Kinetic Study On Aquilaria Malaccensis By Using Vacuum Far Infrared Drying

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***Abstract*—In this study, Far infrared drying behavior of Aquilaria Malaccensis leaves was investigated in advanced of vacuum pressure. The study was aimed to study the effect of VFIR drying in terms of changes of color, moisture content, drying curve and mathematical model. in addition, this would result in less energy conserved, less damaging drying process and contribute the originality of the product. The parameter of this experiment is set to be temperature of 40ºC, 50ºC and 60ºC under vacuum pressure of 5 bar with drying time of 120 minutes long. the drying data were fitted to 3 thin layer drying models. The performance of these models was compared using the determination of coefficient, R^2, reduced chi square, X^2 and root mean square error, RMSE between the experimental and predicted of moisture content. The mathematical model gives a result of Page that the most suitable in analyzing drying curve of Aquilaria Malaccensis.**

***Keywords*—Aquilaria Malaccensis, Vacuum Far Infrared Drying, chromameter, drying characteristics and mathematical model.**

I. Introduction

Aquilaria Malaccensis is growing widely in rocky, sandy and lowland near swamps area at 270m altitudes from Aquilaria genus in family of Thymelaeceae. Malaccensis known as agarwood and Malaccensis species has various names in each different country alsoknown as agarwood, aloeswood, eaglewood, jinkoh and agalloch. Agarwood is found at most countries such as Bangladesh, Philipines, Singapore, Indonesia, Malaysia, Myanmar, Bhutan, Iran and Thailand according to **[1]**

For the past years, Aquilaria tree is the rare and famous, resin-containing heartwood that is highly demand throughout Europe, Middle East and Asia due to its beneficial properties for drugs, incense and fragrance. Though the scientists measure and evaluate that only 10% of Aquilaria trees containing gaharu oil. **[2]**

Many studies have been focused on agarwood that has potential medicinal materials as antidiabetic agent and anticancer activity. **[3]** Nowadays, agarwood become the most valuable wood due to its advantages to people. It has been discussed that extract of gaharu leaves with methanol as solvent contain flavonoids, alkaloids, terpenoids of secondary metabolites that can be extracted. **[3]** Extraction of the composition in Aquilaria Malaccensis leaves has been done by gas chromatography-mass spectrometry (GS-MS) explained the presence of chromones, aromatic compounds, steroids and fatty acids. Nonetheless there is no exeriement is carried out on composition and bioactivity of Malaccensis seeds. The phytochemicals found in this species are 2-(2- phenylethyl) chromenes, lignans, diterpenoids and flavonoid glycosides had claimed by researcher to make it favorable as health supplement. It can be achieved that there are varied medicinal can be obtained from this species. **[4]** Processing and preservation of these bioactive compounds are important to preserve the antidiabetic potential of Aquilaria Malaccensis leaves and its invaluable nutraceuticals.

Drying is one of the important preservation methods in many chemical process industries for example food, pharmaceuticals, chemicals, plastics and others. Process of mass transfers which are removing liquid from solid material, solution, suspension or melt by evaporation from a solid, semi-solid or liquid is called drying. **[5]**

The purpose of drying is applied in many chemical process industries are:

1. To eliminate moisture that can lead to corrosion.
2. To reduce cost such as transportation cost in carrying a larger volume of liquid.
3. A material is much easier to handle such as soap powders.
4. Preservation

Drying process occurs when liquid is vaporized by supplying heat to the wet feedstock. The liquid removed by the drying process could be exists in free moisture (unbound) or bound. Water at the same temperature is controlled is applied when at low vapor pressure called bound moisture. While the free moisture is water is in excess of the equilibrium moisture content. **[5]**

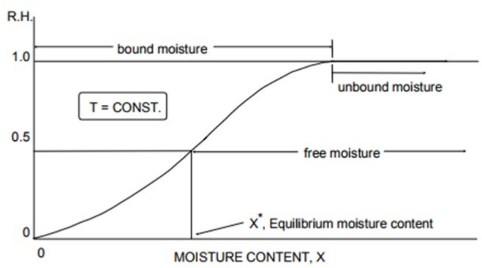


Figure 1: Various type of moisture content

Drying is a process which is the combination of mass and heat transfer. Drying involves two definite drying periods which are known as the constant drying period and the falling drying period. From Figure 1, the constant drying rate is take place from a saturated surface by diffusion of the water vapor. After some period of t, the surface is no longer experienced of supplying free moisture to saturate the air in contact. **[6]**

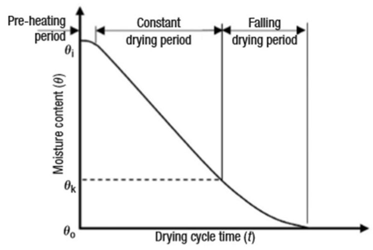


Figure 2: Drying process involves two different phases

Drying curve usually plots the drying rate versus drying time or moisture contents. There are three major stages of drying can be observed in the drying curve. **[7]**

i. Transient early stage occurs during the product is heating up.
ii. Constant rate period happened when moisture is comparatively easy to remove.
iii. Falling rate period take place when the moisture is start to bound or held within the solid matrix.
iv. Critical moisture content where the moisture content at the point when the drying period changes from a constant to a falling rate.

More than century, a convectional convective drying technique such as hot air drying is most widely used in many chemical industries which are provide low energy efficiency and drawn-out drying time during the falling rate period. However, this method resulted in degradation of the product quality in term of color, flavor, nutrient concentration and texture. **[8]** In context of drying time, microwave drying method has proposed as an alternative way regarding this problem to enhance the quality of dehydrated products instead of reducing drying time. Yet, this method still has not been able to achieve the good result in produce more better product quality.

Far infrared dryer has received much attention among the researchers due to minimal energy loss during the drying period. Compared to hot air drying, FIR or infrared radiation resulted in low energy consumption due to the energy transferred without heating the surrounding air. This type of dryer has applied in several dryers in many chemical process industries because its interest in shortened drying duration of time, produce the great energy efficiency and preserve the product quality. **[9]** Recently, a vacuum is used by researchers on drying process because vacuum is usually applied to produce low pressure and low oxygen during heating. Since most foods are heat sensitive in nature, it is desirable to be able to dry these products at low temperature to preserve its quality. Drying under vacuum is generally performed since under vacuum, water evaporates at low temperature hence, drying can be operated at low temperature. A Vacuum Far Infrared Dryer (VFIR) has been studied and several researchers have described their experiment on this method by drying of some products. VFIR had received much attention as an alternative drying technique due to less energy is conserved, less damaging drying process and contribute the originality of the product. **[10]**

Therefore, the objective of this experiment is to study the effect of drying kinetic on Aquilaria Malaccensis leaves by using vacuum far infrared dryer in terms of color and to determine the optimum condition of the leaves in term of temperature and pressure.

II. METHODOLOGY

A. Materials

25 identically size of fresh of Aquilaria Malaccensis leaves were obtained naturally-inoculated plants from producers in Jalan Kebun, Shah Alam. To ensure the freshness of the leaves, the leaves is collected a day before the experiment is carried out. Before the experiment is carried out, the leaves must be washed and cleaned then stored in a cool placed. The initial moisture content of fresh Aquilaria Malaccensis was measured. Each of Aquilaria Malaccensis leaves were labeled by (1a, 1b, 1c, 2a, 2b, 2c and so on) . Each of the Aquiaria Malaccensis leave's weight were weighing by a weighing balance before and after the experiment. A picture of the samples was taken before the experiment is carried out to compare color change after drying process.

B. Experimental VFIR dryer

The dryer was prepared for the experiment to carry out. The Aquilaria Malaccensis leaves were uniformly spread on the middle section of the tray. The drying chamber was sealed tightly and the pump is switched on to evacuate the drying chamber t the desired operating pressure at 5bar. The VFIR heater then turned on and being set at 40°C. The experiment is conducted for each 5 minutes of intervals until it reached the equilibrium (120 minutes). The samples are carried out at various temperatures (50°C and 60°C) at constant pressure 5bar.

In order to get moisture content of Aquilaria Malaccensis leaves, each of sample's weight was weighted and moisture content can be calculated by using the follow equation;

$$M = \frac{W - W_1}{W_1} \quad \text{……….} (1)$$

Where, M is the moisture content, g water/g dry solid; W is the final weight of the samples, g; W_1 is initial weight of samples, g. Because the equilibrium moisture content,M_e was very low and could be negligible,**[10]**the moisture ratio (MR) was simplified as below;

$$MR = \frac{M - M_e}{M_o - M_e} = \frac{M}{M_o} \quad \text{……….} (2)$$

Three of Aquilaria Malaccensis leaves were labeled by (1a, 1b, 1c, 2a, 2b, 2c and so on) then was weighted by a weighing balance and measure the color by a chorma meter before and after the experiment is carried out. A vacuum far infrared dryer was prepared for the experiment to carry out. The samples were uniformly spread on the middle section of the tray. The drying chamber was sealed tightly and the pump is switched on to evacuate the drying chamber t the desired operating pressure at 5 bars. The VFIR heater then turned on and being set at 40°C. the experiment is conducted for each 5 minutes of intervals until its reached an equilibrium (120 minutes). The samples is carried out at various temperature (50°C and 60°C)

C. Mathematical modeling

Drying curve can be fitted by the experimental data by using mathematical modeling that can be described in divided by three categories which are theoretical, semi-theoretical and empirical. (Asiru, 2013) Most condition such as the drying behaviors of the product positively can be explained by theoretical models. For this model, it may include some assumption on moisture mechanism that can lead to several errors. The thin layer drying process is simplified by theoretical equation, Fick's second law. **[17]**

Fick's second law;

$$\frac{\delta c}{\delta t} = D \frac{\delta^2 c}{\delta x^2} \quad \text{.......... (3)}$$

In order to determine the quality of the fit, the drying curves can be well-defined by the following equation;

Root mean square error;

$$RMSE = [\frac{1}{N}\sum_{i=1}^{N}(MR_{pre,i} - MR_{exp,i})^2]^{\frac{1}{2}} \text{.......... (4)}$$

Chi square;

$$X^2 = \frac{\sum_{i=1}^{N}(MR_{exp,i} - MR_{pre,i})^2}{N-z} \quad \text{.......... (5)}$$

Where is MR is the experimental moisture ratio, $MR_{pre,I}$ is the prediction of moisture ratio, N is a number of observation, Z is a number of constant.
The best model is determined by the highest of coefficient of determination, lower of chi square and root mean square error. **[18]**

Table 1: Mathematical modeling used in analyzing of moisture content removal of Aquilaria Malaccensis

Model number	Model name	Equation	References
1	Page	MR=exp(-kt^n)	**[13]**
2	Henderson and Pabis	MR=aexp(-kt)	**[14]**
3	Logarithmic	MR=aexp(-kt) +b	**[15]**

D. EVALUATION OF DRYING QUALITIES

The physical qualities of Aquilaria Malaccensis leaves evaluated were color, texture and moisture content. A picture of Aquilaria Malaccensis leaves was taken before and after the experiment is carried out in order to compare any changes color of the samples. Changes in color of the samples were measured by using chroma meter. For each drying experiment on three dried samples and the color values were compared with those of fresh samples. The data obtained was reported and tabulated in a table.

The changes of color can be calculated by the following formula;

$$\Delta L = \frac{L - L_i}{L_i} \quad \text{.......... (6)}$$

$$\Delta a = \frac{a - a_i}{a_i} \quad \text{.......... (7)}$$

$$\Delta b = \frac{b - b_i}{b_i} \quad \text{.......... (8)}$$

$$\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2} \quad \text{.......... (9)}$$

Where L,a and b represents the lightness, yellowness and redness of the samples, respectively.

The texture of the Aquilaria Malaccensis was measured in terms of shape after the drying process. The texture is compared with the initial samples before the experiment is carried out.

III. RESULTS AND DISCUSSION

A. Effect of vacuum far infrared drying on moisture content removal of aquilaria malaccensis leaves

The experiment is carried out with Vacuum Far Infrared Dryer (VFIR) for drying the leaves. In order to observe the removal of moisture content in Aquilaria Malaccensis leaves, each of samples was weighted the weight of samples before and after the drying process. In each interval of drying, 3 leaves of Aquilaria Malaccensis was prepared and weighted three times the weight to get average value in the reason of to reduce the error in the experiment.

Figure 3 showed the effect of vacuum far infrared dryer's (VFIR) temperature on moisture content, moisture ratio and drying rate of Aquilaria Malaccensis leaves during drying at various time intervals respectively. As expected, the moisture content was decrease by increased temperature. The moisture content was calculated using dry basis and wet basis formula. The results were taken at average reading.

Aquilaria Malaccensis leaves had to be dried for 120 minutes long to achieve a constant moisture content. The moisture content slowly dried out in this temperature of 40ºC. The removal of moisture content was increasing as the time increase. It took longer time as the drying temperature was low. Meanwhile, at 50ºC the moisture content was removed rapidly at 20 minutes of drying period and after that the removal of moisture content moderately increase until achieve 120 minutes of drying. At temperature 60ºC has shown that moisture content removed of Aquilaria Malaccensis leaves can be seen at initial of the experiment. After some period, as drying time increased, the moisture content released increasing steadily. Thus, only at 40ºC took longer time to dry as resulted in moisture content removal from Aquilaria Malaccensis leaves. As a resulted, by increasing drying time, moisture content removal also increased due to heat transfer between the sample and air and the acceleration of water migration inside the Aquilaria Malaccensis leaves.

The Aquilaria Malaccensis leaves had to be dried for 120 minutes long to achieve a constant moisture content. At 40ºC the moisture content slowly dried out as drying time increased. It took longer time as the drying temperature was low. Meanwhile, at 50ºC the moisture content drastically dried out at 20 minutes of drying period and after that the moisture content did not have any drastic changes until achieve 120 minutes of drying. At temperature 60ºC has shown that moisture content in Aquilaria Malaccensis leaves dried at initial of experiment. Thus, only at 40ºC took longer time to dried as resulted in moisture content removal from Aquilaria Malaccensis leaves. As a resulted, by increasing drying time, moisture content removal also increased due to heat transfer between the sample and air and the acceleration of water migration inside the Aquilaria Malaccensis leaves.

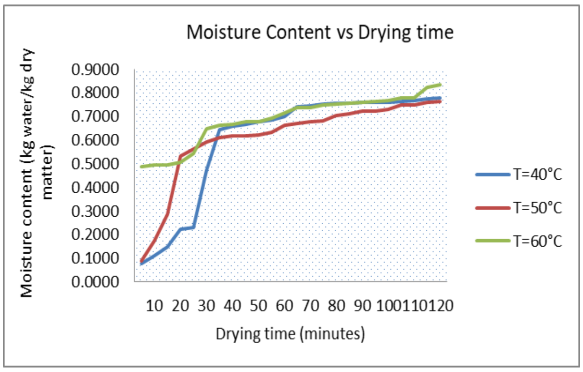
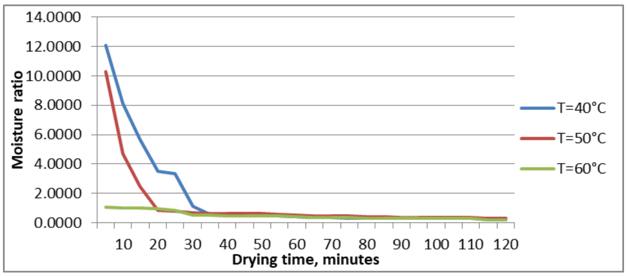


Figure 3: Moisture content of Aquilaria Malaccensis leaves affected by drying time

Moisture ratio can be defined as the ratio of the mass of water in a sample to the mass of solids. The same pattern of graph applied to moisture ratio. Graph of moisture ratio is plotted in Figure 4 below. At fixed VFIR's pressure, as the drying time increase, the drying increase with increasing temperature. At initial drying stage of 40°C, the moisture ratio increases moderately until 25 minutes of drying then rapidly increased at 35 minutes. At vacuum surrounding in the VFIR's chamber, it is desirable to dry the samles at low oxygen content and low temperature in order to maintain the product quality. The same result has been previously reported by several researchers from past experiment to examine the drying behavious of the leaf parts of welsh onion adopting VFIR drying method. **[13]**

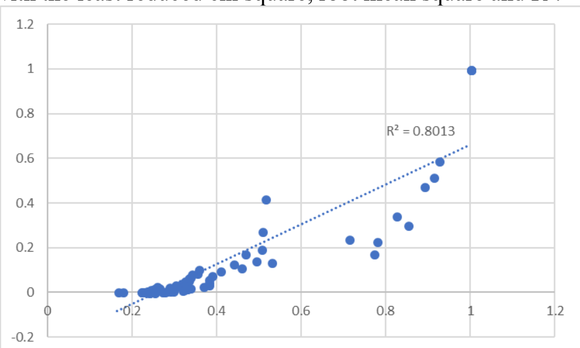
Figure 4: Moisture ratio of Aquilaria Malaccensis leaves vs drying time



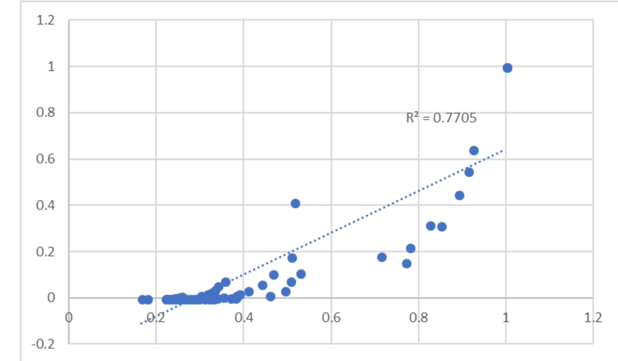
B. *Mathematical model of drying curve*

Mathematical modeling of drying of food products often requires the statistical methods of regression and correlation analysis. This are an important tool to find the relationship between the different variables.

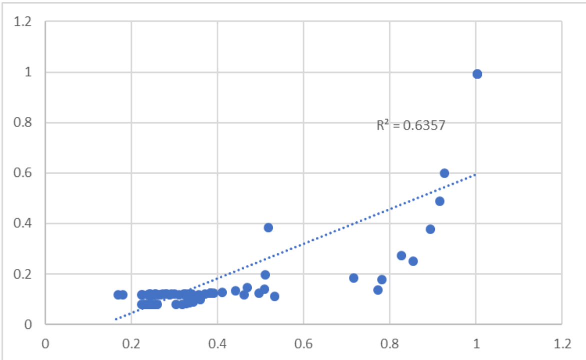
The value of root mean square, RMSE, chi square, X^2 R^2 data is tabulated in Table 2. The best model describing the drying characteristic of Aquilaria Malaccensis leaves was choose as the one with the least reduced chi square, root mean square and R^2.



1. Page model



2. Hnederson and Pabis model



3. Logarithmic model

Figure 5: Experimental versus predicted moisture content by using mathematical model

In this experiment, only three model which are Page, Henderson and Pabis and Logarithmic model were used. All the models gave a steadily and consistent value of RMSE, X^2 and R^2. It showed that all these models could satisfactorily describe the drying of Aquilaria Malaccensis leaves. Among this model, the Page is the most suitable as mathematical model due to the highest R^2 and lowest value of RMSE and chi square, X^2. A detail study showed that the Page model gave higher values than the Lewis and Henderson and Pabis models. As shown in Figure 5, the Page model provided a good agreement between experimental and predicted of moisture content.

C. *Impact of vacuum far infrared on color measurement of aquilaria malaccensis leaves*

Changes of color of Aquilaria Malaccensis leaves during drying process are caused by the reactions taking place inside it, for example pigment degradation and browning reactions. Thus, the final values of color parameters can be used as quality indicators to detect deterioration due to drying process. The physical appearance of the drying leaves is observed by comparing the color of the leaves before and after drying. Deterioration color of Aquilaria Malaccensis leaves also affected by Vacuum Far Infrared Dryer (VFIR) that has been used in this experiment. From Figure 6 below, the experiment is carried out by applying the heat in vacuum conditions, there were discolorations of Aquilaria Malaccensis leaves after drying process.

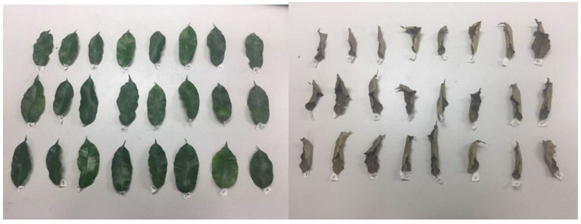
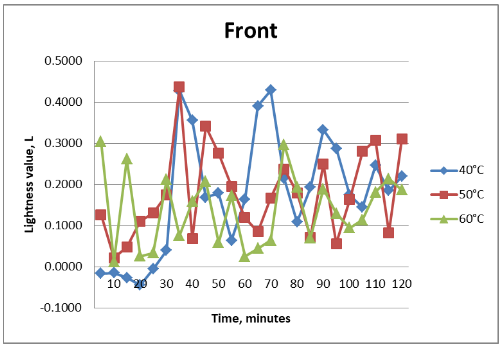


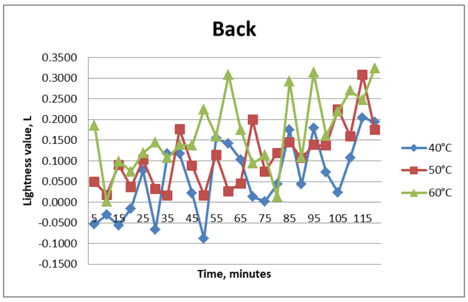
Figure 6: Physical changes of Aquilaria Malaccensis before and after drying

In addition, from the Figure 6 (a-b), the Aquilaria Malaccensis leaves shrink as drying time increased at various temperature (40ºC, 50ºC and 60ºC) with constant pressure at 5 bar and caused the surface of Aquilaria Malaccensis become dried. This is due to the removal of water in the sample being removed. The changes of color of the samples can be measured by using a chromameter.

The color measurement can be defined and reported based on lightness, L, redness, a, yellowness, b, hue angle and total color difference. The range of color parameter can be expressed as following;
Lightness, ΔL from lighter (+) to darker (-)
Redness, Δa from red (+) to green (-)
Yellowness, Δb from yellow (+) to blue (-)



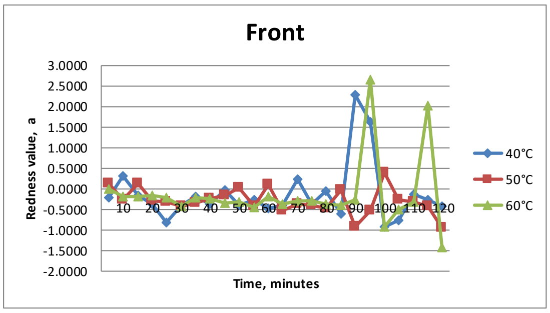
(a)



(b)

Figure 7: Lightness difference value for front and back of Aquilaria Malaccensis leaves

Figure 7 showed the lightness difference for Aquilaria Malaccensis leaves versus time of drying for various temperatures (40ºC, 50ºC and 60ºC). As the time increased the changes of lightness of samples were observed. At temperature of 40ºC, at first the L values increasing 40 minutes of drying process then started fluctuate until reaching the optimal time of 120 minutes with slight increase from the fresh sample. For temperature of 50ºC and 60ºC, the L values varied as time of drying increase.



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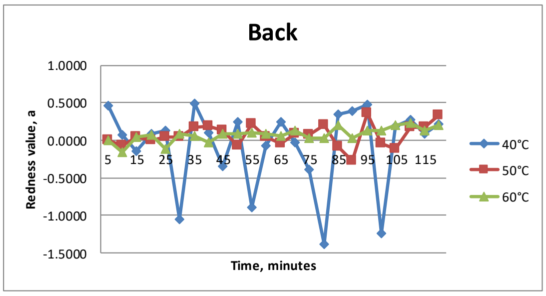
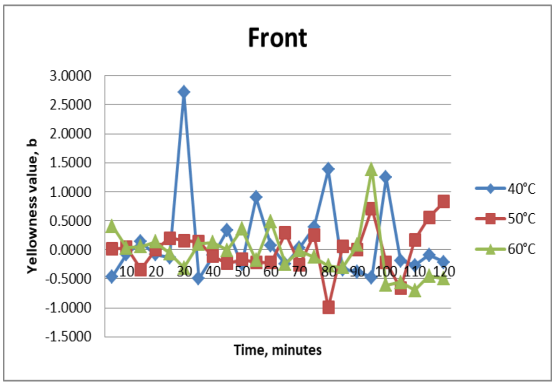


(b)

Figure 8: Redness difference for front and back of Aquilaria Malaccensis leaves

One of the parameters of color difference measured is redness as shown in Figure 8. The temperature of 50ºC showed that the redness value moderately increases and decrease as the time of drying increase. Meanwhile, for 40ºC and 60ºC also showed the gently trend but then suddenly increase at 90 and 95 minutes of drying. This situation may because of the leaves had exposed to surrounding air.



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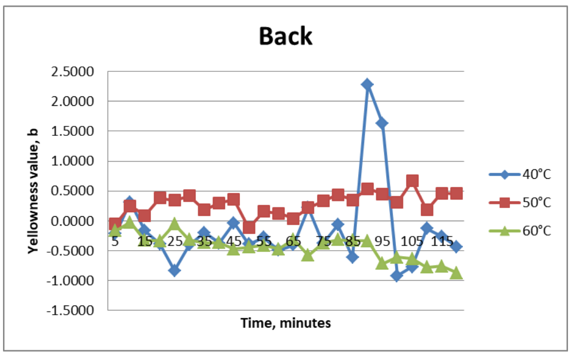
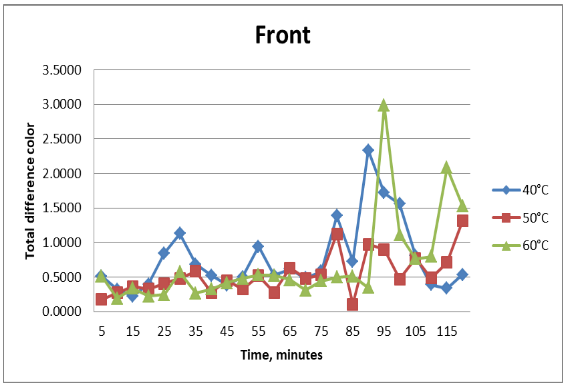


(b)

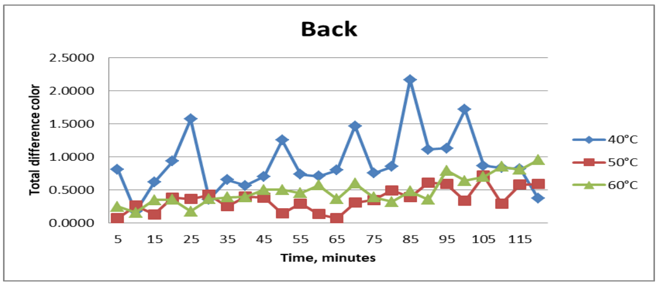
Figure 9: Yellowness difference for front and back of Aquilaria Malaccensis

From figure 9, at 10 minutes of drying process, the yellowness value significantly increases maybe due to the damage of leaves being used. Mostly the trend for both of front and back, the yellowness value gives slightly increase and decreasing back before it started fluctuate until 120 minutes of drying process in Vacuum Far Infrared Dryer.

Overall of drying process, it showed that the Aquilaria Malaccensis leaves got darker compared to before the samples dried. The results obtained indicate that browning reaction may occur during the drying process. **[12]**



(a)



(b)

Figure 10: Total color difference for front and back of Aquilaria Malaccensis leaves

Color difference can be defined as the numerical comparison of samples color to standard. It shows the difference in absolute color coordinates and is referred as delta. By using the formula of color difference, it can help users control the color of their products more effectively.
From figure 10, it showed that for the temperature of 50°C and 60°C slightly increased as drying time increased meanwhile at 40°C fluctuate until 120 minutes for back of Aquilaria Malaccensis. In the meantime, for front of samples, there are moderately changes of total color difference at 50°C along the experiment is carried out. For other temperature, there are drastically increase at 85 and 95 minutes. This may due to the young leaves used which is more sensitive to color change than the mature ones.

IV. Conclusion

In conclusion, this experiment is carried out to study the effect of VFIR drying on the Aquilaria Malaccensis leaves in terms of color change, moisture content removal, drying rate and mathematical model. All the data and observation were tabulated in a table and measured. Color changes is measured before and after drying and the result give a fluctuate value of lightness, redness and yellowness. This may due to the leaves had been exposed to long to air surrounding. In term of drying curve and mathematical modeling, it shows that Page is the most suitable among the other two models due to have highest of R^2 and lowest value of RMSE and X^2.

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