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Cite as: AIP Conference Proceedings **2124**, 030008 (2019); https://doi.org/10.1063/1.5117130
Published Online: 24 July 2019

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Extraction of Crude Palm Oil (CPO) Using Thermally Assisted Mechanical Dewatering (TAMD) and Their Characterization during Storage

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Abstract. Thermally assisted mechanical dewatering (TAMD) is a new technology to separate solid and liquid. In the present study, TAMD was utilized to extract the crude palm oil (CPO) from the palm mesocarp (Elaeis guineensis). The operating parameters examined were temperature and pressure, ranging from 30 to 105 °C and 3 to 12 bar respectively. The extraction was conducted in batch process for 45 minutes of total extraction time. Design of experiment was created using the Response Surface Methodology based on the central composite design (CCD). The CPO yield, carotene concentration, moisture content and free fatty acids (FFA) content were analysed. The maximum oil yield, 70.68 w/w% was extracted at the optimum operating parameters, 7.75 bar and 73.0°C. TAMD demonstrated a promising potential as a viable alternative method for the CPO extraction with lower pressure and shorter extraction time.

INTRODUCTION

Oil palm (Elaeis guineensis Jacq.) is known as agriculture crop that yields the highest edible oil in the world. Currently, Malaysia contributed 11% production and 27 % exportation of palm oil in global market. Crude palm oil and palm kernel oil are produced from mesocarp and palm kernel respectively. Crude palm oil (CPO) is reddish in colour due to the presence of carotenoid pigments in the oil. It contains mainly glycerides and small amount of non-glycerides which are significant for daily applications such as cooking oil, cosmetic and dairy products [1]. Mechanical screw press is commonly used to extract crude palm oil in the Malaysia palm mill. The conventional process includes sterilization of fresh fruit bunches, threshing and threshing, extraction using screw press and screening of oil. The implementation of conventional method contributed to 7% of oil losses from the overall process [2]. Throughout the years, diverse studies were conducted to increase the yield of palm oil such as aqueous enzymatic extraction[3], supercritical carbon dioxide extraction[4], hot compressed water extraction[5] and subcritical R134a extraction[6]. These methods displayed significant improvement on the yield of palm oil up to 0.77 g-oil/g-dried mesocarp. The CPO yield was increased by 20.78% compared to the existing palm mill which was 0.61 g-oil/g-dried mesocarp [4, 6]. Nevertheless, the majority of these solutions remained in research field due to operational cost, practicality and sustainability elements. Thus, it is important to discover the potential alternative processes to improve the yield of palm oil and achieves the world demand. In this study, thermally assisted mechanical dewatering (TAMD) was used as an alternative method to extract the crude palm oil (CPO). It was operated at low pressure in range between 3 – 12 bar by supplying moderate heat at the desired values [7]. It recovered a dewatered solid fraction (the pressed cake) and a filtrate (oil) as the products. Hence, the objective of

6th International Conference on Environment (ICENV2018)
AIP Conf. Proc. 2124, 030008-1–030008-6; https://doi.org/10.1063/1.5117130
Published by AIP Publishing. 978-0-7354-1864-6/$30.00

this study is to examine the effect of TAMD operating parameters on the extraction of crude palm oil. The study also includes the effect of storage time on oil quality in terms of free fatty acid (FFA), moisture content and carotene concentration.

METHODOLOGY

The methodology was divided into 3 main sections which was sample preparation, Thermally Assisted Mechanical Dewatering set up and calculation for the obtained results. The calculation of results involved oil yield, carotene concentration and free fatty acid (FFA) content.

Material and Sample Preparation

The feedstocks were collected from Felda Jengka Seroja, Pahang, Malaysia. The fruitlets were stored in an electrical oven at 25°C within 26 days for the extraction process. The sterilization process was conducted on the fruitlets at 130°C for an hour using a steam sterilizer. The process was assumed to provide the similar effect as the sterilization process in the palm mill. Then, the softened mesocarps were shredded into small pieces, with size ranging in between 20-50mm.

Thermally Assisted Mechanical Dewatering (TAMD)

The experimental set up was consisted of the compression and filtration cell inserted in a CARVER hydraulic press. The maximum operating parameters were 15 bar and 105°C in the thermally assisted mechanical dewatering (TAMD). Figure 1 shows the details of the experimental cell which include compressive piston, a filter medium and a hollowed cylindrical vessel. Three electrical resistances were inserted at the compressive piston to investigate the temperature impact and control the temperature with minimum error at ±0.1 °C. The shredded mesocarps were put into the steel jacket for pressing process. The filter wire was placed under the flakes to remove the remaining solids and fines from the extracted oil. The extracted oil was collected in the beaker. The mass of the extracted oil was calculated on the computer interfaced balance at time interval of 10s. The press cake was remained in the steel jacket.

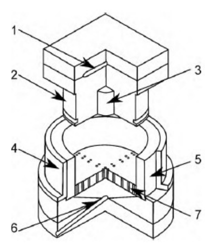


FIGURE 1. Details of experiment. (1) Electric resistance; (2) Copper pistons; (3) Fluxmeter; (4) Steel jacket; (5) Teflon vessel; (6)Filtrate collecter; (7) Filter medium [7]

Calculation on Oil yield, Carotene Concentration and FFA Content

The wet sample was weighed using the mass balance. After the extraction process, the dry sample was dried at 103°C in the electric oven until a constant sample weight was achieved. The reduction of the weight was measured and recorded in one hour interval for the first 5 h and extended to 24 h for the total moisture removal. The extracted oil yield was calculated by using Equation 1.

$$Yoil(\%) = \frac{Ww - Wd}{Ww} \times 100 \quad (1)$$

where *Yoil* is the oil yield percentage, *Ww* is the sample wet weight(g) and *Wd* is the sample dry weight (g).

The carotene concentration was analysed using UV/VIS Spectrophometer (U-2001, Hitachi Instruments Inc., Tokyo, Japan). The extracted oil was filtered using the vacuum-filtered machine to remove the impurities. The filtered oil was heated at 65 °C on the hot plate. The oil was stirred well to ensure it mixed evenly. Then, 0.2g of the oil was weighed and placed into a 50 ml beaker. The hexane was used to dilute the oil until the 500ml mark. The solution was moved into 1cm quartz cuvette and measured at 450 nm against the Hexane. The cuvette error was also measured at the same wavelength. The β-Carotene concentration was calculated by using Equation 2.

$$B\ carotene\ (ppm) = \frac{25 \times 383 \times [as - ab]}{100\ w} \tag{2}$$

where *as* is an absorbance of the sample, *ab* is a cuvette error, and *w* is the weight of sample(g).

The FFA content was determined according to MPOB guideline, standard titration method [8]. In this method, FFA content was assumed as palmitic acid which made up of 39.2 -45.8 % of total FFA content [1]. The FFA content was calculated in Equation 3.

$$FFA\ (\%) = \frac{25.6 \times V_{NaOH} \times M_{NaOH}}{Woil} \tag{3}$$

Where *FFA* is the free fatty acid percentage, V_{NaOH} is the volume of sodium hydroxide (ml) used for titration, M_{NaOH} is the molarity of sodium hydroxide (M) and W_{oil} is the weight of the oil (g).

RESULT AND DISCUSSIONS

Design Expert software 10.0 was used to conduct the experimentation according to central composite design (CCD). The operating temperature and pressure were 30 to 105 °C and 3 to 12 bar respectively. The experiments were conducted for 45 minutes of extraction time. Based on design expert software, 13 runs were conducted to determine the optimum operating parameters.

TABLE 1. ANOVA table of the regression parameter of TAMD extraction

Source	Sum of Squares	Deg of Freedom	Mean Square	F Value	P-Value
Model	903.95	5	180.79	13.41	0.0018
A-Temperature	216.03	1	216.03	16.03	0.0052
B-Pressure	3.59	1	3.59	0.27	0.6219
AB	0.21	1	0.21	0.016	0.9035
A^2	680.05	1	680.05	50.45	0.0002
B^2	29.21	1	29.21	2.17	0.1845
Standard deviation	3.67		R^2	0.9055	
Mean	62.58		Adj-R^2	0.8834	

In Analysis of Variance (ANOVA), the regression model was measured by the p-value. The obtained p value was 0.0018 (much less than 0.05), which indicated a good significance for the regression model. The R-squared is known as the coefficient of determination to determine the precision of data onto the fitted regression line. The high value of R-squared, 0.9055 indicated that the quadratic model was significant as it was fitted well to the actual data. The optimum parameters were identified at 73.0°C and 7.75 bar for 45 minute of extraction time. At these conditions, 70.52 wt/wt% of oil yield were obtained from the model. Three replicates were performed at the optimum parameters to validate the selected condition. The actual oil yield was found 70.68 wt/wt% which concluded that the experiment result was agreed to the predicted value. The CPO yield from TAMD was relatively comparable with other extraction methods such as hot compressed water (HCW) and aqueous enzymatic extraction at the range of 0.70 ± 0.01 g-oil/g-dried mesocarp. This yield was lowered by 6 % compared to supercritical fluid CO_2 which produced the highest oil yield, 0.77 g-oil/g-dried mesocarp [4]. According to the previous studies, the highest CPO yield was extracted through supercritical CO_2 followed by aqueous enzymatic extraction, subcritical R134a and mechanical screw press [3.4.5.6]

Effect of Temperature and Pressure

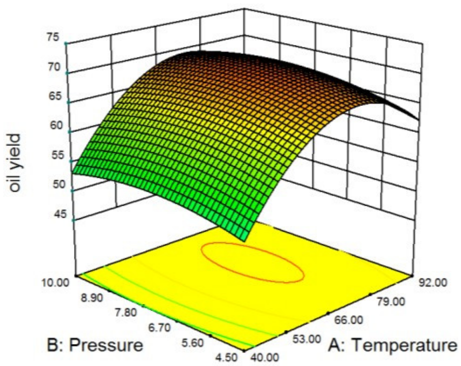
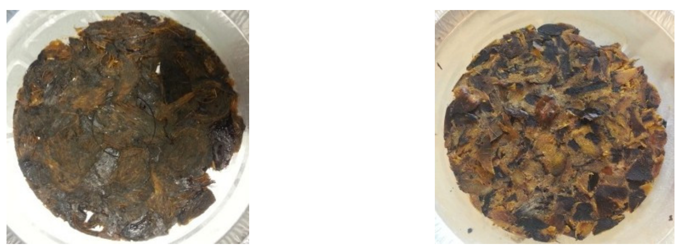


FIGURE 2. Response surface from TAMD statistical modeling

The influence of operating parameters was shown in Figure 2. Temperature was demonstrated a significant effect on the oil yield which in agreement with previous studies on the different oil seeds [9].The oil yield was increased tremendously from 40 -80 °C. Increasing temperature caused the breakdown in the cell walls and increase in the mass transfer rates. The broken cell led to protein denaturation and coagulation subsequently reduced the oil viscosity. It facilitated the flow of oil from the cell into the inner matrix of mesocarp [10]. However, further increasing the temperature above 80 °C reduced the oil yield by 6% as demonstrated in the Fig 2. The colour of pressed cake also became darker and dry at these temperatures as shown in Fig. 3



a) **b)**

FIGURE 3. The pressed cake condition at **a)** 92 °C and **b)** 66 °C

This condition was attributed to the effect of water vaporization. Water evaporated faster than oil at the high temperature and caused moisture loss. The pressed cake became hard and dry thus reducing the oil flow through the matrices. In general, oil yield was significantly affected by the pressure. However, the result displayed weak influence of pressure on the oil yield in Fig.2. This condition was contributed by the usage of small amount of sample and long extraction time where the effect of pressure became insignificant. Long pressing time at applied pressure caused cake deformation and compaction of cake. The flow of oil became limited and reduced the oil expression [11].

Oil Quality Parameters

The quality of oil was determined by carotene concentration, FFA content and moisture content. According to Malaysian Palm Oil Board (MPOB), the accepted requirements for good quality of crude palm oil (CPO) were below 5% of FFA, below 1 % of moisture in oil and carotene concentration in the range of 474-689 ppm [1]. Nonetheless, the quality of oil palm was varied based on the feedstock condition, temperature, pressure and storage time. As the feedstocks supply was limited, the storage time became the main factor that influenced the oil quality. It was expected that the quality of oil was deteriorated within 26 days. Table 2 demonstrated that FFA content was increased from 5.67 % to 35.56 % in 26 days. High FFA content indicates the low quality of the crude palm oil. This condition was caused from the damaged mesocarp and improper storage condition. The FFA content was increased significantly without immediate heating process [12]. The damaged fruits caused contamination of microorganism which contributed to rapid hydrolysis of lipase enzyme and subsequently build up the FFA content [13]. Heating process such as sterilization process helps to inactivate the lipase enzyme in the fruits and prevent the increment of FFA content. Sterilization process is also known as the most important process in the palm mill to achieve low FFA content. Moisture content is the amount of water present in the oil. According to previous studies, the moisture content in the oil was 23.75% after 26 days. Conversely, the moisture content of extracted oil was 2.10% after 26 days which was remarkably lower than previous study. This condition was due to the storage conditions where the fruitlets were stored in the electrical oven at 25 °C. The mesocarp was less exposed to the environment and reduced the microbial activity from microorganisms such as *Lactococcus sp.* and *Leuconostoc sp.* [14]. Carotenoids are red pigments that give out the reddish colour to crude palm oil. Carotene consists of alpha and beta carotene. It acts as the protection to the oil from the oxidation process prior to the triglycerides. The degradation of carotene concentration was observed in Tab 2. Carotene concentrate contains bioactive compound that have high sensitivity toward heat and light during storage at 25 °C [15].

TABLE 2. The oil quality at different operating parameters for 26 days

No of Day	Operating Parameters	FFA Content	Moisture Content	Carotene Concentration
2	66 °C, 7.25 bar	5.67	0.45	589.00
4	40 °C, 10.00 bar	7.80	0.80	556.23
6	102.77°C, 7.25 bar	9.45	1.10	521.90
8	66°C, 7.25 bar	12.34	1.26	504.08
10	40°C, 4.50 bar	14.46	1.33	498.10
12	66°C, 7.25 bar	17.30	1.54	485.21
14	66°C, 3.36 bar	20.83	1.60	484.04
16	66°C, 7.25 bar	22.21	1.75	475.00
18	66°C, 11.14 bar	24.56	1.87	467.90
20	92°C, 10.00 bar	28.10	1.95	449.82
22	66°C, 7.25 bar	30.42	1.98	423.67
24	29.23°C, 7.25 bar	32.60	2.05	387.00
26	102.77 °C, 7.25 bar	35.56	2.10	383.67

CONCLUSION

The extraction of CPO was conducted at low pressures and moderate temperature ranging from/in the range of 3 to 12 bar and 30 to 105 °C respectively using TAMD.The experimental results demonstrated that the oil yield increased with pressure and temperature. However, the temperature displayed higher significant effect to CPO yield compared to pressure. The maximum CPO yield, 70.68 w/w%, was obtained at optimum parameters, 7.75 bar and 73.0°C for 45 minutes. Overall, the quality of extracted CPO was low due to high FFA percentage, high moisture content and low carotene concentration. It was expected that the quality of oil was highly influenced by the storage time. Nevertheless, TAMD showed great performance in term of quantitative analysis where it produced comparable oil yield as other alternative methods with short extraction time.

ACKNOWLEDGMENTS

The authors would like to thank Centre RAPSODEE, Ecoles des Mines, France for the technical assistance throughout this project by providing the facilities.Thank you as well to Universiti Teknologi PETRONAS, Malaysia for the research opportunity and support from Biomass Grant (0153AB-F02).

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