Numerical estimation of deformation energy of selected bulk oilseeds in compression loading

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Abstract. This paper aimed at the determination of the deformation energy of some bulk oilseeds or kernels namely oil palm, sunflower, rape and flax in linear pressing applying the trapezoidal rule which is characterized by the area under the force and deformation curve. The bulk samples were measured at the initial pressing height of 60 mm with the vessel diameter of 60 mm where they were compressed under the universal compression machine at a maximum force of 200 kN and speed of 5 mm/min. Based on the compression test, the optimal deformation energy for recovering the oil was observed at a force of 163 kN where there was no seed/kernel cake ejection in comparison to the initial maximum force used particularly for rape and flax bulk oilseeds. This information is needed for analyzing the energy efficiency of the non-linear compression process involving a mechanical screw press or expeller.

1. Introduction

For agricultural activities such as land preparation, planting, weeding, irrigation, harvesting and among others energy is mainly utilized [1]. Similarly, energy is used for oil separation from vegetable oilseeds or kernels such as oil palm, sunflower, rape, flax and others by either mechanical expression or solvent method [2].

To improve the oil recovery efficiency especially the mechanical screw presses or expellers, it is important to understand the energy utilization of the bulk oilseeds under compression loading where the dependency between the force and deformation curve of the bulk material is described using the universal compression testing machine and pressing vessel with a plunger [3]. The area under the force and deformation curve is denoted as deformation energy which can be numerically determined using the trapezoidal rule [4, 5].

The knowledge of the linear compression loading is required for developing appropriate mathematical models that can be transferred to the non-linear environment involving mechanical screw presses or expellers [5].

The objective of the present study was to evaluate numerically the deformation energy of some bulk oilseeds/kernels under compression loading. The percentage oil of the bulk samples was also calculated.

2. Materials and Method

The bulk oilseeds or kernels of Oil palm (*Elaeis guineensis* Jacq.), Sunflower (*Helianthus annuus* L.), Rape (*Brassica napus* L.) and Flax (*Linum usitatissimum* L.) were used for the compression test.
The moisture content of the bulk samples in the above order was determined to be (8.57, 4.79, 4.62 and 7.32 %) on a wet basis were determined using the standard oven method with a temperature setting of 105 °C and drying time of 17 h [6]. The initial and final weights of the bulk samples before and after oven drying were determined using an electronic balance (Kern 440–35, Kern & Sohn GmbH, Balingen, Germany). The data was evaluated according to [7].

\[
MC_{w.b.} = \left( \frac{m_u - m_b}{m_u} \right) \times 100
\]

where \( MC_{w.b.} \) is the moisture content on a wet basis (%), \( m_u \) 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).

2.1 Compression loading test
The bulk samples were compressed under the universal compression testing machine (ZDM 50, Czech Republic) and pressing vessel of diameter 60 mm at a maximum force of 200 kN and speed of 5 mm/min to establish the dependency between the force and deformation curve. Each bulk sample initial pressing height was measured at 60 mm and repeated three times.

2.2 Deformation energy
The deformation energy was calculated according to [8 -10].

\[
E = \int_0^x F(x)dx \approx \sum_{n=0}^{n_{\text{max}}}(F_{n+1} + F_n)\left(x_{n+1} - x_n\right)
\]

Where \( E \) is the deformation energy (J), \( F(x) \) represents polynomial and exponential functions in relation to the force and deformations (N.mm), \( F_{n+1} + F_n \) 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,……..\( i_{\text{max}} \) observations.

2.3 Percentage oil yield
The percentage oil yield was determined according to[2].

\[
OY = \frac{O_w}{O_m} \times 100
\]

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)

3. Results and Discussion
The relationship between the force and deformation curves of the different bulk oilseeds/kernels is described in Figure 1. At a maximum force of 200 kN and speed of 5 mm/min was the display of the serration pattern among the bulk oilseeds of rape and flax compared to that of bulk oil palm kernels and sunflower bulk oilseeds which showed a smooth curve. The serration effect thus influences the energy efficiency of the oil output [11].

The optimal energy without the serration behaviour was determined at a maximum force of 163 kN as shown in Figure 1. For the deformation energy calculation, the trapezoidal rule which is characterized by the area under the force and deformation curve was also fitted by the polynomial and exponential functions as described in Figure 2, where the integral of the function represents the deformation energy as indicated by equation 2. The estimated amounts
of deformation energy of the various bulk oilseeds/kernels are presented in Table 1 and Figure 3 respectively. The bulk kernels of oil palm showed higher deformation energy followed by sunflower, rape and flax bulk oilseeds. The percentage oil yield of each bulk sample in that order was 27.32±0.79%, 21.08±0.59%, 23.04±0.15% and 14.19±0.61% respectively.

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

\[
F(x) = -5730.6927 + 6688.6552x - 1316.3732x^2 + 113.5437x^3 - 4.0572x^4 + 0.0518x^5
\]

\[
F(x) = 2349.6963 \exp(0.1108x)
\]

Figure 2. Experimental data of bulk oil palm kernels fitted by exponential and polynomial functions at force 200 kN
Table 1. Deformation energy of selected bulk oilseeds/kernels (Mean±Standard Deviation)

| Bulk oilseeds/kernels | Force (kN) | Maximum deformation (mm) | Deformation energy (J) |
|------------------------|------------|--------------------------|------------------------|
|                        |            | Trapezoidal rule          | Polynomial function    | Exponential function |
| Oil palm               |            |                          |                        |                      |
| 39.53±2.21             | 1245.55±20.41 | 1583.67±160.21            | 1284.67±32.35          |
| Sunflower              | 45.36±0.37  | 675.94±5.55              | 627.30±11.19           | 616.37±8.27          |
| Rape                   | 35.64±0.59  | 1202.58±44.95            | 1154.33±17.21          | 1083±43.92           |
| Flax                   | 37.96±0.60  | 2137.56±218.51           | 2128.33±244.27         | 2338±309.82          |
| Oil palm               | 38.91±0.20  | 1133.72±15.44            | 1372.33±121.74         | 1185.33±27.06        |
| Sunflower              | 44.97±0.37  | 604.77±8.57              | 601.59±46.09           | 575.10±11            |
| Rape                   | 33.03±0.56  | 718.27±29.41             | 721.53±24.93           | 699.27±17.19         |
| Flax                   | 29.68±0.52  | 600.96±4.62              | 601.08±7.85            | 612.11±9.24          |

*a* No serration effect.

*b* Serration effect on the force-deformation curve.

*c* Optimal force for rape and flax bulk oilseeds.

Figure 3. Box plot of numerical deformation energy (J) of bulk oilseeds/kernels at optimal force of 163 kN

4. Conclusion

Rape and flax bulk oilseeds experienced a serration effect on the force and deformation curves at an initial force of 200 kN compared to oil palm bulk kernels and sunflower bulk oilseeds which indicated smooth curve behaviour.

The optimal force of 163 kN without the serration effect was observed for rape and flax bulk oilseeds. The deformation energy for recovering the oil of oil palm bulk kernels,
sunflower, rape and flax bulk oilseeds was 1245.55±20.41 (J), 675.94±5.55 (J), 1202.58±44.95 (J) and 2137.56±218.51 (J) respectively. In future study, the present results will be analyzed theoretically using the tangent curve mathematical model applicable in MathCAD 14 software. The study among other studies is a step forward towards optimizing the vegetable oil processing technology.

References
[1] Jakayinfa S O and Bamgboye A I 2007 Development of equations for estimating energy requirements in palm-kernel oil processing operations J. of Food Eng.79(1):322–329
[2] Deli S, Farah Masturah M, Tajul Aris Y and Wan Nadiah W A 2011 The effects of physical parameters of the screw press oil expeller on oil yield from nigella sativa I. seeds Int. Food Res.18:1367–1373
[3] Munson-Mcgee S H 2014 D-optimal experimental designs for uniaxial expression J. of Food Pro. Eng. 37:248–256
[4] Grzegorz L 2007 Fracture toughness of pea: Weibull analysis J. of Food Eng.83:436 – 443
[5] Herak D, Kabutey A, Divisova M and Simanjuntak S 2013 Mathematical model of mechanical behaviour of Jatropha curcas L. seeds under compression loading Bio. Eng.114(3):279–288
[6] ISI 1996 Indian standard methods for analysis of oilseeds IS:3579 New Delhi Indian Stand. Ins.
[7] Blahovec J 2008 Agromaterials Study Guide. Czech University of Life Sciences Prague Prague
[8] Divisova M, Herak D, Kabutey A, Sleger V, Sigalingging R and Svatonova T 2014 Deformation curve characteristics of rapeseeds and sunflower seeds under compression loading. Sci. Agric. Bohemica45(3):180–186
[9] Herak D, Kabutey A, Sedlacek A and Gurdil G 2012 Mechanical behaviour of several layers of selected plant seeds under compression loadingRes. in Agric. Eng.58(1):24-29
[10] Kabutey A, Herak D, Dajbych O,Boatri W E and Sigalingging R 2014 Deformation energy of Jatropha curcas L. seeds under compression loadingRes. in Agric. Eng.60(2): 68-74
[11] Kabutey A, Herak D and Sedlacek A 2011 Behaviour of different moisture contents of Jatropha curcas L. seeds under compression loading Res. in Agric. Eng.57(2):72–77