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Linear pressing of coconut copra meal (*Cocos nucifera* L.) under different temperatures

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Abstract. Pressing of vegetable oils plays an important role in the food processing. This study described the compression behaviour of copra (*Cocos nucifera L.*) using the universal compression testing machine and vessel diameter of 60 mm with a plunger. The influence of heat treatment on oil recovery efficiency and specific mechanical energy were determined. Compression tests at the rate of 1 mm s^{-1} under five different temperatures 20, 40, 60, 80 and 100 °C were performed. The measuring range of force was between 0 kN and 50 kN. It has been found that the amount of obtained oil increased and specific mechanical energy decreased with increased temperature. Measured data were analysed by computer software Mathcad 14 (MathCAD 14, PTC Software, Needham, MA, USA). Mathematical model describing the mechanical behaviour of bulk copra under compression loading was represented.

Key words: coconut oil, compression loading, compressive force, specific mechanical energy.

INTRODUCTION

Coconut (*Cocos nucifera L.*) is the fruit of a tree that grows in tropical areas and is commonly used for oil production. It consists of three layers: mesocarp, endocarp and solid endosperm, which is also referred to as coconut meat (Heathcock & Chapman, 1983). Endosperm is approximately 1–2 cm thick, white and fleshy edible part of the fruit. Dried and crushed material is known as copra, which is used to obtain oil.

Coconut oil is used in the food industry and exhibits good digestibility (Che Man & Marina, 2006). Two methods are used to obtain coconut oil, dry processing and wet processing. The wet process is to extract oil directly from coconut milk. Various ways of obtaining oil have been studied by many authors (Rosenthal et al., 1996; Seow & Gwee, 1997; Chen & Diosady, 2003) This methods eliminates the use of solvents which reduce the cost and energy requirements (Mariana et al., 2009). The disadvantage of this method is in the low oil recovery efficiency, therefore, it is unsuitable for commercial applications (Rosenthal, Pyle & Niranjan, 1996). The most common way of processing is the dry oil extraction process. Dried, ground copra is pressed by screw press or hydraulic press to obtain coconut oil. The vegetable oils obtained by mechanical pressing are characterized by high quality and can be used for special applications (Willems et al., 2008).

To design a suitable pressing technology with minimum input power it is necessary to know the mechanical behavior of copra under compression loading. The available literature on the mechanical behaviour of copra shows the need for further research to address the effect of temperature on amount of oil obtained and energy requirements. The relationship between the compressive force and deformation of bulk copra needs to be transformed to the deformation characteristics used in nonlinear environments that are in screw presses. Therefore, the aim of this study was to describe the linear pressing of bulk copra under different temperatures and to determine the mathematical model describing the pressing behaviour.

MATERIALS AND METHODS

Sample

Dried, clean and ground copra from coconut (*Cocos nucifera L.*) obtained from North Sumatra, Indonesia was used in this experiment. The moisture content $M_c = 5.6 \pm 0.6\%$ (w.b.) of sample was determined using the standard oven method, ASAE method (ASAE S410.1 DEC97, ASAE, 1998). The procedure was that the initial mass of the sample before and after oven drying was weighed. For measuring of mass of each sample m_s (g) an electronic balance (Kern 440–35, Kern & Sohn GmbH, Balingen, Germany) was used. The oil content of copra $O_c = 65.5 \pm 3.2\%$ was determined using the Soxhlet apparatus. For Soxhlet extraction 10 g of find ground copra was extracted with petroleum in a Soxhlet apparatus for 6 h at 60 °C.

Compression test

To determine the relationship between the pressing force and deformation, the compressive device (Labortech, MPTest 5.050, Czech Republic) was used to record the course of deformation function. The amount of 100 g of copra was filled into a pressing vessel of diameter 60 mm and pressing height 100 mm. The pressing vessel was equipped with a heating element for change of temperature. Compression tests at the rate of 1 mm s^{-1} under five different temperatures 20, 40, 60, 80 and 100 °C were performed. For each temperature, the material was preheated in the oven (MEMMERT GmbH + Co. KG, Germany) for 15 minutes. The material temperature was checked using a thermometer (Comet System, C0111, Czech Republic). The measuring range of force was between 0 kN and 50 kN, which represents the normal pressure range commonly used for natural materials. The experiment was repeated five times for each temperature. The schema of pressing vessel is shown in the Fig. 1.

The volume energy is the area under the compressive force – deformation curve and was calculated using Eq. 1 (Kabutey et al., 2015).

$$E_x = \sum_{n=0}^{n=i-1} \left[\left(\frac{F_{n+1} + F_n}{2} \right) \cdot \left(X_{n+1} - X_n \right) \right] \quad (1)$$

where E_x – deformation energy, J; F_{n+1} and F_n – values of compressive force, N; X_{n+1} and X_n – values of deformation, m.

The specific mechanical energy was calculated as the ratio of mechanical energy and total oil yield.

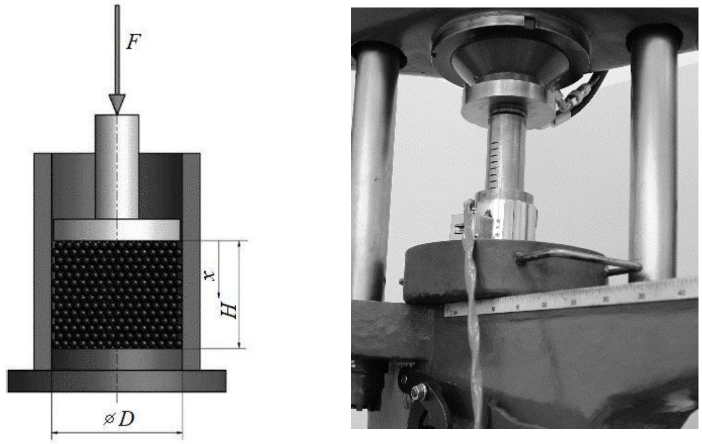

Figure 1. Scheme of pressing vessel diameter *D* of 60 mm with plunger (Herák et al., 2013) and compression test.

Processing of measured data

The measured amounts of compressive force and deformation of copra for different temperatures were analysed with computer program Mathcad 14 (MathCAD 14, PTC Software, Needham, MA, USA), (Pritchard, 1998) uses Levenberg-Marquardt algorithm for data fitting (Marquardt, 1963). The determined model of curves was statisticaly verified by using ANOVA.

RESULTS AND DISCUSSION

Measured data of individual pressing curve for different temperatures of pressed material are shown in Fig. 2. Dependency between compressive force and deformation for temperatures 40, 60, 80 and 100 °C was fitted by tangent curve equations (Eq. (2)) and the coefficients are presented in Table 1.

$$F(x) = G_0 \times \tan(G_1 \times x) \qquad (2)$$

where $F(x)$ – compressive force, N; G_0, G_1 – force coefficients of mechanical behaviour, N; x – deformation of bulk copra, mm.

From statistical analysis ANOVA (Table 1) follows, that measured amounts of compressive force at diferent temperatures and results from the tangent curve (Eq. 2) were statistically significant at significance level 0.05, that is, the values of F_{crit} (critical value comparing a pair of models) were higher than the F_{rat} values (value of the F – test) and values of P_{value} (significance level at which it can be rejected the hypothesis of equality of models) (Table 1) were higher than 0.05 which is also confirmed by very high coefficients of determination R^2.

Table 1. Determined coefficients of deformation characteristics of pressing vessel for bulk copra and their statistical analysis

Temperature (°C)	G_0 (N)	G_1 (N)	F_{rat} (-)	F_{crit} (-)	P_{value} (-)	R^2 (-)
40-100	$3.281 \cdot 10^3$	0.024	$9.462 \cdot 10^{-3}$	4.301	0.923	0.897

The authors Herák et al., 2013 used a tangent curve to describe the mechanical behavior of oilseeds under compression loading.

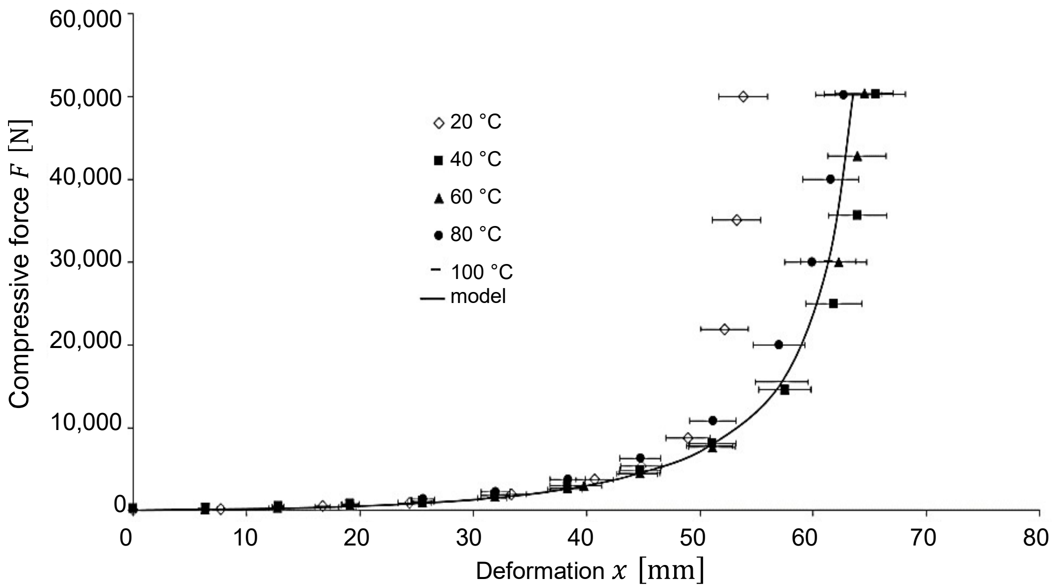

Figure 2. Measured amounts of mechanical characteristic of copra under different temperatures with displayed amounts of coefficients of variation.

Fig. 3 shows the dependence between oil recovery efficiency and temperature of pressed copra. From the Fig. 3 is evident, that with increasing temperature also increases the quantity of obtained oil.

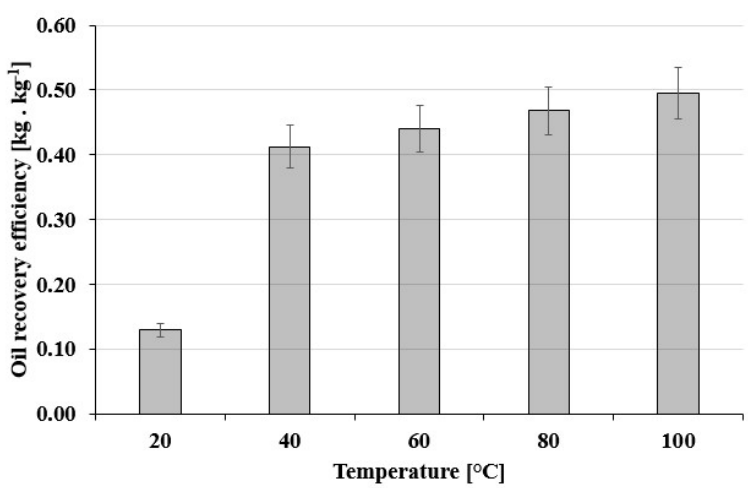

Figure 3. The effect of temperature of coconut copra on oil obtained ratio.

Fig. 4 shows the correlation of specific energy input versus temperature of copra. It is also evident that specific energy decreases as the temperature increases. This is also confirmed by the authors Kabutey et al., 2017. They examined the influence of temperature on mechanical energy by linear pressing of rapeseeds. Copra reaches lower values of specific mechanical energy compared to oil seeds (Mizera et al., 2017).

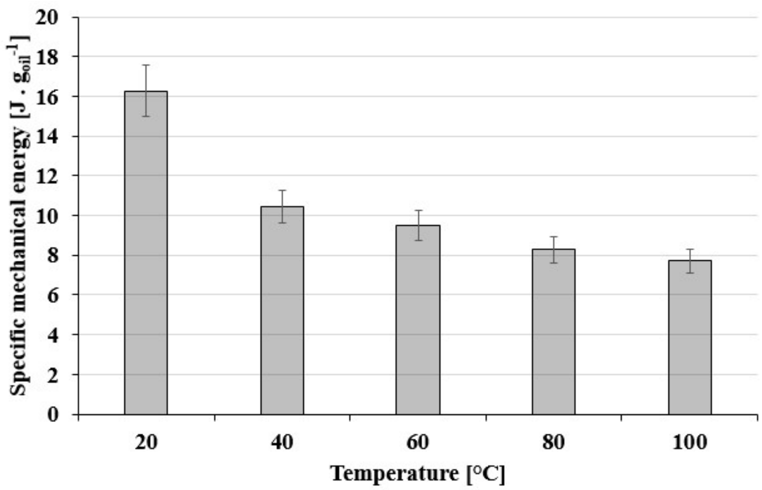

Figure 4. Dependence between temperature and mechanical energy for obtaining one gram of coconut oil.

By pressing at 20 °C was obtained 11.4 g of coconut oil (of the total weight of 88 g). When the temperature increased to 40 °C, an oil gain of 36.3 g was obtained. It can be seen from the individual figures that the greatest difference occurs when the temperature reaches 40 °C. When increasing the temperature above 40 °C there is a linear increase in oil recovery efficiency and even decrease in specific mechanical energy.

CONCLUSIONS

In this study, the compression behaviour of bulk coconut copra was examined at different heat treatment temperatures. A general equation describing the mechanical behaviour of bulk copra under compression loading was determined by tangent curve equation. The results showed that the optimal temperature for copra pressing is about 40 °C. When the temperature is raised to 40 °C, specific mechanical energy for one gram of oil reduced from 16.3 J g_{oil}^{-1} to 10.4 J g_{oil}^{-1} and oil recovery efficiency increased from 0.13 to 0.41 (kg kg^{-1}), compared to room temperature. Future studies should focus on analysing different pressing speed, pressing diameter and physical properties of the copra material as well as temperature influence on oil quality.

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