CHAPTER III

RESEARCH METHODOLOGY

1. The proceeding of the study

1.1 Procedures of methodology

1.1.1 Study literature review and theoretical of drying and continuous fluidized bed drying.

1.1.2 Design and construction dryer machine that shown in Figure 3.1, 3.2 and 3.13.

1.1.3 Conduct the experiment and collect the data

1.1.4 Analyze the data: check the changing of weight, moisture content, moisture content ratio, drying rate and energy consumption in each experiment.

1.1.5 Study chili drying characteristics.

1.1.6 Thin layer model of moisture content ratio and compare to analyze several models such as Lewis's model, Henderson's model, Wang and Sigh's model,Two-term's model, Aghabaslo et al.'s model, and Logarithmic's model via computer program and develop new model for describe the changing of moisture content ratio of chili.

1.1.7 Determine energy consumption analysis using computer program and make the discussion and results.

1.1.8 Make conclusions and recommendations.

1.1.9 Write a full thesis paper.

1.2 The experiment process for study drying characteristics of dried chili

The schematic diagram of experimental set up is shown in Figure 3.1 and 3.2.

1.2.1 Install heat exchanger (heating unit), insulator, kilowatt hour meter, inverter, temperature system control and data logger.

1.2.2 Set up drying temperature of 50°C and velocity of hot air of 4 m/s.

1.2.3 Feed fresh chili into the chamber and drying 1.0 kg/time.

1.2.4 Check weight of chili every 5 minutes, record data of weight and energy consumption and record drying time when the moisture content chili reduce up to 13% wet basis.

1.2.5 Experiment until almost chili particles motion from dryer chamber and record drying time.

1.2.6 Set up drying temperature of 50°C and velocity of hot air of 5 m/s and experiment similarity with 1.2.3, 1.2.4 and 1.2.5 respectively.

1.2.7 Set up drying temperature of 50°C and velocity of hot air of 6 m/s and test similarity 1.2.3, 1.2.4 and 1.2.5 respectively.

1.2.8 Set up drying temperature of 60°C and velocity of hot air of 4, 5 and 6 m/s and experiment similarity with 1.2.2, 1.2.3, 1.2.4 and 1.2.5 respectively.

1.2.9 Set up drying temperature of 70°C and velocity of hot air of 4, 5 and 6 m/s and experiment similarity with 1.2.2, 1.2.3, 1.2.4 and 1.2.5 respectively.

1.2.10 Set up drying temperature of 80°C and velocity of hot air of 4, 5 and 6 m/s and experiment similarity with 1.2.2, 1.2.3, 1.2.4 and 1.2.5 respectively.

1.2.11 Set up drying temperature of 90°C and velocity of hot air of 4, 5 and 6 m/s and experiment similarity with 1.2.2, 1.2.3, 1.2.4 and 1.2.5 respectively.

1.2.12 Set up drying temperature of 100°C and velocity of hot air of 4, 5 and 6 m/s and experiment similarity with 1.2.2, 1.2.3, 1.2.4 and 1.2.5 respectively.

The experiments in this study consists of 18 experiments, 6 levels of drying temperature; (50, 60, 70, 80, 90 and 100°C) and 3 levels of drying air velocity (4, 5 and 6 m sec^{-1}). The results from experiments above were used in the study drying characteristics of dried chili, energy consumption and develop thin layer drying model.

1.3 The experiment process for study effect of bed thickness

1.3.1 Install experiment equipment similarity with 1.2.1.

1.3.2 Set up drying temperature of 80°C and velocity of hot air of 4 m/s.

1.3.3 Feed fresh chili into the dryer chamber with bed thickness equal 2 cm.

1.3.4 Experiment similarity with 1.2.4, 1.2.5 and 1.2.6 respectively.

1.3.5 Set up drying temperature of 80°C and velocity of hot air of 5 m/s and experiment similarity 1.3.3 and 1.3.4.

1.3.6 Set up drying temperature of 80°C and velocity of hot air of 6 m/s and experiment similarity 1.3.3 and 1.3.4.

1.3.7 Set up drying temperature of 80°C and velocity of hot air of 4, 5 and 6 m/s, and bed thickness 3, 4 and 5 cm respectively, and experiment similarity 1.3.3 and 1.3.4.

1.3.8 Set up drying temperature of 90°C and velocity of hot air of 4, 5 and 6 m/s, and bed thickness 2, 3, 4 and 5 cm respectively, and experiment similarity 1.3.3 and 1.3.4.

1.3.9 Set up drying temperature of 100°C and velocity of hot air of 4, 5 and 6 m/s, and bed thickness 2, 3, 4 and 5 cm respectively, and experiment similarity 1.3.3 and 1.3.4.

The experiments in this study consist of 36 experiments, 3 levels of drying temperature; (80, 90 and 100°C), 3 levels of drying air velocity (4, 5 and 6 m sec^{-1}) and 4 levels of bed thickness; (2, 3, 4 and 5 m/s). The results from experiments above were used in the study effect of bed thickness that affected to drying time.

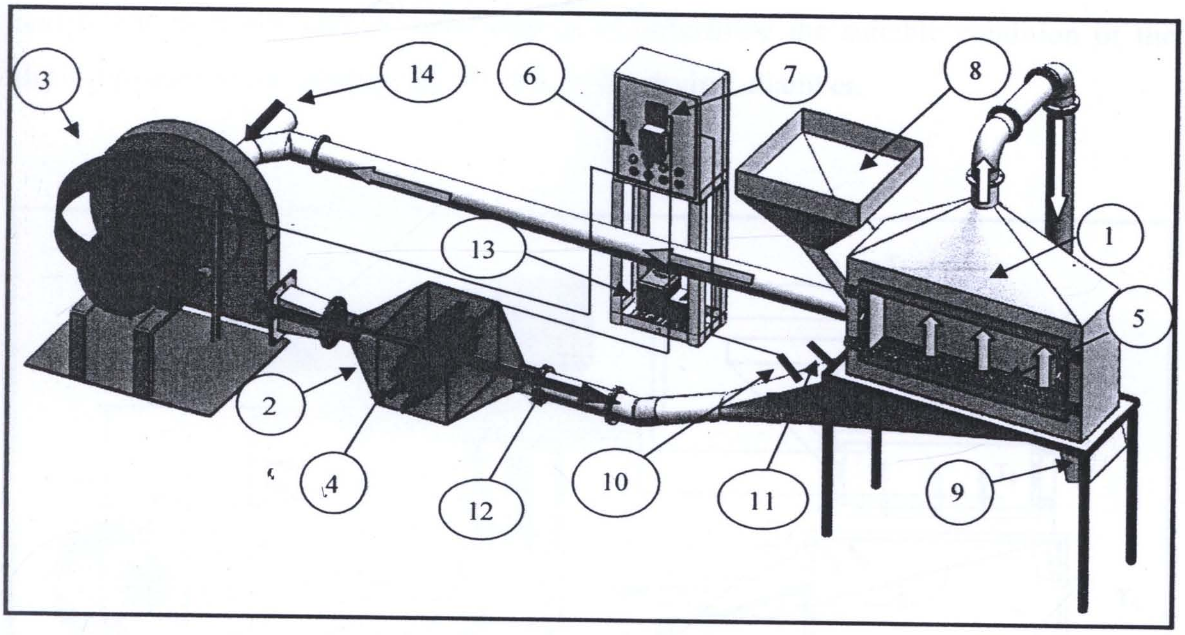

Figure 3.1 Schematic of the dryer (1) drying chamber, (2) heating unit casing, (3) blower, (4) heat coil, (5) tray for insert chili, (6) revolution inverter, (7) temperature control system, (8) inlet gate of products, (9) outlet gate of products, (10) thermocouple, (11) hot air velocity measure point, (12) air flow direction, (13) watt hour meter and (14) return of fresh air

1.4 Experimental set-up

Figure 3.1 and 3.2 shows a schematic diagram of a dryer, a continuous chili artificial dryer which consisted of it essential device, heaters, drying chamber, instruments for measurement and centrifugal blower—3 horsepower motor driven and 1450 rpm of revolution. The air flow rate was adjusted by the blower speed control which was reused again by the use of air circulation, delivering to the drying process. The heating system consisted of an electric 8 sets of 1.5 kW heater placed inside the duct. The drying chamber temperature was adjusted by the heater power control. The drying chamber was conducted from stainless steel sheets as rectangular tunnel in 1000 cm length, 30 cm width and 50 cm height was brought into this research that relied on the continuous fluidized bed technique. Drying air with the temperature of 50, 60, 70, 80, 90 and 100 degree Celsius, and the velocity of 4.0, 5.0 and 6.0 meters per second were applied to determine the suitable condition of the drying processes of 1000 grams of chili in the drying chamber.

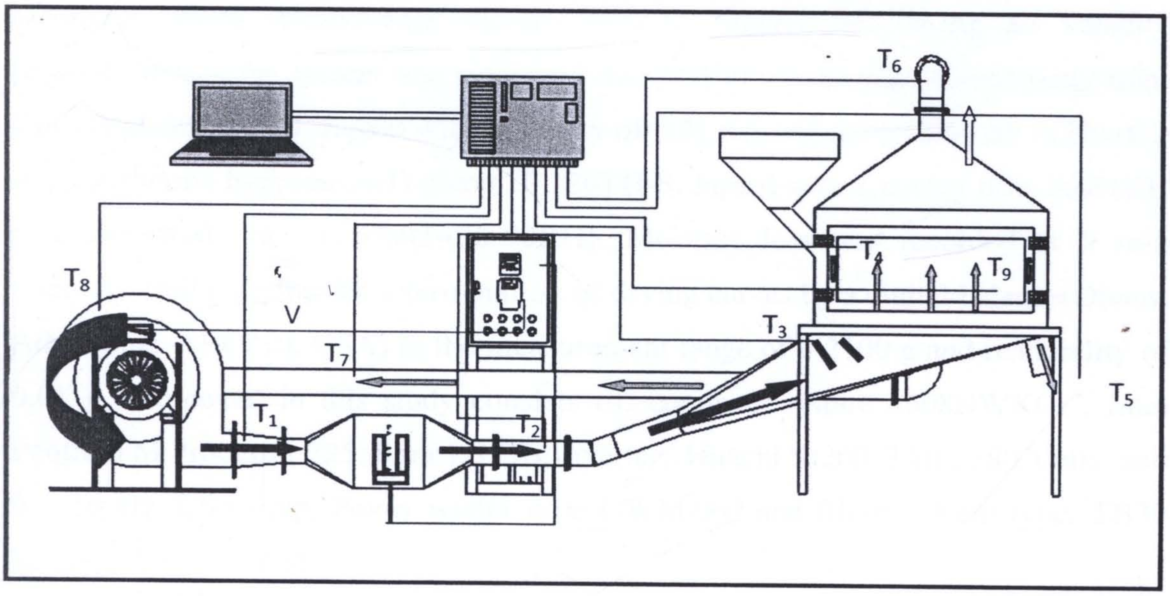

Figure 3.2 Shows air flow direction and point of measure temperature

1.5 Materials

Raw materials in this study were fresh chili (Jinda type). Since there are many kinds of chili, the researcher decided to use Jinda type, a kind of chili which was largely sold in the Northeastern market in both a fresh type and dried type. The cleaned chili would be processed in the central laboratory(Thailand) LTD., in order to specify the initial moisture content 72.98% on wet basis by AOAC(2000) method 930.04 and contained 0.07 g of quantity capsaicin substance (g/100g) by HPLC based on AOAC(2005) 995.03© in house method , before the fluidized bed technique used in the experiment, where the chili's weighted 1000 grams, would be started.

1.6 Equipments

In the measurements of temperatures, K type thermocouples were used with a manually controlled temperature(Shinko, MCD-130-R/E, Japan), with uncertainly of ±1°C. The temperature recorder with a manually controlled 32-channel automatic digital thermometer (Hioki, 8422-51, Japan). The drying air velocity passing through the system was measured by a 0.8-12.0 m/s range anemometer mini vane(Digicon, DA-45, Japan) with accuracy of 0.01 m/s and uncertainly of ±(2%+0.2 m/s). A thermo hygrometer(Digicon, T-126TH-S, Japan) with accuracy of 0-100%RH and uncertainly of ±2.5%RH(30-90RH). Moisture loss was recorded at 5 min intervals during drying for determination of drying curves by a digital balance(Ohaus, Adventurer-ARC210, USA) in the measurement range of 0-2100 g and readability of 0.01 g. Moreover, in this study consists of: computer Aspire 3608NWXCi , Intel Pentium M Processor 725, Ram 1.5 GB,Inverter, Hitachi SJ200, 3 HP, 380 Volts and 0 – 50 Hz, Clip-Amp, Power wieter type GWM-009 and Blower, Vent type, TB30 Series, 3 HP, 380 Volts.

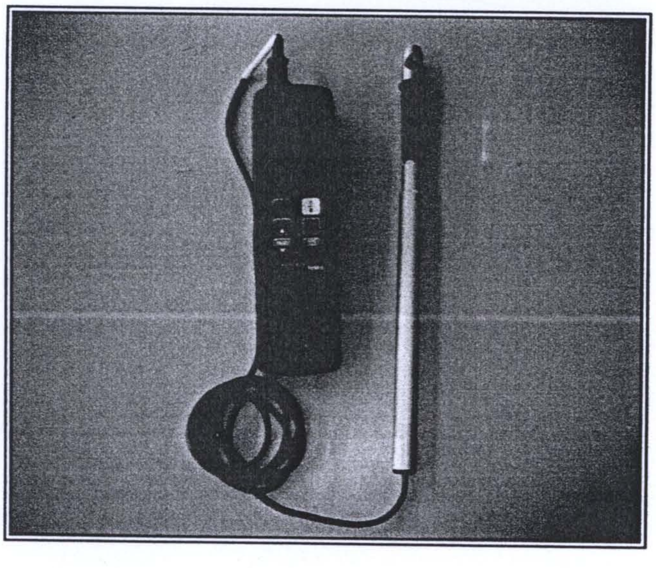

Figure 3.3 Anemometer, Digicon type (DA-45)

Figure 3.4 Inverter, Hitachi SJ200 type, 3 HP, 380 Volt and 0 – 50 Hz

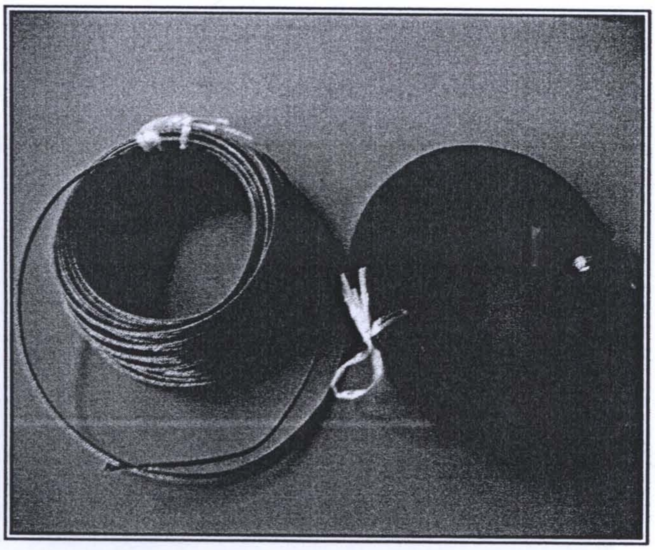

Figure 3.5 Thermocouples (type K)

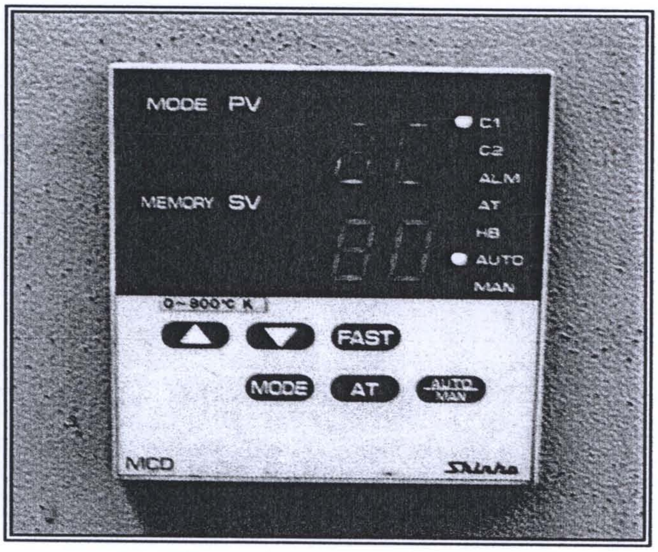

Figure 3.6 Temperature control (Shinko, MCD-130-R/E, Japan)

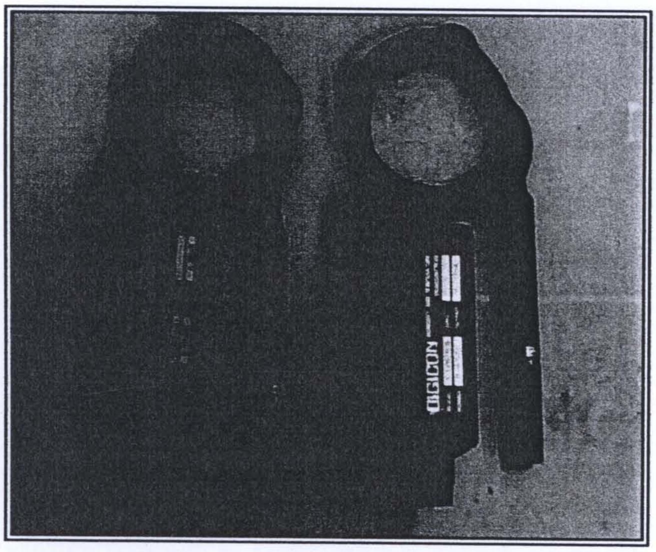

Figure 3.7 Humidity instrument (Digicon, T-126TH-S, Japan)

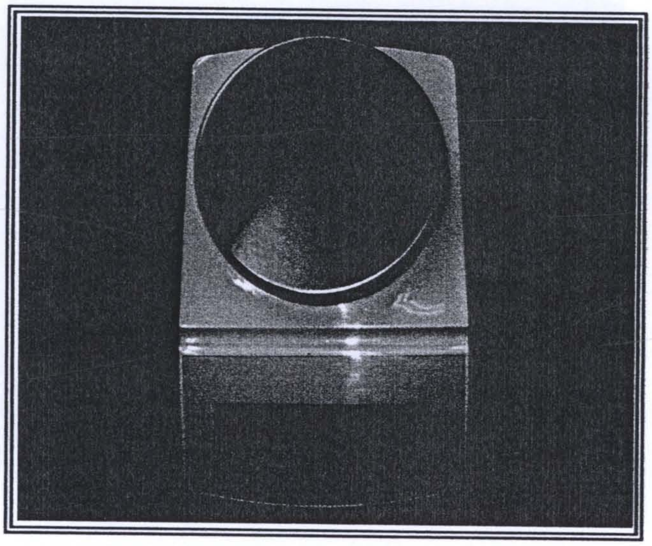

Figure 3.8 Digital balance (Ohaus, Adventurer-ARC210, USA)

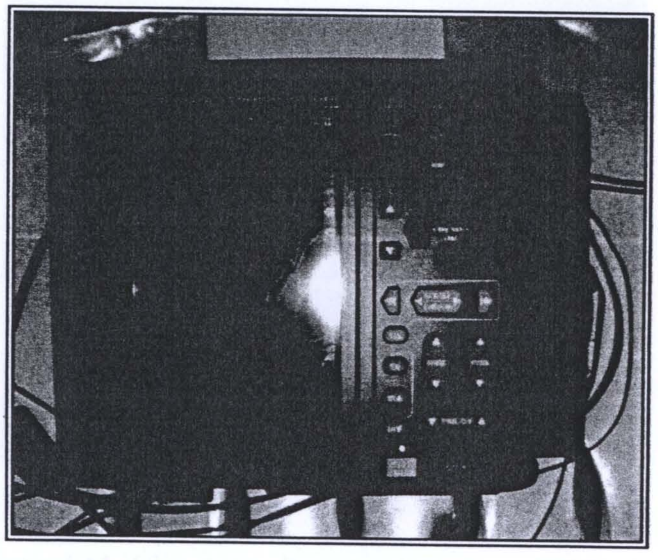

Figure 3.9 The temperature recorder (Hioki type, 8422-51)

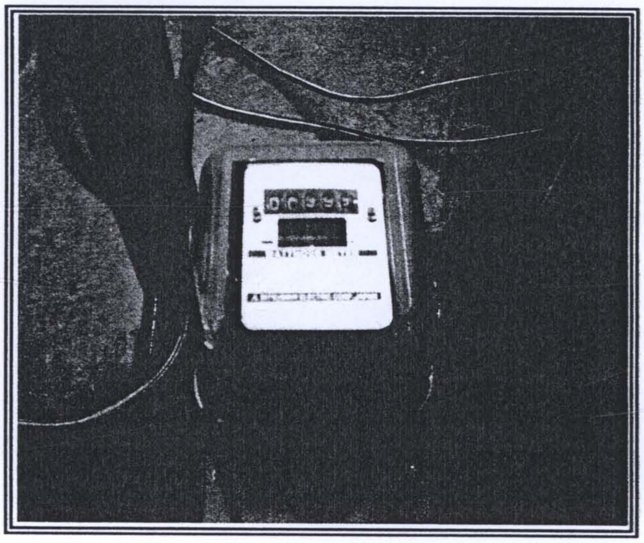

Figure 3.10 Kilowatt hour meter, Mitsubishi type

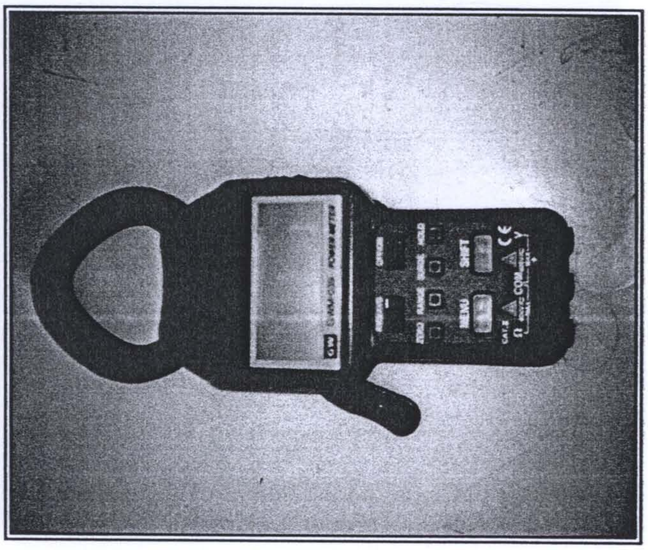

Figure 3.11 Clip-Amp, Power wieter type GWM-009

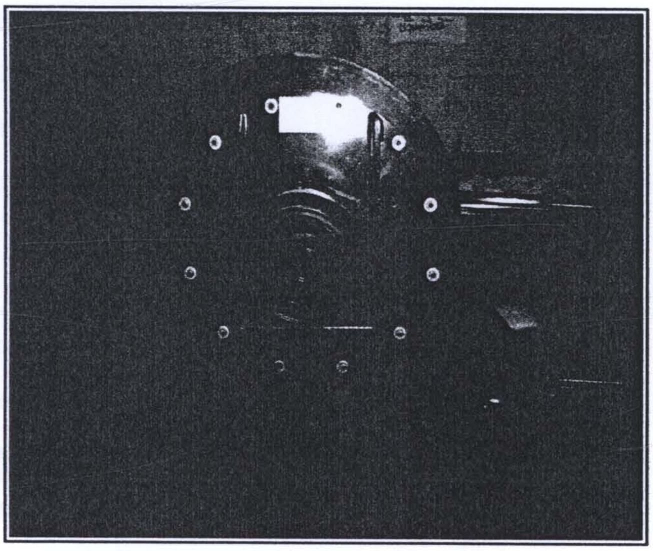

Figure 3.12 Blower, Vent type, TB30 Series, 3 HP, 380 V

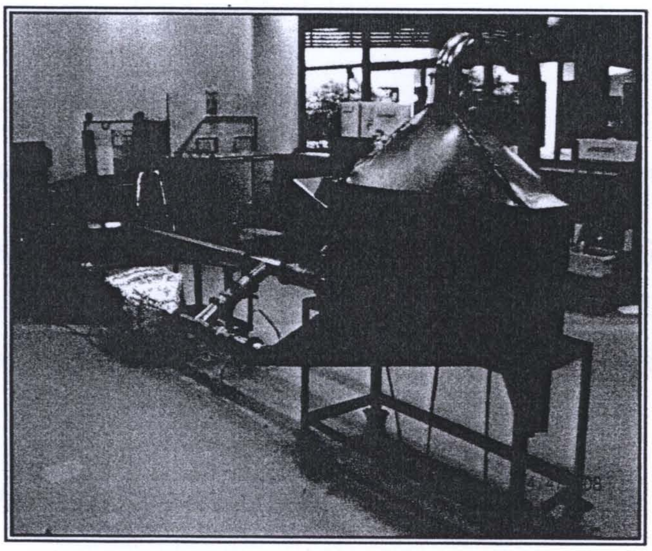

Figure 3.13 Prototype of continuous fluidized-bed dryer

2. Compare the changing of moisture content from experiments and empirical mathematical model

The comparison can be divided into 2 parts as follows:

2.1 The results from experiments

2.2 The results from empirical mathematical model using computer program

In this study the author used coefficient of determination (R^2), Adjusted coefficient of determination (Adj.R^2) and Summation of square error(SSE) for identify the accuracy of mathematical model and predicted the results of experiments compare with the model. The best model could be described coefficient of determination (R^2) and coefficient of determination (Adj.R^2) were nearly 1.0 and Summation of square error(SSE) was nearly zero(0).

3. Mathematical model

The mathematical model analysis in this work was applied from Supawan(2004) and used non-linear regression for analysis the results experiments of chili drying using continuous fluidized bed drying.

3.1 Basic parameters of continuous fluidized bed drying

Mean residence time is defined as the time which chili stays in drying chamber until it leaves from it. This residence time is directly related to the mass of chili in drying chamber(hold up) and is inversely related to the feed rate of chili as given by

$$\tau = \text{Hold up} / F \qquad (3.1)$$

where: τ = mean residence time, min

Hold up = mass of fresh chili in drying chamber, kg

F = feed rate of chili, kg/min

A = cross section area of drying chamber, m^2

ρ_p = density of fresh chili, kg/m^3

H = height of weir, m

The hold up can be calculated by :

Hold up = (cross section area of drying chamber)×(density of chili)×(height of weir);

$$\text{Hold up} = A\rho_p H \tag{3.2}$$

A mathematical model for predicting the moisture content ratio and time in this work was applied from Henderson's model and Agbahaslo et., al.'s model that relation with drying temperature and velocity of hot air by non-linear regression analysis. The schematic diagram of a continuous fluidized bed drying system shown in Figure 3.14 The deviations of energy and mass equations are based on basic physical laws.

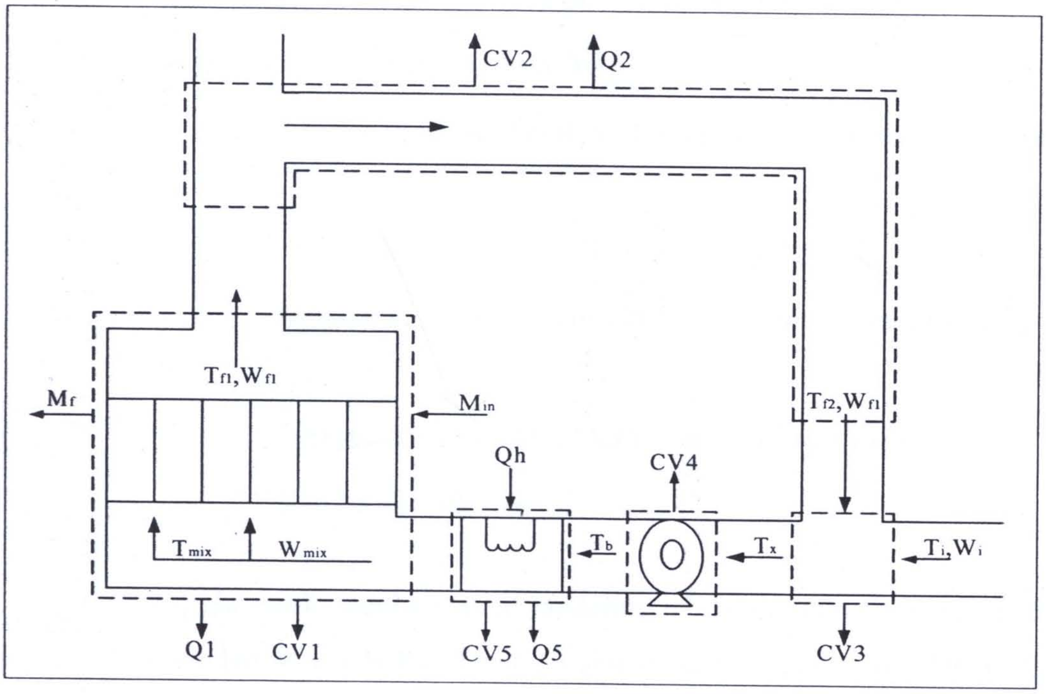

Figure 3.14 Schematic diagram of a fluidized bed dryer

where:

CV1 = control volume of drying chamber

CV2 = control volume of recycle air in pipe

CV3 = control volume of mixing air before entrance to blower

CV4 = control volume of blower

CV5 = control volume of heater

Q_h = energy for supply to heater, kW

Q_1 = heat losses from control volume CV1 to surrounding, kW

Q_2 = heat losses from control volume CV2 to surrounding, kW

Q_5 = heat losses from control volume CV5 to air from blower, kW

T_i = surrounding temperature, °C

W_i = moisture content ratio of fresh air, $kg_{water}/kg_{dry-air}$

W_{f1} = moisture content ratio of air after drying, $kg_{water}/kg_{dry-air}$

T_{f1} = temperature of air after drying, °C

T_{f2} = temperature of recycle air, °C

T_x = temperature of mixing air before entrance to blower, °C

T_b = temperature of exit air from blower, °C

M_f = moisture content of chili at drying chamber at the i^{th}, % on wet basis

M_{in} = initial moisture content of chili,% on wet basis

T_{mix} = temperature of air before entrance to bed layer or drying temperature, °C

W_{mix} = moisture content ratio of air before entrance to bed layer, $kg_{water}/kg_{dry-air}$

In this work, mathematical modeling of continuous fluidized bed chili drying is composed of series of thin layer. As shown in control volume 1(CV1), the chili bed in drying chamber is horizontally divided to n layer. At the i^{th} layer, the drying time(t) used for moving from the i^{th} layer to the $(i+1)^{n}$ layer is written as follows:

$$t_i = \frac{\tau}{n} \tag{3.3}$$

air mass flow rate at the i^{th} layer can be written as:

$$\dot{m}_{mixi} = \frac{\dot{m}_{mix}}{n} \tag{3.4}$$

and hold up of chili is also written as :

$$hp_i = \frac{hp}{n} \tag{3.5}$$

Where

t_i = time used for moving from the i^{th} layer to the $(i+1)^{n}$ layer, min

hp_i = dry mass of chili at the i^{th} layer, kg

hp = total mass of chili at the n^{th} layer, kg

$\dot{m}_{mix}$ = air mass flow rate, kg/min

$\dot{m}_{mixi}$ = air mass flow rate at the i^{th} layer , kg/min

n = number of layer for chili

3.2 Energy conservation of drying chamber

To consider a given thin layer drying, the energy equation is derived based on the first law of thermodynamics. It is assumed that the flow of chili in drying chamber is the uniform hot air flow passing through each chili layer is considered. As shown at the control volume CV1 in Figure3.14 change of enthalpy of air and internal energy change of chili and drying chamber are equal to total heat transfer between drying chamber and environment. To determine the outlet air temperature from the i^{th} drying layer, the following equation can be written as:

$$\frac{Q_1}{\dot{m}_{mix}} + C_a T_{mix} + (h_{fg} + C_v T_{mix})W_{mix} = C_a T_{f(i)} + (h_{fg} + C_v T_{f(i)})W_{f(i)} + \Delta u_p$$

or
$$T_{f(i)} = \left[\frac{\frac{Q_l}{\dot{m}_{mixi}} + C_a T_{mix} + (h_{fg} + C_v T_{mix}) W_{mix} - (W_{f(i)}) - \Delta u_p}{C_a + W_{f(i)} C_v} \right] \quad (3.6)$$

and

$$Q_l = UA(\Delta T) \quad (3.7)$$

C_a = specific heat of dry air, kJ/kg-°C

C_v = specific heat of water vapor, kJ/kg-°C

h_{fg} = latent heat of vaporization of water, kJ/kg

Q_l = heat losses from control volume CV1 to surrounding, kW

U = overall heat transfer coefficient, kW/m^2/°C

A = surface area of system(CV1), m^2

ΔT = temperature difference between system (CV1) and surrounding, °C

$T_{f(i)}$ = outlet air temperature at the ith layer, °C

Δu_p = change of internal energy of chili per unit mass of dry air, kJ/kg-dry air

$W_{f(i)}$ = outlet humidity ratio of air at the ith layer , kg$_{water}$/kg$_{dry\text{-}air}$

W_{mixi} = humidity ratio of air before entrance to bed layer, kg$_{water}$/kg$_{dry\text{-}air}$

3.2.1 Mass conservation at drying chamber

In a small time of Δt, a certain amount of moisture evaporates from the grain bed at the i^{th} layer into the air, resulting in a change of the humidity ratio of inlet air. The equation of mass balance can thus be written as:

$$(W_{f(i)} - W_{mix})\dot{m}_{mixi}\, t_i = (M_i - M_f)hp_i$$

or

$$W_{f(i)} = \frac{hp_i(M_i - M_{i+1})}{\dot{m}_{mixi}\, t_i} + W_{mix} \tag{3.8}$$

Where :

M_i = average moisture content at time = t, decimal(dry basis)

M_f = average moisture content at time = $t+\Delta t$, decimal(dry basis)

t_i = drying time of chili at at the i^{th} layer, min

Finally, the humidity ratio($W_{f(i)}$) and outlet temperature of exit air($T_{f(i)}$) can be determined by Eqns.(19) and (20), respectively.

$$W_{f1} = \frac{\int_1^n W_{f(i)} dn}{\int_0^n dn} \tag{3.9}$$

$$T_{f1} = \frac{\int_1^n T_{f(i)} dn}{\int_0^n dn} \tag{3.10}$$

where:

T_{f1} = average outlet temperature at drying chamber exit, °C

W_{fl} = average outlet humidity ratio at drying chamber exit, decimal

3.2.2 The analysis control volume (CV1)

The moisture content of chili in drying chamber were considered by control volume(CV1) method. The analysis moisture of chili after drying could calculated using horizontal nth layer of drying chamber—this were calculated any layer. The moisture content of chili after drying at the 1th layer were the initial moisture content of chili at the 2th layer and other layer above this layer respectively were depended on the assume the optimum period of drying time—the condition of air after drying coming from air condition average after drying in the layers.

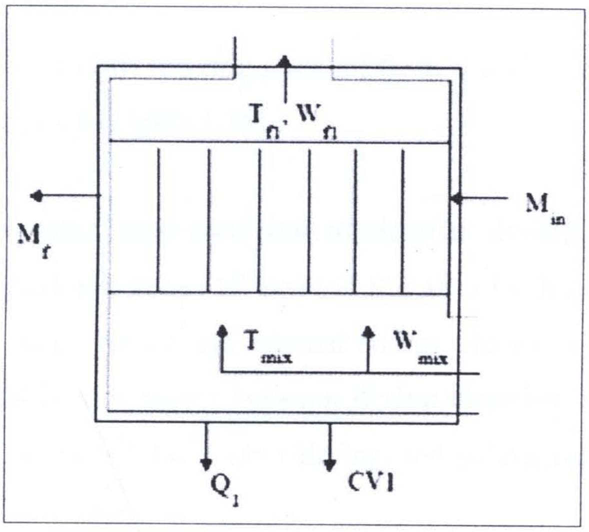

Figure 3.15 Control volume of drying chamber(CV1)

3.2.3 Moisture content of chili at the ith layer

The drying rate of chili depend on temperature air before into bed layer and specific air circulation rate. Changing of moisture content of chili were use in form of new model (chapter IV) – were developed for this work and considered the control volume of any bed layer that showed in Figure 3.16

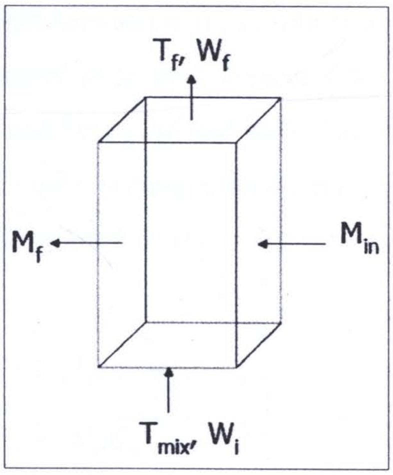

Figure 3.16 Control volume of the ith bed layer

Drying time of chili moving outward from the ith layer to the n layer defined as Equation (3.13), (3.14) and (3.15).

3.2.4 The calculated condition of air after drying

Considered at the ith layer in Figure 3.15 from conservation of energy, the change of enthalpy of air and internal energy change of chili and drying chamber are equal to total heat transfer between drying chamber and environment. The Temperature of air at the ith layer after drying, the following equation can be written as :

$$T_{f(i)} = \left[\frac{\frac{Q_l}{M_{mix}} + C_a T_{mix} + W_{mix}(h_{fg} + C_v T_{mix}) + RC_{pw} T_{mix} - W_{f(i)} h_{fg}}{C_a + W_{f(i)} C_v + RC_{pw}} \right] \tag{3.11}$$

$$R_p = \frac{hp_i}{m_{mixi} t} \tag{3.12}$$

where:

C_{pw} = Specific heat of chili, kJ/kg

R_p = The ratio of dry mass of chili per unit mass of dry air

3.2.5 Energy conservation at recycle tube

As illustrated in control volume CV2 in Figure 3.17, the outlet temperature from recycle tube can be calculated by balancing the change of enthalpy of air stream and summation of heat exchanger between recycled air and environment. The following equation of exit temperature at recycle tube is given by:

$$T_{f2} = \left[\frac{\dfrac{Q_2}{RCM_{mix}} + C_a T_{f1} + W_{f1} C_v T_{f1}}{C_a + W_{f1} C_v} \right] \qquad (3.13)$$

where :

T_{f2} = air temperature at recycle tube exit, °C

RC = fraction of recycled air, decimal

Q_2 = rate of heat loss from control volume CV2 to surrounding, kJ/s

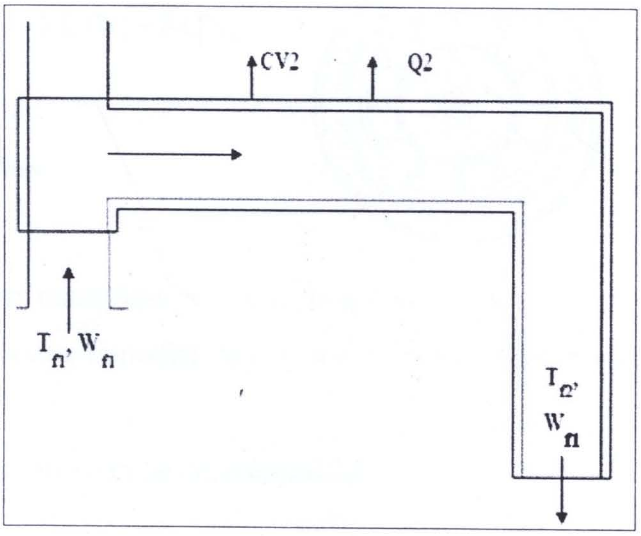

Figure 3.17 Showed control volume of air recycle tube(CV2)

3.2.6 Mass conservation before fan entrance(Soponronarit, 1997)

To determine the humidity ratio after mixing air between fresh air and recycled air as shown in Figure 3.15, the conservation of mass is made with control volume CV4 in which amount of water vapor after mixing is equal to the summation of water vapor from fresh air stream and recycled air. The mass balance equation for water vapor can be written as follows:

$$\dot{m}_{RC} W_f + \dot{m}_i W_i = (\dot{m}_{RC} + \dot{m}_i) W_{mix} \qquad (3.14)$$

Finally, dry mass flow rate of in let drying air at drying chamber entrance is equal to the summation of dry mass flow rate of fresh air and recycled air. Thus, the following equation is written as:

$$\dot{m}_{mix} = \dot{m}_{RC} + \dot{m}_i \qquad (3.15)$$

From Eqns.(3.24) and(3.25), the humidity ratios after mixing between recycled air and fresh air is determined by:

$$W_{mix} = (1 - RC)W_i + RC W_{fi} \qquad (3.16)$$

$$RC = \frac{\dot{m}_{RC}}{\dot{m}_{mix}} \qquad (3.17)$$

where :

$\dot{m}_{RC}$ = dry mass flow rate of recycled air, kg/s

W_i = mixing humidity ratio of air, kg water/kg-dry air

Mixing humidity ratio can be determined by:

$$W_i = 0.62189 P_v / (P - P_v) \qquad (3.18)$$

$$P_v = \Phi P_{vs} \tag{3.19}$$

$$W_i = 0.62189\Phi P_{vs}/(P - \Phi P_{vs}) \tag{3.20}$$

$$P_v = \frac{1.608 W_{mix} P}{(1 + 1.608 W_{mix})} \tag{3.21}$$

$$P_{vs} = \exp\begin{bmatrix} (\frac{-7511.52}{T}) + 89.63121 + 0.0239989T - 1.1654551\times10^{-5}T^2 - \\ 1.2810336\times10^{3} + 2.0998405\times10^{-11}T^4 - 12.150799\ln(T) \end{bmatrix} \tag{3.22}$$

$; 273.15\ \text{K} \le T \ge 393.16\ \text{K}$

$$W_{(i)} = \frac{(2501 - 2.411T_{wb})W_{wb} - 1.006(T_\infty - T_{wb})}{2501 + 1.775T_\infty - 4.186T_{wb}} \tag{3.23}$$

$$W_{wb} = 0.62189P_{vs}/(P_{atm} - P_{vs}) \tag{3.24}$$

where :

Φ = relative humidity of air, decimal

P = pressure of air, kPa

P_{atm} = atmosphere pressure of air, kPa

P_v = pressure vapor of materials, kPa

P_{vs} = pressure of saturated vapor, kPa

T_{wb} = wet bulb temperature, °C

W_{wb} = moisture content ratio at T_{wb}, kg water/kg-dry air

T_∞ = temperature at i^{th} layer, °C

$W_{(i)}$ = moisture content ratio at i^{th} layer, kg water/kg-dry air

4. Energy consumption of system

4.1 Calculation the temperature of air before entrance to blower

The energy balance is applied for control volume(CV3) in Figure 3.8 to determine the temperature after mixing between mixing air and fresh air, thus yielding:

$$\begin{aligned} & M_{mix}C_aT_x + M_{mix}W_{mix}(h_{fg} + C_vT_x) - M_iC_aT_i + M_iW_i(h_{fg} + C_vT_i) \\ & -M_i(RC)C_aT_{f2} + M_i(RC)W_{f1}(h_{fg} + C_vT_{f2}) = 0 \end{aligned} \tag{3.25}$$

or

$$T_x = \frac{[(1-RC)C_aT_i + (1-RC)W_i(h_{fg} + C_vT_i) + RC[((C_aT_{f2} + W_{f1}(h_{fg} - C_vT_{f2})) - W_{mix}h_{fg}]}{(C_a + C_vW_{mix})} \tag{3.26}$$

Where :

T_x = Temperature of mixing air before entrance to blower, °C

T_i = Surrounding temperature, °C

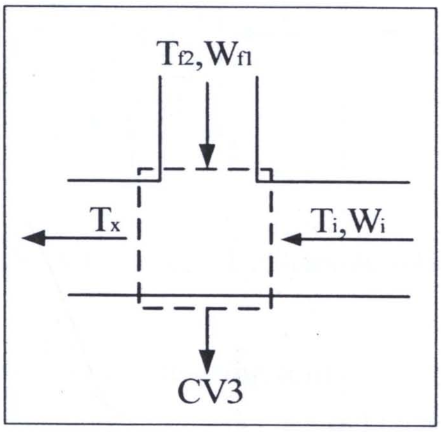

Figure 3.18 Control volume (CV3)

4.2 Temperature rise of air within blower

The energy balance is applied for control volume(CV4) in Figure 3.9 to determine the temperature after mixing between mixing air and fresh air as follows:

$$\Delta T_{blower} = P/[(\rho_a \eta)(C_a + W_{mix} C_v)] \tag{3.27}$$

$$T_b = T_x + \Delta T_{blower} \tag{3.28}$$

where :

ρ_a = density of dry air, kg/m^3

P = pressure drop across the blower, kPa

η = mechanical efficiency, decimal

T_b = temperature of air exit from blower, °C

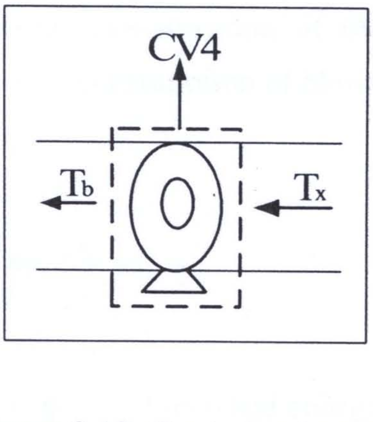

Figure 3.19 Control volume (CV4)

4.3 Energy consumption of heating unit

As shown in the control volume CV5 in Figure 3.10, the change of enthalpy of air stream is equal to heat loss and supplemental heat from electrical heater. The equation can be written as follows:

$$Q_5 + Q_h = M_{mix}[C_a + (W_{mix} C_v)](T_{mix} - T_b) \tag{3.29}$$

where :

Q_h = electrical energy consumption of heater, kJ/s or kW

Q_5 = heat loss at heating unit, kJ/s or kW

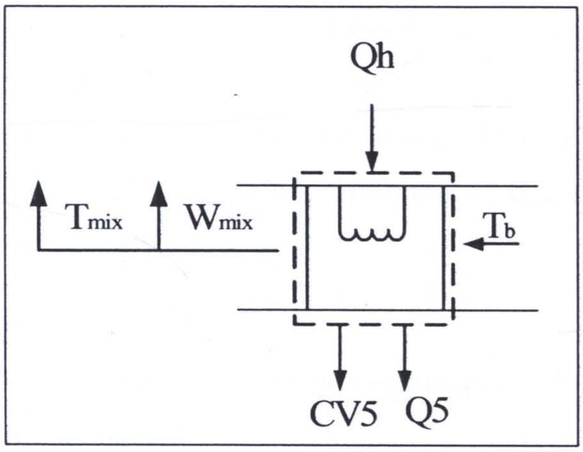

Figure 3.20 Control volume (CV5)

4.4 Electrical energy consumption of blower

Electrical energy consumption of blower is determined from following equation:

$$W_s = \frac{(dp)M_{mix}/\rho_a}{\eta} \tag{3.30}$$

where :

W_s = Electrical energy consumption of blower, kW

M_{mix} = mass flow rate of air, kg/s

η = mechanical efficiency, decimal

ρ_a = density of dry air, kg/m^3

dp = pressure drop at blower, kPa

To compare energy consumption among different inlet drying air temperature, the specific energy consumption of this fluidization is considered. The specific energy consumption for each drying condition is defined as energy consumption divided by total water evaporated and multiplied by drying time. The total specific energy consumption is a summation of specific thermal energy consumption and specific electrical energy consumption multiplied by total drying time.

In the simulation, assumption is stated that the continuous fluidized bed drying was used for drying chili at the temperature between 50 and 100 °C using inlet air velocity of 4, 5 and 6 m/s and fraction of recycled air was 70%. Initial moisture contents of 72.98% wet basis and equilibrium moisture contents of 2.3% wet basis. Ambient temperature was fixed at the condition of dry bulb temperature of 30°C and relative humidity of 70%.

5. The procedure of comparison energy consumption between experiment and empirical mathematical model

5.1 To set initial data for calculation, calculate residence time of chili in dryer chamber from Eq. 11 and 12.

5.2 Divided n layer of chili after calculate t_i, m_{mixi} and hp_i from Eq. 3.3, 3.4 and 3.5 respectively.

5.3 Calculated W_{mix} from Eq. 26 using assume W_{fl} equal 0.02.

5.4 Calculated T_{fi} and W_{fi} of air after drying from 1 layer to n layer from Eq. 3.6 and 3.8.

5.5 Calculated T_{fl} and W_{fl} of air after drying from 1 layer to n layer from Eq. 3.9 and 3.10.

5.6 Compared W_{fl} from calculation with W_{fl} from the assume, repeat calculation if the difference more than 0.000001

5.7 Calculated T_x if the difference between W_{fl} from calculation with W_{fl} from the assume less than 0.000001 from Equation 3.26.

5.8 Calculated air temperature exit from blower (T_b) from Equation (3.27), and (3.28).

5.9 Calculated heat consumption rate (Q_h) from Eq. 3.31;

$$Q_h = \dot{m}_{mix}\left[C_a + C_v W_{mix}\right](T_{mix} - T_b) \tag{3.31}$$

5.10 Calculated electricity energy consumption from blower (W_s) from Eq. (3.30).

5.11 Calculated total energy consumption (ΔE) from Eq.3.32;

$$\Delta E = W_s + Q_h \tag{3.32}$$

5.12 Calculated every experiments and simulation in this study using Figure 3.21.

6. Data analysis and computer program simulation

The results of moisture content ratio(MR) from the experiments were regression analysis using SPSS program, which the empirical constant from regression analysis of each model were compared the results and selected the best model that showed the results nearly or lees contrast with the experiments. After, all empirical constant were used in the simulation using computer program(MATLAB) for simulate the operation of this drying using continuous fluidized bed technique, this simulation flow chart of continuous fluidized bed drying can be showed in Figure 3.21.

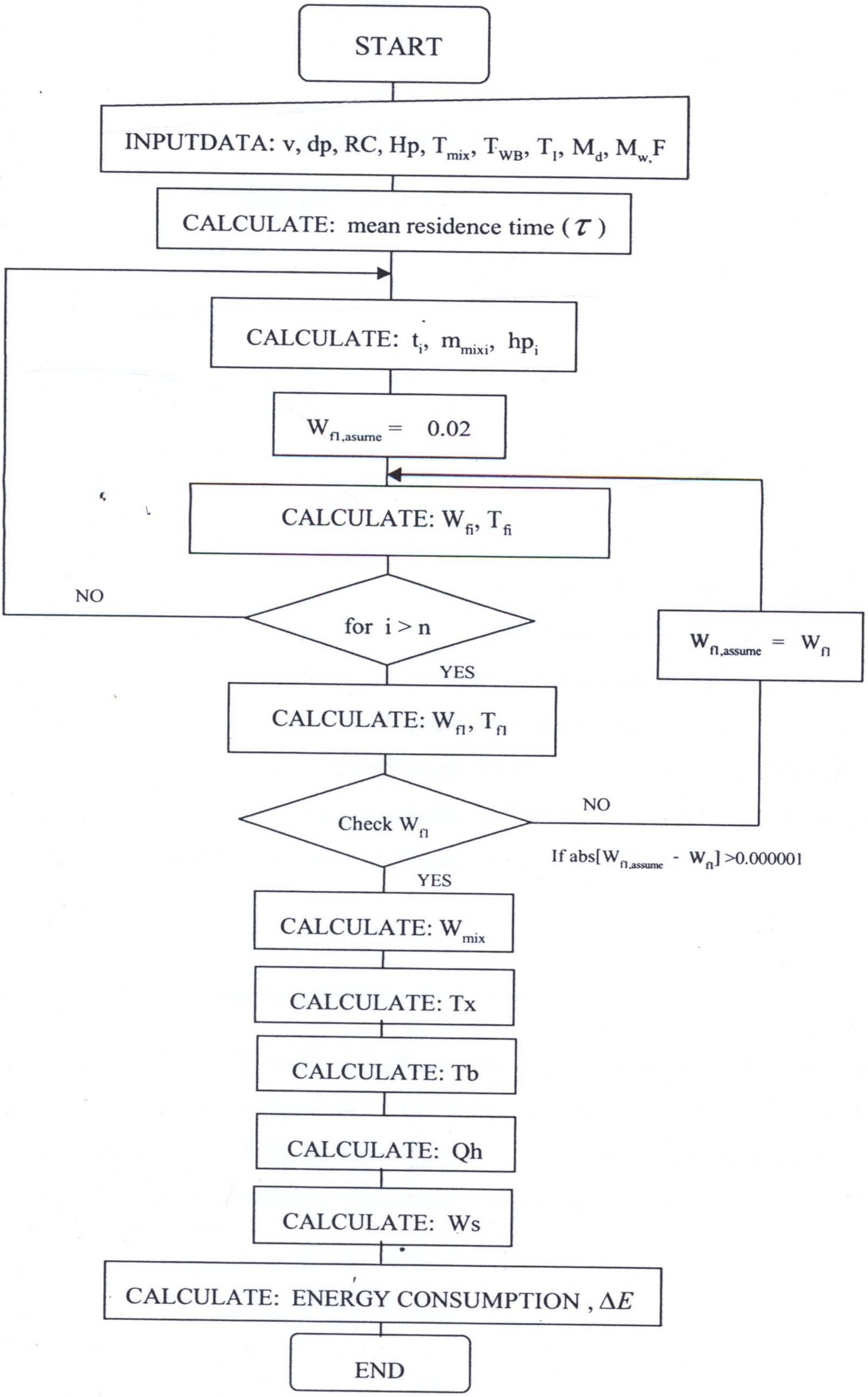

Figure 3.21 Simulation flow chart of continuous fluidized bed drying