INFLUENCE OF POROSITY, PERMEABILITY AND EXPRESSION FORCE ON OIL YIELD OF JATROPHA SEEDS*

R. Sigalingging[1], Sumono[1], D. Herák[2], A. Kabutey[2], C. Sigalingging[3]

[1]Universitas Sumatera Utara, Department of Agricultural Engineering, Medan, Indonesia
[2]Czech University of Life Sciences Prague, Department of Mechanical Engineering, Prague, Czech Republic
[3]Universitas Sumatera Utara, Department of Food Technology, Medan, Indonesia

A mathematical model for effective porosity, effective force and permeability was derived using the experimental results. A universal compression machine was used to press oil of jatropha seeds at maximum force 100 kN, pressing vessel diameter 60 mm, initial pressing height 60 mm with different compression speeds ranging from 1 to 50 mm.min^{-1}. The analysis of variance showed significant effects of compression speed on oil yield, oil point deformation, effective porosity and time of oil flow ($P < 0.05$), while the compression speed effect was not significant on the maximum deformation, oil point force, effective force, flow rate of oil and permeability ($P > 0.05$). Oil yield decreased significantly with increasing speed hence lower driving effective force. In addition, lower effective porosity required higher effective force to drive oil flow due to lower permeability and flow rate of jatropha seeds oil. Equilibrium force between effective force and oil point force at force 100 kN was determined to be 50 kN with corresponding compression speed approximately 42.74 mm.min^{-1}. This knowledge is important in the industrial technology of oil processing where higher pressure is needed to achieve maximum leakage of oil.

jatropha seeds, oil expression, effective force, permeability, mathematical model,

oi: 10.2478/sab-2019-0009
Received for publication on February 27, 2017
Accepted for publication on June 22, 2018

INTRODUCTION

The continuing struggle of engineers to design and develop an efficient technology for oil expression of oilseed crops such as jatropha is of great concern to researchers since extra energy or cost is always needed to obtain the residual oil from the press cake. Although there are different categories of screw presses available including expellers, expanders and twin-screw systems primarily to increase the oil recovery, the press cake thus contains appreciable oil. Therefore, detailed knowledge of the physical characteristics during oil expression relating to the process parameters and equipment geometry, namely pressure, temperature, deformation speed, moisture content, friction and screw press rotation speed will improve the oil recovery prediction. In connection with energy consumption, Karaj, Muller (2011) reported that oil recovery increased with increasing energy requirement and decreased with decreasing screw press rotational speed. Kabutey et al. (2015) also indicated that energy decreased significantly with higher compression speed. The available literature on the effect of speed on energy requirement and oil yield of jatropha bulk seeds under compression loading, however, shows the need for further research to address mathematically the parameters such as the effective porosity and force as well as permeability relationship with oil recovery efficiency. But, the oil expression is a solid-liquid separation process, therefore the specific

* Supported by the Internal Grant Research of the University of Sumatera Utara, Indonesia BP-PTN 2016 (No. 6049/UN.5.1.R/PPM/2016)

energy consumption should be linked to the efficiency of the separation (Chapuis et al., 2014).

In order to gain accurate information on the effect of compression speed on energy requirement and oil recovery of jatropha bulk seeds, effective force and coefficient of permeability (k) are also important parameters in mechanical expression. The permeability characterises the ease with which liquid will flow through a porous medium including mechanical expression. Factors which affect permeability include the size of seed-cake making up the porous medium and the porosity. Pore size and its distribution can also describe the permeability.

However, Zheng et al. (2012) reported that deformation, geometry shape, and the pore size of press cake are extremely irregular, random and complicated resulting in great difficulty if the pore structure of press cake is described by classic Euclidean geometry. The structural characteristics and properties of the cell network depend on a cellular material where each elementary particle consists of a well-organized network of cells that is interfaced by several plasmodesmata (Lanoiselle et al., 1996). Dimensional change occurs along the three axes of the jatropha bulk seeds. Average seed diameter increases as a result of changes in the three axes indicating that pores volume of the contact diameter of the seeds enlarged. For spherical seeds, porosity increases with increasing seed size. Similar results were indicated by Pradhan et al. (2009) and Karaj, Muller (2010) for jatropha seeds.

During expression, the air dissipates and the cell rupture significantly modifies the bulk seeds compressibility of the cake affecting the intra-particle and extra-particle volumes to become compressible. Initially, the cake is saturated by liquid. Cake deformation depends only on the reorientation of individual incompressible particles within the cake. The reorientation of liquid containing particles and the evolution of particle microstructure affect the local stress gradients and consequently the expression performances. Therefore the aim of this study was to describe mathematically the effective force, effective porosity and permeability of jatropha bulk seeds under compression loading. The relationships between effective force, effective porosity, permeability and oil recovery were analysed.

MATERIAL AND METHODS

Sample and compression test

Jatropha bulk seeds of variety IPB2 were obtained from North Sumatera, Indonesia. Geometrical dimensions (length, width and thickness) were determined as 18.5 ± 1.7 mm, 11.3 ± 0.21 mm, and 7.9 ± 0.72 mm, respectively (Fig. 1). The initial moisture content of two batches of jatropha bulk seeds sample was determined by the conventional method using a standard hot air oven with a temperature setting 105°C and a drying time of 17 h (ISI 1966). The electronic balance (Kern 440-35, Kern & Sohn GmbH, Balingen, Germany) having an accuracy of 0.001 g was used to measure the mass (g) of samples before and after drying (67.12 ± 0.11 g and 57.04 ± 1.71 g, respectively). The moisture content of jatropha bulk seeds was calculated 8.64 ± 1.41% (in wet basis) using the equation given by Blahovec (2008).

The compression test was performed using a universal compression device (Tempos ZDM 50, Czech Republic) at maximum force 100 kN, pressing vessel diameter 60 mm, initial pressing height 60 mm with different compression speeds ranging from 1 to 50 mm.min^{-1}. The oil point of jatropha bulk seeds was measured when the first drop or leakage of oil from the 0.2 mm holes around the bottom of the pressing vessel was obtained.

Mathematical theories of bulk density, porosity and permeability

The bulk density, ρ_b (kg.m^{-3}) is the ratio of the sample mass, m (kg) to its container volume (Eq. 1). It was measured by weighing a filled measuring cylinder (pressing vessel) with known volume, V (m^3):

$$\rho_b = \frac{m}{V} \quad (1)$$

Porosity is divided into two types (total porosity and effective porosity). Total porosity is the ratio of the total volume of pores to the total bulk volume of jatropha seed at time $t = 0$, whereas effective porosity is that portion of total pores space of a porous material that is capable of transmitting a fluid at time $t_{op} \leq t \leq t_{dm}$, where t_{dm} represents time of maximum deformation and t_{op} time of oil point. According to Mohsenin (1986) porosity indicates the amount of pores in the bulk material, which is given by Eq. (2), where ε_t is total porosity (%) and ρ_s is solid density or true density (kg.m^{-3}). The literature true density value of jatropha bulk seeds of 980 ± 12 kg.m^{-3} (Herak et al., 2013a, b, 2014) was used.

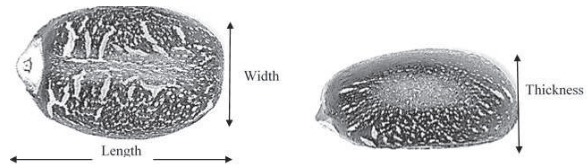


Fig. 1. Geometrical dimensions (length, width and thickness) of jatropha seeds

$$\varepsilon_t = \left(1 - \frac{\rho_b}{\rho_s}\right) 100\% \quad (2)$$

Effective porosity occurs because the fluid in a saturated porous media is not flowing through all pores, but only through the pores which are interconnected. The interconnected pore space is the effective pore space with total pore space. This happens when the porous medium contains unconnected pores, which are pores or channels with only a narrow single connection to the interconnected pore space so that almost no flow through it. Particle size, shape, and packing arrangement are among the factors that determine the occurrence of dead-end pores. In addition, some fluid contained in interconnected pores is held in place by molecular and surface-tension forces. In this study, the effective porosity (ε_{ef}, %) is a function of both spatial position and time $\varepsilon_{ef}(x, t)$ at constant force which is not zero ($F \neq 0$) and time when the first oil flows out ($t \leq t_{op}$). The initial solid of a volume (V_0, m^3) mass of the solid matrix (m_s, kg) is given by Eq. (3). By assumption the time $t = 0$; $F = 0$ that the solid matrix occupies a liquid volume (V_{l0}, m^3).

$$m_s = \rho_s \left(V_0 - V_{l0}\right) \quad (3)$$

By analogy, the total porosity is the ratio of volume liquid to the initial volume of the solid matrix (Eq. 4)

$$\varepsilon_t = \frac{V_{l0}}{V_0} \quad (4)$$

By substituting Eq. (4) into Eq. (3), it can be obtained the following equation Eq. (5):

$$m_s = \rho_s V_0 \left(1 - \varepsilon_t\right) \quad (5)$$

By assumption the time $t = t_{op}$; $F = F_{op}$ that the solid matrix occupies a liquid volume (V_{l0}, m^3) and the effective porosity is the ratio of volume liquid flows (V_l, m^3) to the initial volume of the solid matrix so that be obtained Eq. (6) as the relationship between mass of the solid matrix and the effective porosity:

$$m_s = \rho_s V_{l0} \left(1 - \varepsilon_{ef}\right) \quad (6)$$

The local volume of liquid (a liquid which occupies the pores) can be obtained by the following relationship between the effective porosity ε_{ef} (δ_{op}, t_{op}) and the volume strain (e), where δ_{op} is deformation when the first drop of liquid (oil) flows out of the cake (m). Natural volume strain or true volume strain can be calculated using Eq. (7):

$$\varepsilon = \ln\left(\frac{V_l}{V_0}\right) \quad \text{or} \quad -\varepsilon = \ln\left(\frac{V_0}{V_l}\right) \quad (7)$$

By assumption the local volume of liquid as given in Eq. (8) and after some rearrangement using Eqs. (5-7) can be obtained Eq. (9); D is the diameter of the pressing vessel (m) and H is the initial pressing height of bulk seeds (m) as shown in Fig. 2.

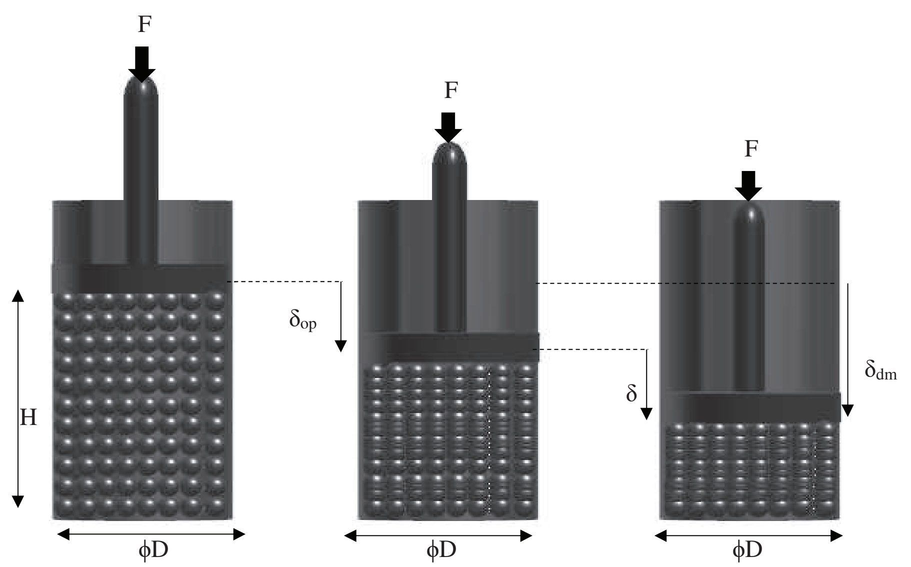
$$V_l = \frac{\pi}{4} D^2 \left(H - \delta_p\right) \quad (8)$$

Substituting Eqs (7) and (6) into Eq. (5), the effective porosity can be determined using Eq. (9):

$$\varepsilon_{ef} = 1 - \left(1 - \varepsilon_t\right) e^{-\varepsilon} \quad (9)$$

The fundamental of mechanical oil expression of jatropha seeds has three successive stages. The first stage is the constant force (F) applied by the piston

Fig. 2. Scheme of pressing vessel 60 mm in diameter (D) with plunger and initial pressing height (H) 60 mm



called maximum applied force (N). This is divided into two parts: one part is the force (F_{op}), which allows the compression and evacuation of the air from the bulk seeds and the cake through the extra-particle channels. The other part is transferred to the particles, which cause the liquid to flow out called the effective force (F_{ef}). The liquid force increases to allow the liquid to emanate from the intra-particle volume to the extra-particle volume. As the compression force increases, the effective force (F_{ef}) increases causing the initial reorientation of the elementary particles and consequently the initial decrease of the extra-particle and intra-particle volumes. The first stage ends when the first drop of liquid (oil) flows out of the cake, which is called oil point. The second stage, the extra-particle air is progressively replaced by oil and air/oil mixture is evacuated from the cake. The instantaneous flow rate of oil increases rapidly up to maximum that determines the end of the stages. Then the air is totally eliminated. The third stage of mechanical oil expression starts at the maximum instantaneous flow rate of oil when the intra-particle (intracellular and extracellular) and extra-particle volumes are completely filled with oil. This is the consolidation stage of press cake.

The total force required for oil flow out is shown in Eq. (10):

$$F = F_{op} + F_{ef} \qquad (10)$$

The permeability (k) for jatropha seed in mechanical expression is generally defined by the expression equation Eq. (11) based on Darcy's law which describes the flow of a fluid through a porous medium:

$$k = \frac{\frac{dV_l}{dt}\, \eta\, \frac{dx}{dP}}{S} \qquad (11)$$

where:
dV_l/dt = rate volume of jatropha seed ($m^3.s^{-1}$)
η = dynamic viscosity (Pa.s)
dx = deformation of cake at $t_{op} \le t \le t_{dm}$ (m)
dP = effective pressure at $t_{op} \le t \le t_{dm}$ (Pa)
S = cross sectional area of the cake (m^2)

The effective pressure is the ratio of the effective force to the cross sectional area of the cake at $t_{op} \le t \le t_{dm}$ (Eq. 12). By assumption the density of oil is constant during expression; the rate volume of oil is defined as the ratio of mass of oil to pressing time (Eq. 13) at $t_{op} \le t \le t_{dm}$ ($kg.s^{-1}$):

$$dP = \frac{dF}{S} \qquad (12)$$

$$\frac{dV}{dt} = \frac{1}{\rho}\frac{dm}{dt} \qquad (13)$$

Commonly, two types of viscosity are dynamic viscosity and kinematic viscosity. Both of these relationships can be written by Eq. (14), m is kinematic viscosity ($m^2.s^{-1}$), η is dynamic viscosity (Pa.s) and ρ is density of jatropha oil ($kg.m^{-3}$) (Marinescu et al., 2004; Rapp, 2017). The density of jatropha oil at temperature 20°C was 903.17 $kg.m^{-3}$ (Akbar et al., 2009; Sigalingging et al., 2014).

$$\mu = \eta\, \rho \qquad (14)$$

Combining Eqs (11), (12) and (13), we can obtain the permeability at time $t_{op} \le t \le t_{dm}$ given in Eq. (15):

$$k = \frac{\eta}{\rho}\frac{dm}{dt}\frac{dx}{dF} \quad \text{or} \quad k = \frac{\eta}{\rho}\, q\, \frac{\delta}{F_{ef}} \qquad (15)$$

where:
k = permeability of jatropha seeds (m^2)
dm/dt or q = flow rate of oil ($kg.s^{-1}$)
η = dynamic viscosity (Pa.s)
δ = deformation of the cake during oil leakage until attaining the maximum deformation (δ_{dm}) as given by Eq. (16):

$$\delta = \delta_{dm} - \delta_{op} \qquad (16)$$

Using Vogel's equation (Eq. 17) dynamic viscosity of 0.0786138 Pa.s for jatropha seeds under temperature 20°C was determined, where η is dynamic viscosity (Pa.s), T is the absolute temperature (K) and *a, b, c* are the Vogel's constants. The values of *a, b* and *c* for jatropha seeds were 0.759865 10^{-4} Pa.s, 1137.107536 K and 129.3428974 K, respectively (Macedo et al., 2013). The Vogel's equation is the most accurate to determine the dynamic viscosity of oil seeds at a specific temperature compared with Reynold, Slotte and Walther's equation by numerical method.

$$\eta = a\, e^{\frac{b}{(T-c)}} \qquad (17)$$

Parameters including oil yield, flow rate of oil, time of oil flow, maximum deformation, oil point deformation and oil point force were measured while bulk density, total porosity, effective porosity, effective force, and permeability were determined using Eqs (1), (2), (9), (10) and (15), respectively. Minitab Version 16 was used to analyse the statistical significance and correlation between parameters.

RESULTS

In Tables 1 and 2 are presented the mean and standard deviation of deformation, effective force, effective porosity, flow rate of oil and permeability of jatropha seeds. One way analysis of variance (Table 3) showed that the effect of compression speed on oil yield, oil point deformation, effective porosity and time of oil flow was significant ($P < 0.05$). Table 4 shows that the correlation analysis of the effect of compression

Table 1. Mean (± standard deviation) values of oil point force, effective force, bulk density, total porosity, effective porosity, and oil yield of jatropha bulk seeds at different compression speed

Speed (mm.min^{-1})	F_{op} (kN)	F_{ef} (kN)	ρ_b (kg.m^{-3})	ε_t (%)	ε_{ef} (%)	m_{oil} (g)
1	17.03 ± 2.33	80.97 ± 2.33	395.4 ± 0.58	59.66 ± 0.06	13.20 ± 0.24	12.76 ± 0.76
10	20.49 ± 1.69	79.511 ± 1.69	395.36 ± 0.67	59.66 ± 0.07	13.95 ± 0.20	10.92 ± 0.18
20	36.32 ± 17.12	63.68 ± 17.12	396.54 ± 0.83	59.54 ± 0.08	14.56 ± 0.02	10.66 ± 0.52
30	35.02 ± 4.11	64.98 ± 4.11	395.15 ± 0.12	59.68 ± 0.01	14.56 ± 0.17	9.38 ± 0.29
40	44.75 ± 17.76	55.25 ± 17.76	395.30 ± 0.33	59.66 ± 0.03	14.99 ± 0.08	8.96 ± 0.43
50	59.52 ± 31.17	40.48 ± 31.17	396.07 ± 0.17	59.58 ± 0.02	15.03 ± 0.67	7.84 ± 0.54

F_{op} = compression force reaching oil point, F_{ef} = effective force, m_{oil} = mass of oil, ρ_b = bulk density, ε_t = total porosity, ε_{ef} = effective porosity

Table 2. Mean (± standard deviation) values of pressing time, flow rate of oil, and permeability for jatropha bulk seeds at different compression speed

Speed (mm.min^{-1})	t_{op} (s)	t_{dm} (s)	$t_{oilflows}$ (s)	q (g.s^{-1})	k (μm^2)
1	2293.31 ± 30.33	2701.61 ± 17.21	408.30 ± 47.54	0.031 ± 0.002	0.18 ± 0.01
10	238.48 ± 2.29	272.74 ± 0.23	34.26 ± 2.52	0.320 ± 0.029	1.62 ± 0.09
20	120.76 ± 0.03	131.06 ± 6.22	10.30 ± 6.19	1.245 ± 0.698	4.08 ± 0.90
30	81.01 ± 0.72	87.39 ± 0.04	6.38 ± 0.76	1.483 ± 0.223	4.44 ± 1.47
40	62.18 ± 0.82	66.64 ± 1.87	4.46 ± 1.05	2.053 ± 0.385	6.09 ± 0.52
50	50.5 ± 1.67	52.59 ± 3.75	2.09 ± 2.08	7.162 ± 6.864	15.91 ± 11.53

t_{op} = time of pressing reaching oil point, t_{dm} = pressing time reaching maximum deformation, $t_{oilflows}$ = total time for oil flows, q = flow rate of oil, k = permeability

Table 3. Statistical analysis of variance (one-way ANOVA) for the effect of compression speed on measured parameters of jatropha bulk seeds

Measured parameters	R^2	F	P-value
Oil yield	0.9544	25.09	< 0.05
Maximum deformation	0.3525	0.651	> 0.05
Oil point deformation	0.8912	9.83	< 0.05
Oil point force	0.6239	1.99	> 0.05
Effective force	0.6239	1.99	> 0.05
Effective porosity	0.8930	10.01	< 0.05
Time of oil flow	0.9913	136.95	< 0.05
Flow rate of oil	0.5885	1.72	> 0.05
Permeability	0.6950	2.73	> 0.05

significant ($P < 0.05$), non-significant ($P > 0.05$)

Table 4. Correlation analysis of compression speed, maximum deformation, oil point deformation, oil point force, effective force, effective porosity, time of oil flow, flow rate of oil and permeability on oil yield of jatropha seeds

Parameters	R	P-value
Speed	–0.955	< 0.05
Maximum deformation	0.286	> 0.05
Oil point deformation	–0.951	< 0.05
Oil point force	–0.645	< 0.05
Effective force	0.645	< 0.05
Effective porosity	–0.895	< 0.05
Time of oil flow	–0.752	< 0.05
Flow rate of oil	0.784	< 0.05
Permeability	0.741	< 0.05

significant ($P < 0.05$), non-significant ($P > 0.05$)

speed, oil point deformation, oil point force, effective force, effective porosity, time of oil flow, flow rate of oil and permeability was significant ($P < 0.05$).

Dependency between oil yield and compression speed, between effective porosity and compression speed; between effective force and compression speed; between permeability and compression speed of jatropha bulk seeds is displayed in Figs. 3, 4, 5 and 7, respectively. On the other hand, linear relationship between effective force and oil-point force; between effective pressure and compression speed is showed in Figs. 6 and 8.

DISCUSSION

The effective porosity slightly increased with increased compression speed (Table 1). In this study, the effective porosity was denoted at the first leakage of oil. Effective porosity pertains exclusively to the portion of the total volume of pores available for oil flow. Effective porosity values of 13.20 ± 0.24 (%) and 15.03 ± 0.67 (%) at compression speeds 10 and 50 mm.min^{-1} were observed, increasing with the increased compression speed. The effective porosity

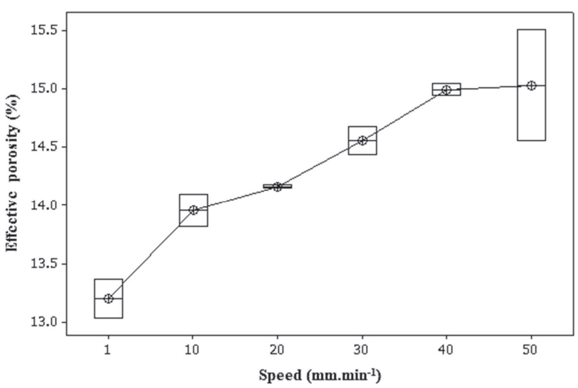


Fig. 3. Dependency between oil yield (g) and compression speed (mm.min^{-1}) of jatropha bulk seeds

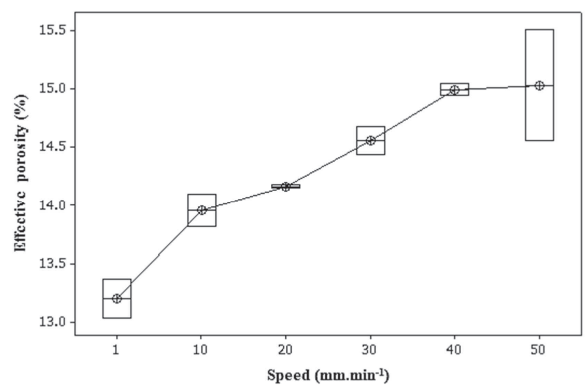


Fig. 4. Dependency between effective porosity (%) and compression speed (mm.min^{-1}) of jatropha bulk seeds

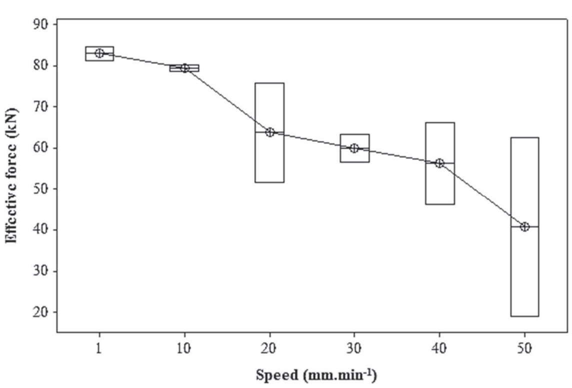


Fig. 5. Dependency between effective force and compression speed (mm.min^{-1}) of jatropha bulk seed

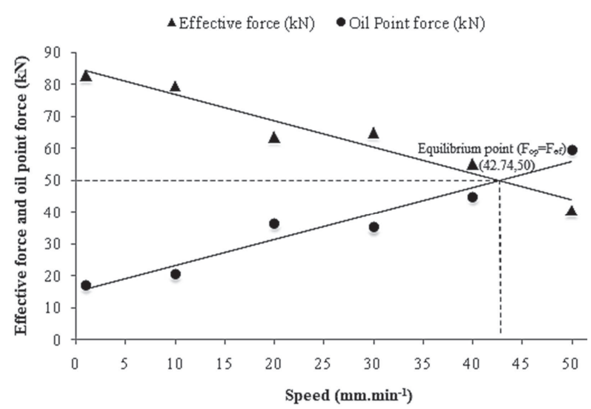


Fig. 6. Linear relationship between effective force and oil point force with different compression speeds

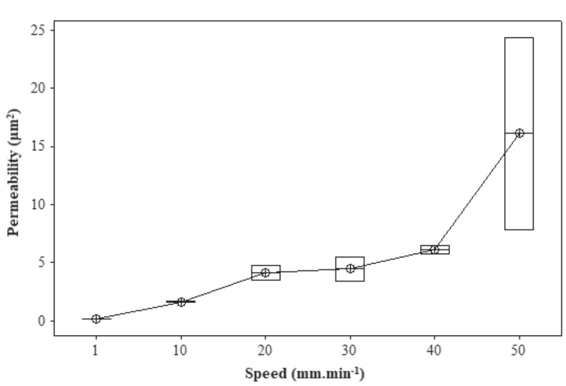


Fig. 7. Dependency between permeability (μm^2) and compression speed (mm.min^{-1}) of jatropha bulk seeds

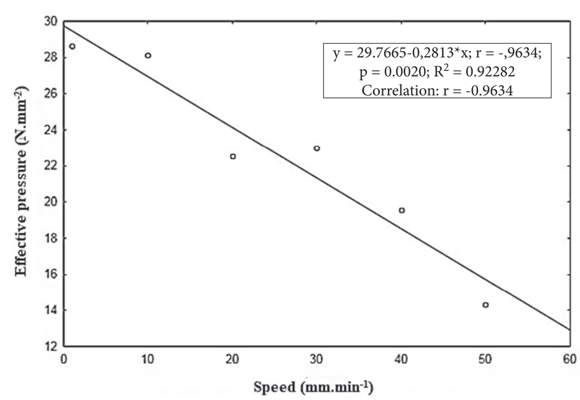


Fig. 8. Relationship between effective pressure and compression speed

has a direct impact on the number of driving forces (effective force) and indirectly can contribute to the conversion of the specific surface value of grain size on the seed-cake which is the carrier of drag resistance. According to Urumovic, Urumovic (2014), forces affect the moving fluid that makes effective porosity an active factor only to pores through which the fluid flows. The low porosity and the small size of pores on the cell wall could result in a high resistance to fluid flow (Mrema, Mcnulty, 1985). Therefore, the grain size of seed-cake is a key factor for the rate of crack growth because when the porosity limit reaches zero, then the cake seeds become non-porous meaning that oil cannot flow out from the seed-cake. As the force increases, the pore volume decreases along where the packing of seeds draws nearer, the bulk seeds deform and the cell of seeds opens resulting in the leakage of oil through the smaller pores. The amount of oil produced is equal to the reduction of volume of the seed-cake. Increased compression speed would decrease oil yield (Fig. 3) because of effective force decrease (Fig. 5).

The effective force decreased as oil yield decreased significantly (Table 4). On the other hand, the oil point force (F_{op}) increased with increasing compression speed thereby decreasing the effective force (F_{ef}) (Table 1). The force increased with increasing compression speed for the first leakage of oil which was denoted as oil point force. Because the total applied force was constant (100 kN) that means, if the oil-point force increased, the effective force decreased (based on Eq. 10). Based on a linear relationship between effective force and oil point force at different compression speeds (Fig. 6) an equilibrium point of compressive force 50 kN at speed around 42.74 mm.min^{-1} (R^2 = 0.93847) was noticed. The effective force allows the oil to flow from the intra-particle volume to the extra-particle volume of the seed-cake.

The permeability for jatropha seed-cake during pressing was determined using Eq. (15). Increasing compression speed decreased the time of oil flow, which increased permeability (Table 2). This means that the rate of oil flow increased across the seed-cake until oil leakage. The effective force decreased with increasing compression speed which did not only influence oil yield but also permeability. Oil yield decreased with decreasing effective force (Figs. 3 and 5). In contrast, permeability declined with increasing effective force (Figs. 4 and 6). Nevertheless, increasing speed decreased effective force which decreased oil yield even though permeability and effective porosity increased (Figs. 3, 5 and 7). It was indicated that high percentage oil is left in the seed-cake during oil expression. However, pressing time increased with increasing compressive force and decreased with increasing compression speed significantly ($P < 0.05$) due to the changing of effective porosity and permeability of jatropha bulk seeds. Beerens (2007) and Deli et al. (2011) indicated that a higher compression speed thus decreases oil recovery efficiency in situation of mechanical screw presses as well as under loading for sunflower bulk seeds (Sigalingging et al., 2015). Obviously, higher speed reduces the residence time of the oil to discharge from the bulk oilseeds. With increased speed, the oil yield decreased and time of oil flows also decreased because the flow rate of oil increased. However, the time to reach 100 kN force (as a maximum applied force) using higher speed was shorter than if using a lower speed, so the only small amount of oil yield was out. Therefore, in this study maximum oil was obtained at the lower speed because of increasing the effective force. Faborode, Favier (1996) and Ogunsina et al. (2008) reported similar information that the lower the oil point pressure the higher the effective pressure for oil expression which maximizes oil yield. As shown in Fig. 8, effective pressure decreased with increasing compression speed. In addition, the oil point pressure decreased with the increase in temperature (Ajibola et al., 2002). The present findings are important in the industrial technology of oil processing where pressure must increase slowly to cause maximum leakage of oil.

CONCLUSION

The effect of compression speed on oil yield, oil point deformation, effective porosity and time of oil flows was significant ($P < 0.05$), while the compression speed effect was not significant on the maximum deformation, oil point force, effective force, flow rate of oil and permeability ($P > 0.05$). The linear relationship among compression speed, oil point deformation, oil point force, effective force, effective porosity, time of oil flow, the flow rate of ail and permeability on oil yield was strongly significant. Oil yield decreased significantly with increasing speed hence lower driving effective force. In addition, lower effective porosity required higher effective force to drive oil flow due to lower permeability and flow rate of oil jatropha. Equilibrium force between effective force and oil point force was found to be 50 kN with compression speed around 42.74 mm.min^{-1}. This knowledge is important in the industrial technology of oil processing where higher pressure is needed to achieve maximum leakage of oil.

REFERENCES

Ajibola OO, Okunade DA, Owolarafe OK (2002): Oil point pressure of soybean. Journal of Food Process Engineering, 25, 407–416. doi: 10.1111/j.1745-4530.2002.tb00574.x.

Akbar E, Yaakob Z, Kamarudin SK, Ismail M, Salimon J (2009): Characteristic and composition of *Jatropha curcas* oil seed

from Malaysia and its potential as biodiesel feedstock. European Journal of Scientific Research, 29, 396–403.
Beerens P (2007): Screw-pressing of jatropha seeds for fueling purpose in less developed countries. Eindhoven University of Technology, Department of Sustainable Energy Technology, Netherlands.
Blahovec J (2008): Agromaterials study guide. Czech University of Life Sciences Prague, Czechia.
Chapuis A, Blin J, Carre P, Lecomte D (2014): Separation efficiency and energy consumption of oil expression using a screw-press: The case of *Jatropha curcas* L. seeds. Industrial Crops and Products, 52, 752–761. doi: 10.1016/j.indcrop.2013.11.046.
Deli S, Farah M, Tajul A, Wan N (2011): The effects of physical parameters of the screw press oil expeller on oil yield from *Nigella sativa* L. seeds. International Food Research Journal, 18, 1367–1373.
Faborode MO, Favier JF (1996): Identification and significance of the oil-point in seed-oil expression. Journal of Agricultural Engineering Research, 65, 335–345. doi: 10.1006/jaer.1996.0107.
Herak D, Kabutey A, Divisova M, Simanjuntak S (2013a): Mathematical model of mechanical behaviour of *Jatropha curcas* L. seeds under compression loading. Biosystems Engineering, 114, 279–288. doi: 10.1016/j.biosystemseng.2012.12.007.
Herak D, Kabutey A, Hrabe P (2013b): Oil point determination of *Jatropha curcas* L. bulk seeds under compression loading. Biosystems Engineering, 116, 470–477. doi: 10.1016/j.biosystemseng.2013.10.006.
Herak D, Blahovec J, Kabutey A (2014): Analysis of the axial pressing of bulk *Jatropha curcas* L. seeds using reciprocal slope transformation. Biosystems Engineering, 121, 67–76. doi: 10.1016/j.biosystemseng.2014.02.009.
ISI (1966): Indian standard methods for analysis of oilseeds, IS: 3579. Indian Standard Institute, New Delhi.
Kabutey A, Herak D, Choteborsky R, Sigalingging R, Mizera C (2015): Effect of compression speed on energy requirement and oil yield of *Jatropha curcas* L. bulk seeds under linear compression. Biosystems Engineering, 136, 8–13. doi: 10.1016/j.biosystemseng.2015.05.003.
Karaj S, Muller J (2010): Determination of physical, mechanical and chemical properties of seeds and kernels of *Jatropha curcas* L. Industrial Crops and Products, 32, 129–138. doi: 10.1016/j.indcrop.2010.04.001.
Karaj S, Muller J (2011): Optimizing mechanical oil extraction of *Jatropha curcas* L. seeds with respect to press capacity, oil recovery and energy efficiency. Industrial Crops and Products, 34, 1010–1016. doi: 10.1016/j.indcrop.2011.03.009.
Lanoiselle JL, Vorobyov EI, Bouvier JM, Piar G (1996): Modeling of solid/liquid expression for cellular materials. Journal of American Institute of Chemical Engineers, 42, 2057–2068. doi: 10.1002/aic.690420726.
Macedo TDO, Pereira RG, Pardal JM, Soares AS, Lameira VJ (2013): Viscosity of vegetable oils and biodiesel and energy generation. International Scholarly and Scientific Research & Innovation, 7, 184–189.
Marinescu ID, Rowe WB, Dimitrov B, Inasaki I (2004): Tribology of abrasive machining processes. William Andrew Publishing, New York.
Mohsenin NN (1986): Physical properties of plant and animal materials. Gordon and Breach Science Publishers, New York.
Mrema GC, McNulty PB (1985): Mathematical model of mechanical oil expression from oilseeds. Journal of Agricultural Engineering Research, 31, 361–370. doi: 10.1016/0021-8634(85)90111-8.
Ogunsina BS, Owolarafe OK, Olatunde GA (2008): Oil point pressure of cashew (*Anacardium occidentale*) kernels. International Agrophysics, 22, 53–59.
Pradhan RC, Naik SN, Bhatnagar N, Vijay VK (2009): Moisture-dependent physical properties of jatropha fruit. Industrial Crops and Products, 29, 341–347. doi: 10.1016/j.indcrop.2008.07.002.
Rapp BE (2017): Microfluidics: Modelling, mechanics and mathematics. Micro & Nano Technologies Series. Elsevier Inc., New York.
Sigalingging R, Herak D, Kabutey A, Divisova M, Svatonova T (2014): A review of the physical, mechanical, thermal, and chemical properties of *Jathropa curcas* seeds as basic information for oil pressing. Journal of Art, Science & Commerce, 5, 44–53.
Sigalingging R, Herak D, Kabutey A, Dajbych O, Hrabe P, Mizera C (2015): Application of a tangent curve mathematical model for analysis of the mechanical behaviour of sunflower bulk seeds. International Agrophysics, 29, 517–524. doi: 10.1515/intag-2015-0060.
Urumovic K, Urumovic K (2014): The effective porosity and grain size relations in permeability functions. Hydrology and Earth System Sciences Discussions, 11, 6675–6714. doi: 10.5194/hessd-11-6675-2014.
Zheng X, Wang JZ, Lin GX, Sun ZX, He DP (2012): Mathematical model incorporated fractal geometry and permeability of compressed peanut and sesame for oil extraction. Advanced Materials Research, 676–681. doi: 10.4028/www.scientific.net/AMR.550-553.676.

Corresponding Author:

Riswanti S i g a l i n g g i n g , Ph.D., University of Sumatera Utara, Department of Agricultural Engineering, Prof. A. Sofyan No. 3 Kampus USU, Medan, Indonesia, phone: +62 61 8211 924, e-mail: riswanti@usu.ac.id