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Drying Studies of Oil Palm Decanter Cake for Production of Green Fertilizer

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ABSTRACT

The oil palm tree (*Elaeis guineensis*) yields palm oil from the flesh of its fruit that can be used in various industries. The extraction process produces decanter cake as one of their waste products. Drying process can be applied to the decanter cake for repurposing. The aim of this study is to determine the drying characteristics of decanter cake from the palm oil mill waste. Four thin layer drying models were used to define the drying characteristics of the decanter cake. The models are Newton model, Henderson and Pabis model, Logarithmic models and Two Term model. The samples were dried at 105°C by using convection oven, following ASTM D2974-20e1 to obtain the moisture content. Non-linear regression by using LAB Fit Curve Fitting Software was used for the statistical analysis to get the predicted data. The predicted data was compared to the experimental data carried out at three different thickness (0.3 cm, 0.5 cm and 1 cm). Coefficient of determination (R^2), reduced chi-square (X^2) and root mean square error (RMSE) were the statistical parameters involved. Higher R^2 with lower X^2 and RMSE indicates good correlation and similarities of the model prediction. Results shows that 1 cm is not suitable to be dried within three hours using mechanized dryers. From the analysis, Logarithmic model generated the best predictability for 0.3 cm and 0.5 cm thickness.

1. Introduction

The oil palm tree *(Elaeis guineensis)* belongs to the Arecaceae family, which had been previously known as Palmaceae [1]. Palm oil is one of the most significant agricultural commodities in the world, as well as one of the largest agricultural industries. Oil palm is a type of commercial plantation that is widely grown in Indonesia, Malaysia, and Thailand [2]. Malaysia is the world's second-largest producer of palm oil, after Indonesia, and palm oil has always been Malaysia's primary agricultural export. In 2019 alone, the gross domestic product (GDP) contribution from palm oil in Malaysia was estimated to be at 2.7%. In Malaysia, there are approximately 416 palm oil mills working since about

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2009 [3]. The oil palm tree could grow to a height of 20 metres. It also has an estimated economic lifespan of 20 to 25 years.

Malaysia is blessed with ideal weather conditions which last throughout the year, allowing palm oil growing in this location and have produced the largest yields [4]. Since the 1830s, palm oil was widely applied in the food and non-food industries [5]. Over the years, the fruit of the oil palm tree will begin to develop and can yield a total up to 10 to 35 tonnes per year for one hectare of palm oil and 168 million tonnes of biomass waste been produced [6,7]. The main product of palm oil is oil obtained from fresh fruit bunches (FFB). In order to obtain quality oil, harvesting activities must be carried out in accordance with good harvesting practices. Quality oils have a low free fatty acid (FFA) content of 2%-3% [8]. The percentage of dry weight composition of fruit and mesocarp is given in Table 1.

Table 1
Dry weight composition of fruit and mesocarp (%) (Yusoff, 2006)

Fruit		Mesocarp	
Palm oil	29	Palm oil	46 – 50
Water	27	Palm oil (dry basis)	77 – 81
Residue	8	Moisture	36 – 40
Shell	30	Non-fatty solids	13 – 15
Kernel	6		

It is called FFB because the palm oil tree's fresh fruits are joined and bunched together, producing a quite large structure for a single bunch. Kernel (endosperm), mesocarp, exocarp, and endocarp are all parts of the fruit's structure. The endocarp is the fruit's centre unit, which contains the shell, testa, and the kernel or endosperm. The exocarp is the fruit's exterior protective skin, often known as the skin or peel, which is a more common term. The mesocarp is one of the major structures, on which the fleshy centre layer of the fruit has an orange-red colour. The cross-section of an oil palm fruit is shown in the diagram below, and the table above illustrates the dry weight % content of FFB and the mesocarp [9].

Crude palm oil (CPO) and palm kernel oil (PKO), both obtained from the FFB, are the two major products needed by all palm oil mills. Additionally, according to Yusoff [4], the CPO and PKO can be extracted from the mesocarp and kernel, separately. Carotenoids are contained in the mesocarp, which give the flesh an orange-red colour [10]. The cross-section of the oil palm fruit is given in Figure 1.

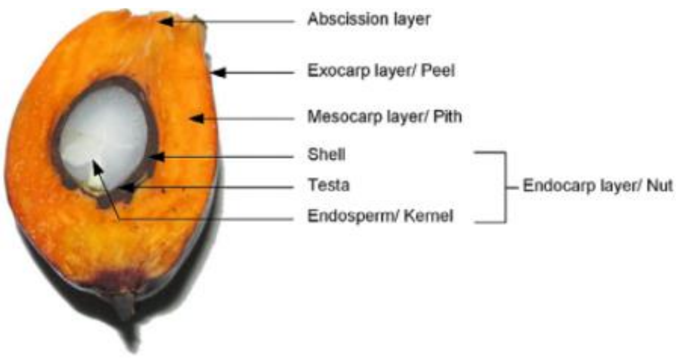


Fig. 1. Cross-section of the oil palm fruit [9]

Palm oil mills will perform the extraction process for both forms of palm oil, CPO and PKO, from the fruit of the oil palm tree. The FFB collected from the oil palm tree farm will be sent to palm oil mills and be processed as soon as possible in order to maintain the highest grade and quality of palm oil [11]. The extraction of CPO and PKO in palm oil mills would greatly benefit Malaysia's economy and agriculture industries. Unfortunately, palm oil mills would increase environmental pollution at the same time [12].

The oil palm business will create a considerable amount of garbage of various forms. All wastes generated during the manufacturing process have the potential to damage the environment [13]. There are few processes of palm oil should go through before it ends into by-products. Empty fruit bunches, palm fibre, and palm kernel shell are the main solid phases produced by milling processes. These solids could be widely used for a variety of purpose, such solid fuels. A by-product of the palm oil milling decantation process includes decanter cake. The decanter cake production rate is around 4–5 wt% of the FFB processed. While crude palm oil (CPO) is converted to crude palm kernel oil (CPKO) in 5.2 wt%, the other 71.3 wt% is released into nature as solid or liquid phases [14]. Figure 2 shows the flowchart of oil palm extraction.

Figure 2(a), Figure 2(b) and Figure 2(c) illustrate the flow chart for the whole process of CPO and PKO extraction in the palm oil mill industries. Sterilization, threshing (stripping), digesting, and screw pressing are the major initial processes [15]. To separate the residual oil from the sludge, decanter machines was be used [11]. In palm oil mills there are two types of decanter machines usually used, two-phase decanter and three-phase decanter. The centrifugal force theory was used in a two-phase decanter to separate decanter cake (heavy phase) from oil and water (light phase) by gravity force, which forces the highest density to the outermost layer. Decanter cake contains large amounts of carbon (C), nitrogen (N), phosphorous (P), potassium (K), and magnesium (Mg), the decanter cake may be recycled and reused as animal food and plant fertilizers [16]. Decanter cake still maintains moisture from the extraction process, and more than 70% of moisture is still present in the new decanter cake created by the extraction process. Decanter cake drying is another waste management method which can be used to reduce waste products and turn them into green fertilizer [17].

The term drying refers to the process of removing moisture from a subject of matter. The process is mainly used in the food industry to preserve food since it could remove moisture from the product, helping it to last longer and avoid rotting. The drying procedure prevents the development of microorganisms in the food [18]. The heat transmission concept and theory are used in the drying method. The thermal gradient is the driving force of heat transfer, and it travels from a hot to a cold substance through convection, conduction, and radiation. Figure 3 illustrates the heat and mass transfer during drying process. The size and form of the subject, the drying temperatures, the velocity of the surrounding air flow, and the surrounding relative humidity are the variables that can affect the drying rate [19].

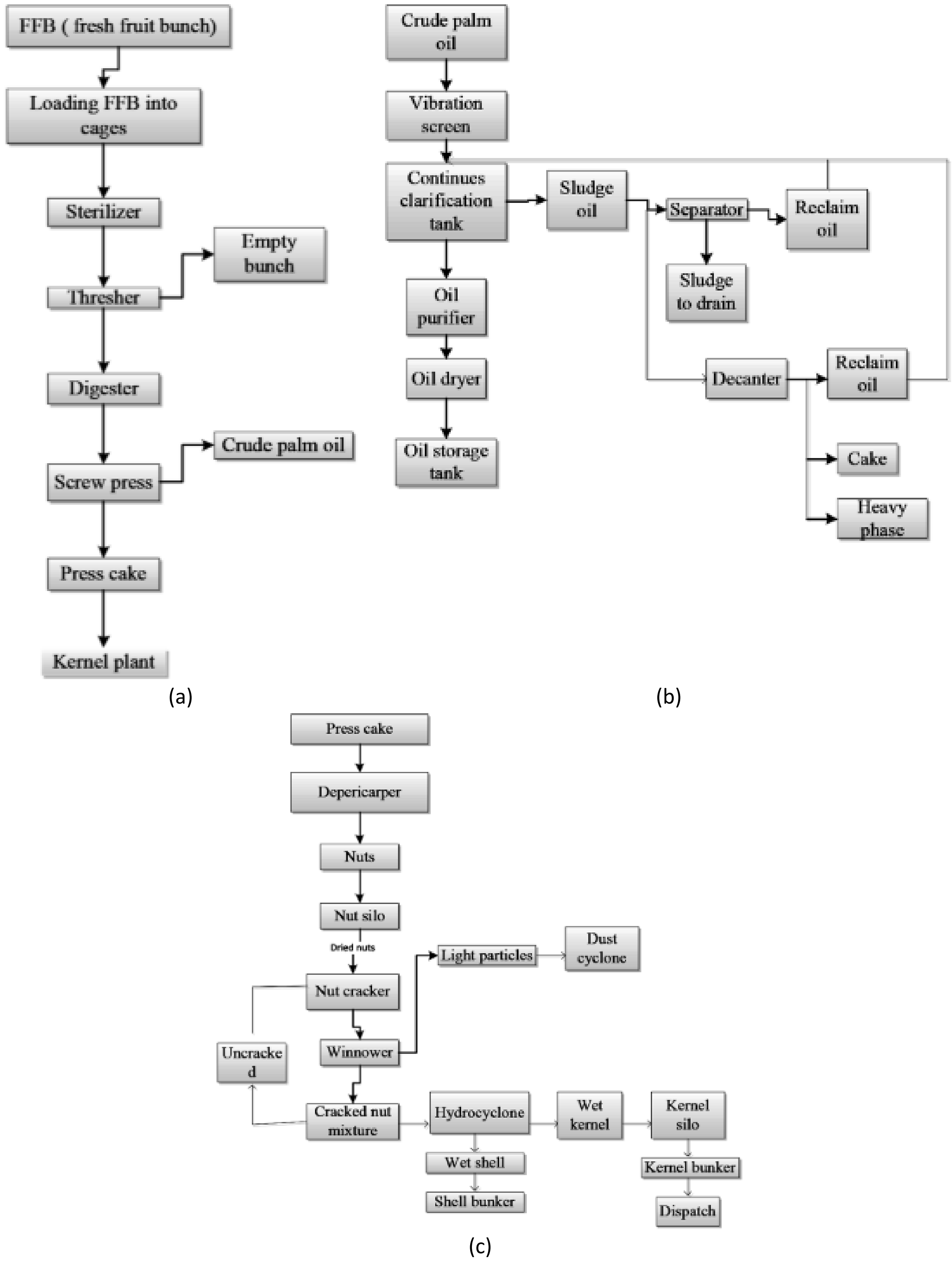


Fig. 2. (a) Flow chart of initial extraction process, (b) Flow chart of CPO yield process after screw press, (c) Flow chart of kernel separation process [14]

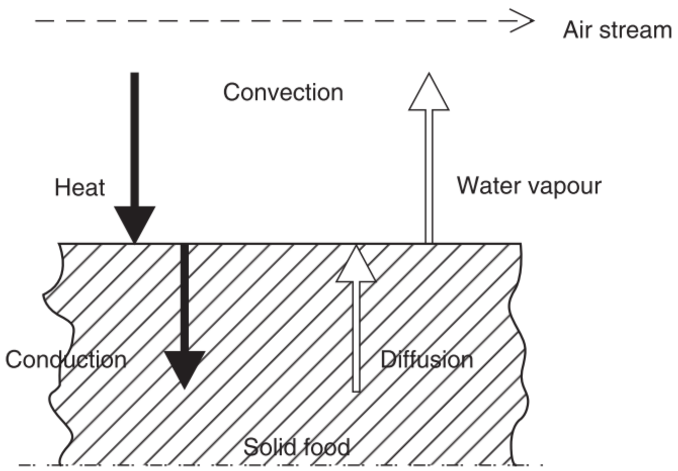


Fig. 3. Heat and mass transfer during drying process [18]

2. Materials and Methods

2.1 List of Materials and Equipment

Oil palm decanter cake, aluminum sampling pans, Memmert convection oven, analytical balance.

2.1.1 Description of the experiment

Decanter cake was obtained from Kilang Sawit PPNJ Kahang owned by Pertubuhan Peladang Negeri Johor in Kahang, Kluang. The universal oven UNB 100-500 by Memmert was being used for drying decanter cake and was set at 105°C and dried to produce the maximum drying temperature and mathematical model. The drying temperature was adjusted to 105°C for drying the baseline specimen and varied accordingly for other drying temperatures. Following table shows several drying thicknesses that were set for the experiment.

Table 2
Drying thickness for the experiment

Test	1	2	3
Thickness (cm)	0.3	0.5	1.0

Previous study for water content determination of municipal sludge used American Society for Testing and Materials (ASTM) D2974 as their drying standards [20]. The standards used is for determining the water (moisture) content of peat and other organic soils. Water content determination is by drying the peat or organic soils sample inside an oven at temperature of 110°C ± 5°C [21]. The air flow mechanism of the Memmert universal oven is shown in Figure 4. Since the UNB series uses natural ventilation, the convection oven does not have a fan. The air was drawn from the oven's bottom and warmed inside the preheat chamber before being discharged via the ventilation openings. The heated air will enter the chamber to heat up the decanter cake. Provide sufficient spacing between multiple subjects inside the oven to obtain proper air circulation [22].

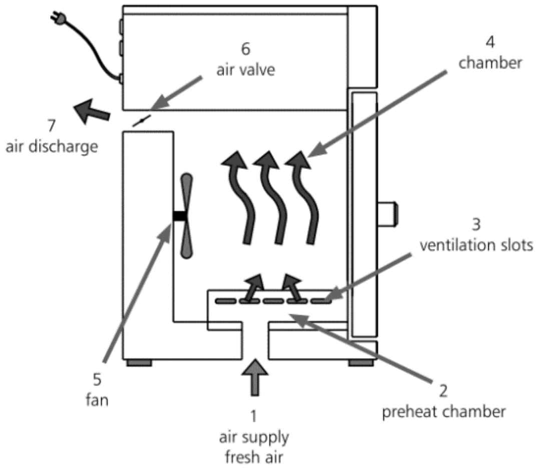


Fig. 4. Air flow of Memmert convection oven

The moisture content of the decanter cake was evaluated by drying the samples in the oven and weighing them at 1-hour intervals until the samples doesn't have any change of mass pan. Decanter cake samples can be weighed and dried on sampling pans. The aluminium sample pan as shown in Figure 5 will keep the sample inside the pan if it cracks or falls apart during the drying process, allowing us to find the actual moisture content of the sample accurately. To achieve the best results, always use a new sample pan instead of reusing the same pan that has the residue from the prior sample.

Fig. 5. Sampling pan

Analytical balance will be used to find the weight of the decanter cake and aluminium pan. The model used was the A&D Company, Limited's GR-200. The mass of the aluminium sample pan will be measured first, then by the mass of the decanter cake samples on an aluminium pan. The weighing capacity for this model is 210 g and has a minimum weighing value of 0.1 mg. It also has a linearity of ±0.2 mg and a repeatability (standard deviation) of 0.1 mg. Figure 6 shows the photo of the analytical balance.

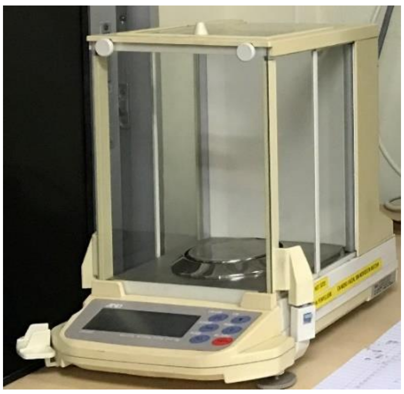


Fig. 6. Analytical balance used in the present study

To calculate the moisture content inside the decanter cake samples, Eq. (1) is used, while the moisture ratio and drying rates were calculated using Eq. (2) and Eq. (3) respectively

$$M(t) = \frac{w(t) - d}{w} \times 100\% \tag{1}$$

$$MR = \frac{M(t) - M_e}{M_o - M_e} \tag{2}$$

$$DR = \frac{M_t - M_{t+\Delta t}}{\Delta t} \tag{3}$$

In Eq. (1), *w(t)*, *w* and *d* are mass of wet decanter cake at certain time, mass of wet decanter cake and mass of dry decanter cake respectively. Moisture Ratio equation are shown in Eq. (2) where *M(t)* is the moisture content of sample at any drying time, M_o is the initial value of moisture content and M_e is the equilibrium moisture content. In Eq. (3), *t* is the drying time, M_t is moisture content at *t* and $M_{t+\Delta t}$ is moisture content at $t + \Delta t$. The experiment data was then compared to the predicted data from non-linear regression analysis by using LAB Fit Curve Fitting Software. Thin layer semi-empirical models were used to generate a predicted data in the software. The models are tabulated in Table 3 where *a*, *b* and *c* are dimensionless empirical constants and k, k_1 and k_2 are drying constants (min^{-1}).

2.2 Thin Layer Drying Models

To calculate the moisture content inside the decanter cake samples, Eq. (4) is used, while the moisture ratio and drying rates were calculated using Eq. (5) and Eq. (6) respectively

$$M(t) = \frac{w(t) - d}{w} \times 100\% \tag{4}$$

$$MR = \frac{M(t) - M_e}{M_o - M_e} \tag{5}$$

$$DR = \frac{M_t - M_{t+\Delta t}}{\Delta t} \tag{6}$$

In Eq. (4), *w(t)*, *w* and *d* are mass of wet decanter cake at certain time, mass of wet decanter cake and mass of dry decanter cake respectively. Moisture Ratio equation are shown in Eq. (5) where *M(t)* is the moisture content of sample at any drying time, M_o is the initial value of moisture content and M_e is the equilibrium moisture content. In Eq. (6), *t* is the drying time, M_t is moisture content at *t* and $M_{t+\Delta t}$ is moisture content at $t + \Delta t$. The experiment data was then compared to the predicted data from non-linear regression analysis by using LAB Fit Curve Fitting Software. Thin layer semi-empirical models were used to generate a predicted data in the software. The models are tabulated in Table 3 where *a*, *b* and *c* are dimensionless empirical constants and k, k_1 and k_2 are drying constants (min^{-1}).

Table 3
Thin layer drying models

No.	Model Name	Mocel Equation	Reference
1	Newton	$MR = \exp\,(-kt)$	Bruce [23]
2	Henderson and Pabis	$MR = a \exp\,(-kt)$	Henderson [24]
3	Logarithmic	$MR = a\, exp(-kt) + c$	Yağcıoğlu *et al.,* [25]
4	Two Term	$MR = a\, exp(-k_1 t) + b\, exp(-k_2 t)$	Henderson [26]

Important statistical parameter from the result such as coefficient of determination (R^2), reduced chi-square (X^2) and root mean square error (RMSE) must be analysed. The model that obtained higher R^2 value and lower X^2 and RMSE value will be selected as the best suitable mathematical model for the drying process [27,28]. The criteria R^2, X^2, and RMSE formulas are listed in Eq. (7), Eq. (8) and Eq. (9) respectively where MR_{exp} and MR_{pre} are the experimental and predicted moisture ratio, *N* is the number of data observations and *P* is the number of constants in the drying model.

$$R^2 = 1 - \frac{\sum_{i=1}^{N}\left(MR_{exp,i} - MR_{pre,i}\right)^2}{\sum_{i=1}^{N}\left(MR_{exp,i} - \overline{MR_{exp}}\right)^2} \tag{7}$$

$$X^2 = \frac{\sum_{i=1}^{N}\left(MR_{exp,i} - MR_{pre,i}\right)^2}{N-P} \tag{8}$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(MR_{exp,i} - MR_{pre,i}\right)^2} \tag{9}$$

3. Result and Discussion

3.1 Experimental Measurement Mass of Decanter Cake

The results collected during the drying process had been used to determine the moisture content, moisture ratio, and drying rate. The method took three hours in a convection oven, with the three samples being weighed every five minutes for the first two hours and every ten minutes for the third hour before being left in the oven to dry completely at a set temperature. Figure 7 to Figure 9 illustrate the results of the experiment for each thickness of decanter cake, indicating the moisture content.

Figure 7 shows the moisture content of decanter cakes of thicknesses of 0.3, 0.5, and 1 cm against drying time during a three-hour convection oven drying technique. The longer the drying period, the lower the moisture content of the decanter cake, as seen in the graph. The figure also displays that over the three hours of drying in 105°C, the 1 cm sample only had a constant rate period, but the 0.3 cm and 0.5 cm samples had such a falling rate period and constant period. This was seen by the graph produced by 1 cm experiment thickness, which has an almost straight line since the moisture eliminated by drying is nearly constant over a three-hour period. For the first 80 minutes, the moisture content of the 0.3 cm sample thickness was rapidly dropped. During the first 120 minutes, the moisture content of the 0.5 cm experiment thickness decreased significantly. It may be shown that a sample with a smaller thickness will have a greater difference in moisture content from the start.

When the drying time is increased, the moisture ratio decreases, as shown in Figure 8. This is applicable for all sample thicknesses, including 0.3, 0.5, and 1 cm. Figure 7 and Figure 8 illustrate that a decanter cake sample with a thickness of 1 cm does not reach an acceptable moisture ratio or moisture content because it takes time to dry. One of the reasons that a 1 cm sample thickness takes longer to dry is because its size is larger and contains significantly more moisture than the other samples. After three hours of drying, decanter cake samples with 0.3 cm and 0.5 cm thickness obtained an appropriate moisture ratio and moisture content, showing that they are suitable for drying at 105°C in a convection oven. Compared to those other sample thicknesses, the 0.3 cm sample thickness has the biggest gradient of moisture ratio, while the 1 cm sample thickness does have the smallest slope of moisture ratio.

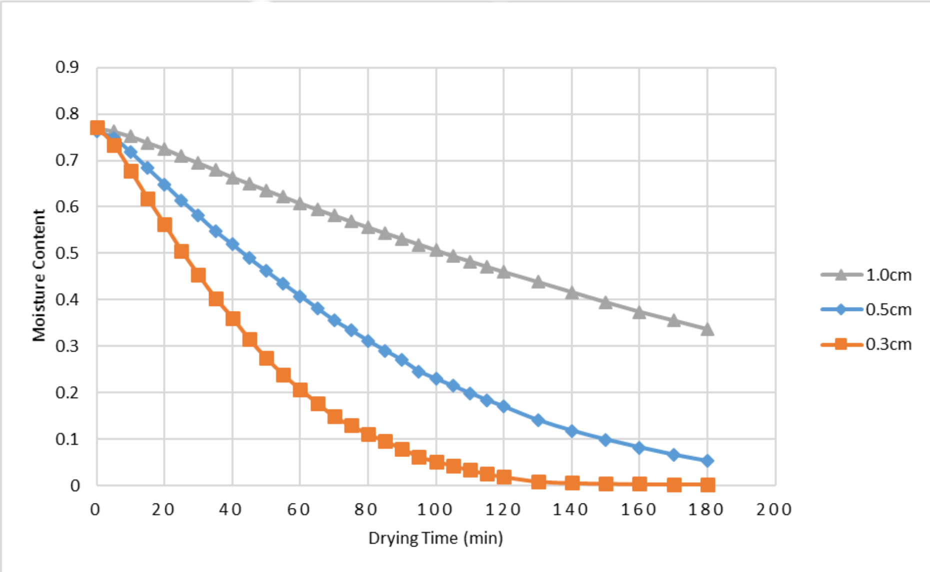


Fig. 7. Moisture content against drying time

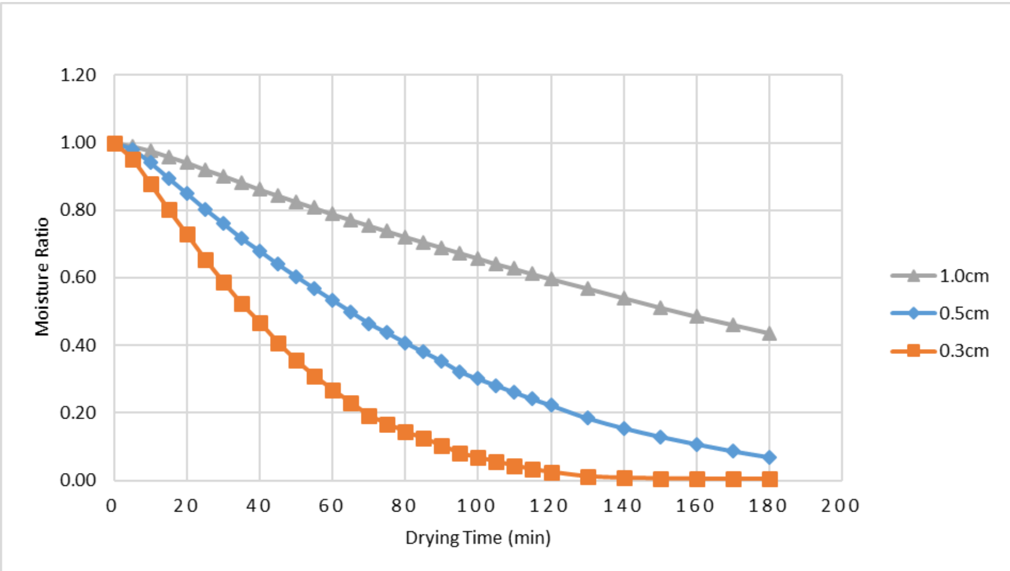


Fig. 8. Moisture Ratio against drying time

Figure 9 shows the three-hour drying rate for each decanter cake sample thickness. Generally, the drying rate for each thickness started to rise at the beginning of the experiment and gradually fell as the drying duration increased. The drying rate will gradually slow until the equilibrium moisture content is achieved. For the drying process, the thinnest sample, 0.3 cm, had the greatest drying rate, while the thickest sample, 1 cm, had the lowest drying rate. This is because moisture from the inside of the decanter cake sample moves a shorter distance to the surface when it becomes thin. Moreover, because the moisture released is originating from the sample's surface, which requires easy moisture releases, all the samples achieved the optimum drying rate at an initial drying time. It will become harder to expel water to the surrounding air later, thus having lower drying rate.

A 1 cm sample thickness takes longer to analyse, this sample is removed from the study. This is because the thickness is insufficient to be dried in three hours using mechanical dryers, resulting in a higher cost for industrial firms. If the decanter cake thickness is greater than 1 cm, instead of using mechanized dryers, it is preferable to use solar drying which is cost effective.

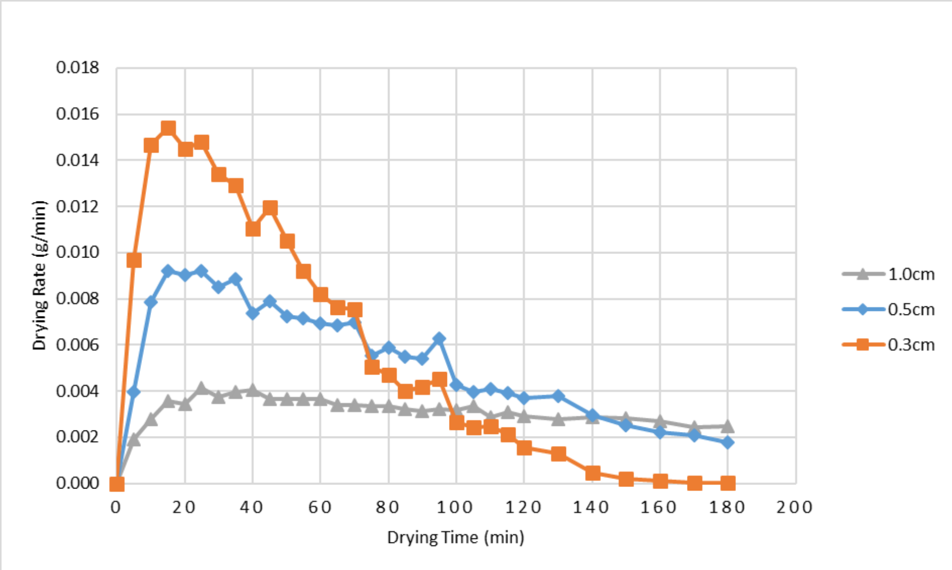
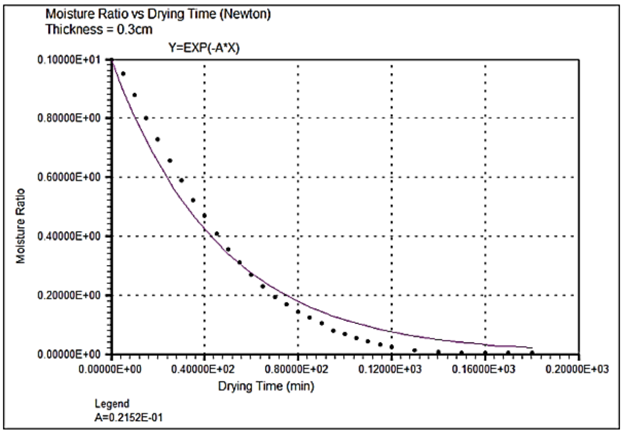


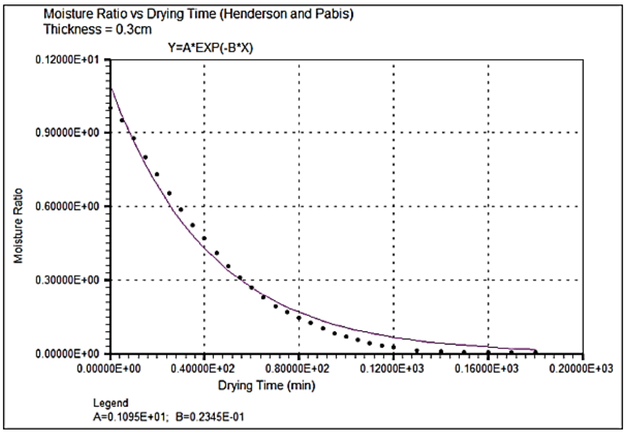
Fig. 9. Drying rate against drying time

Based on Figure 10 and Figure 11, Logarithmic model illustrates the best similarities between experiment data and predicted data when compared to other models for both 0.3 cm and 0.5 cm thickness. For 0.3 cm sample thickness, the Logarithmic model's prediction is almost the same with the experiment data throughout the drying curve even though not all experimental data points coincide with the predicted line. As for the 0.5 cm sample thickness, Logarithmic model's prediction line almost coincide with all of the experimental data points. This analysis is supported by using statistical analysis parameters R^2, X^2 and RMSE obtained from LAB Fit Curve Fitting Software which is presented in Table 4 and Table 5.

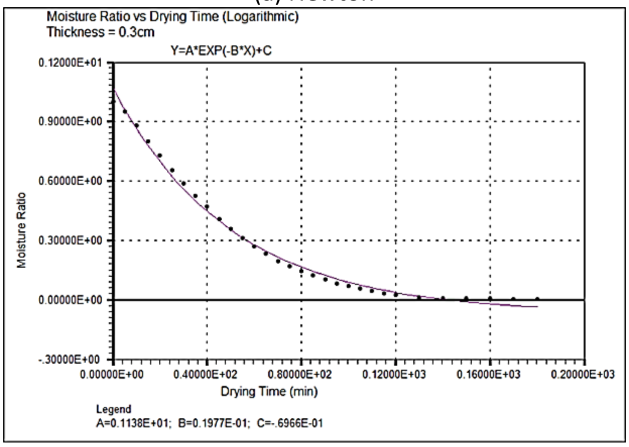
The model that acquired higher R^2 value and lower X^2 and RMSE value will be selected as the best mathematical model for the drying process of decanter cake. Based on Table 4, Logarithmic semi-empirical model showed the best results from the statistical analysis parameters at 0.3 cm sample thickness. Additionally, the parameter value of X^2 for this model are much lower when compared to the other models. It can be concluded that Logarithmic model is the best semi-empirical model for drying process at 0.3 cm sample thickness because it produced the highest accuracy and repeatability. According to Table 5, Logarithmic model indicated as the best semi-empirical model for 0.5 cm thickness. It has the highest value of R^2 and lowest value of X^2 and RMSE. Thus, Logarithmic model produced the highest accuracy and repeatability for 0.5 cm thickness.



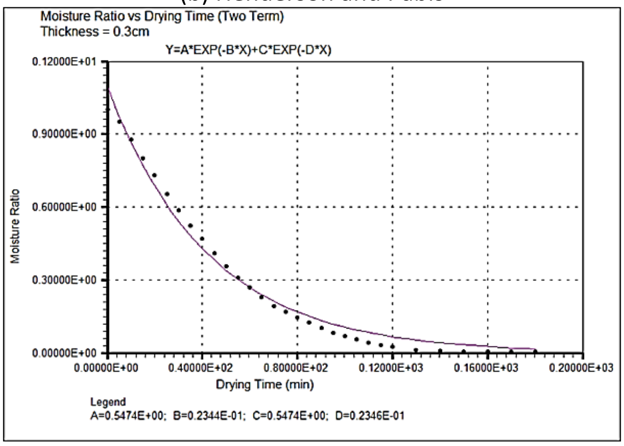
(a) Newton



(b) Henderson and Pabis

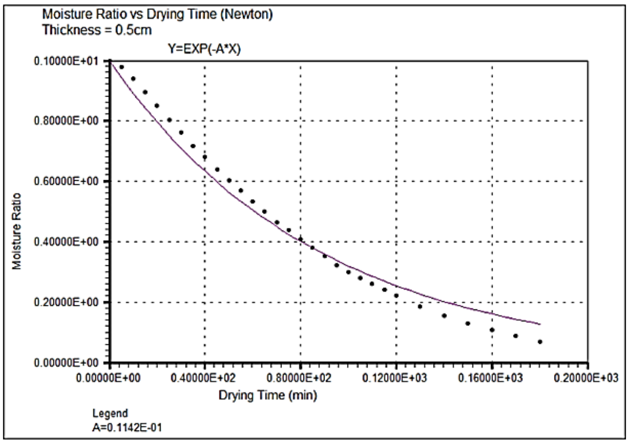


(c) Logarithmic

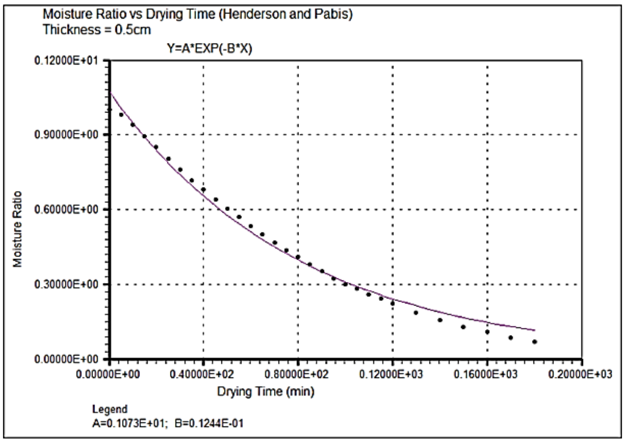


(d) Two Term

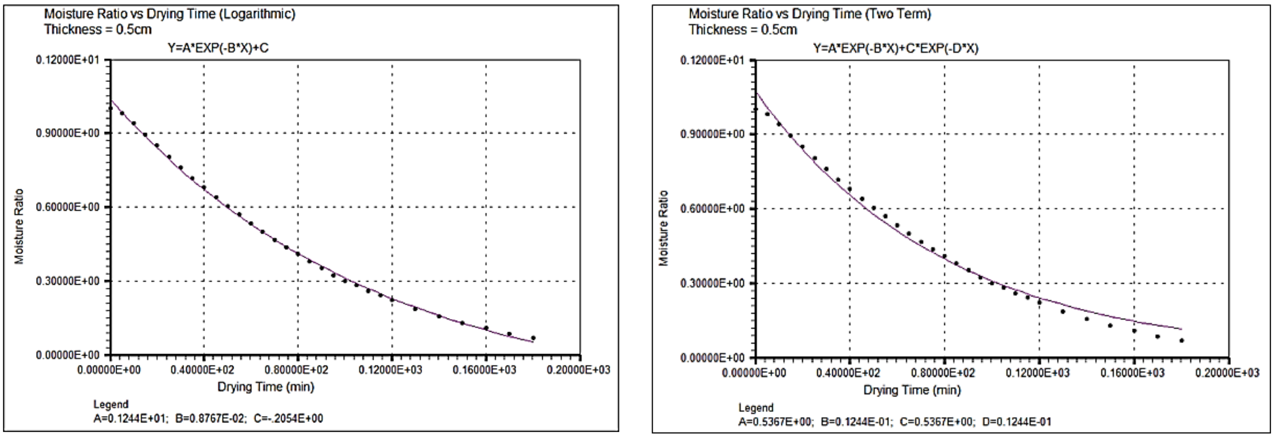
Fig. 10. Comparison between experimental and predicted moisture ratio of 0.3 cm



(a) Newton



(b) Henderson and Pabis



(c) Logarithmic (d) Two Term

Fig. 11. Comparison between experimental and predicted moisture ratio of 0.5 cm

Table 4
Decanter cake linear regression data for 0.3 cm thickness

Model	R^2	X^2	RMSE
Newton	0.9930924	0.210331×10^{-2}	0.458619×10^{-1}
Henderson and Pabis	0.9897233	0.129250×10^{-2}	0.359513×10^{-1}
Logarithmic	0.9941421	0.629139×10^{-3}	0.250826×10^{-1}
Two Term	0.9897240	0.138824×10^{-2}	0.372591×10^{-1}

Table 5
Decanter cake linear regression data for 0.5 cm thickness

Model	R^2	X^2	RMSE
Newton	0.9949333	0.150321×10^{-2}	0.387713×10^{-1}
Henderson and Pabis	0.9917535	0.766776×10^{-3}	0.276907×10^{-1}
Logarithmic	0.9985685	0.125484×10^{-3}	0.112020×10^{-1}
Two Term	0.9917538	0.823574×10^{-3}	0.286980×10^{-1}

4. Conclusion

This study is a preliminary attempt towards investigating the drying characteristics of decanter cake which is one of the waste available from the oil palm mill. The decanter cake was dried in a convection oven dryer with thickness samples of various thicknesses, 0.3 cm, 0.5 cm, and 1 cm. Using the relevant equations, the experiment's moisture content, moisture ratio, and drying rate for all thicknesses were calculated. The findings of the experiment revealed that a 1 cm sample thickness cannot be dried entirely in a convection oven at 105°C in three hours. Moisture could travel a greater distance from the inside of a thicker sample to the outside surface. To lower the cost of the drying process for related sectors, it is preferable to dry decanter cake with a thickness of 1 cm or more using open sun drying. The drying procedure may be completed in three hours with only 0.3 cm and 0.5 cm sample thickness. The higher R^2 value and lower X^2 and RMSE value expressed the preciseness and validity. Among the models, Logarithmic model shows high accuracy and repeatability for both 0.3 cm and 0.5 cm sample thickness. At 0.3 cm thickness, Logarithmic model obtained $R^2 = 0.9941421$, $X^2 = 0.629139\times10^{-3}$ and RMSE = 0.250826×10^{-1}. As for 0.5 cm thickness, Logarithmic model obtained $R^2 = 0.9985685$, $X^2 = 0.125484\times10^{-3}$ and RMSE = 0.112020×10^{-1}. Based on the results, Logarithmic model achieved the highest R^2 value and lowest X^2 and RMSE value. Therefore, Logarithmic model was selected as the best model to describe the drying kinetic characteristics of palm oil mill decanter cake for 0.3 cm and 0.5 cm thickness via convection oven drying.

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