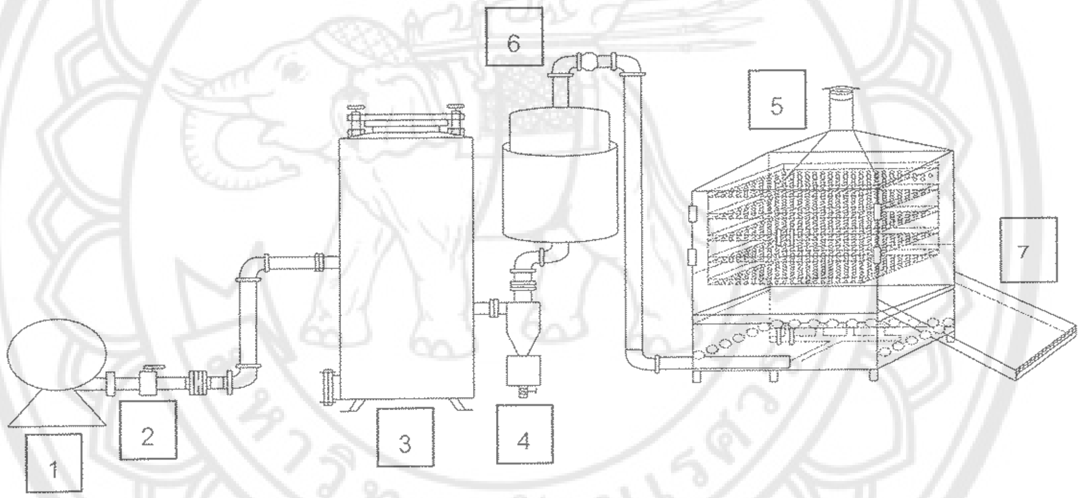
CHAPTER III

RESEARCH METHODOLOGY

Research Instruments

1. Dryer System

The diagram of dryer system using biomass and solar energy is shown in the following figure.



1. Blower 2. Butterfly Valve 7. Solar Collector

3. Reactor 4. Cyclone

5. Solar Dryer 6. Storage Tank

Figure 9 Dryer System Using Biomass and Solar Energy

The dryer system was developed for chilies drying consists of 3 main parts:

1. The solar collector
2. The drying chamber
3. The biomass gasifier system.

Solar Collector

The solar collector was used to transform solar radiant energy to be heat. Heat transferred from the solar collector to the forced air in flow-channels, which was later exit at a collector outlet. Overall dimension of the solar collector is 1.9 m^2 (1.0 m x 1.9 m). A corrugated absorber plate of back pass solar collector is made from black-painted corrugated iron as shown in Figure 13. There is air flow-channel 1.5 cm height laid on 2.0 cm thick polyurethane foam insulation. Glass sheet of 3.0 mm thick was used as a transparent cover to prevent the top heat losses.

Drying Chamber

The drying chamber is a cabinet type with a capacity of 20.0 kilograms fresh chillies. It was made from 1.0 mm thick metal sheet. The dimension of the cabinet dryer is 1.0 m×1.0 m×1.3 m. A combustion chamber (1.0 m×1.0 m×0.3 m) with 4 burners inside, made from 1.0 mm thick metal sheet, is located under the drying chamber as shown in Figure 10. The heat from the burners is transferred through the iron plate to the drying chamber. Thus flue gas from the combustion chamber and the drying air can not be mixed with the heated air in the drying chamber. This can protect the product from contaminating with the exhausted gas. In addition, the drying temperature can be controlled by the automatic ignition system. The side and back walls of the drying chamber is insulated by 2.5 cm thick poly urethane foam. The front wall is made of 3.0 mm thick glass to be easy to investigate the products inside. The chamber accommodates a total of 5 trays made of aluminum wire mesh. The 6.0 inches blade fan is positioned at the chimney on the roof of the drying chamber.

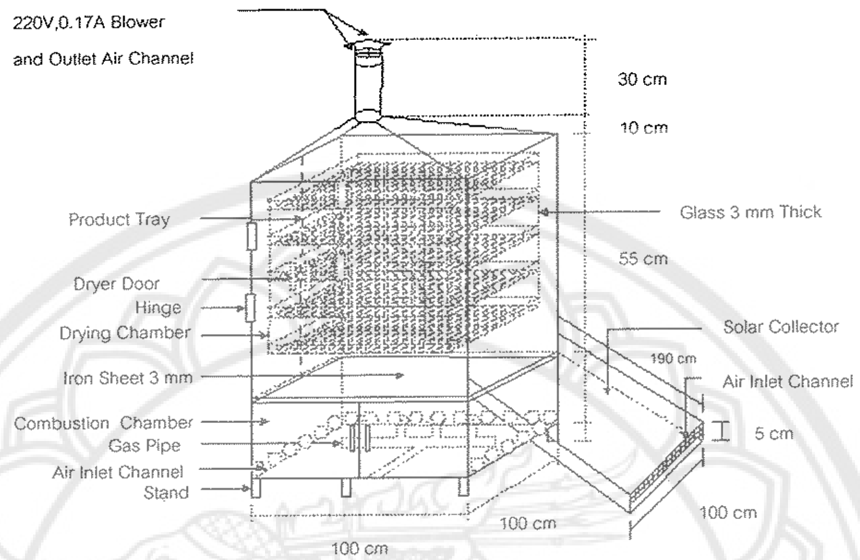


Figure 10 Side View of Solar Dryer

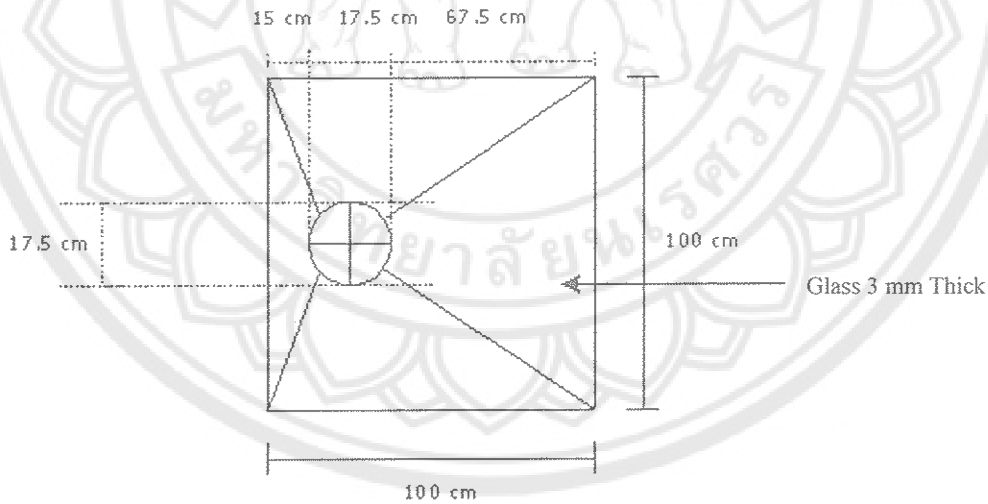


Figure 11 Roof of the Dryer

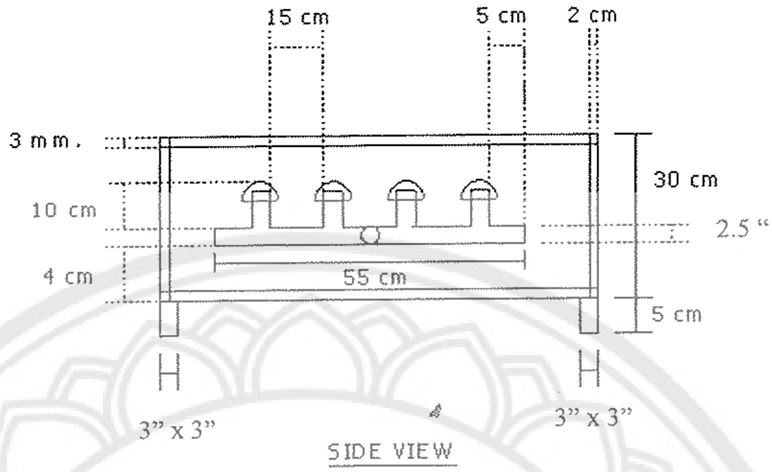


Figure 12 Side View of Burning Chamber

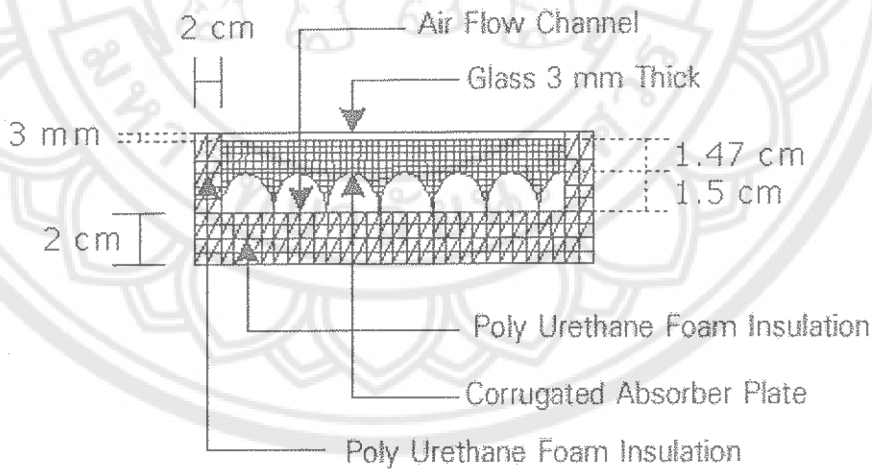


Figure 13 Front View of a Flat Plate Solar Collector

Biomass Gasifier System

The biomass gasifier system comprises 3 components:

1. The reactor
2. The cyclone
3. The Storage tank.

Reactor

The reactor is a downdraft type with 0.0025 m^3 volumetric was fuel by corn cob which is average size was 2.5 cm diameter and 7.5 cm length as shown in Figure 14. The corn cob was fed into the reactor at the top (Figure 15) and it flows through all zones in the reactor to produce the combustible gas, which exits at the bottom of the reactor. The reactor composes of three main components:

1. The fuel hopper
2. The combustion and reduction zone
3. The ash pit

The fuel hopper is positioned vertically on the top of the reactor with 63.0 cm diameter and 120.0 cm height as shown in Figure 15. It is made of 3.0 mm thick steel sheet and insulated with 3.0 cm thick fiberglass and 3 cm thick refractory brick.

The combustion and reduction zone is 55.0 cm height under the fuel hopper. The supplied air flows through steel pipe with diameter of 40.0 mm. The steel pipe consists of six stainless steel nozzles which have diameter of 2.34 mm in each. Its throat with 7.42 cm diameter which is made of 9.0 mm thick steel sheet with 7.42 cm diameter is positioned 9.0 cm under the nozzles which is shown in Figure17. The size of the reduction zone is 23.26 cm in diameter and 26.0 cm in length.

The ash pit, as shown in Figure 18, is positioned at the bottom of the reactor. Its size is 63 cm diameter and 20.0 cm height.

Dust removal was done by passing the producer gas from the reactor through a cyclone. This is a simple chamber with no moving parts into which the gas is directed and caused to swirl into a vortex under its own velocity. Centrifugal force drives the dust particles to the wall of the cyclone where they can be removed as necessary. The cyclone is made of 1 mm thick steel sheet as shown in Figure19. Its size is 10.0 cm diameter and 40.0 cm height.

The storage tank (Figure 19) is made of 57.5 cm diameter with 95.0 cm height steel sheet and 54.0 cm diameter with 52.5 cm height aluminum sheet. The small cylindrical container was put upside down into the larger container which contained the water inside. The producer gas from the reactor will flow into the storage tank by the pipe at the bottom of the tank. The pressure inside the tank then can lift the small container up to the highest fix level. The released valve will release the gas from the storage tank in order to avoid the over pressure.

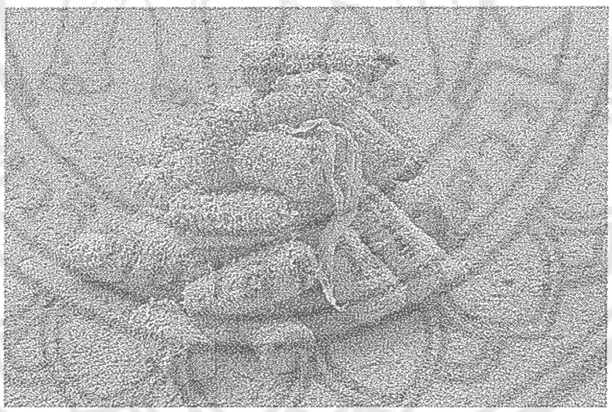


Figure 14 Corn Cobs which Was Used as Fuel

Figure 15 Top of the Reactor

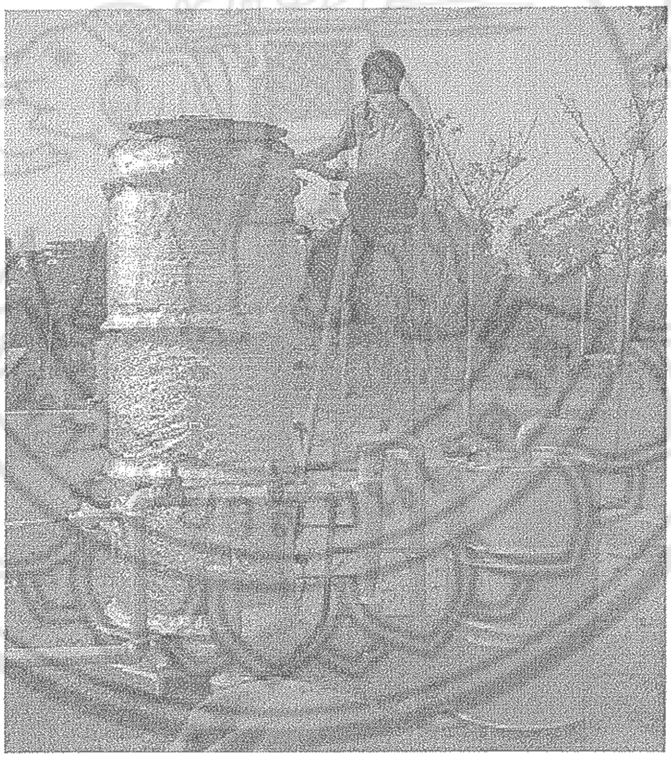


Figure 16 Biomass Gasifier System

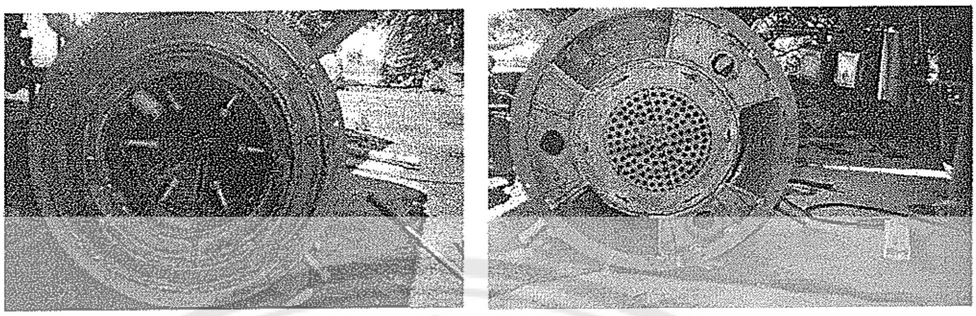


Figure 17 Combustion and Reduction Zone

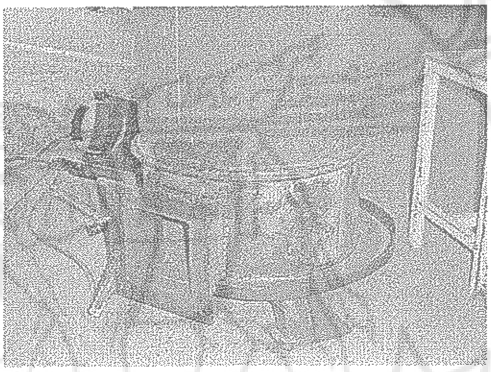


Figure 18 Ash Pit

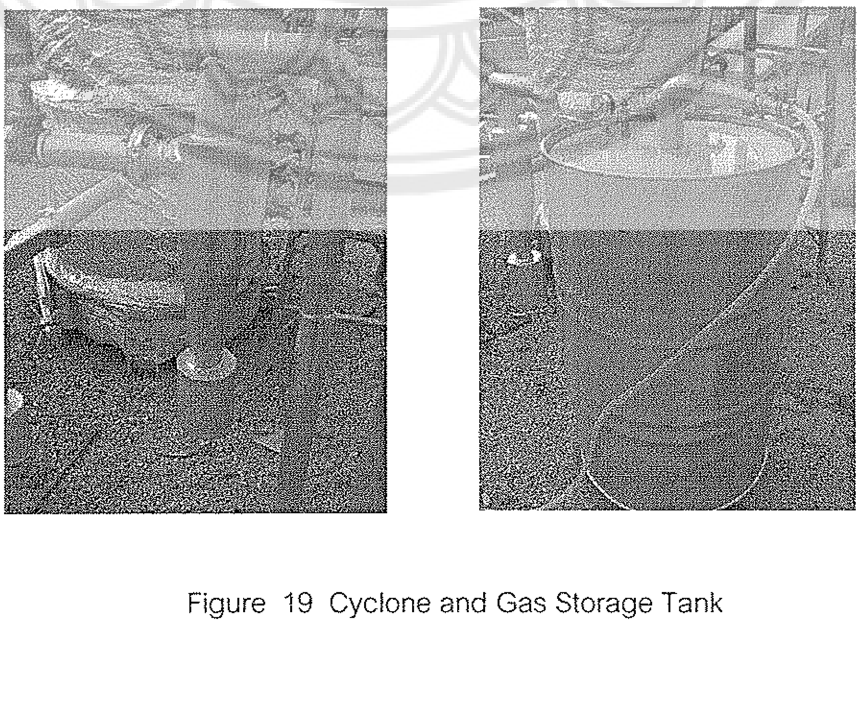


Figure 19 Cyclone and Gas Storage Tank

From the storage tank, the producer gas can be provided through a rubber tube and the automatic valve which will be controlled by automatic ignition system, to be used as auxiliary energy at the combustion chamber under the drying chamber.

Figure 20 Control Panel of an Automatic Ignition System

Methodology

The methodology adopted in this research comprises of following items:

1. Designed and installed the dryer system using solar radiation as the main energy and biomass as a supplementary source of energy to dry 20 kg of chillies per batch. The design of the hybrid drying system was base on the following conditions:

1.1 The heating will be indirect, i.e. exhausted gas from the combustion chamber and the drying air would not be mixed.

1.2 The temperature of drying air entering the drying chamber would be in range of 55-70^{o}C which is suitable for most of vegetables and fruits drying.

1.3 The drying temperature was automatically controlled by the use of electronic valve and automatic ignition system.

2. Preliminary tested for equilibrium moisture content of chillies

The moisture content of the product at equilibrium is known as the equilibrium moisture content or hygroscopic equilibrium. Thermodynamically equilibrium is reached when the free energy change for a material is zero. Equilibrium moisture content is important for the drying process. The plot between equilibrium moisture content and relative humidity at constant temperature is called equilibrium moisture isotherm. There are many methods to investigate equilibrium moisture content. One of the most popular methods is the use of saturated solution of a certain salt. The sample will be left in the chamber for a period of time until the equilibrium conditions obtained. At this stage, the sample moisture content will be equal to the RH above the solution.

In this preliminary study, the static gravimetric method, which is based on the use of saturated salt solutions to maintain a selected relative humidity when the equilibrium will be reached, was used. The mass transfers between the product and ambient air are saturated by natural diffusion of water vapor. The atmosphere surrounding the product has fixed air moisture content for every temperature applied to the salt solution [30]. The samples were sealed up in small glass containers with base diameter of 9 cm and height of 17.5 cm which contained saturated salt solutions. The salt solutions used and corresponding relative humidity at different temperature are given in table 3 [31].

Table 4 Relative Humidity Exhibited by Saturated Salt Solutions at Different Temperature

Salt	Relative humidity (RH), %		
	32.2°C	48.9°C	68.3°C
LiCl	11.9	11.5	11.1
$MgCl_2 6H_2O$	32.6	31.6	30.3
$Mg(NO_3)_2 6H_2O$	51.9	47.3	42.2
NaCl	75.6	74.8	73.2
$(NH_4)_2SO_4$	80.0	79.1	78.0
KNO_3	90.0	85.3	78.0
K_2SO_4	96.5	95.8	95.0

The glass containers with the sample and saturated salt solutions inside were put in a hot air oven to maintain the temperature. When the moisture content of the Chillies reached equilibrium with relative humidity of the atmosphere maintained in the glass container, the equilibrium moisture content of the sample was calculated on dry basis from the weight change and dry matter weight. All experiments were replicated three times and the average values were used in the analysis.

The equilibrium moisture content data of Thai red Chillies were fitted to the six moisture sorption isotherm models as follows:

Halsey model [32]

$$RH = \frac{1}{\left[\frac{(A+BT)}{M}\right]^{C}+1} \tag{1}$$

$$M = (A+BT)\left[\frac{RH}{1-RH}\right]^{C} \tag{2}$$

Modified Henderson model [33]

$$RH = 1-\exp[-A(T+B)M^{C}] \tag{3}$$

$$M = \left[\frac{-\ln(1-RH)}{A(T+B)}\right]^{1/C} \tag{4}$$

Modified Halsey model [34]

$$RH = \exp\left[\frac{-\exp(A+BT)}{M^{C}}\right] \tag{5}$$

$$M = \left[\frac{-\exp(A+BT)}{\ln(RH)}\right]^{1/C} \tag{6}$$

Modified Oswin [35, 36, 37,38]

$$RH = \frac{1}{\left[\frac{(A+BT)}{M}\right]^{C} + 1} \tag{7}$$

$$M = (A+BT)\left[\frac{RH}{1-RH}\right]^{C} \tag{8}$$

Modified BET model [39, 40]

$$M = \frac{(A+BT)\cdot C(RH)}{(1-RH)[1-RH+C(RH)]} \tag{9}$$

$$M_m = A + BT \tag{10}$$

Where M_m is the monolayer moisture content. The BET is valid for RH<0.5

Modified Smith model [41]

$$RH = \exp\left[\frac{(A+BT)-M}{C+DT}\right] - 1 \tag{11}$$

$$M = (A+BT) - (C+DT)\ln(1-RH) \tag{12}$$

Where *M* is the equilibrium moisture content in %d.b., *RH* is the equilibrium relative humidity in decimal, A, B,C and D are model coefficients, and T is the temperature in $^{\circ}$C. The statistical parameter mean relative error (MRE) as a % and standard error of estimate (SEE) were used to determine the quality of the fit.

$$MRE = \frac{100}{N}\sum_{i=1}^{N}\left|\frac{M_{i,\exp} - M_{i,pre}}{M_{i,\exp}}\right| \tag{13}$$

$$SEE = \sqrt{\frac{\sum_{i=1}^{N}(M_{i,\exp} - M_{i,pre})^2}{d_f}} \qquad (14)$$

$$R^2 = \frac{\sum_{i=1}^{N}(M_{i,pre} - \overline{M})^2}{\sum_{1=1}^{N}(M_{i,\exp} - \overline{M})^2} \qquad (15)$$

Where $M_{i,exp}$ is the *i*th experimental moisture content, $M_{i,pre}$ is the *i*th predicted moisture content, *N* is the number of data points, and d_f is the number of degrees of freedom of regression model. [41] In general, larger value of R^2, and small values of MRE and SEE, associated with randomly residual distributions indicate good fitting ability. Then the sorption isotherm of chillies would be developed.

3. Developed sorption isotherm of chillies.
4. Setting up the experimental design was done into 6 steps.

Step 1 Tested for the specific heat of chillies.

Specific heat is heat that can increase 1 degree of 1 unit material at constant pressure and volume. Specific heat of food always depends on its moisture content. From the first law of thermodynamics;

$$\Delta U = \Delta Q - W \qquad (16)$$

Where ΔU is internal energy change.

ΔQ is heat exchanged between a system and an environment.

W is work exchanged between a system and an environment

ΔU will be zero, if there is no heat exchanged between a system and an environment. Specific heat of material is investigated by using copper calorimeter mixing with water. It will be calculated from heat equilibrium equation from heat loss of water, receiving heat of calorimeter and receiving heat of samples. This bases on the assumption; equilibrium temperature of calorimeter is equal to equilibrium temperature of water as the following.

$$m_c C_c (T_c - T_e) + m_p C_p (T_p - T_e) + m_w C_w (T_w - T_e) = 0$$

$$C_p = \frac{-m_c c_c (T_c - T_e) - m_w C_w (T_w - T_e)}{m_p (T_p - T_e)} \qquad (17)$$

Where subscript c, p and w are defined for calorimeter, samples and water, respectively. And e is equilibrium state of mixed phase. The chillies would be investigated for specific heat then equation (17) would be used to calculate for it.

Step 2 Tested for producer gas generation from the gasifier system.

1. Prepared 60 kg of dry corn cob.
2. Started an experiment by feed some corn cob into the fuel hopper, and then ignited the corn cob inside the reactor.
3. After the fire was caught well by corn cob, feed the rest of corn cob into the reactor and closed a reactor cover.
4. Adjusted the air flow rate which fed into the reactor by using the butterfly valve to get 4 m/s air velocity and turned the stirrer to make the corn cob slide down well.
5. The producer gas will flow into the pipe which was connected with the burner. Burned the gas and analyze the producer gas from the pipe by using gas analyzer (Testo 350M/XL) in every 15 minutes and record the composition of it until there was no gas flow from the reactor.

Figure 21 shows the process to generate the producer gas from the gasifier system by using corn cob as fuels.

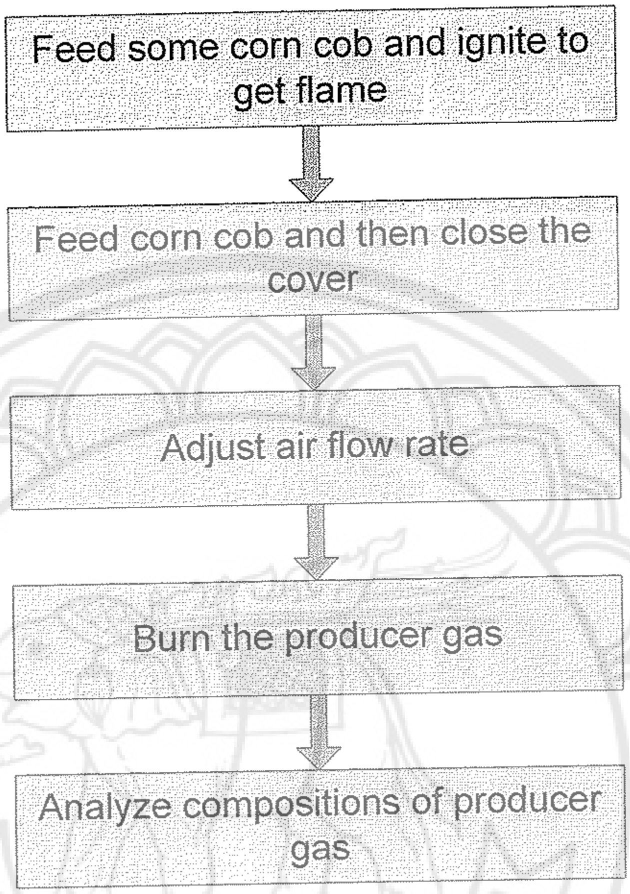


Figure 21 Process to Generate the Producer Gas

Step 3 Tested for the performance of the solar collector.

Step 4 Tested for the performance of the dryer system using only solar energy with about 20 kg of chillies.

Step 5 Tested for the performance of the dryer system using both biomass and solar energy with about 20 kg of chillies by drying temperature fixing at 50, 60 and 70 ^{o}C.

Step 7 Established a drying model of chillies by using the results from experiments.

5. The following parameters were measured during the tests in step 2, 3, 4 and 5: solar radiation, initial and final weight of chillies, weight of corncob, temperatures, relative humidity, moisture content, wind speed, electrical energy, time and air flow rate at the dryer and the gasifier. The measuring positions show in Figure 22. A combination

of hand-held instruments and sensors connected to a data logger (GRANT 2020 Series) were used to make and record the measurements. The temperature and humidity censors were calibrated before and after use, solar radiation was measured with a pyranometer (Kipp & Sonen CM11) with an accuracy of ± 0.5%. Air velocities were measured with a digital hot wire anemometer (Control Company Model No.4330) with an accuracy of ±1%. The weight of chillies and corn cob was measured with commercial balance and digital balance (METTLER TOLEDO Model PL303 Max. 310 g) with readability of 0.001 g. The producer gas flow rate was measured with flow meter (Testo 0638.1545). The compositions of producer gas were analyzed with gas analyzer (Testo 350M/XL).

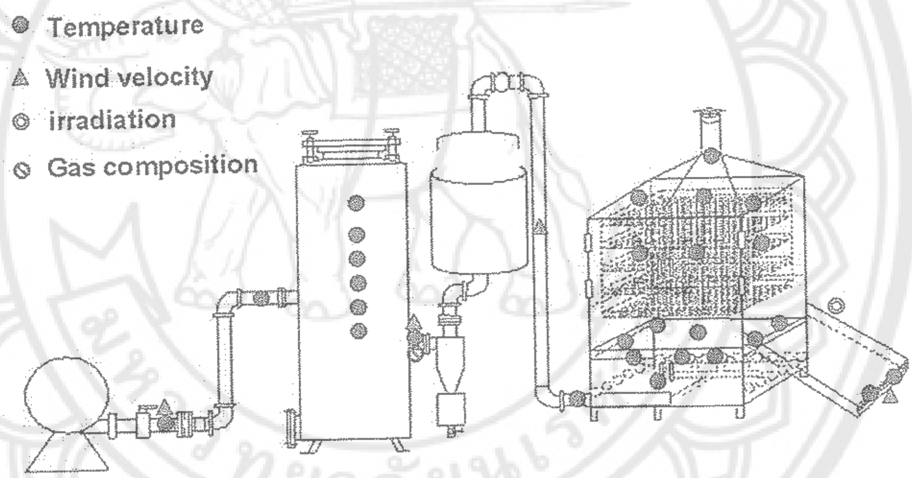


Figure 22 Measuring Positions

6. Evaluated the efficiency of the biomass/solar dryer system for chillies.

7. The moisture content of chillies would be determined during the tests. The moisture content M of a product is an index of the quality of the dried product and expressed in a percentage of moisture based on dry matter (dry basis, d.b.), which can be calculated by the following equation.

$$M_d = \frac{w-d}{d} \qquad (18)$$

Where w = weight of wet sample, kg

d = weight of dry matter, kg

M_d = moisture content (dry basis)

Moisture determination (A.O.A.C, 1990)

The dried chillies samples were randomly collected from the dryer and grounded. 10 g of grounded dried chillies were weighed and put in the known weight moisture can. The sample would be in the hot air oven at 103 ^{o}C for 72 hours. Then the moisture can would be put into the desiccators and left it to be cool down. The samples would be weighed at intervals until the constant weigh would be obtained. Then the moisture content would be calculated using equation (18).

8. During the tests, the color of the chillies was investigated by using Hunter Lab model DP9000 color tester. The Hunter Lab color space is organized in a cube form. The L axis runs from top to bottom. The maximum for L is 100, which would be a perfect reflecting diffuser. The minimum for L would be zero, which would be black. The a and b axes have no specific numerical limits. Positive a is red. Negative a is green. Positive b is yellow. Negative b is blue. Below is a diagram of the Hunter Lab color space.

The Hunter Lab color scale may be used on any object whose color may be measured. It is not used as frequently today as it was in the past because the CIE L*a*b* scale, which was released in 1976, has gained popularity. Therefore, in this research the result from Hunter Lab would be converted to CIE L*a*b* color scale too.

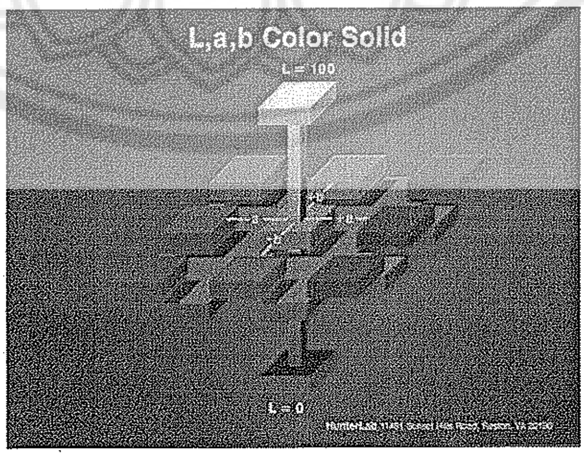


Figure 23 Diagram of the Hunter Lab Color Space

9. The processes for chillies drying.

Varieties of Chillies can effect to quality of dried Chillies. Different varieties of chillies can be various in shapes, color, thickness, pungency, and number of seeds. So market demand could be used for the selection of Chillies. In this research, the chillies named Jinda were use and brought from the local market. The chillies were washed in clean or tap water which chlorine not less than 3 ppm. After that, the chillies were blanched in 95 ^{o}C boiled water for 3 minutes to inhibit enzyme activities. Normally, blanching is undertaken to achieve the following objectives:

9.1 Inactivation of the enzymes.

9.2 Softening of the product (which facilitates the packing process).

9.3 Partial elimination of water content from tissues.

9.4 Fixing and brightening of the natural color.

9.5 Reduce off flavor of the product.

9.6 Partial reduction of the microbial content.

The inactivation of the enzymes improves the quality of the product, reducing undesirable alterations in its color, taste and smell. In addition, it aids the retention of certain vitamins, such as vitamin C. Blanching is an inactivation of the enzymatic systems and is applied frequently in order to inhibit darkening or enzymatic browning in the product.

After blanching, chillies were spread out to drain off the excessive water before drying. The flow chart of chillies preparation for drying is shown in Figure 24.

Then, chillies were be placed on the tray and put into the drying chamber, left them there until the moisture content reach to the specified level (not more than 14% db).

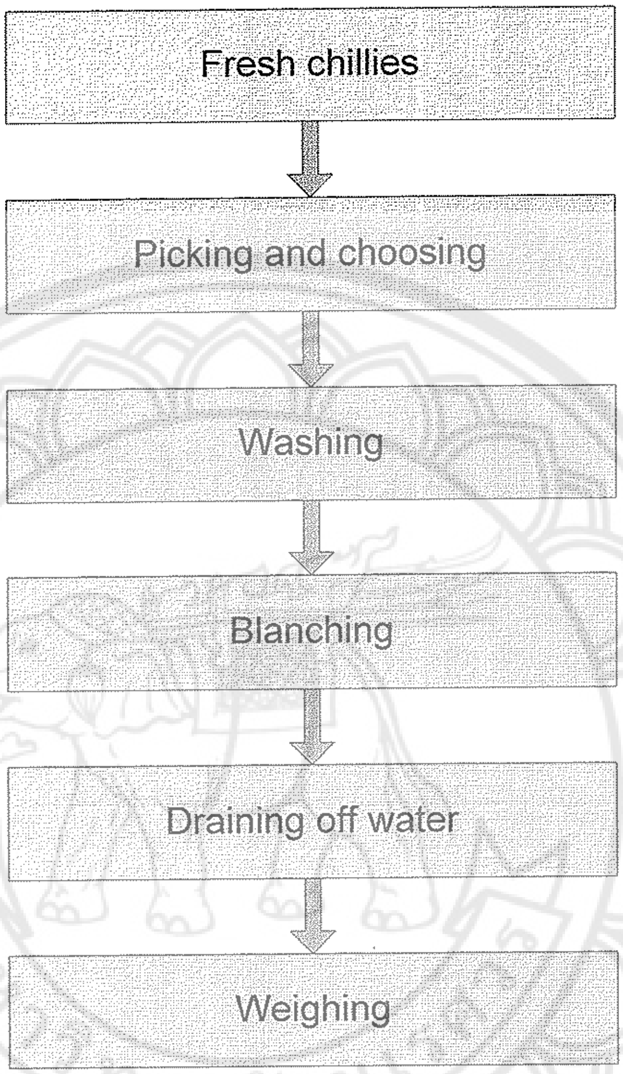


Figure 24 Flow Chart of Chillies Preparation for Drying