COMPARISON OF DEFORMATION ENERGY OF PARTICULAR OIL-BEARING CROPS

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Abstract
The study focused on the description of the empirical and theoretical relationship between the force and deformation as well as the deformation energy of bulk oilseeds of oil palm, sunflower, rape and flax. Each of the bulk material initial height of 60 mm was loaded using the universal compression machine and pressing vessel of diameter 60 mm at a maximum force of 200 kN and speed of 5 mm/min. The tangent curve model was used to describe the experimental data. The amounts of numerical deformation energy of oil palm and sunflower bulk materials at a force of 200 kN were1245.55±20.41 (J) and 675.94±5.55 (J) whiles that of the analytical were 1283.96±29.55 (J) and 823.31±123.20 (J). At an optimal force of 163 kN for rape and flax bulk oilseeds, the amounts of experimental and analytical model of deformation energy were 718.27±29.41 (J) and 690.55±45.71 (J) then 600.96±4.62 (J) and 566.82±5.31 (J).

Key words: *bulk oilseeds; compression loading; empirical data; mathematical model*

INTRODUCTION

Oil is usually extracted from oil-bearing materials by mechanical expression or solvent method (*Owolarafe, et al., 2008*). Compression test of bulk systems also requires that the materials be placed in an enclosure to withstand the resulting pressure or compressive force (*Raji & Favier, 2004*). The knowledge of the required amount of energy of the oil-bearing materials during compression is useful in developing the appropriate equipment design and optimized processing conditions for greater oil recovery from oilseeds (*Chapuis, et al., 2014*). From the literature, the use of a mathematical model for the estimation of the energy in compression test has been reported for some bulk oilseeds (*Herak et al., 2011; Sigalingging et al., 2014, 2015*). Adequate information in this subject area is still needed to developing a more detailed mathematical model for energy requirement of oil-bearing materials during compression loading test and mechanical screw press. The objective of this study was to determine the numerical and analytical deformation energy of some bulk oilseeds/kernels of oil-bearing crops under compression loading.

MATERIALS AND METHOD

Sample and moisture content

The moisture content of the bulk oil palm kernels and the bulk oilseeds of sunflower, rape and flax was determined using the standard oven method with a temperature setting of 105 °C and drying time of 17 h (*ISI, 1996*). The initial and final weights of the bulk materials before and after oven drying were determined with the electronic balance (Kern 440–35, Kern & Sohn GmbH, Balingen, Germany). The determined amounts were 8.57, 4.79, 4.62 and 7.32 % on a wet basis according to equation (1) (*Blahovec, 2008*).

$$MC_{w.b.} = \left[\left(\frac{m_a - m_b}{m_a} \right) 100 \right] \quad (1)$$

where: $MC_{w.b.}$ is the moisture content on a wet basis (%), m_a is the mass of the bulk samples in the initial state and m_b is the mass of the bulk samples after drying or heat treatment (g).

Compression test of bulk oilseeds/kernels
The bulk oil-bearing materials were compressed at a maximum force of 200 kN and speed of 5 mm/min using the universal compression testing machine (ZDM 50, Czech Republic) and pressing vessel of diameter 60 mm. The initial pressing height of the bulk samples was measured at 60 mm where they were repeated three times. The obtained amounts of the force and corresponding deformation were further processed using the MathCAD 14 software (*Mathsoft, 2014; Marquardt, 1963; Pritchard, 1998*).

Deformation energy
The deformation energy was calculated using equation (2) (*Herak et al., 2012*).

$$D_E = \sum_{n=0}^{n=i-1}\left[\left(\frac{F_{n+1}+F_n}{2}\right)(x_{n+1}-x_n)\right] \quad (2)$$

where D_E is the deformation energy (J), $F_{n+1}+F_n$ and $x_{n+1}-x_n$ are values of the force (N) and deformation (mm), *n* is the number of observed values and *i* is 1, 2, 3…………$i_{\max}$ observations.

Percentage oil yield
The percentage oil yield of the bulk oilseeds/kernels was calculated using equation (3) (*Deli et al., 2011*).

$$OY(\%) = \frac{O_w}{O_m}100 \quad (3)$$

where OY is the oil yield (%), O_w is the mass of oil (g) and O_m is the mass of bulk oilseeds/kernels (g)

Theoretical fitted curves and deformation energy
The theoretical dependency between the force and deformation curves of the bulk oil-bearing materials was described using the tangent curve function as indicated in equation (4) (*Herak et al., 2011; Sigalingging et al., 2014, 2015*).

$$F(x, A, B) = A \cdot (\tan(B \cdot x))^n \quad (4)$$

Where F is the compressive force (kN), x is the deformation of bulk material (mm), A is the force coefficient of mechanical behaviour (kN), B is the deformation coefficient of mechanical behaviour (mm^{-1}) and n is the value of the fitting function (-). The integral of equation 4 is the deformation energy (J).

RESULTS AND DISCUSSION
The results of the numerical and analytical evaluation of the bulk oilseeds of oil palm, sunflower, rape and flax are presented in Tab. 1 and 2 as well as Fig. 1 to 3 respectively. For rape and flax bulk oilseeds, the optimal force without the ejection of the seedcake through the pressing vessel holes was observed at a maximum force of 163 kN. However, the initial maximum force of 200 kN for oil palm and sunflower bulk oilseeds/kernels was without any ejection process. The ejection process is characterized by the serration behaviour on the force and deformation curve (Fig. 1). Both the smooth curve pattern and serration effect exhibited by the oil-bearing crops are important for analyzing the energy requirement for the output oil (*Divisova et al., 2014*).

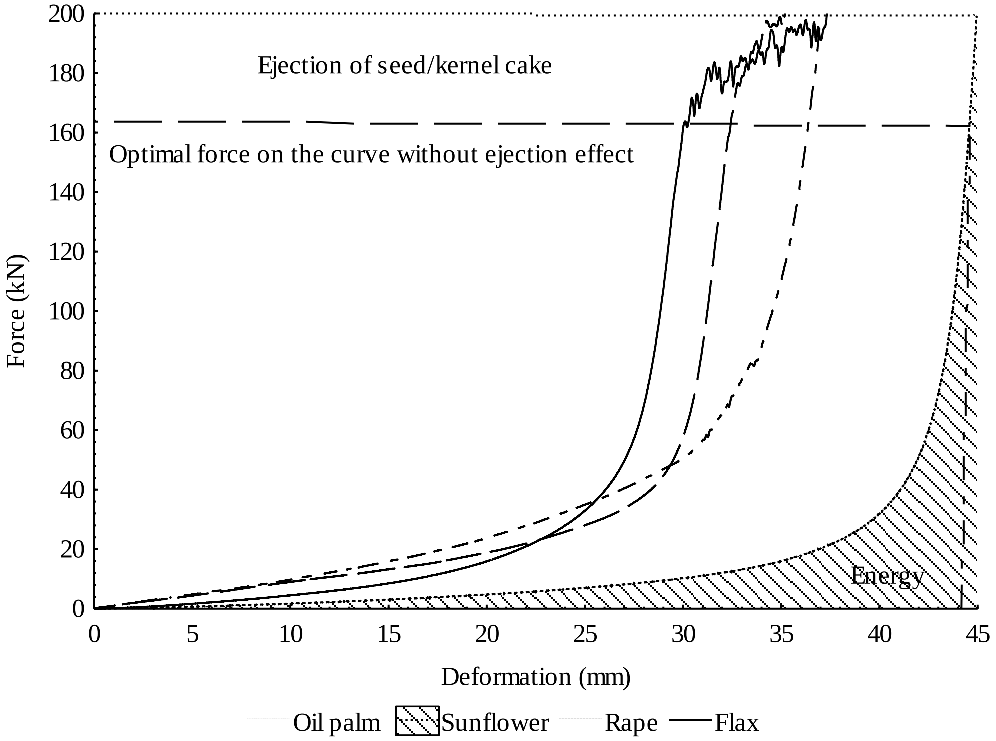

Fig. 1 Force and deformation curves of bulk oilseed or kernel of oil palm, sunflower, rape and flax

The empirical amounts of deformation energy of oil palm, sunflower, rape and flax bulk materials were 1245.55±20.41 (J), 675.94±5.55 (J) 718.27±29.41 (J) and 600.96±4.62 (J). Similarly, the analytical deformation energy values based on the tangent curve model of the above-mentioned bulk oilseeds/kernels in that order were 1283.96±29.55 (J), 823.31±123.20 (J), 690.55±45.71 (J) and 566.82±5.31 (J) (Tab. 1). Flax bulk oilseeds indicated the lowest deformation energy at a speed of 5 mm/min. These amounts are described graphically in Fig. 2. Following in that order the oil yield amounts were 27.32±0.79 (%), 21.08±0.59 (%), 23.04±0.15 (%) and 14.19±0.61 (%).

Tab. 1 Evaluation of numerical and analytical deformation energy of different bulk oilseeds

Bulk oilseeds/kernels	Force (kN)	Deformation (mm)	Deformation energy (J)	
			Numerical	Analytical
Oil palm	200	39.53±2.21	1245.55±20.41	1283.96±29.55
Sunflower		45.36±0.37	675.94±5.55	823.31±123.20
Oil palm	*163	38.91±0.20	1133.72±15.44	1151±31.51
Sunflower		44.97±0.37	604.77±8.57	634.20±60.91
*Rape		33.03±0.56	718.27±29.41	690.55±45.71
*Flax		29.68±0.52	600.96±4.62	566.82±5.31

* Optimal force without seedcake ejection from the pressing vessel holes.

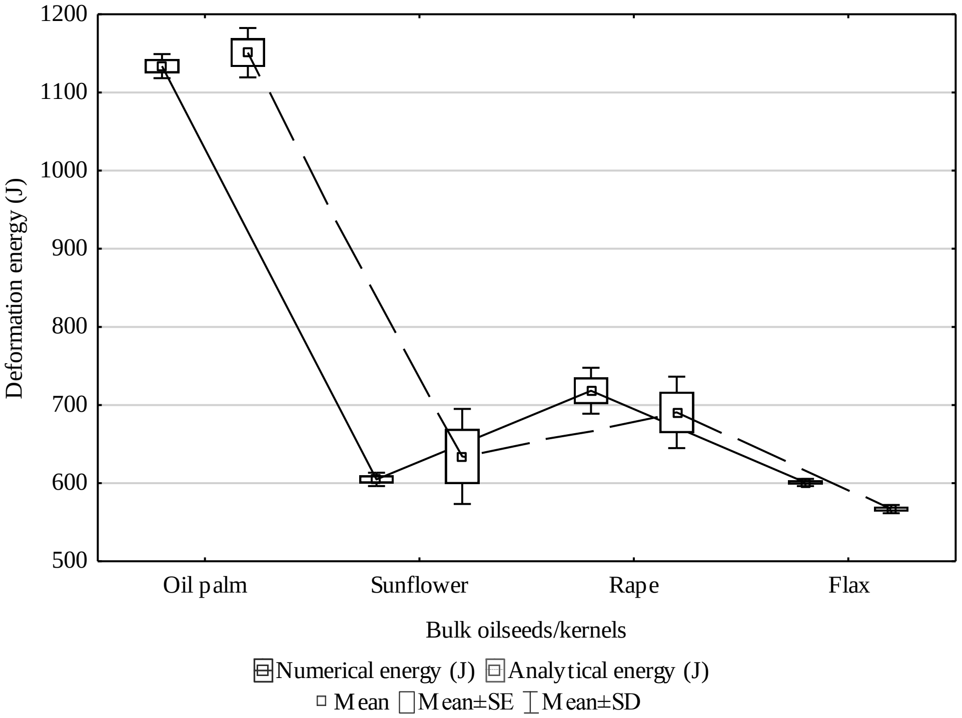

Fig. 2 Relationship between the numerical and analytical deformation energy of bulk oilseeds at force 163 kN

The statistical analyses of the tangent curve mathematical model are given in Tab. 2. The results were significant where the values of $F_{critical}$ were higher than F_{ratio} for all determined coefficients. Further, the amounts of P_{value} were also higher than the alpha level of 0.05.

Tab. 2 Tangent model coefficients and statistical analyses at force 200 and 163 kN

Bulk oilseeds/kernels	A (kN)	B (mm^{-1})	n (-)	F_{ratio} (-)	$F_{critical}$ (-)	P_{value} (-)	R^2 (-)
			At force 200 kN				
Oil palm	19.577	0.038		0.002	3.858	0.969	0.999
	±1.161	±0.002	1	±0.003	±0.001	±0.030	±0.001
Sunflower	7.573	0.034		0.067	3.860	0.799	0.996
	±0.241	±0.001	1	±0.024	±0.001	±0.039	±0.001
			At force 163 kN				
Oil palm	19.460	0.038		0.004	3.860	0.952	0.999
	±1.166	±0.002	1	±0.006	±0.002	±0.034	±0.001
Sunflower	6.781	0.034		0.025	3.860	0.878	0.999
	±0.095	±0.001	1	±0.013	±0.002	±0.031	±0.001
Rape	11.373	0.046		0.011	3.864	0.934	0.992
	±1.124	±0.001	1	±0.017	±0.005	±0.064	±0.002
Flax	7.170	0.046		0.057	3.868	0.816	0.996
	±0.517	±0.001	2	±0.028	±0.004	±0.048	±0.001

F_{ratio} is the value that compares the joint effect of variables (-), $F_{critical}$ is the critical value that compares a pair of models (-), P_{value} is the significance level within a statistical hypothesis test (-), R^2 is the coefficient of determination of fitted data (-).

The coefficients of determination (R^2) of the tangent model were between 0.992 and 0.999 indicating the accuracy of the mathematical model for describing the empirical data of bulk oilseeds under compression loading (Fig. 3).

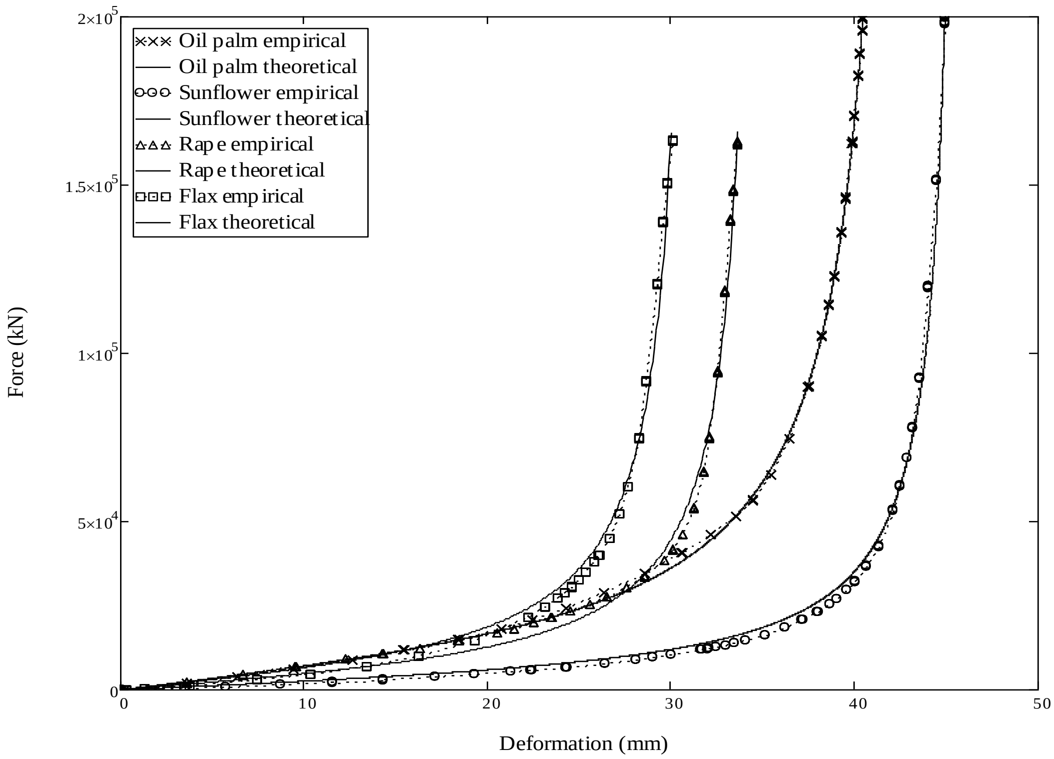

Fig. 3 Empirical and theoretical descriptions of force and deformation of some bulk oilseeds

The present results were in agreement with other published studies focused on the mechanical behaviour of bulk oilseeds or kernels under compression loading (*Herak et al., 2011; Sigalingging et al., 2014, 2015*). However, research is still needed for developing a general model which takes into account the effects of speed, moisture content, heat treatment temperature and friction which thus influence the pressing process. This knowledge can be transferred to the non-linear pressing involving a mechanical screw press or expeller for optimizing the energy requirement and oil recovery efficiency.

CONCLUSION

A good fit was obtained between the experimental data of the different oil-bearing seeds/kernels and predicted data based on the tangent curve model. The coefficients of determination (R^2) of the tangent model were between 0.992 and 0.999. However, the incorporation of other pressing factors in the tangent curve model is required to describe the mechanical behaviour of bulk oilseeds under compression loading.

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