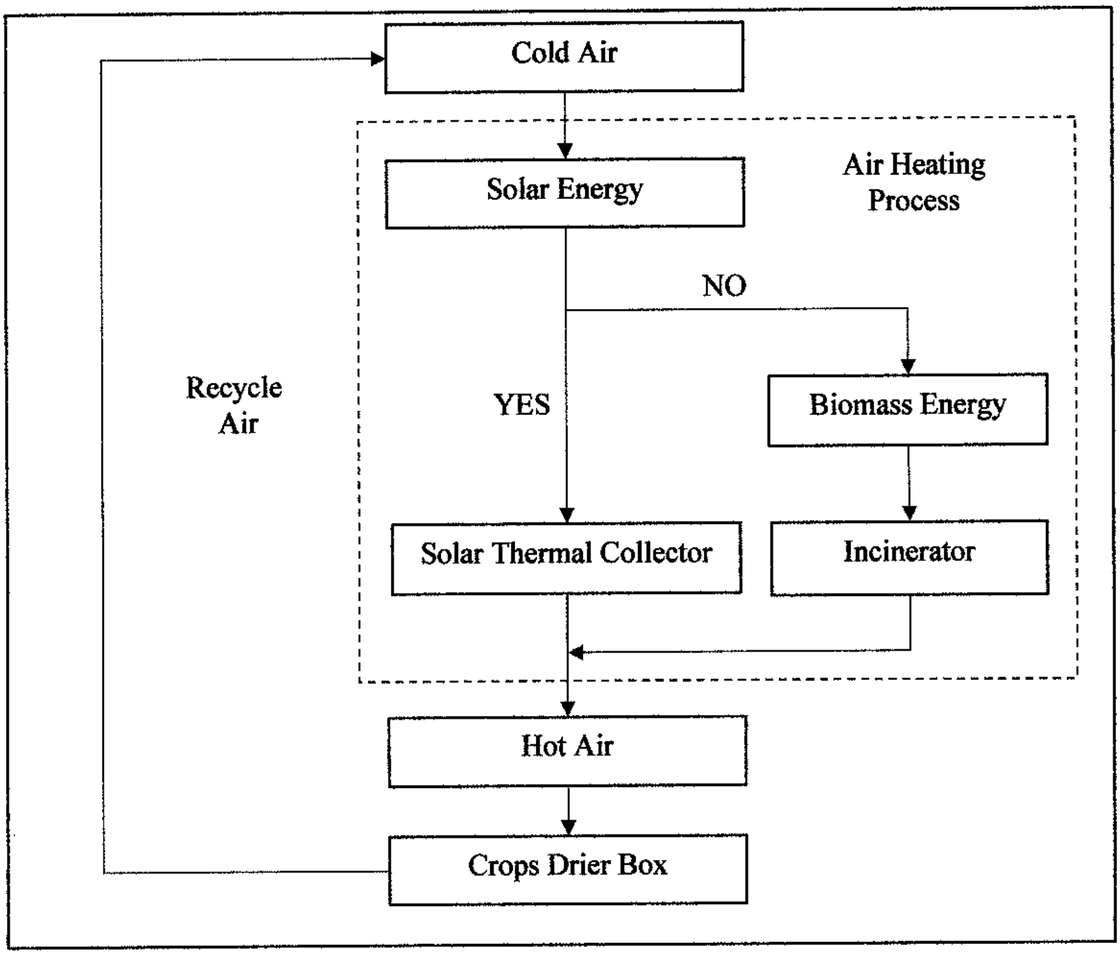


Figure 3.3: Hybrid Solar-Biomass Hybrid Drier Flow Diagram

3.3.2 Process Flow

The total process of the hybrid solar biomass drier can be present with the diagram as figure 4.2 above. This hybrid drier is work to dry the crops using the heat from the sun. While there is no present of sun, the heat will be produce by the biomass incinerator.

3.3.3 Design Calculation

The drier parameter is calculated using one type of crop sample that is tapioca. The hot air needed to remove the moisture of the 5 kg tapioca is calculated from step below based on Saber Chemkhi, Fethi Zagrouba and Ahmed Bellagi, in their desalination of "Drying of Agricultural Crops by Solar Energy" [8].

This calculation is based on the hypothesis that are the condition of air is taken from the average on one day on February 15, 2008 at Ipoh, Malaysia as shown in Appendix A. Because of the solar energy cannot be collected for whole 24 hours, the condition has been split into two that is on day and on night. On day which considered from 9 AM to 5 PM, the average condition of air is 30°C with the humidity of 60%. While on the night which considered from 5 PM to 9 AM, the average condition of air is 25°C with the humidity of 80%.

The sample has having a moisture content of 80%. In order to have a good condition for a long storage, the moisture content must be reduce. In this calculation the tapioca moisture content will be reduce from 80% to 15%.

In the day time, from the equation (2.5), in order to reduce the moisture content as state above, the mass of water to remove from the tapioca is ma=3.82 kg. By looking the Carrier Psychometric Chart no 1 (figure 3.4), the ambient air at T_a=30°C, RH 60% is heated to T_p=55°C then RH is become 17%. Then the heated air is used to remove the moisture of the sample until equilibrium RH of 90% the temperature is reduce to T_c=31°C. The humidity ratio will change from w = 0.0262 to w = 0.0160 where the humidity ratio of this process is 0.0102.

From the equation (2.9), the volume of air that is needed for drying 5 kg of tapioca is V_a = 326.89 m^3. By using alternative calculation from equation (2.10), Va = 333.16 m3. By taking the average, the volume of air needed is Va = 330.03 m^3.

This drier has to be design to drying the 5 kg of crop in 24 hour time. So, in 24 hours, the volume flowrate of the air is $\dot{V}_a$ = 3.81x10^{-3} m^3/s or 66 m^3/kg and the mass flowrate of hot air needed is $\dot{m}_a$ = 4.44x10^{-3} kg/s. Suppose the density of the tapioca is 1.5x10^3 kg/m^3, with the mass of 5kg, the volume of the tapioca is 3.0x10^{-3} m^3. The required air flow across a unit volume of tapioca is 3.81x10^{-3}/3.0x10^{-3} per second or it is about 1.3 complete air changes in the food bed per minute.

The bed of drying food is chosen to be x ≈ 0.01m, so the resistance to the air flow will be in minimum. The bed area will be 0.3 m^2.

In the night, the ambient air is 25°C with the humidity of 80%. By heating up until 55°C, it will give the same line as removing water in day time. So, the Δw is same and make the volume flowrate and mass flowrate is same.

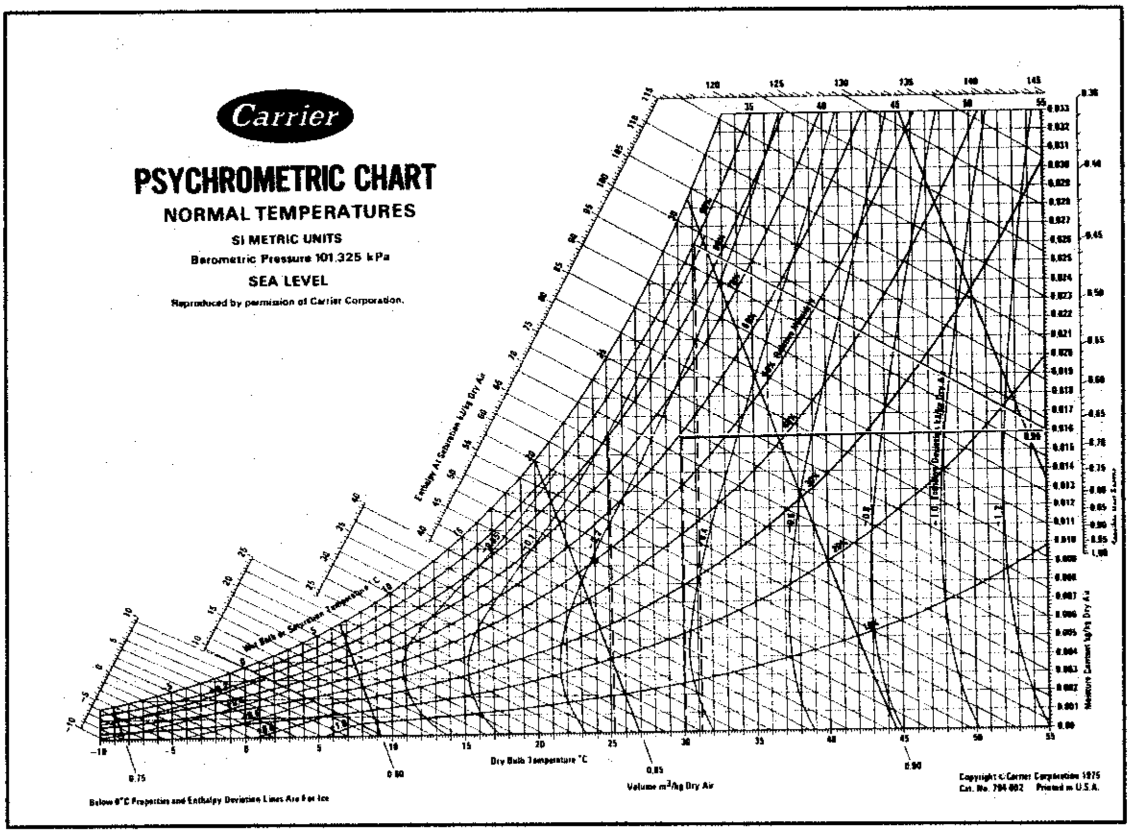


Figure 3.4: Drying process line on day time (red line) and on night time (yellow line) on the psychometric chart.

3.3.4 Solar Air Heater Collector

In order to heat up the air, the solar air heater is used. With the condition of air needed is $\dot{m}_a$ = 4.44x10^{-3} kg/s to be heat up from 30°C to 55°C, the heat energy needed is calculated from equation (2.15) that is 109.19 W.

Assuming the solar collector is flat plate collector, ambient temperature is 30°C, sky temperature is 10°C and solar radiation falling to the surface is 600W/m^2. The solar plate collector will used one single glazing.

The selected parameter is selected by looking which is the best parameter. For this solar collector the selected parameter is:

Cover plate: single glazing.

- Glass Absorbance, a = 0.13
- Glass transmittance, t = 0.85
- Emissivity, e = 0.83

Absorber plate: Aluminium painted black

- Absorbance, a = 0.97

By simplify the equation (2.12) and equation (2.13) at chapter 2, the energy balance equation is become

$$q''_u = \alpha_{gs} (G_{gs}) + \alpha_{ap,s} (\tau_{g,s}) G_s - q''_{conv,o} + q''_{rad,g\text{-}sky} \qquad (3.1)$$

From the equation above, the energy useful from flat plate solar collector per area is 332W/m^2 and having the efficiency of 47%. As the needed energy is 109.19 the area of solar collector is around 0.4 (0.5 x 0.8) which give heat energy of 132.8W. This heat energy is sufficient for used in drying the crops.

3.3.5 Incinerator

While in night, the incinerator is used to heat up the air. The condition of air needed is $\dot{m}_a$ = 4.44x10^{-3} kg/s to be heat up from 25°C to 55°C, the heat energy needed is calculated from equation (2.15) that is 130.85 W.

By taking the design is mostly like the set of stove (incinerator) and pot (air heating pot), the gap and length of the channel between stove wall and heating pot is having a highest efficiency. For this design, the gap taken is 8mm and the length is 100mm. From figure 2.6, as per plot by Samuel F. Baldwin in his book, with this channel design, it will give the efficiency around 40%.

The body of the incinerator will be using the lightweight metal with 10mm insulation, from figure 2.5; it will give combustion chamber heat lost around 20%.

Assuming the biomass used for burning is wood shave. From the experiment, the heat useful in the wood shave is for heating is around 6000kJ/kg. With the effecieny of the burner is 40% and heat loss is 20%, the energy collected by heating pot is 1920 kJ/kg. In hour, it will give 533.33 W/kg. In order to gain the heat as 130.85W, the wood needed to burn is about 0.245kg per hour. The actual wood rate for firing is being determined in the testing period.

3.3.6 Drying Box

From the calculation at part 4.3, the drying bed for drying process will be about 0.01m. With 5kg of tapioca, its volume will be about 3.0x10^{-3}m3. So, the area of drying bed will be 0.3 m^2 or 0.5m x 0.6m. The dimension of drying box will be about 0.7m x 0.6m x 0.5m. The drying box will be built using the plywood due to easy to fabricate and available in the market.

3.3.7 Drawing

As per design, the drawing of the hybrid drier is done by using an AutoCAD software for producing the 2D drawing and CATIA software in producing the 3D drawing. The drawing set of the hybrid drier is shown in APPENDIX C.

3.4 Fabrication of Hybrid Dryer

In this topic, it covers the fabrication process of the solar-biomass hybrid drier for crops. All the materials, tools and processes are described in fabricate the hybrid drier unit that has been design in previous chapter.

3.4.1 Fabrication Process

Fabrication process of this hybrid dryer unit is started with the material gathering. As per design, the material such as wood, aluminium, metal sheet and polyvinylchloride (PVC) are the most used for this fabrication process.

This fabrication process divided in to four (4) main areas that are drying box as known as drying chamber, solar air heater panel, incinerator and piping. The other area is its base that is optional for mobilizing purpose.

3.4.2 Fabrication of Drying Box

The body of the drying box for this hybrid drier is made from the plywood. The specification of the plywood used is 0.3 inches thick and it is 3 layer rating. The plywood is cut in dimension as per design as there are 8 pieces of cut plywood of base, 2 sides, back, top, front, and 2 for door. The plywood is cutting by using a handy plywood saw powered by electricity.

Before the plywood sheet is combining together, the one of the edge of 4 sheets of plywood that is base, top and sides is attached with the 1"x1" of wood beam as shown in figure 3.5a below. The holes for piping are made also before combine together in making the process became easy.

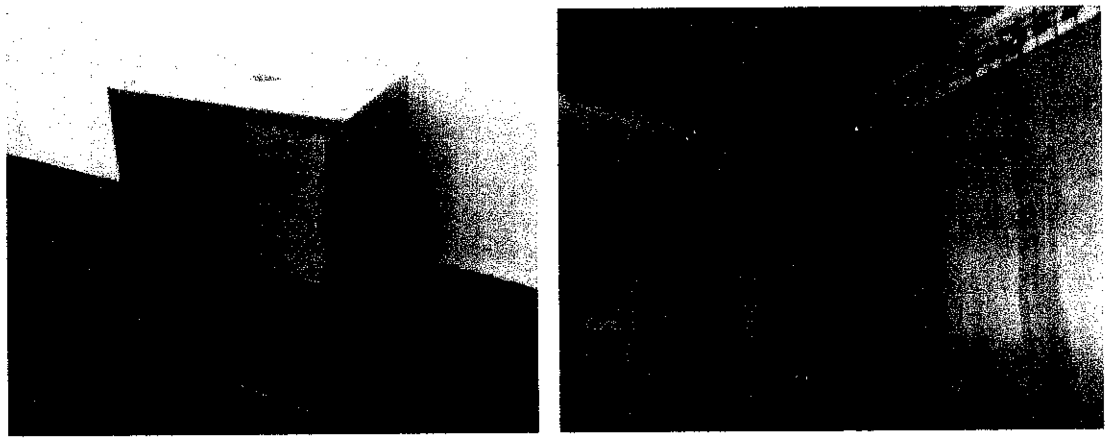


Figure 3.5: a) The edge of the box's body is attached with wood beam in order to avoid curving also for the door hinges. **b)** The holes are made first before the plywood is attached together. **c)** The plywood is attached using the L-beam with bolt and nut.

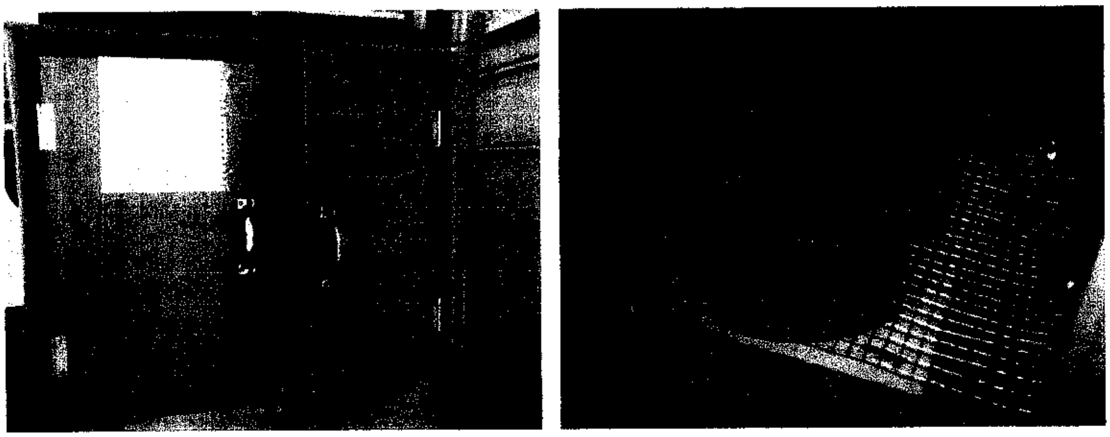


Figure 3.6: a) The hinges are used to attach the door and the door is attached together with the holder. **b)** The fan is attached inside the box with the 0.1 inch plywood with the shape of the fan. **c)** The wire mesh as a place for crops or foods for drying.

The plywood sheet that is combining by using an L-metal beam tied together by bolt and nut. See figure 3.5b above. The door then is attached to the box with hinges. Inside the box, the fan is attached at the bottom part. The 0.1 inch plywood is cut into the shape of fan in order there is no air current through the side of fan. The wire mesh also is put above fan as a crops or foods place for drying. See figure 3.6.

3.4.3 Fabrication of Solar Air Heater panel

The solar air heater panel is built with the wood and aluminum sheet as a main material. The base of this panel that is made from plywood is attached with the wood beam. The side wall of the panel is also attached with the wood beam as the skeleton of this panel. It can be used for holding the glass. The holes of the side as for piping system are made before it is attached with the base using a nail.

As the requirement in designing period, this panel is built with the aluminum absorber. This absorber (aluminum) is painted with the matte-black as reducing the reflectivity. This absorber than is attached to the panel's body after installing the shredding paper as the insulation underneath the absorber.

The divider walls for the air flow path is installed by attach it with the absorber using a rivet. The glass then is put above the panel body by adding the silicone between the glasses with the body also with the divider walls to make sure it has no air infiltration.

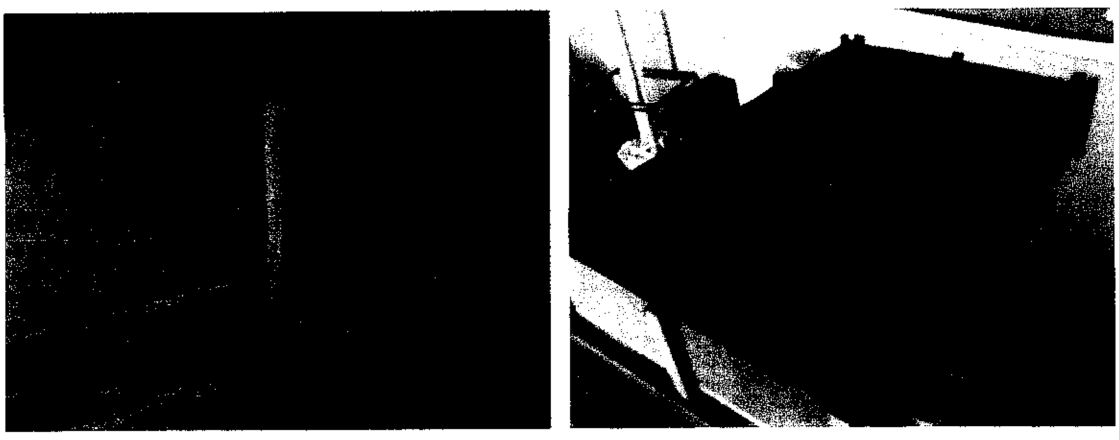


Figure 3.7: a) The wood beam is attached with the base and the wall as the frame of solar heater panel. **b)** The matte-black painted aluminum absorber.

3.4.4 Fabrication of Incinerator

The incinerator is build with the metal. The drum is used for the body and it is cut as the desire shape as in drawing by using the metal cutter. Inside the incinerator body is placed a set of metal as the part (where the wood is burned) of rocket stove.

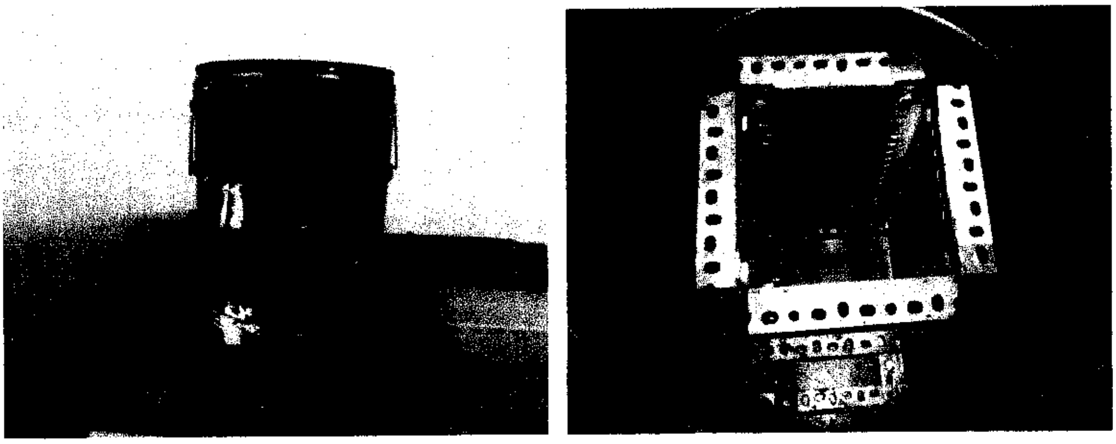


Figure 3.8: a) The drum is used as the incinerator body. **b)** Inside the incinerator body: the rocket-stove configuration.

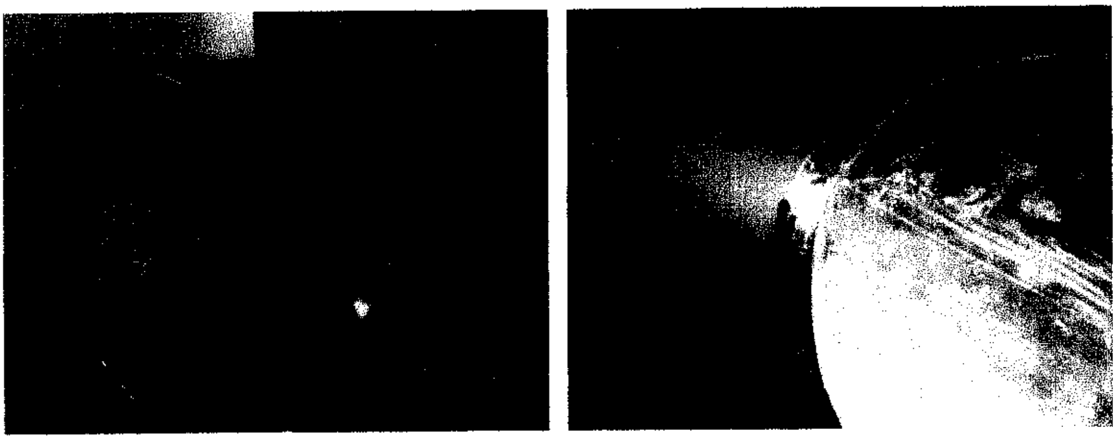


Figure 3.9: a) The heater pot in configuration. **b)** The gap between PVC's pipe and heater pot is having an insulation to reduce the heat conduction.

The heater pot as a heat exchanger in this system is made from the aluminum sheet for the wall and metal sheet for the base. The connection of heater pot and PVC's pipe is having a special component in between that is called insulation in order the convection of heat from the pot to the PVC's pipe is reduce.

3.4.5 Fabrication of Piping System

The piping system is made using the polyvinylchloride (PVC), 3 inch diameter pipe. The pipe is cut using the PVC saw as the desire length. It is connected with the elbow for 90 degree turn and a tee for 3-junction. All the connection made is glued by using PVC's glue.

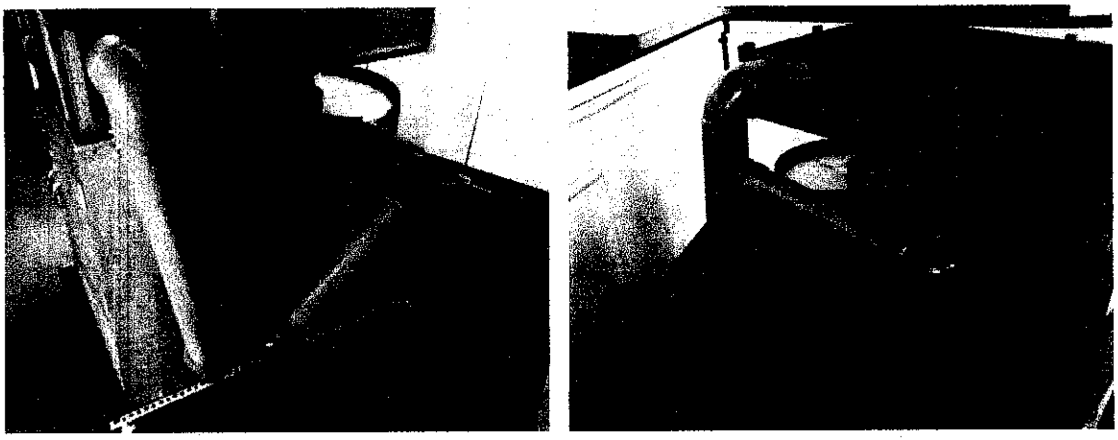


Figure 3.10: a) The PVC's pipe and elbow in piping system. **b)** The 3-juntion that is using the tee as a component in piping system.

3.4.6 Fabrication of Hybrid Drier's Base

The drier can be fixed in one place. But for this project, the dryer is build with mobilizing ability. The base then is build in order to make the drier having the mobilizing ability. The base is build with by using the holes' L-metal beam, bolt and nut and wheel. The beam is cut with the metal cutter as the desirable dimension and it is joint using a bolt and nut. The wheel then is placed on the four edge of the base.

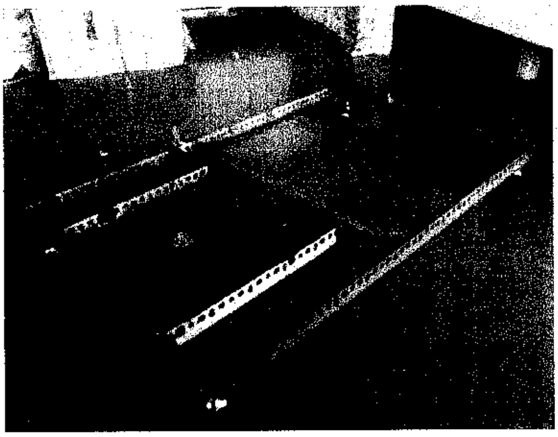


Figure 3.11: The base of the hybrid dryer that can make it become mobilizing dryer.

3.4.7 Assembly

After finishing the part, the fabrication is finished by assembly the part. The drying box is put above the base also with the incinerator. Then the solar heater panel is put above the drying box and screws it. Lastly, the piping is attached as to complete the system.

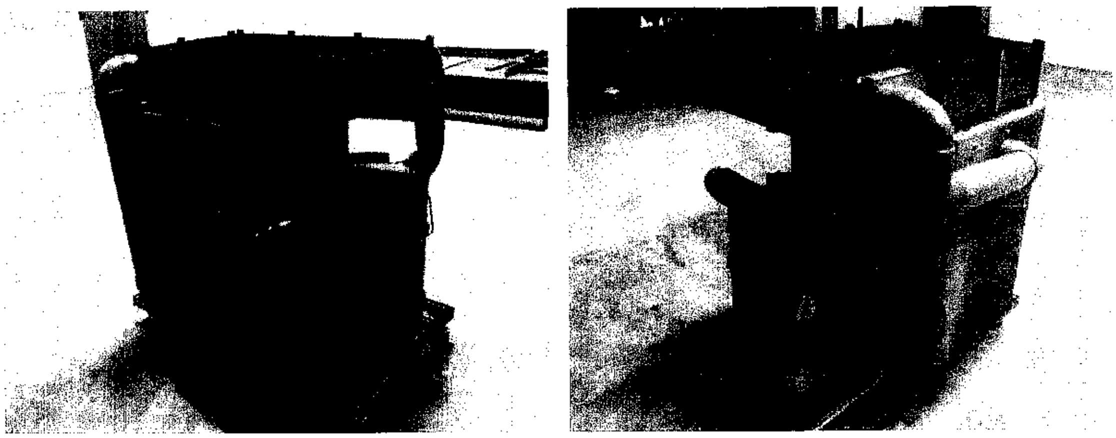


Figure 3.12: The assembly configuration of hybrid solar-biomass drier from 2 different angle of view.

3.5 Testing of Hybrid Drier

This topic will goes to the discussion on the testing matters of the hybrid of solar-biomass dryer. The equipment, method and data will be provided as the information of this final year project.

3.5.1 Method

The testing is started with the preparation of the data collection equipment, hybrid drier itself, and the space of testing. For the place and it space, the testing is conducted in the wide sky area which is the radiation of solar to the hybrid-drier from morning to evening is not interrupted by the trees or buildings. The equipment also must be prepare by arrange and attach it to the dryer. This will be discussed in section 3.5.2 and 3.5.3.

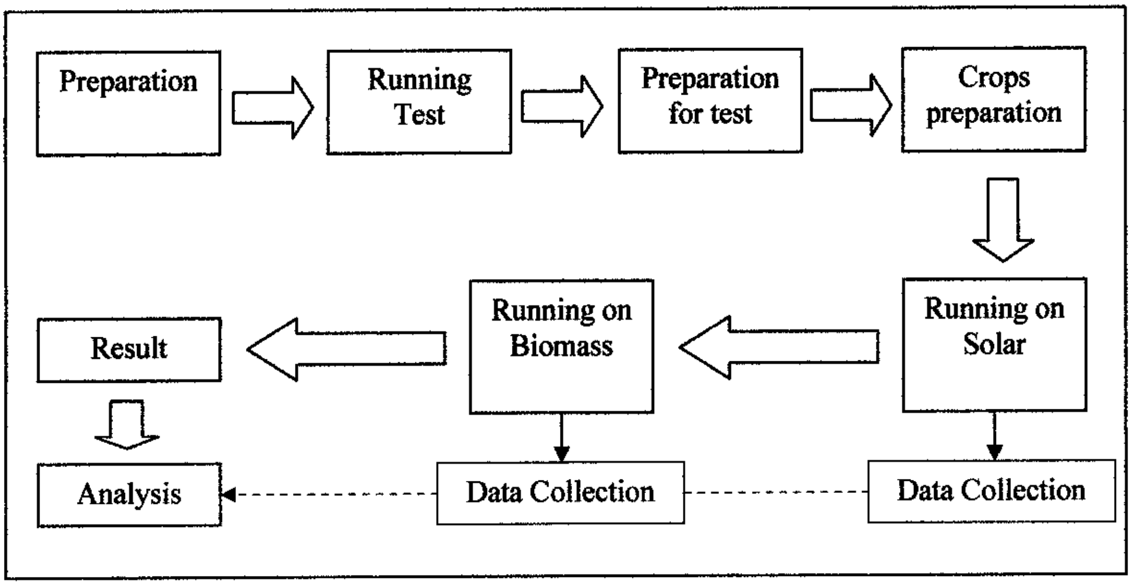


Figure 3.13: Method Use in Test Period

After all has been ready, the crops (potato is used in this testing) will be place inside the drying chamber, close, and switch on the fan. Before started, the crop is slice into thick slice. After the drying process is started, it will be monitored and after one hour period, the data will be collected.

3.5.2 Equipment

In this testing, temperature and humidity of air at outlet and inlet of drier, velocity and flow rate of the air, and the moisture content of the crop are the main data collected. The equipment must be fully ready for uninterruptable in data monitoring process.

The equipment used is as follow: temperature reading is using thermocouple attached to data logger, humidity by using humidity probe, velocity by using anemometer.

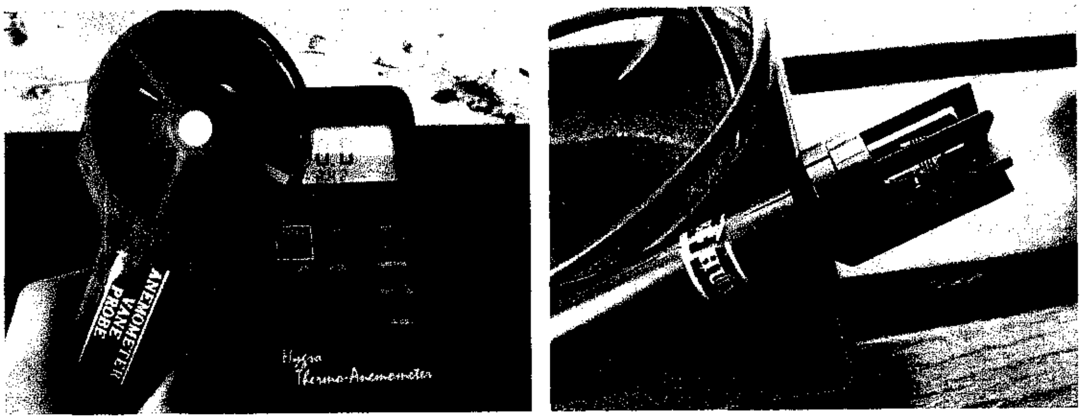


Figure 3.14: Hygro-Thermo-Anemometer with anemometer vane probe + temperature sensor (a) and humidity probe + temperature sensor (b)

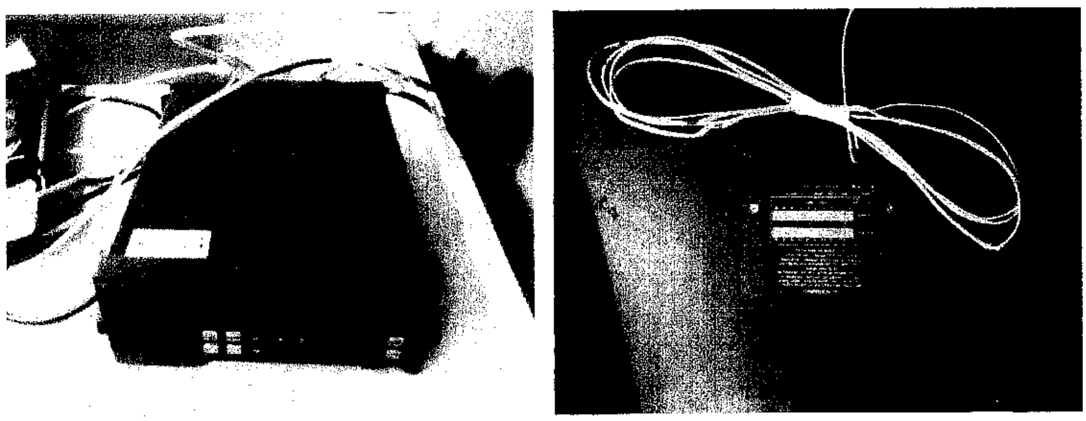


Figure 3.15: FLUKE Data logger (a) with its removable Universal Input Module (b) for using in determine the temperature

3.5.3 Equipment Arrangement

The equipment for the testing period is installed to the hybrid dryer especially the thermocouple at different place. There are 6 thermocouples installed and there are at inlet & outlet of the solar air heater, inlet & outlet of incinerator, and inlet & outlet of drying chamber. There are also 6 holes at the side of thermocouple respectively for velocity reading purpose. The hole is made for the velocity probe can take the reading inside the pipe. (See figure below).

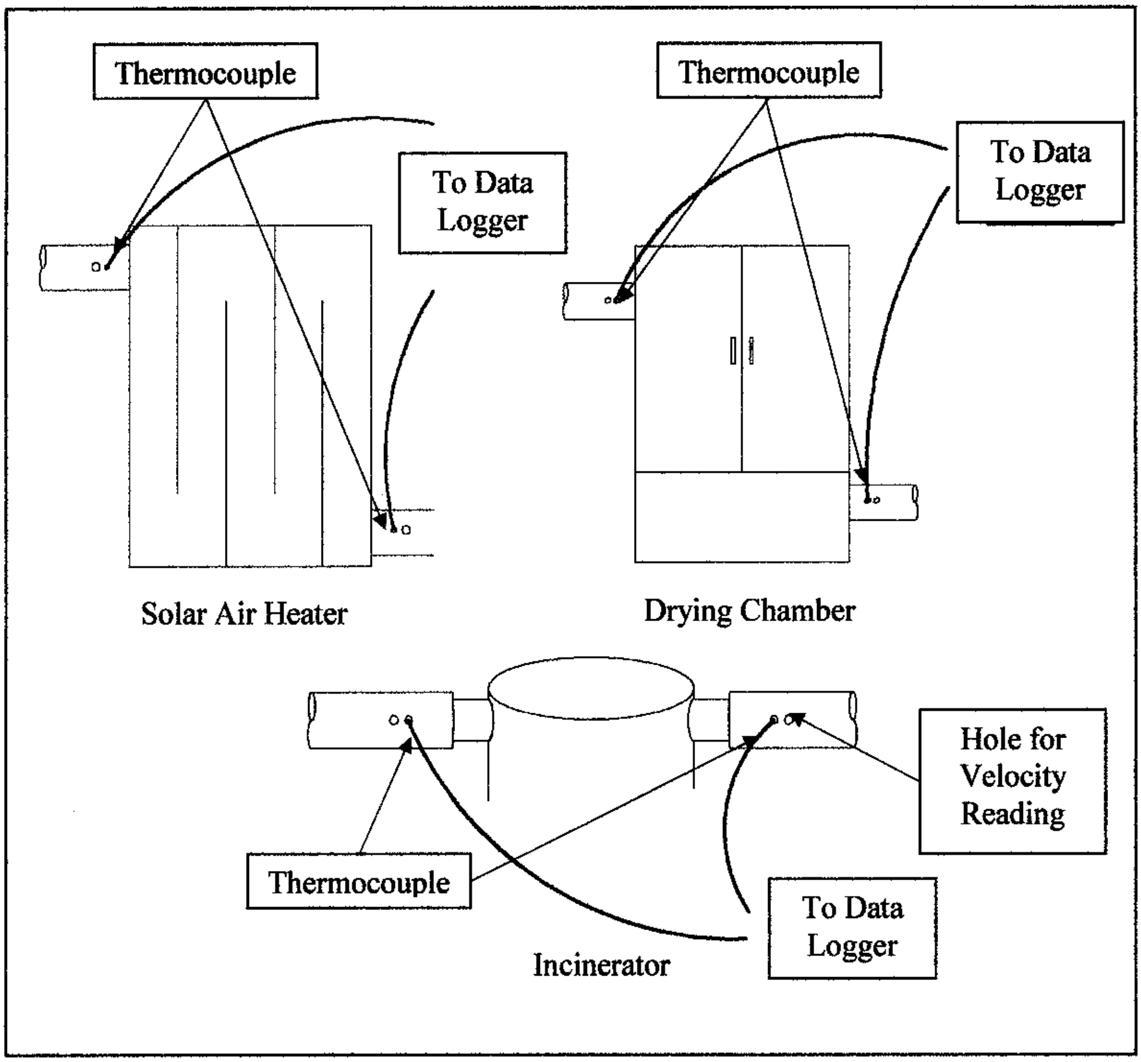


Figure 3.16: Thermocouples Attachement Configuration and Holes for Velocity Measurement Placement into Hybrid Dryer.

CHAPTER 4

RESULTS AND DISCUSSIONS

Drying or dehydration is the application of heat under a controlled After going through the testing phase, the data is collected and it is analysed to get the result of this experiment in this chapter. The testing is done on 13-14 September 2008 which is start from 11.00 am to 11.00 am on the next day.

4.1 Environment Condition

In the experiment, the condition of the environment data is collected. The data is then converted into graph and it is shown in figures below. From the two graphs below, it is shown that the condition of the experiment day is in good condition (clear sky). Until 4pm, the temperature is dropped and the relative humidity is going up due to cloudy condition. At night time, it shown that the temperature is low and the relative humidity is very high because the condition in that time is rainy. On the next day, in the morning, the relative humidity is drop but not much as it is a cloudy day.

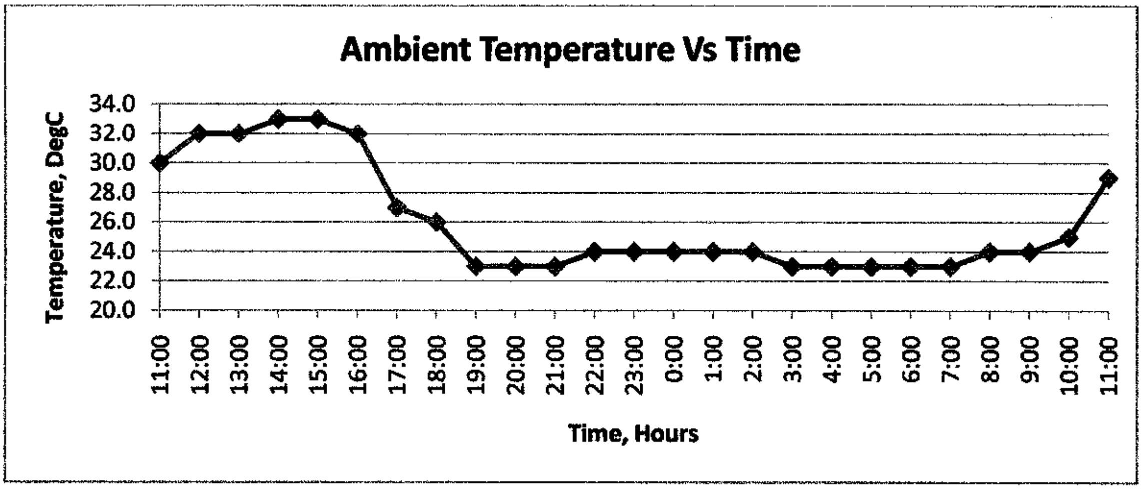


Figure 4.1: Graph of Ambient Temperature versus Time on 13-14 September 2008

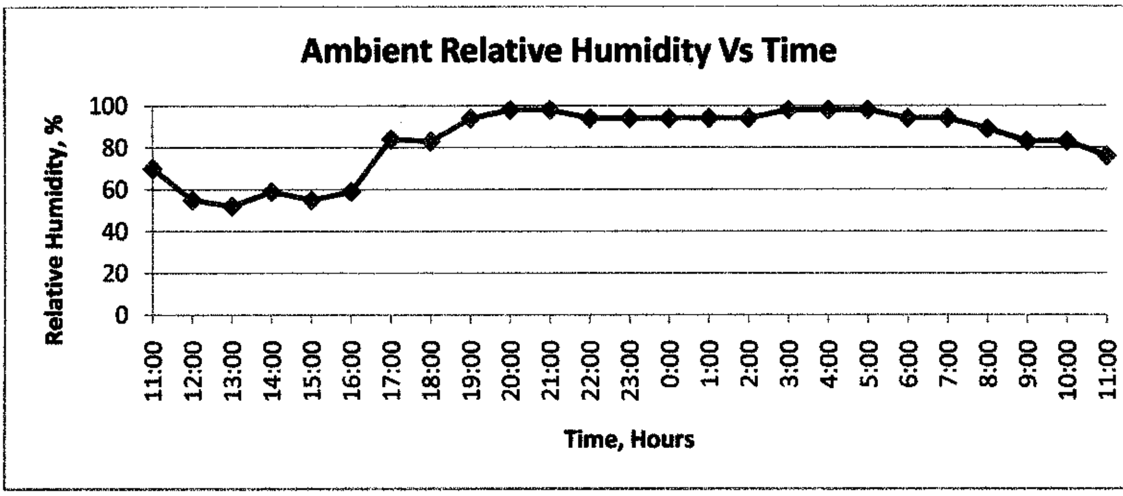


Figure 4.2: Graph of Ambient Humidity versus Time on 13-14 September 2008

From the two graphs above, it is shown that the condition of the experiment day is in good condition (clear sky). Until 4pm, the temperature is dropped and the relative humidity is going up due to cloudy condition. At night time, it shown that the temperature is low and the relative humidity is very high because the condition in that time is rainy. On the next day, in the morning, the relative humidity is drop but not much as it is a cloudy day.

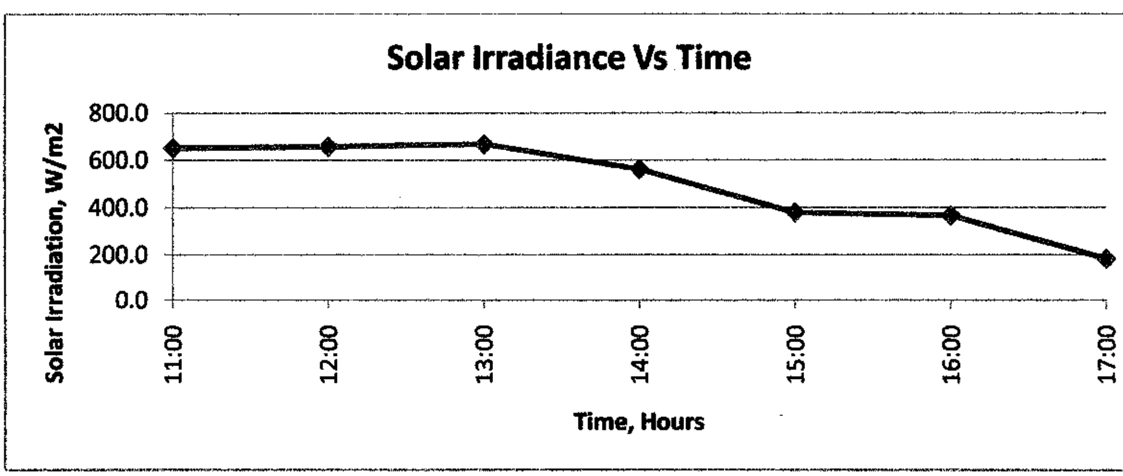


Figure 4.3: Graph of Solar Irradiation versus Time on 13-14 September 2008

For the solar radiation falling on the earth surface, the graph is shown in the figure 4.3. From that graph it is shown that at the evening, the solar radiation is falling. It is due to the weather which at that time it is cloudy. In late evening, the cloud becomes more dark and waiting for rain.

4.2 The Performance of Hybrid Dryer.

4.2.1 Solar Collector.

While the hybrid drier is running the testing with the mass flowrate of the air ($\dot{m}_a$) is about 4.94x10^{-3} kg/s from 11am to 6pm, the data of the temperature inlet and outlet of the solar air heater is collected. The different temperature is calculated in order to calculate the heat usefull that this solar air heater is collected using equation 2.15. The efficiency for this solar air heater is calculated using the equation below:

$$Solar\ Air\ Heater\ Effeciency, \eta = \frac{Q_{useful}}{Solar\ Radiation\ Falling\ on\ surface\ x\ Area\ of\ Collector} \qquad (4.1)$$

The result then is shown in table x below:

Table 4.1: Result of the performance of Hybrid Drier's Solar Air heater on 13-14 September 2008

Time	Inlet Temperature (°C)	Outlet Temperature (°C)	ΔT	Solar radiation (W/m^2)	Heat Useful (W)	Efficiency η (%)
11:00	41.2	59.6	18.4	651.5	91.42	35.08
12:00	43.5	64.5	21.0	657.4	104.33	39.68
13:00	41.6	58.0	16.4	668.2	81.48	30.48
14:00	41.3	60.5	19.2	562.0	95.39	42.43
15:00	39.2	51.9	12.7	380.1	63.10	41.50
16:00	36.0	41.8	5.8	366.8	28.82	19.64
17:00	34.8	38.5	3.7	184.8	18.38	24.86

From the result above, the average efficiency for this hybrid's solar collector is around 33 %. There is the lowest point of the percentage of its efficiency around 19 %. This is due to inaccurate reading taken at that time. When the reading of the temperature inlet and outlet of the solar air heater is taken, there is a time gap to take the solar radiation reading. With the fast movement of the cloud, this could be happen. The temperature reading is taken when the sun was covered by cloud and the solar radiation was taken when there is suddenly no cloud.

4.2.2 Biomass Incinerator

From 6pm to 11am on the next day, the experiment is running on the biomass incinerator. The wood is used as the fuel that is burned in the incinerator. The data of the temperature inlet and outlet of air that pass through the incinerator is collected. With the data of heat useful of wood burning, 4.4kW/kg, and the average fuel load of 150g per hour, the efficiency of the incinerator is calculated with the equation below.

$$Biomass\ Incinerator\ Effeciency, \eta = \frac{Q_{useful}}{Q_{Fuel\ Burning}} \qquad (4.2)$$

The result and calculated data is shown on table 5.2 below.

Table 4.2: Result of the performance of Hybrid Drier's Biomass Incinerator on 13-14 September 2008

Time	Inlet Temperature (°C)	Outlet Temperature (°C)	ΔT	Heat Useful (W)	Efficiency, η (%)
18:00	37.6	65.0	27.4	136.13	20.63
19:00	37.3	81.2	43.9	218.11	33.05
20:00	32.7	63.6	30.9	153.52	23.26
21:00	34.4	68.4	34.0	168.92	25.59
22:00	38.3	82.1	43.8	217.61	32.97

23:00	38.7	92.4	53.7	266.80	40.42
0:00	35.6	76.0	40.4	200.72	30.41
1:00	38.6	95.8	57.2	284.19	43.06
2:00	36.7	84.7	48.0	238.48	36.13
3:00	38.4	88.5	50.1	248.91	37.71
4:00	34.8	80.1	45.3	225.06	34.10
5:00	35.9	77.4	41.5	206.18	31.24
6:00	35.6	73.8	38.2	189.79	28.76
7:00	36.5	83.5	47.0	233.51	35.38
8:00	36.2	76.2	40.0	198.73	30.11
9:00	38.1	81.8	43.7	217.11	32.90
10:00	38.7	76.4	37.7	187.30	28.38

As for biomass incinerator performance, it is shown that the average useful heat for the system is about 211.44 W with average efficiency of 32%. This can show there are loses from the burning gas to air flow inside the heat exchanger. As the biomass incinerator is operate in the night, with the low ambient temperature that make a big different temperature, there is a big heat flow from the incinerator body to the environment which is mean heat lost. Then, the body of the biomass incinerator should be insulated as to reduce the heat lost through environment.

4.2.3 Piping System

In the experiment, the thermocouple is placed at the 2 point in each piping (one at outlet of energy source and one at inlet of the drying chamber). The data of that temperature is converted into graph and it is shown in figure 4.4 below.

As shown in the graph above, from 11.00 to 17.00 the heat source is from solar and the rest from biomass. There is a different in temperature from the drying chamber inlet and heat source outlet. It is clear that there is some heat loses to the environment especially in the night time where the ambient temperature is low. The piping system should be also insulated in order to reduce the temperature drop in piping system.

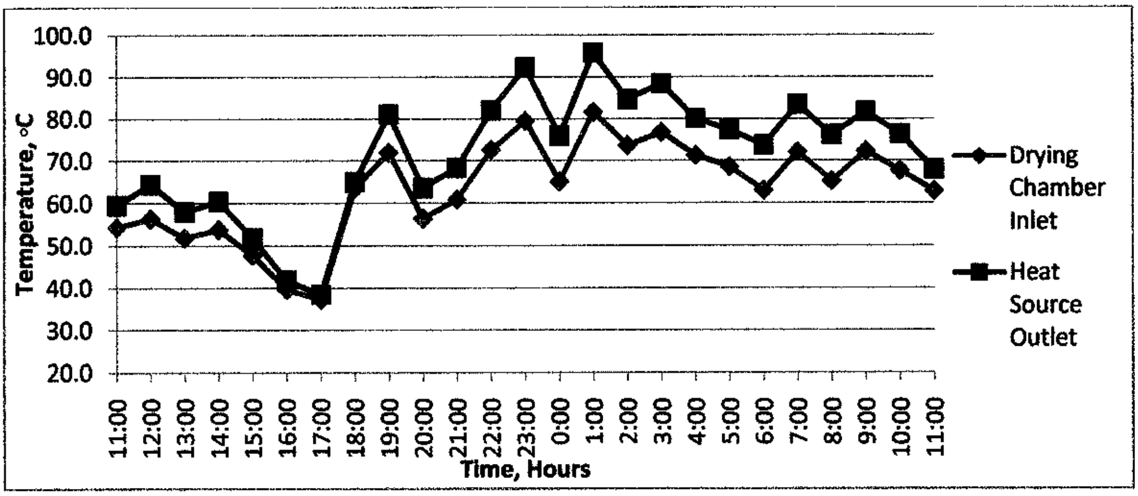


Figure 4.4: Graph of Temperature of Drying Chamber Inlet and Heat Source Outlet Temperature versus Time on 13-14 September 2008

4.3 Drying Operation

In the experiment, the crop used is slice's potato. The temperature inlet and outlet of drying chamber are shown in figure 4.5 below. The inlet temperature is influenced by the outlet of source energy. There are the different in inlet and outlet temperature of the drying chamber. This is happen due to the heat transfer process in drying where the heat energy is being used to evaporate the water from the crop.

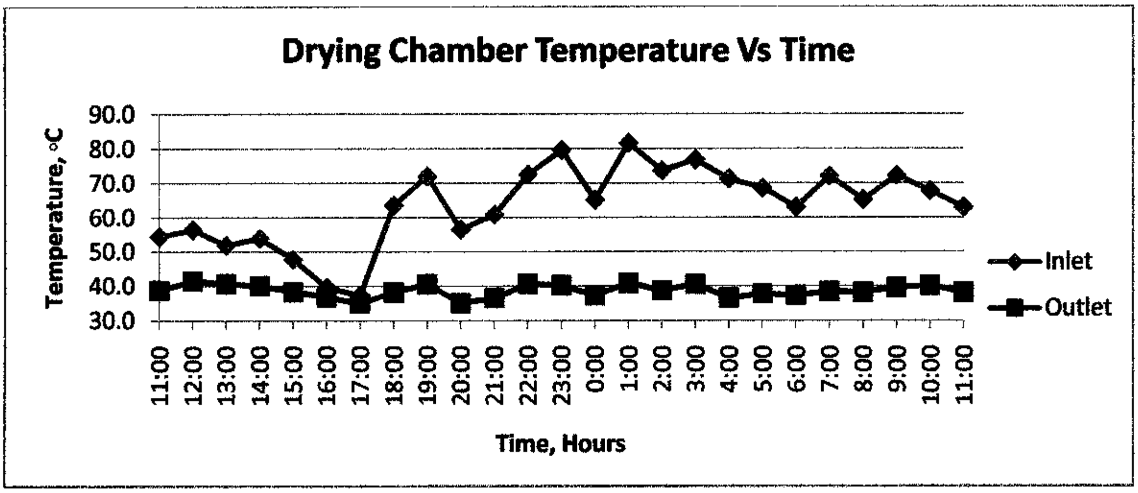


Figure 4.5: Graph of Inlet and Outlet of Drying Chamber versus Time on 13-14 September 2008

In the drying process, the moisture inside the crop is removed. By that principle, the weight of the crop is reduced. For this experiment, the weight of the slice's potato is reduced from 5 kg and it is shown in figure 4.6 below.

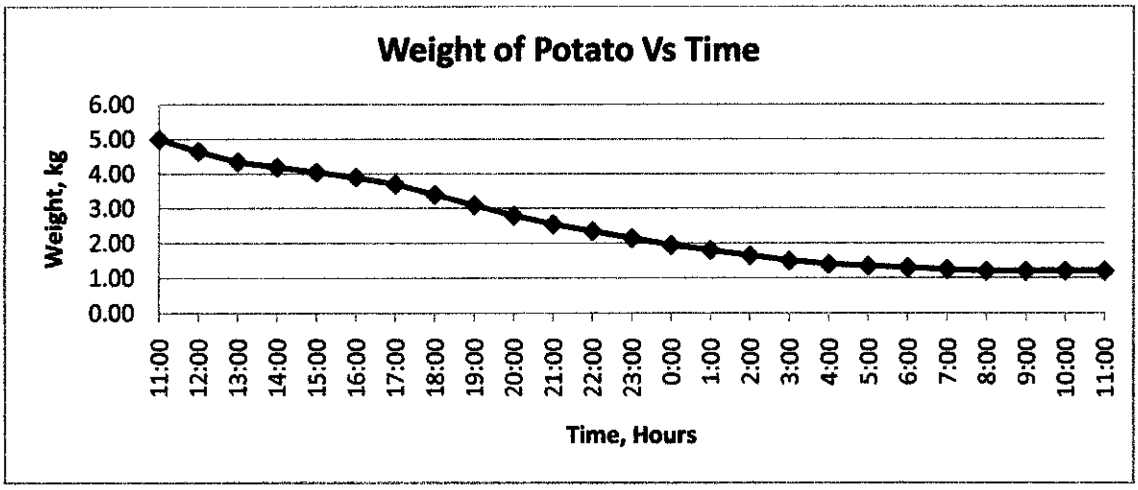


Figure 4.6: Graph of Potato's Weight versus Time on 13-14 September 2008

From this graph, the weight of potato start drop drastically but then due to low source of energy in the late evening, the process is becoming slow. After the half of experiment, the process become slowly as the moisture inside is less and hard to move due to resistance at crop's surface. At the last 3 hours, there is no change of the weight. From that, it is considered there is no moisture inside the crop anymore. In this case the moisture content of that potato is about 76%.

With the knowing the total moisture content of that crop, it is can be used to plot the moisture content graph of the process as it calculate by using equation 2.1. The graph is shown in figure 4.7 below. By that graph, the total moisture content from 76% is dropped every hour shown that water is evaporated due to drying process.

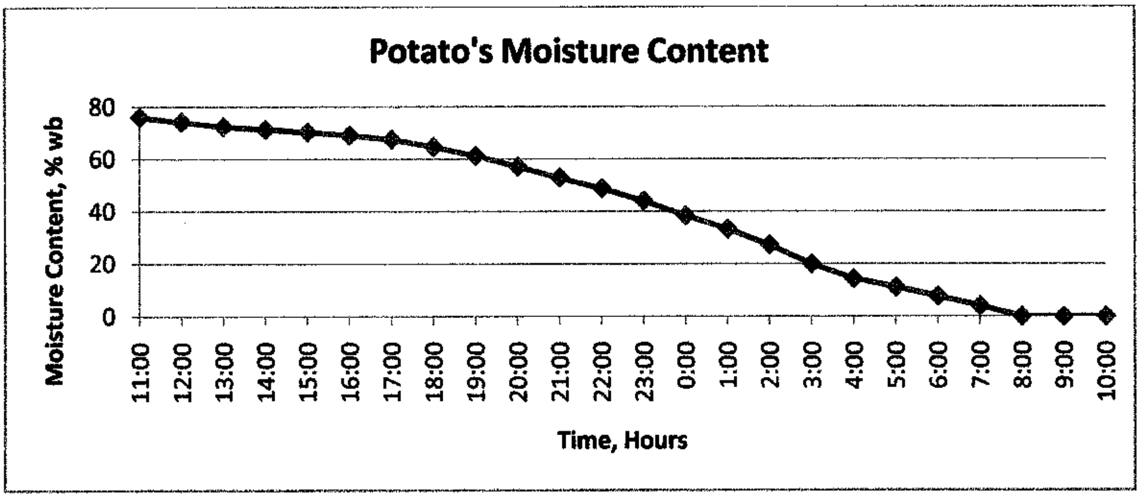


Figure 4.7: Graph of Potato's Moisture Content versus Time on 13-14 September 2008

The physical of the crop also will be change as the moisture inside is remove in the drying process. Definitely, after water has been removed, the potato is shrunken as been shown in figure 4.8 below.

The color of the potato also changes in certain area. As per state in Handbook of Poultry Feed from Waste by Adel R. Y. El Boushy, Antonius Franciscus Bernadus Poel, page 216, this is due to enzyme inside the potato that is called Tyrosinase which is acidic base enzyme. In the article written by Charles Kenneth Thinkler from the Chemistry Department, King's College of Household and Social Science, Kensington, he state the same reason why there is blackening or darkening on peeled potato when exposed with air that is caused by that acidic base.

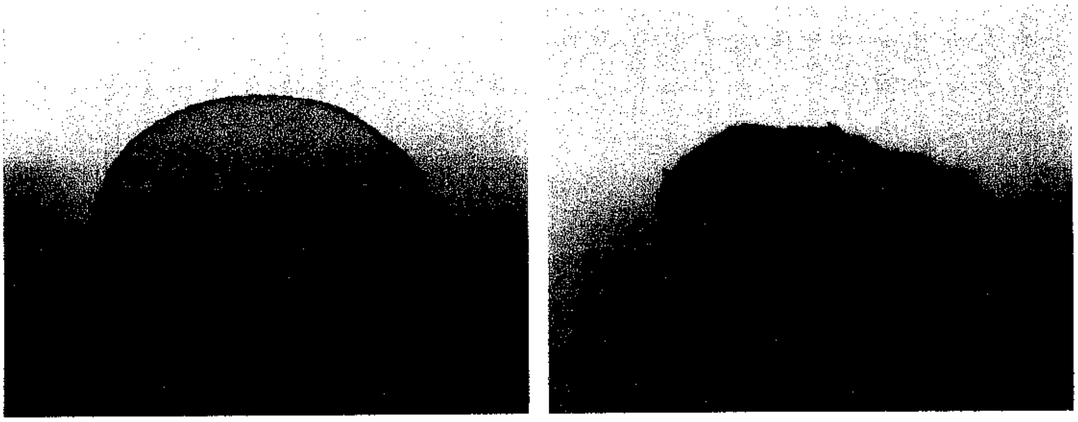


Figure 4.8: The picture of before dried potato slice (left) and after dried potato slice (right)

When this enzyme is exposed with air (oxygen) as the potato been peel or slice, the oxidation process is happen. Result from that reaction, there is a change of color. As the comparison to the open air drying, here are the pictures from homeschool experiment done by Justine [11]. It is show the effect of the certain food on open air drying.

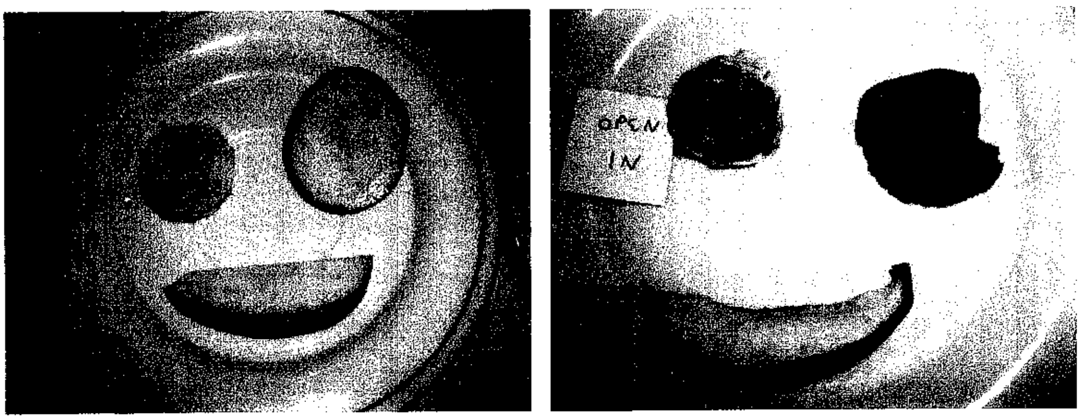


Figure 4.9: Food before the experiment (left) and food after 8 days exposed to open air drying (right)

In that picture as shown in the figure 4.9 above, the potato (upper right) is becoming dark as the effect of exposing the enzyme inside the potato with air.

CHAPTER 5
RECOMMENDATIONS AND CONCLUSIONS

The proposed project title can help in improvement of the crops drying system. The design and fabrication of this crops drier system will give the benefit to agricultural world.

By using theory calculation, the volume of dry air needed for dehydrating 5kg tapioca with moisture content is 80% to 15% is 746.1 m^3. By 24 hour time, the mass flowrate of air needed is 4.34x10-3 kg/s.

This crops drying equipment will used of 3 main elements that is solar thermal collector unit, biomass incinerator and dryer box with force flow of air that supported by fan. The material for hybrid solar-biomass drier is selected due to cheap and locally available. The design has been decided and the drawing is done and showed in the Appendix C.

The fabrication process has been done as the one more phase in this project. The project will be continue on testing and analysis test phase as the next requirement in this project.

The testing and analysis is also done. The hybrid drier has worked to drying the potato in day and night. It works in all conditions of weather such as rainy or cloudy. The potato has been dried to achieve the desire value of moisture content less than 24hour with the quantity of fuel usage is around 150g per hour for incinerator.

For the future work, the piping of this hybrid dryer unit should be isolated with insulation in order to reduce the heat loss and also to insulate the biomass incinerator body that can affect the fuel consumption. The additional device can be attached together with this hybrid drier unit such as mechanical device for controlling the fuel feeding for burning that would be more practically rather than using manual feeding especially when running in the night. To achieve maximum gaining from solar radiation, the solar panel can be attached with the control system that can move the solar panel to be perpendicular to solar radiation but it should be consider the cost and practicality. As the additional that come from result and discussion in this project, the crops especially potato should be treated with the salt solution in order to avoid the surface darkened.

As the whole conclusion, with full commitment towards completing the project tasks, this project is successful as it is meet the objectives of the project and also the working unit through hard work and good engineering judgment.

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APPENDIX A

Gant Chart - Project Milestone

Project Milestone for the First Semester of Final Year Project

20 Jan - 26 Jan	27 Jan - 2 Feb	3 Feb-9 Feb	10 Feb - 16 Feb	17 Feb - 23 Feb	24 Feb - 1 Mar	2 Mar-8 Mar	9 Mar - 15 Mar	16 Mar - 22 Mar	23 Mar - 29 Mar	30 Mar - 5 Apr	5 Apr - 12 Apr	13 Apr - 19 Apr	20 Apr - 26 Apr	27 Apr - 3 May	4 May - 10 May
Lecture Weeks Semester Jan 2008							Mid Sem Break	Lecture Weeks Semester Jan 2008							Study Week
1	2	3	4	5	6	7		8	9	10	11	12	13	14	
Topic Proposal		Preliminary Research		Research Work / Literature Review				[redacted]							
								Design Parameter							
										2D Drawing					
												3D Drawing			

11 May - 17 May	18 May - 24 May	25 May - 31 May
Examination Weeks		
1	2	3

Project Milestone for the Second Semester of 2-Semester Final Year Project

1 Jun 7 Jun	8 Jun 14 Jun	15 Jun 21 Jun	22 Jun 28 Jun	29 Jun 5 Jul	6 Jul 12 Jul	13 Jul 19 Jul	20 Jul 26 Jul	27 Jul 2 Aug	3 Aug 9 Aug	10 Aug 16 Aug	17 Aug 23 Aug	24 Aug 30 Aug	31 Aug 6 Sep	7 Sep 13 Sep
Semester Break							Lecture Weeks Semester July 2008							Mid Sem Break
1	2	3	4	5	6	7	1	2	3	4	5	6	7	
Fabrication Process									Testing and Analysis					
Incinerator									Preparation					
		Solar Panel								Testing				
				Drying Box								Analysing		
Incinerator Feeding System													Result	
					Assembly									
	Re-testing													
							Finishing							

14 Sep 20 Sep	21 Sep 27 Sep	28 Sep 4 Oct	5 Oct 11 Oct	12 Oct 18 Oct	19 Oct 25 Oct	26 Oct 1 Nov
Lecture Weeks Semester July 2008						
8	9	10	11	12	13	14
Result Finalizing						
Final result		Dissertation Preparation				

APPENDIX B

Weather Data – Ipoh, February 15, 2008

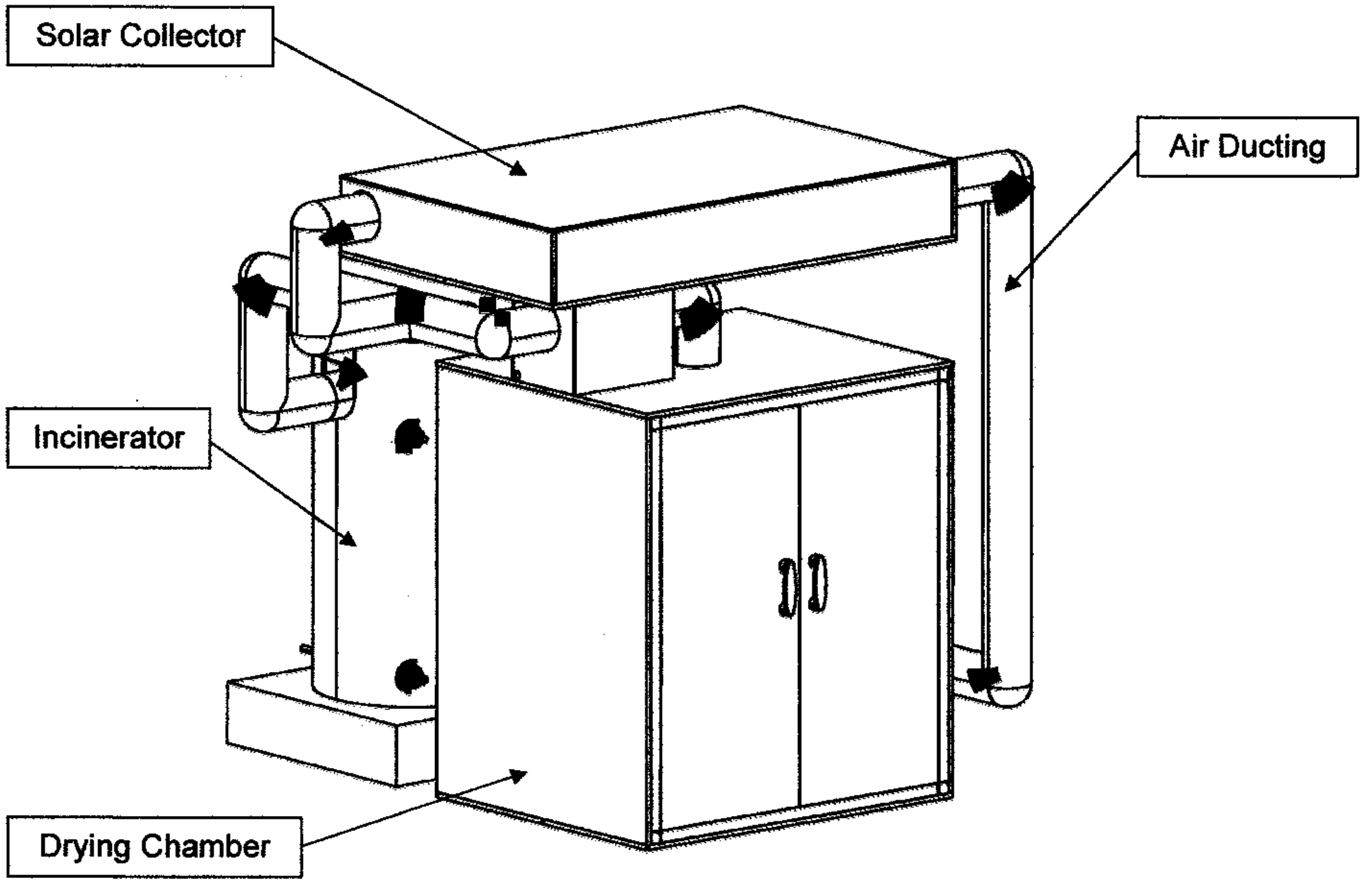
Weather Observation

Ipoh, Malaysia February, 15 2008

Hourly Observations											
Time (MYT):	Temp.:	Dew Point:	Humidity:	Sea Level Pressure:	Visibility:	Wind Dir:	Wind Speed:	Gust Speed:	Precip:	Events:	Conditions:
12:00 AM	73.4 °F / 23.0 °C	68.0 °F / 20.0 °C	83%	29.95 in / 1014 hPa	6.2 miles / 10.0 kilometers	East	3.5 mph / 5.6 km/h / 1.5 m/s	-	N/A		Mostly Cloudy
1:00 AM	71.6 °F / 22.0 °C	68.0 °F / 20.0 °C	88%	29.92 in / 1013 hPa	6.2 miles / 10.0 kilometers	ENE	2.3 mph / 3.7 km/h / 1.0 m/s	-	N/A		Mostly Cloudy
2:00 AM	71.6 °F / 22.0 °C	68.0 °F / 20.0 °C	88%	29.92 in / 1013 hPa	5.6 miles / 9.0 kilometers	East	3.5 mph / 5.6 km/h / 1.5 m/s	-	N/A		Mostly Cloudy
3:00 AM	71.6 °F / 22.0 °C	68.0 °F / 20.0 °C	88%	29.89 in / 1012 hPa	5.6 miles / 9.0 kilometers	ENE	3.5 mph / 5.6 km/h / 1.5 m/s	-	N/A		Mostly Cloudy
4:00 AM	71.6 °F / 22.0 °C	68.0 °F / 20.0 °C	88%	29.89 in / 1012 hPa	5.6 miles / 9.0 kilometers	NNE	3.5 mph / 5.6 km/h / 1.5 m/s	-	N/A		Mostly Cloudy
5:00 AM	71.6 °F / 22.0 °C	68.0 °F / 20.0 °C	88%	29.89 in / 1012 hPa	5.6 miles / 9.0 kilometers	NE	4.6 mph / 7.4 km/h / 2.1 m/s	-	N/A		Mostly Cloudy
6:00 AM	73.4 °F / 23.0 °C	68.0 °F / 20.0 °C	83%	29.89 in / 1012 hPa	5.6 miles / 9.0 kilometers	NE	4.6 mph / 7.4 km/h / 2.1 m/s	-	N/A		Mostly Cloudy
7:00 AM	71.6 °F / 22.0 °C	68.0 °F / 20.0 °C	88%	29.89 in / 1012 hPa	6.2 miles / 10.0 kilometers	NNE	1.2 mph / 1.9 km/h / 0.5 m/s	-	N/A		Mostly Cloudy
8:00 AM	73.4 °F / 23.0 °C	68.0 °F / 20.0 °C	83%	29.92 in / 1013 hPa	6.2 miles / 10.0 kilometers	NNE	4.6 mph / 7.4 km/h / 2.1 m/s	-	N/A		Mostly Cloudy
9:00 AM	75.2 °F / 24.0 °C	68.0 °F / 20.0 °C	78%	29.92 in / 1013 hPa	6.2 miles / 10.0 kilometers	NNE	4.6 mph / 7.4 km/h / 2.1 m/s	-	N/A		Mostly Cloudy
10:00 AM	78.8 °F / 26.0 °C	69.8 °F / 21.0 °C	74%	29.95 in / 1014 hPa	6.2 miles / 10.0 kilometers	NNE	10.4 mph / 16.7 km/h / 4.6 m/s	-	N/A		Mostly Cloudy
11:00 AM	82.4 °F / 28.0 °C	69.8 °F / 21.0 °C	66%	29.95 in / 1014 hPa	6.2 miles / 10.0 kilometers	NE	8.1 mph / 13.0 km/h / 3.6 m/s	-	N/A		Mostly Cloudy
12:00 PM	86.0 °F / 30.0 °C	68.0 °F / 20.0 °C	55%	29.95 in / 1014 hPa	6.2 miles / 10.0 kilometers	NNE	5.8 mph / 9.3 km/h / 2.6 m/s	-	N/A		Mostly Cloudy
1:00 PM	87.8 °F / 31.0 °C	68.0 °F / 20.0 °C	52%	29.92 in / 1013 hPa	6.2 miles / 10.0 kilometers	North	6.9 mph / 11.1 km/h / 3.1 m/s	-	N/A		Mostly Cloudy
2:00 PM	89.6 °F / 32.0 °C	68.0 °F / 20.0 °C	49%	29.89 in / 1012 hPa	6.2 miles / 10.0 kilometers	NNW	3.5 mph / 5.6 km/h / 1.5 m/s	-	N/A		Mostly Cloudy
3:00 PM	91.4 °F / 33.0 °C	68.0 °F / 20.0 °C	46%	29.86 in / 1011 hPa	6.2 miles / 10.0 kilometers	NNW	3.5 mph / 5.6 km/h / 1.5 m/s	-	N/A		Mostly Cloudy
4:00 PM	89.6 °F / 32.0 °C	71.6 °F / 22.0 °C	55%	29.83 in / 1010 hPa	6.2 miles / 10.0 kilometers	South	2.3 mph / 3.7 km/h / 1.0 m/s	-	N/A		Mostly Cloudy
5:00 PM	89.6 °F / 32.0 °C	69.8 °F / 21.0 °C	52%	29.80 in / 1009 hPa	6.2 miles / 10.0 kilometers	SW	6.9 mph / 11.1 km/h / 3.1 m/s	-	N/A		Mostly Cloudy
6:00 PM	87.8 °F / 31.0 °C	73.4 °F / 23.0 °C	62%	29.83 in / 1010 hPa	6.2 miles / 10.0 kilometers	SSW	3.5 mph / 5.6 km/h / 1.5 m/s	-	N/A		Mostly Cloudy
7:00 PM	86.0 °F / 30.0 °C	73.4 °F / 23.0 °C	66%	29.83 in / 1010 hPa	6.2 miles / 10.0 kilometers	South	2.3 mph / 3.7 km/h / 1.0 m/s	-	N/A		Mostly Cloudy
8:00 PM	82.4 °F / 28.0 °C	71.6 °F / 22.0 °C	70%	29.86 in / 1011 hPa	6.2 miles / 10.0 kilometers	SSE	1.2 mph / 1.9 km/h / 0.5 m/s	-	N/A		Mostly Cloudy
9:00 PM	80.6 °F / 27.0 °C	73.4 °F / 23.0 °C	79%	29.89 in / 1012 hPa	6.2 miles / 10.0 kilometers	SSE	2.3 mph / 3.7 km/h / 1.0 m/s	-	N/A		Mostly Cloudy
10:00 PM	78.8 °F / 26.0 °C	73.4 °F / 23.0 °C	83%	29.92 in / 1013 hPa	6.2 miles / 10.0 kilometers	South	1.2 mph / 1.9 km/h / 0.5 m/s	-	N/A		Mostly Cloudy
11:00 PM	78.8 °F / 26.0 °C	73.4 °F / 23.0 °C	83%	29.92 in / 1013 hPa	6.2 miles / 10.0 kilometers	SE	1.2 mph / 1.9 km/h / 0.5 m/s	-	N/A		Mostly Cloudy

APPENDIX C

Drawing Set - Hybrid Solar-Biomass Dryer



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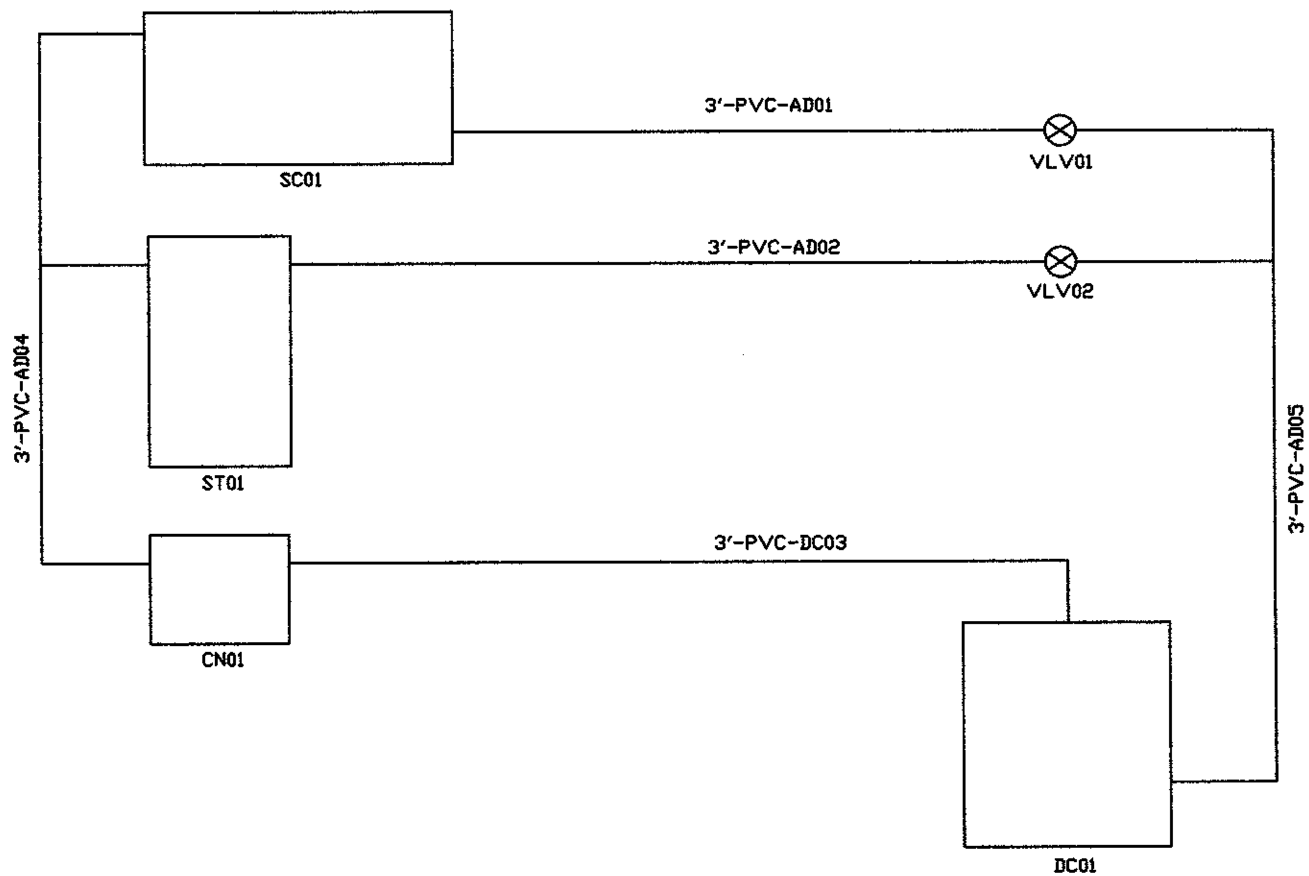
Solar Biomass Hybrid Drier
3D Drawing

Drawn By	Document No AS-01-01	Date April 20, 2008	Scale None
IRWAN SYAH MOHD YASIN 7971 MECHANICAL ENGINEERING DEPT.	Checked By		
	Checked Date	Revision REV 1	Sheet AS-01



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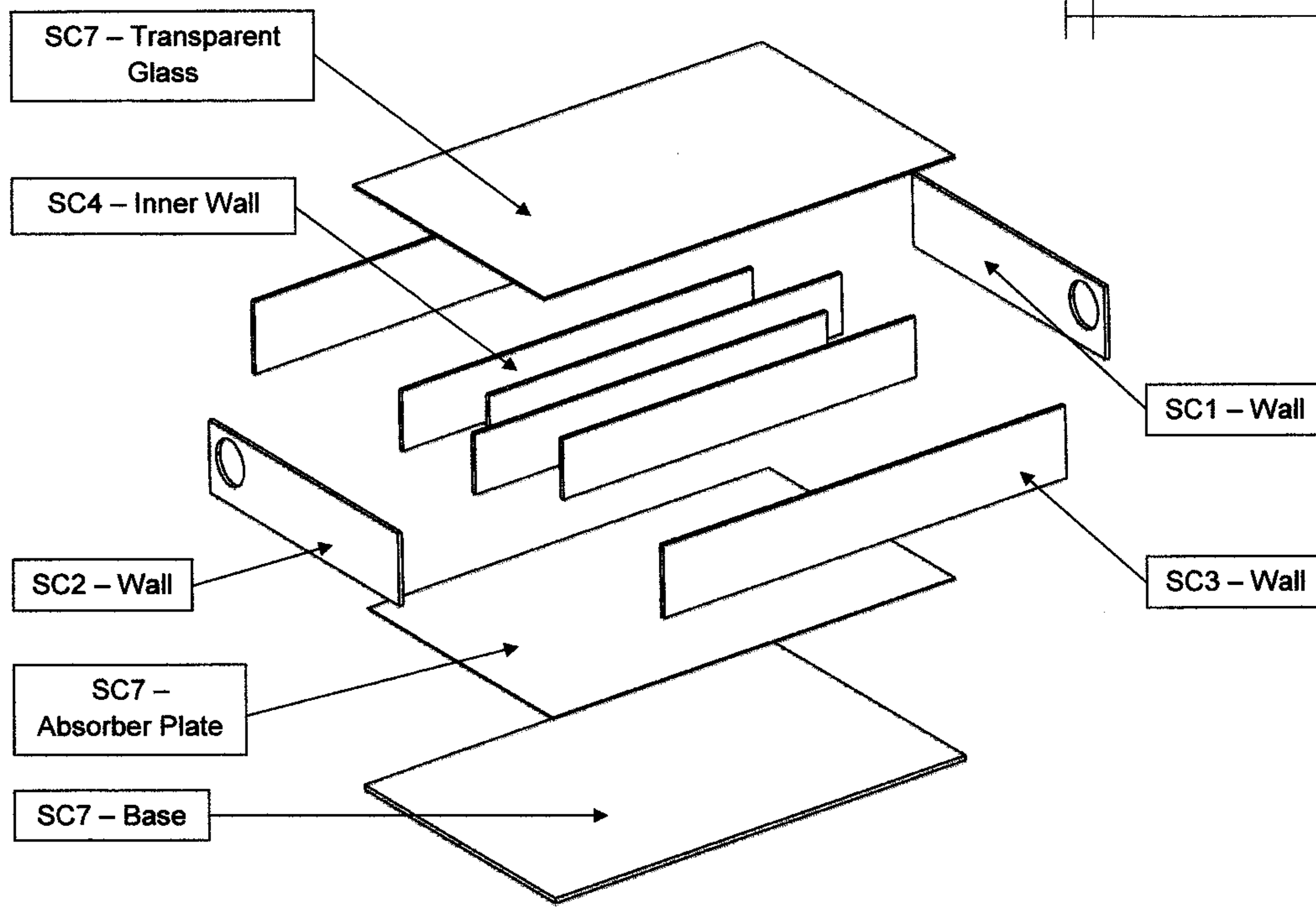
Solar Biomass hybrid Drier
Air Duct

Drawn By	Document No AD-01-01		Date April 21, 2008	Scale None
IRWAN SYAH MOHD YASIN 7971 MECHANICAL ENGINEERING DEPT.		Checked By		
		Checked Date	Revision REV 1	Sheet AD-01



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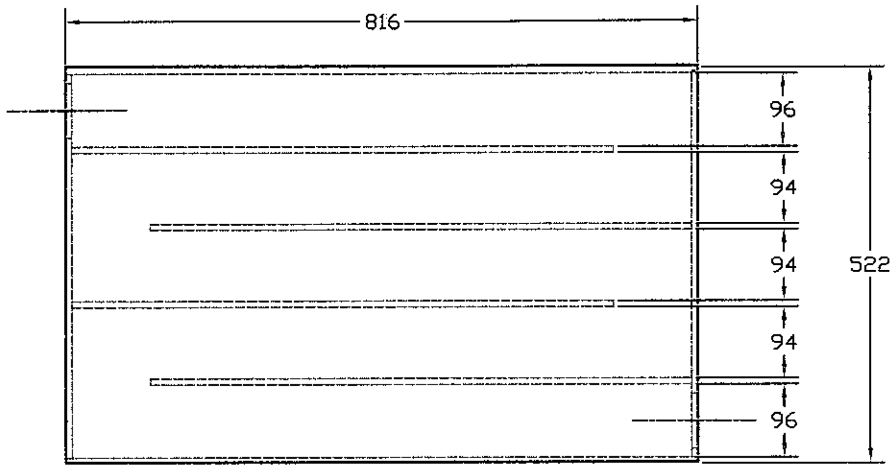
Solar Collector
3D Drawing

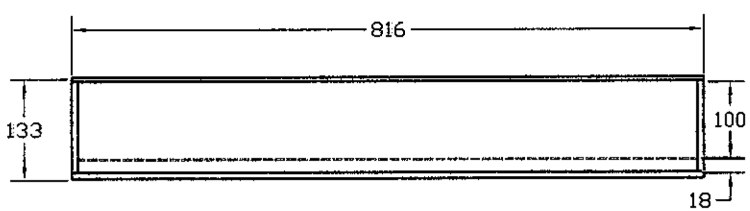
Drawn By	Document No SC-01-01		Date April 20, 2008	Scale None
IRWAN SYAH MOHD YASIN 7971 MECHANICAL ENGINEERING DEPT.		Checked By		
		Checked Date	Revision REV 1	Sheet SC-01

2		
3		
4		
5		

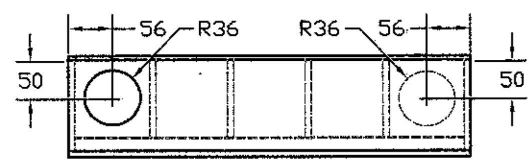
in mm unit.
2) Detail measurement is shown in the next drawing.



Top View



Front View



Side View

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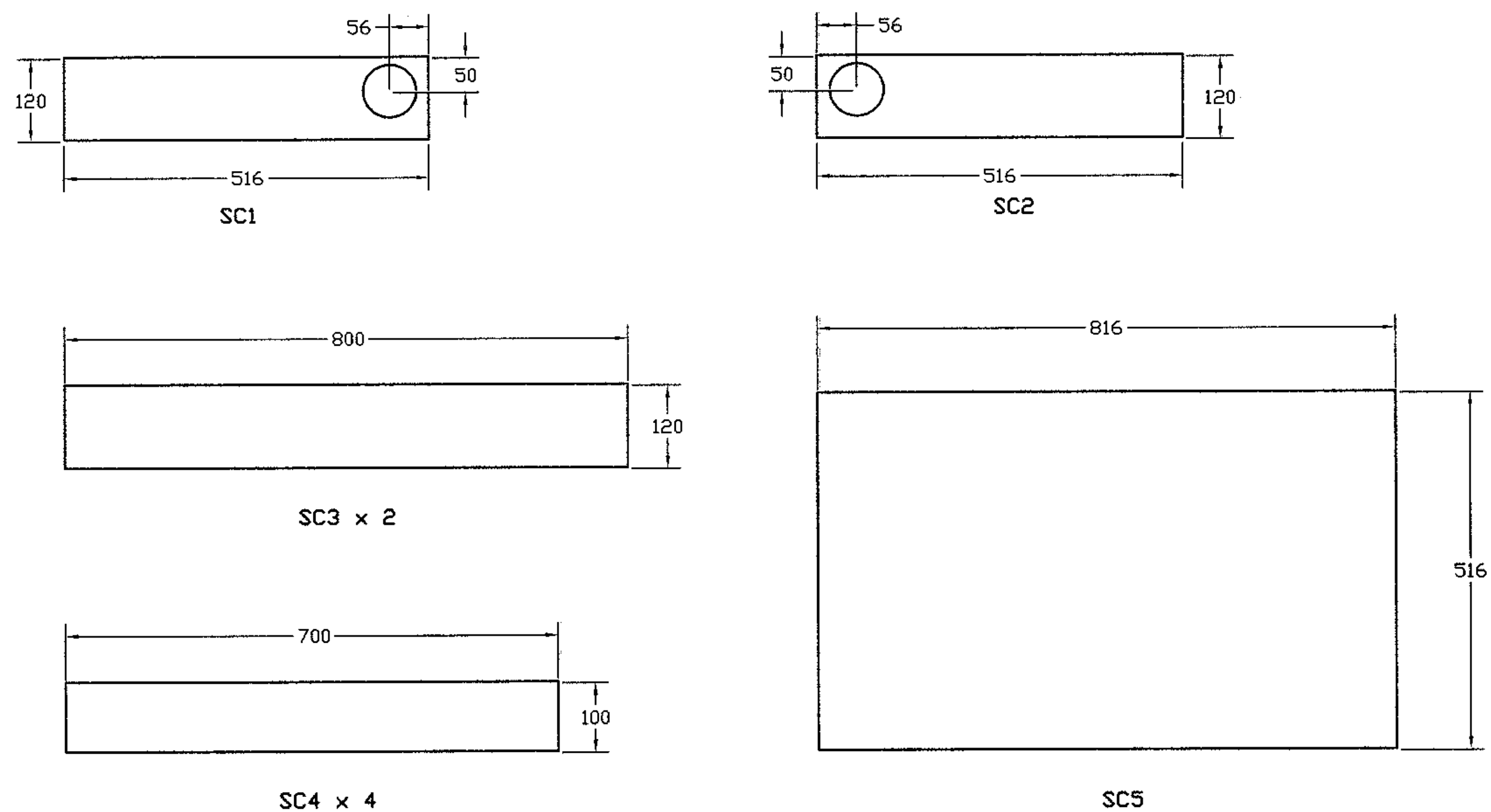
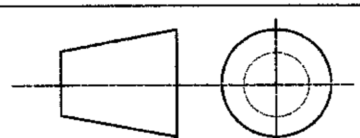
Solar Collector Top, Front and Side View

Drawn By	Drawing No SC-02-01		Date April 21, 2008	Scale 1 : 10
IRWAN SYAH MOHD YASIN 7971 MECHANICAL ENGINEERING DEPT.		Checked By		
		Checked Date	Revision REV 1	Sheet SC-02

in mm unit.
2) All the part has a thickness 8mm
3) All part SC1, SC2, SC3 and SC4 is made from playwood.
4) The hole for part SC1 and SC2 is in upper position.

2		
3		
4		
5		





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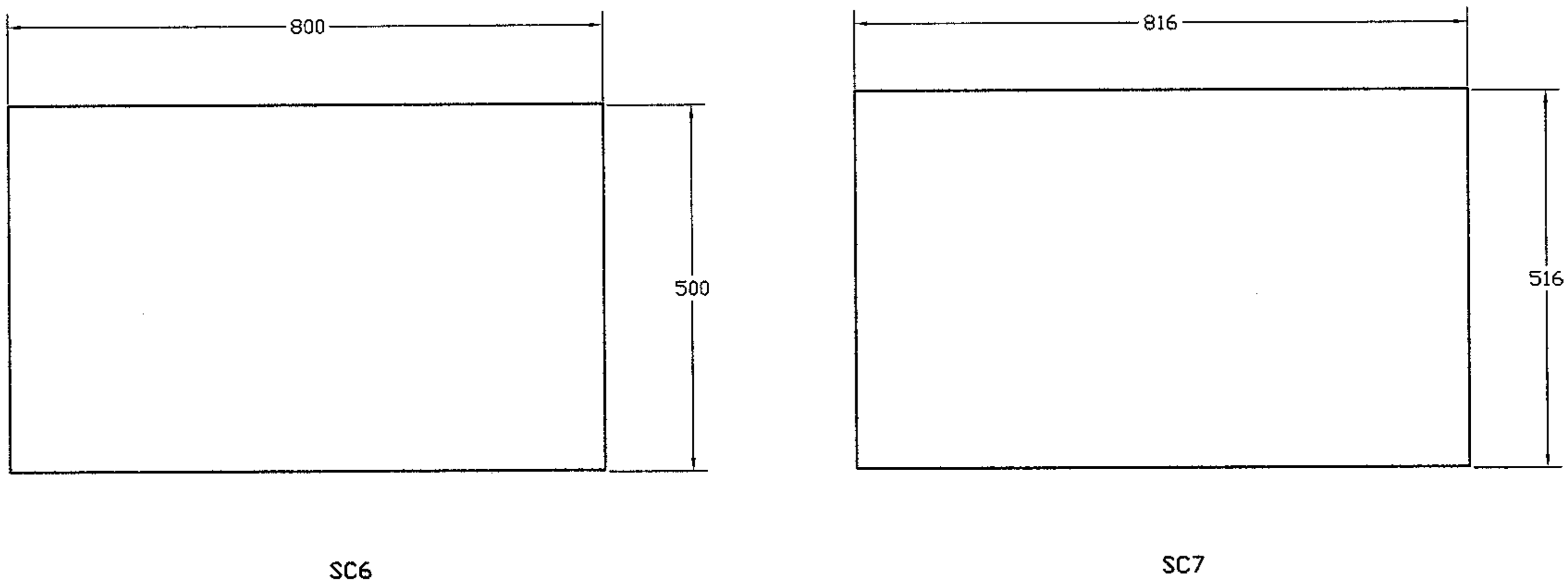
Solar Collector SC1, SC2, SC3, SC4 & SC5

Drawn By	Drawing No SC-03-01	Date April 21, 2008	Scale 1 : 10
IRWAN SYAH MOHD YASIN 7971 MECHANICAL ENGINEERING DEPT.	Checked By		
	Checked Date	Revision REV 1	Sheet SC-03

	Black) - SC6	
2	Transparent Glass - SC7	
3		
4		

in mm unit.
2) All the part has a thickness 2mm
3) All part SC6 is made from transparent glass.
4)



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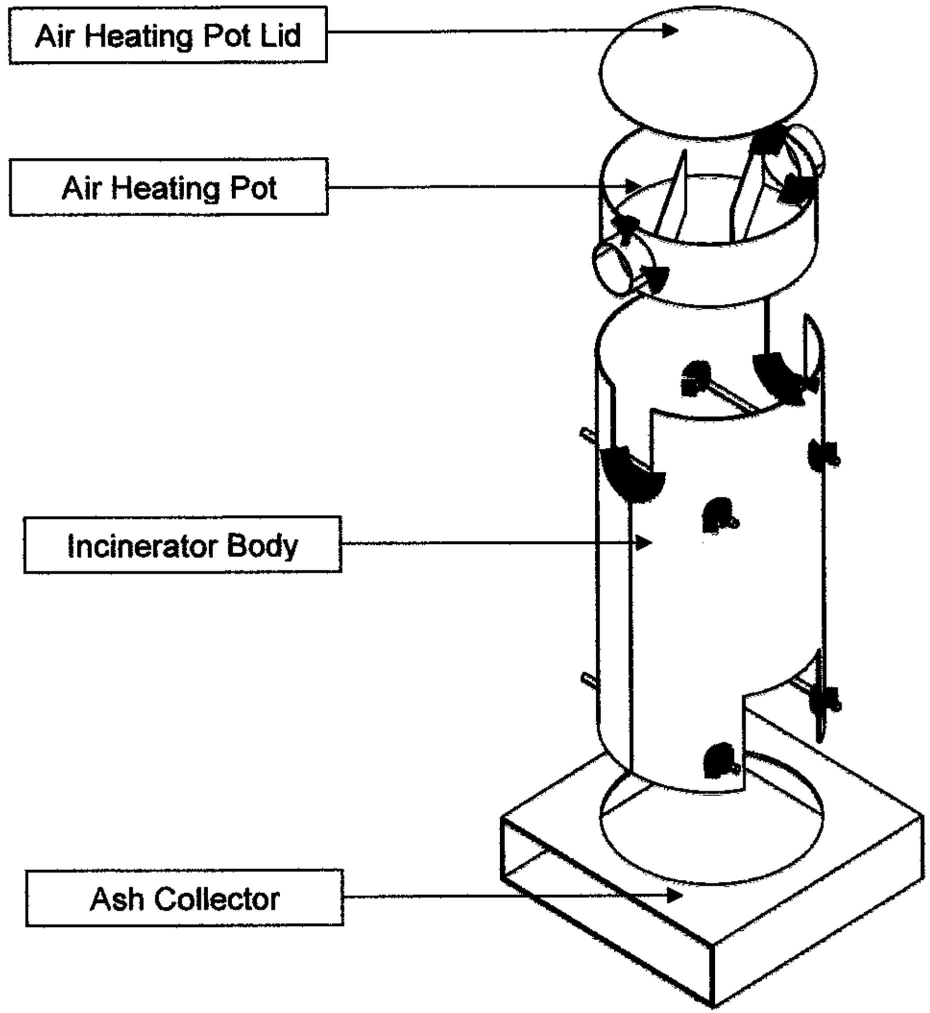
Solar Collector SC6 & SC7			
Drawn By	Drawing No SC-03-02	Date April 21, 2008	Scale 1 : 10
IRWAN SYAH MOHD YASIN 7971 MECHANICAL ENGINEERING DEPT.	Checked By		
	Checked Date	Revision REV 1	Sheet SC-04



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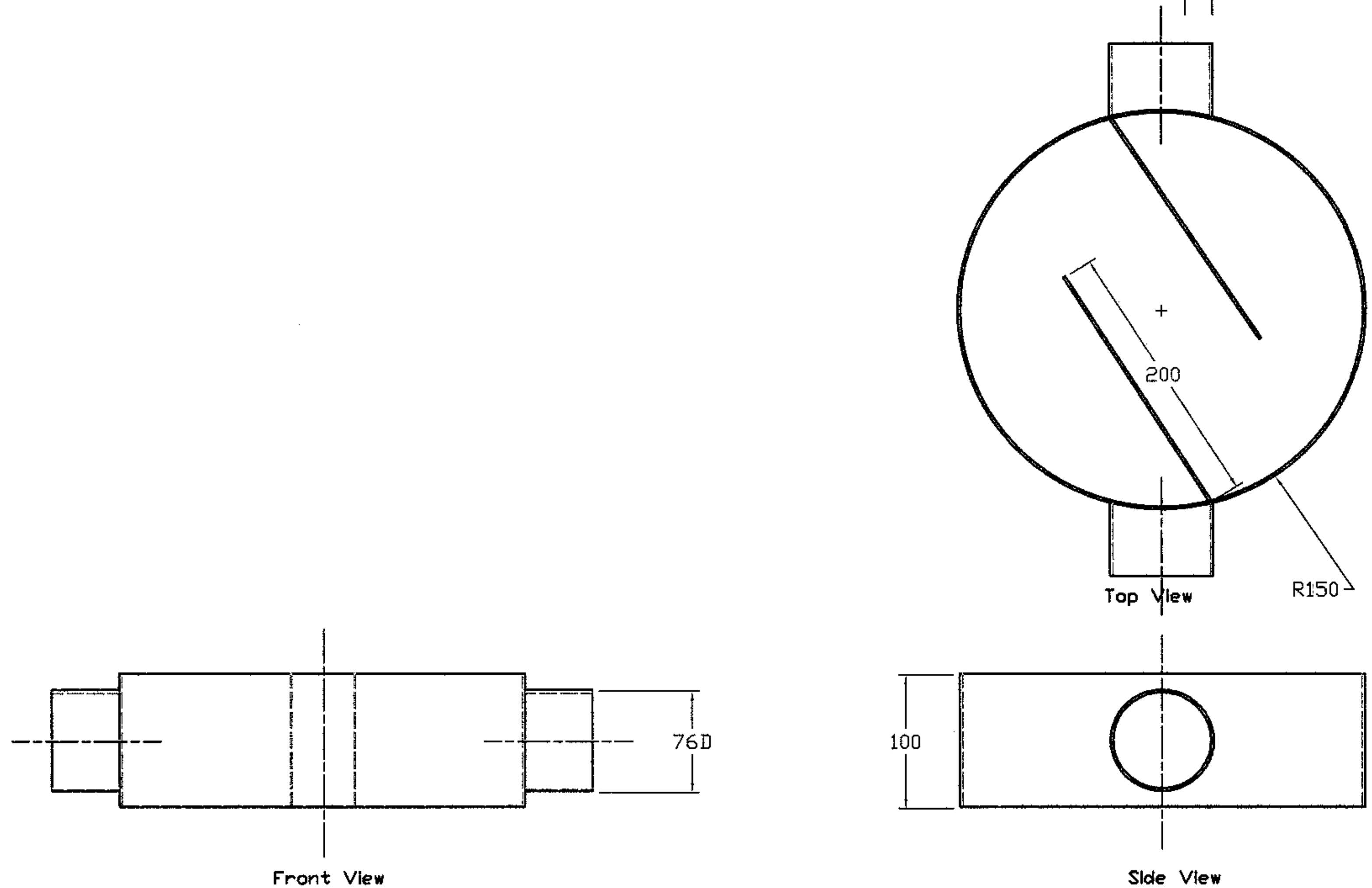
Incinerator
3D Drawing

Drawn By	Document No INC-01-01		Date April 20, 2008	Scale None
IRWAN SYAH MOHD YASIN 7971 MECHANICAL ENGINEERING DEPT.		Checked By		
		Checked Date	Revision REV 1	Sheet INC-01



ST2-Air Heating Pot

in mm unit.
2) All the pot body is made from the metal sheet.
3) The metal thickness is 2mm.
4) The measurement of diameter of pot is taken from the outside of the pot body.
5) The two piece of plate inside the pot is having a same length that is 200mm

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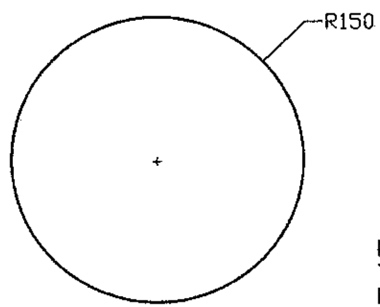
Incinerator
Air Heating Pot

Drawn By	File Name INC-02-02		Date April 8, 2008	Scale 1 : 5
IRWAN SYAH MOHD YASIN 7971 MECHANICAL ENGINEERING DEPT.		Checked By		
		Checked Date	Revision REV 1	Sheet INC-03

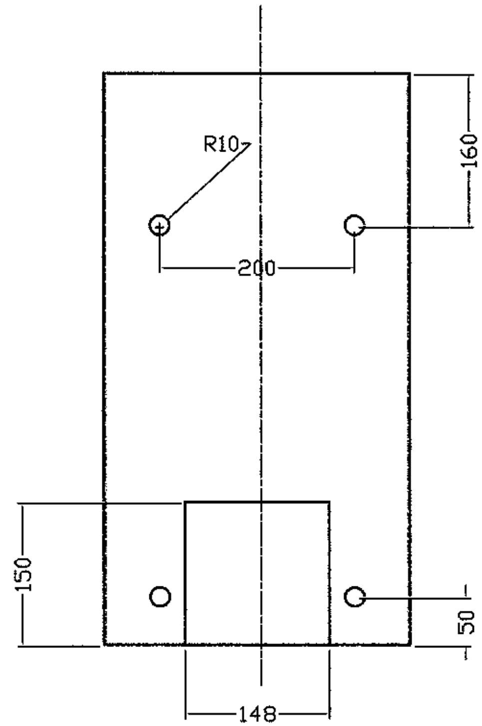
in mm unit.
2) All the stove body is made from the metal sheet.
3) The metal thickness is 2mm.
4) The measurement of diameter of stove is taken from the outside of the stove body.



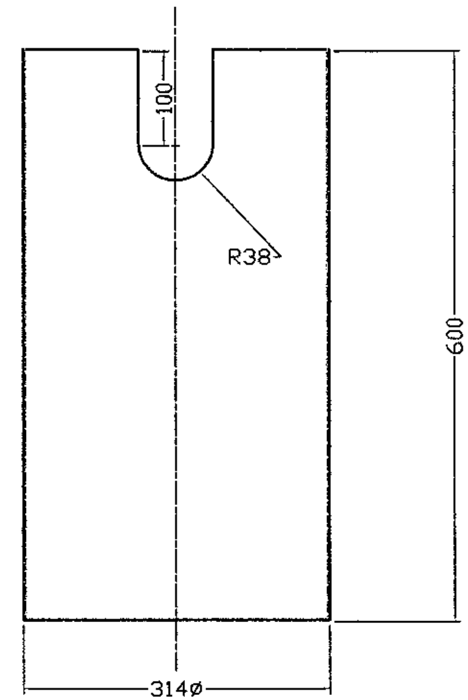
Top View

Note: The air heating pot lid is having a thickness of 2mm.

ST1-Air Heating Pot Lid



Front View



Side View

The four hole at the stove body will be change due to support shaft that to be used.

ST3-Incinerator Body

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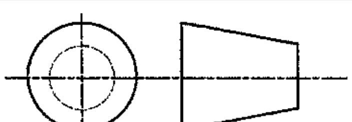
Incinerator Body & Air Heating Pot Lid



Drawn By	File Name INC-02-01		Date April 10, 2008		Scale 1 : 8
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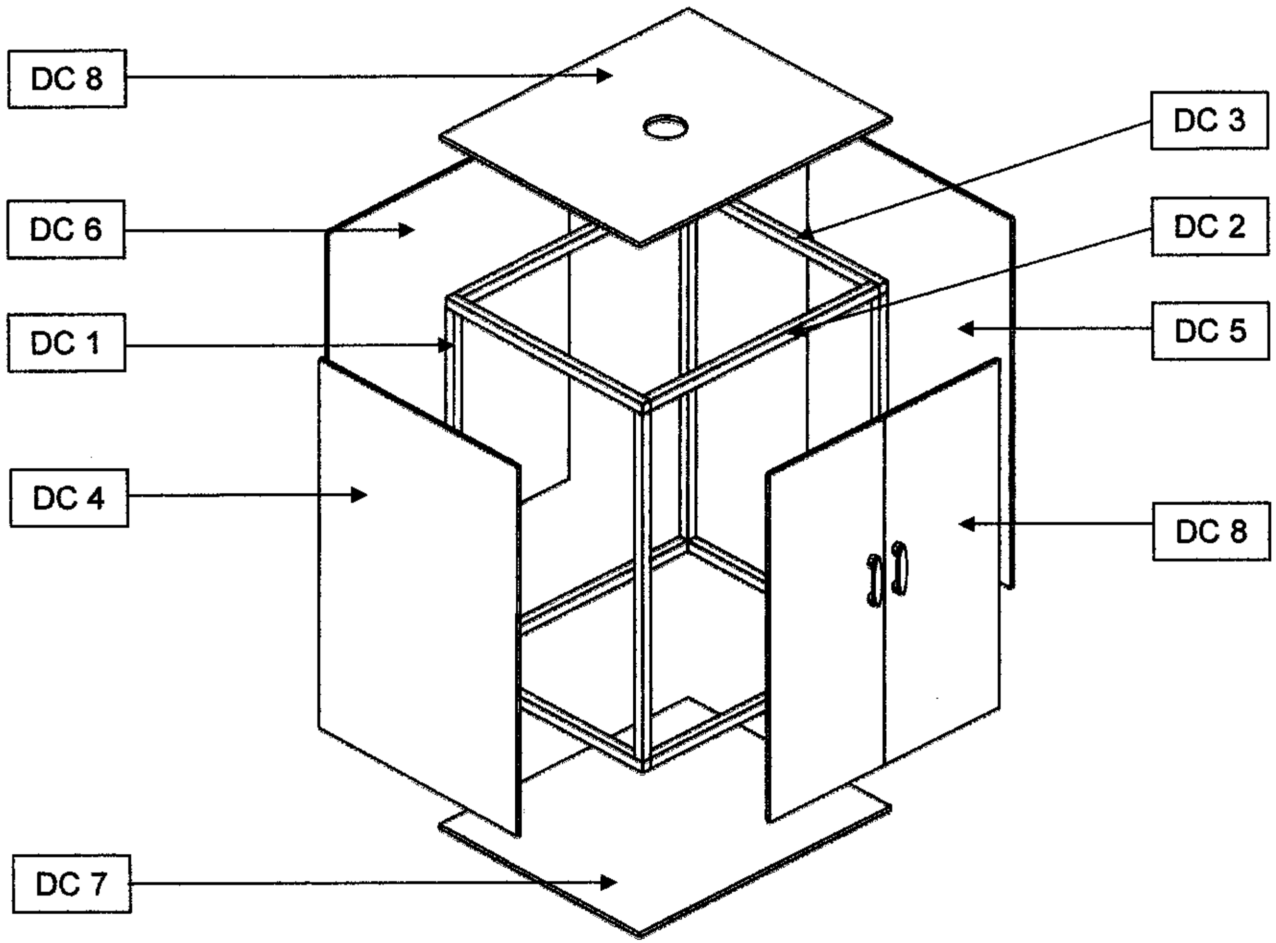
		Checked Date		Revision REV 1	Sheet INC-02



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Drying Chamber
3D Drawing

Drawn By	Document No	Date	Scale
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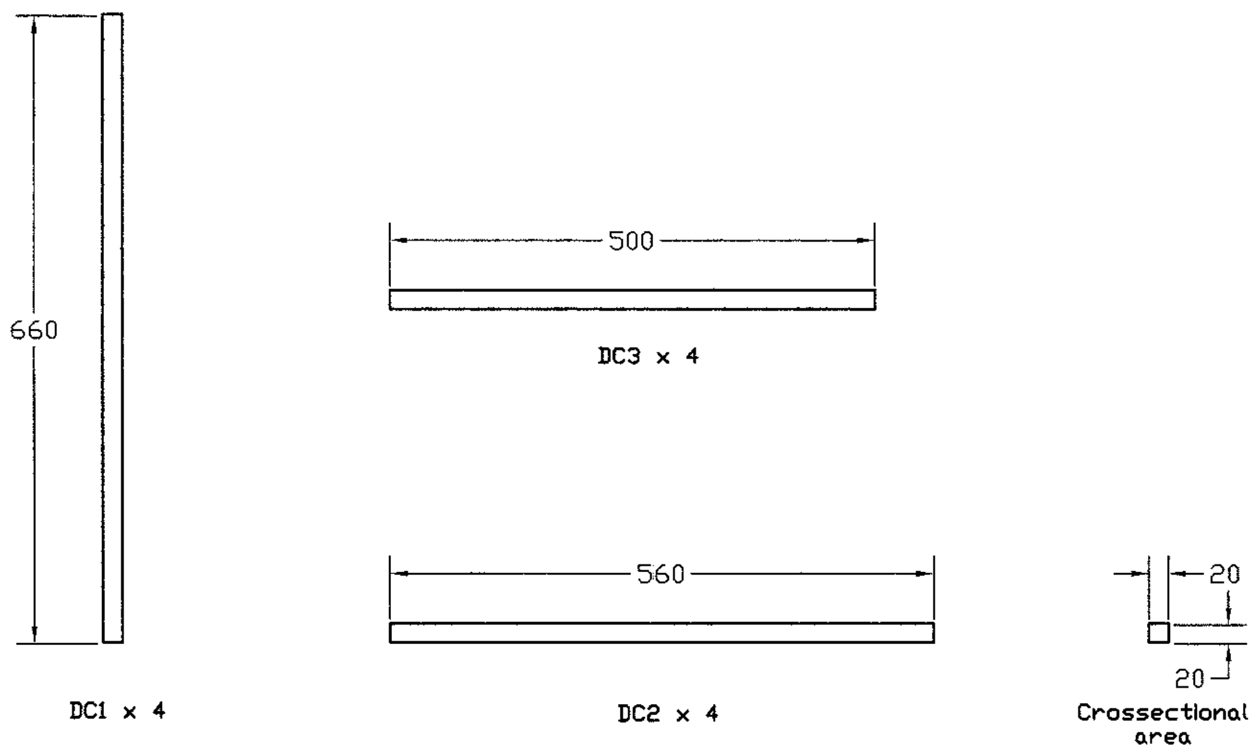
IRWAN SYAH MOHD YASIN 7971 MECHANICAL ENGINEERING DEPT.	Checked By		
	Checked Date	Revision REV 1	Sheet DC-01



2		
3		
4		
5		

In mm unit.
2) The part has crossectional 20mm x 20mm
3) All part: DC1, DC2, DC3 is duplicate into 4.

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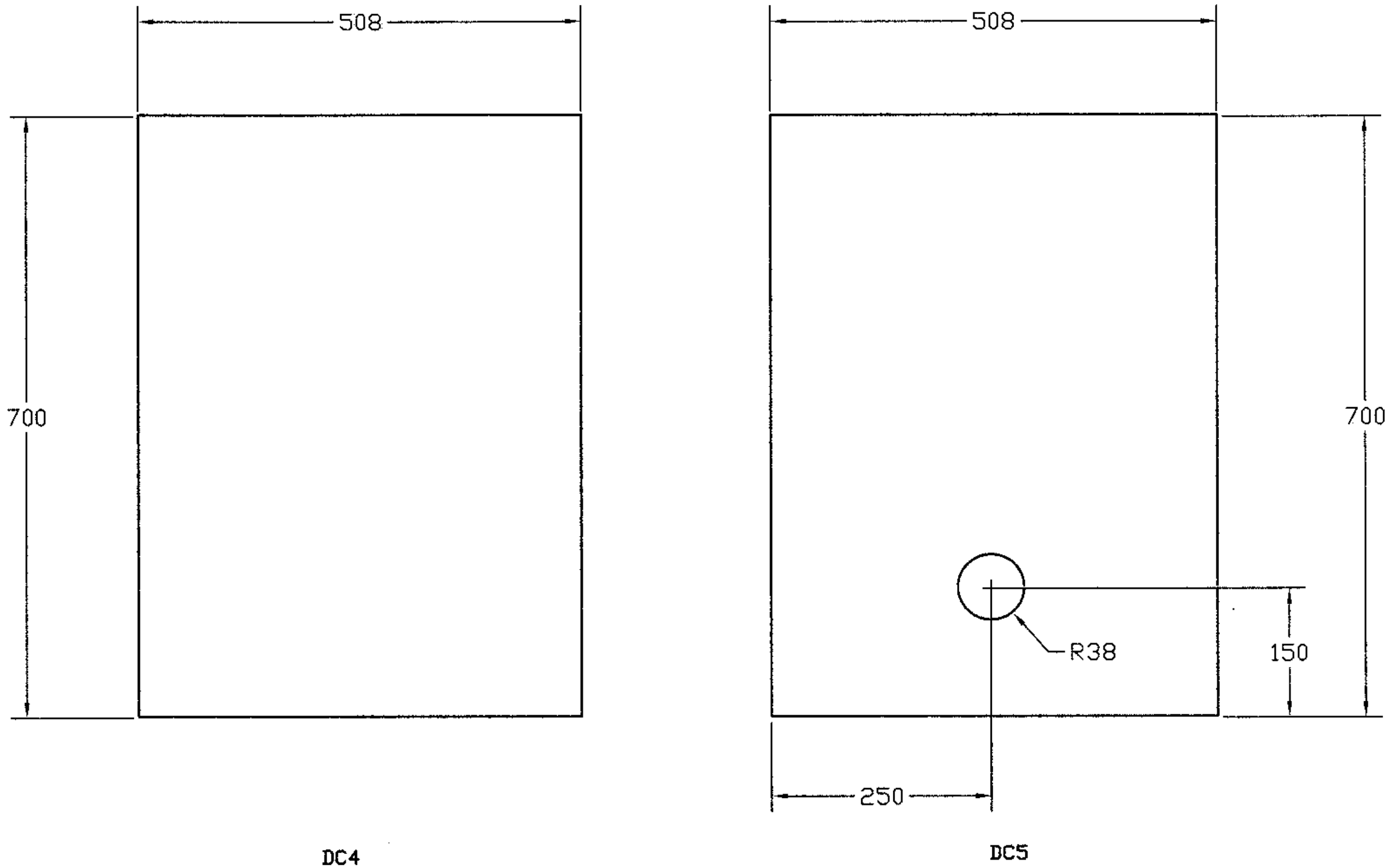
Drying Chamber DC1, DC2, DC3

Drawn By	Drawing No DC-02-01	Date April 20, 2008	Scale 1 : 8
IRWAN SYAH MOHD YASIN 7971 MECHANICAL ENGINEERING DEPT.	Checked By		
	Checked Date	Revision REV 1	Sheet DC-02

in mm unit.
2) The part has thickness 8mm
3) All part: DC4, DC5 is made from playwood



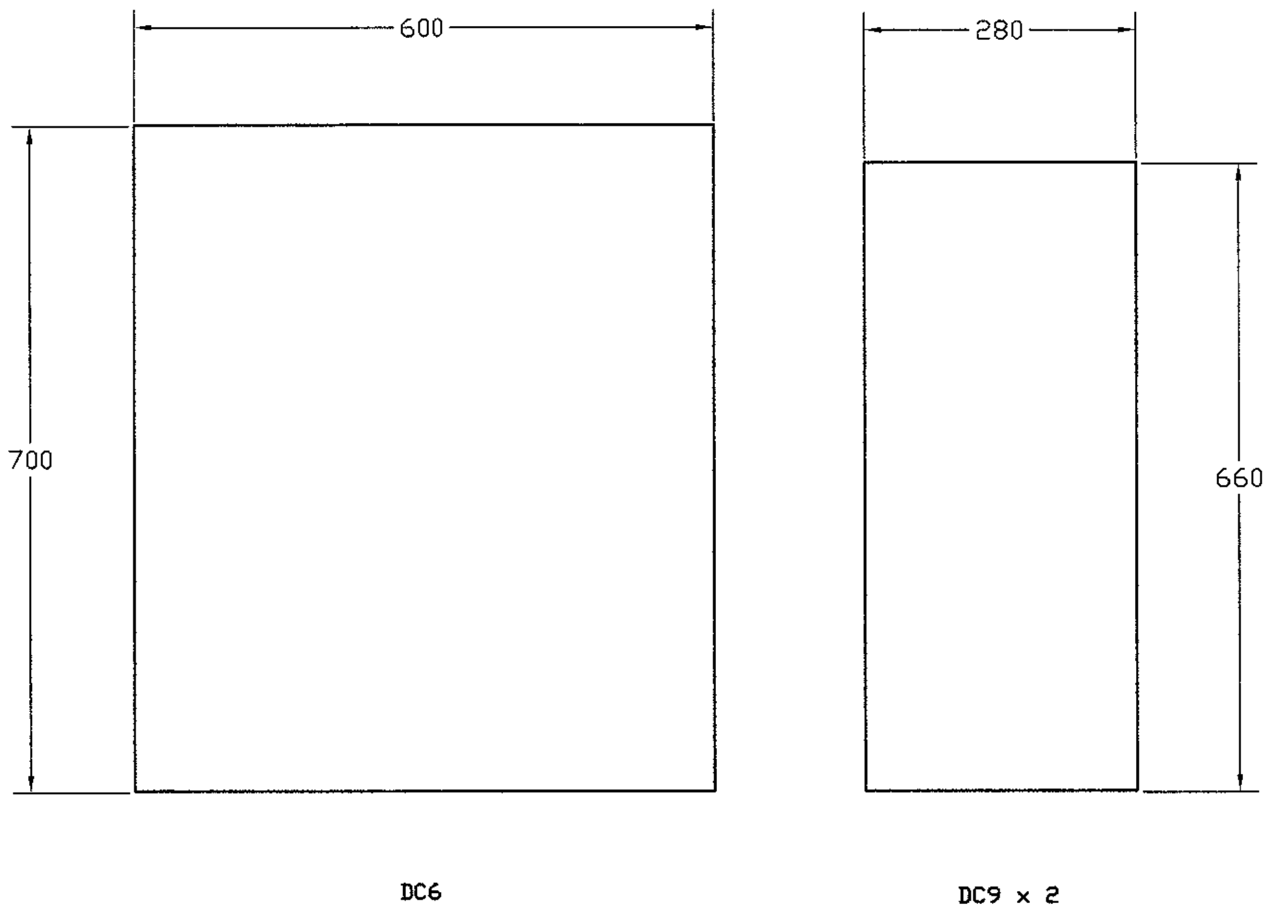
UNIVERSITI TEKNOLOGI PETRONAS

Drying Chamber DC4, DC5

Drawn By	Drawing No DC-02-02	Date April 20, 2008	Scale 1 : 8
IRWAN SYAH MOHD YASIN 7971 MECHANICAL ENGINEERING DEPT.	Checked By		
	Checked Date	Revision REV 1	Sheet DC-03

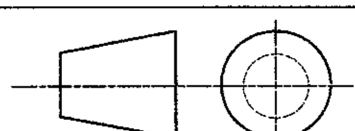
2		
3		
4		
5		

In mm unit.
2) The part has thickness 8mm
3) All part: DC6, DC9 is made from playwood



UNIVERSITI TEKNOLOGI PETRONAS

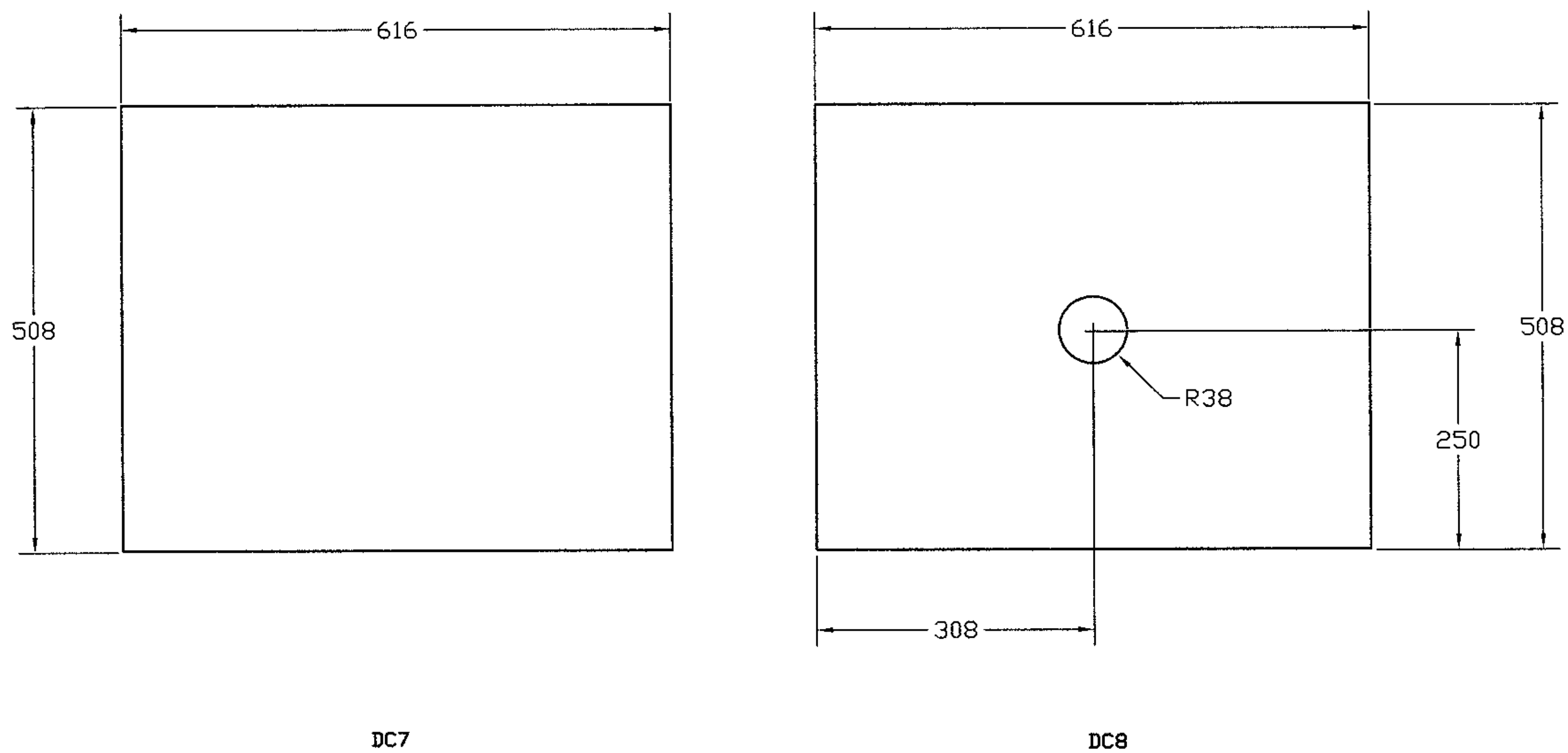
Drying Chamber
DC6, DC9



Drawn By	Drawing No DC-02-03		Date April 20, 2008	Scale 1 : 8
IRWAN SYAH MOHD YASIN 7971 MECHANICAL ENGINEERING DEPT.		Checked By		
		Checked Date	Revision REV 1	Sheet DC-04

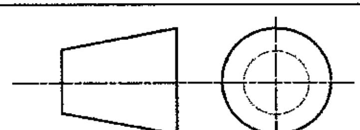
in mm unit.
2) The part has thickness 8mm
3) All part: DC7, DC8 is made from playwood

2	
3	
4	
5	



UNIVERSITI TEKNOLOGI PETRONAS

Drying Chamber
DC7, DC8



Drawn By	Drawing No DC-02-04	Date April 20, 2008	Scale 1 : 8
IRWAN SYAH MOHD YASIN 7971 MECHANICAL ENGINEERING DEPT.	Checked By		
	Checked Date	Revision REV 1	Sheet DC-05