Repetitive loading of unroasted bulk palm kernels using UCTM for analysing optimum percentage kernel oil recovery and energy demand

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Abstract. Repetitive loading test of bulk palm kernels (unroasted) was conducted to determine the percentage kernel oil yield and energy demand using the universal compression testing machine (UCTM) of the maximum load of 200 kN and speed of 5 mm min⁻¹.Pressing vessels of varying diameters (60, 80 and 100 mm) with a plunger were used together with the UCTM. The bulk palm kernels initial height of 60 mm was repeatedly compressed until permanent deformation was reached. The total amounts of mass of kernel oil leakage, deformation, percentage kernel oil and energy were measured/calculated. The main part of the study will be done using the mechanical screw press Farmer 20 – duo (Farmer 20, Farmet a.s., Ceska Skalice, Czech Republic) to determine the optimum processing conditions for achieving maximum kernel yield and specific energy requirement.

1. Introduction

In the industry, the palm kernel oil is extracted from palm kernels of oil palm fruits either by solvent extraction or mechanical pressing and/or their combination [1,2,3]. However, solvent extraction is widely used in large-scale production [4]. From our previously published studies which focused on the mechanical behaviour of bulk palm kernels at different pressing conditions under compression loading, it was concluded that repetitive or continuous pressing of the bulk palm kernels would be necessary in order to achieve maximum kernel oil recovery [5,6,7,8]. Here, it is important also to analyse or take into consideration the specific energy requirement. In compression loading test, the bulk materials contained in a vessel with holes beneath allowing oil leakage are pressed using a universal compression testing machine (UCTM) where the actual load and speed of interest are specified [9,10]. The values of force and deformation from the output data are further processed to determine the energy demand which is characterized by the area under the force and deformation curve [11,12]. The aim of this present study was to determine the maximum kernel yield and the corresponding energy usage from bulk palm kernels through repetitive loading using UCTM.
2. Materials and methods
Bulk oil palm kernels were obtained from Afosu/Abirim in the Birim North District in the Eastern Region, Ghana. The moisture content of the bulk oil palm kernels was determined to be 11% w.b. using the standard procedure [13]. Pressing vessels of diameter 60, 80 and 100 mm with a plunger together with the UCTM (ZDM 50, Czech Republic) was used [14]. The initial pressing height of the bulk oil palm kernels was measured at 60 mm for all vessels, and each was subjected to a continuous compression at a maximum force of 200 kN and speed of 5 mm min\(^{-1}\) until permanent deformation of the bulk kernels was reached. In each loading test, the mass of the kernel leakage and the corresponding energy were measured/calculated.

2.1 Calculation of energy demand and kernel oil yield
The energy demand [12,14] of the bulk kernels at each repeated loading (Figure 1) was also calculated using equation 1.

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

(1)

Where \(E\) 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 the number of subdivisions of the deformation axis. The kernel oil yield [15] was determined as the ratio of the mass of kernel oil (the difference between the mass of initial height of kernels and mass of kernel cake) to that of the mass of initial pressing height multiplied by 100 as given by Equation 2.

\[
O_y = \frac{O_w}{O_m} \cdot 100
\]

(2)

Where \(O_y\) is the kernel oil yield (%), \(O_w\) is the mass of kernel oil (g) and \(O_m\) is the mass of initial pressing height of bulk kernels (g).

3. Results and discussion
Tables 1 to 3 indicate the amounts of mass of kernel oil (g), deformation (mm), kernel oil yield (%) and energy (kJ). The relationship between the compressive force and deformation curves of the bulk oil palm kernels for all repeated loadings for vessel diameter 60 mm is shown in Figure 1. This was similar to the vessel diameters 80 and 100 mm respectively. The graphical representation of the responses: kernel oil yield and energy in relation to the repeated loadings are displayed in Figures 2 and 3 respectively.

Based on the results described (Tables 1 to 3) and (Figures 1 and 2); the amounts of kernel oil mass (g), deformation (mm), kernel oil yield (%) and energy demand (kJ) decreased in relation to the repeated loadings for all the vessel diameters (60, 80 and 100 mm). However, the decreasing and increasing amounts of the kernel oil mass and/or kernel oil yield at the sixth and seventh pressings could be due to the position/orientation of the individual kernels inside the pressing vessels during the compression process and/or non-homogeneity of the bulk kernels. Generally, a polynomial function of the second-order suitably described the various dependencies with high coefficients of determination (\(R^2\)) between 93% and 97% compared to a linear or exponential trends. After the seventh repeated test, the bulk oil palm kernels achieved permanent deformation hence there was no further compression. It was also observed that the bulk kernels in the smallest vessel of diameter 60 mm showed plastic deformation in comparison with the bigger vessels of the diameter 80 and 100 mm, thus higher kernel oil yield [8]. This can be explained based on the assumption that with a smaller vessel diameter the seeds are closed to each other hence few free spaces, unlike the bigger vessels which have more free spaces [14,15].
### Table 1. Measured amounts of bulk oil palm kernels using vessel diameter 60 mm

| Repeated loading | Pressing height (mm) | Bulk palm kernels mass (g) | Kernel oil mass (g) | Deformation (mm) | Kernel oil yield (%) | Energy demand (kJ) |
|------------------|----------------------|---------------------------|-------------------|-----------------|---------------------|-------------------|
|                  |                      | Before loading            | After loading  |                 |                     |                   |
| 1                | *60                  | 108.3                     | 79.3            | 29              | 36.95               | 26.78             | 1.18              |
| 2                | 55                   | 79.3                      | 68.4            | 10.9            | 32.79               | 13.75             | 0.81              |
| 3                | 50                   | 68.4                      | 63.3            | 5.1             | 27.36               | 7.46              | 0.69              |
| 4                | 45                   | 63.3                      | 59.7            | 3.6             | 25.07               | 5.69              | 0.61              |
| 5                | 40                   | 59.7                      | 58.4            | 1.3             | 22.77               | 2.18              | 0.53              |
| 6                | 38                   | 58.4                      | 57.6            | 0.8             | 20.10               | 1.37              | 0.54              |
| 7                | 36                   | 57.6                      | 56.6            | 1               | 19.85               | 1.74              | 0.49              |
| Total            |                      |                           |                  | 51.7            | 184.89              | 58.95             | 4.85              |

* Initial height of bulk kernels

### Table 2. Measured amounts of bulk oil palm kernels using vessel diameter 80 mm

| Repeated loadings | Pressing height (mm) | Bulk palm kernels mass (g) | Kernel oil mass (g) | Deformation (mm) | Kernel oil yield (%) | Energy demand (kJ) |
|-------------------|----------------------|---------------------------|-------------------|-----------------|---------------------|-------------------|
|                   |                      | Before loading            | After loading  |                 |                     |                   |
| 1                 | *60                  | 195.3                     | 155.3            | 40              | 36.02               | 20.48             | 1.57              |
| 2                 | 55                   | 155.3                     | 134.5            | 20.8            | 31.79               | 13.39             | 1.17              |
| 3                 | 50                   | 134.5                     | 125.5            | 9               | 28.66               | 6.69              | 0.94              |
| 4                 | 45                   | 125.5                     | 118.6            | 6.9             | 25.94               | 5.50              | 0.78              |
| 5                 | 40                   | 118.6                     | 113.9            | 4.7             | 23.53               | 3.96              | 0.75              |
| 6                 | 38                   | 113.9                     | 112.1            | 1.8             | 24.15               | 1.58              | 0.71              |
| 7                 | 36                   | 112.1                     | 110.4            | 1.7             | 21.91               | 1.52              | 0.64              |
| Total             |                      |                           |                  | 84.9            | 192                 | 53.12             | 6.56              |

* Initial height of bulk kernels

### Table 3. Measured amounts of bulk oil palm kernels using vessel diameter 100 mm

| Repeated loading | Pressing height (mm) | Bulk palm kernels mass (g) | Kernel oil mass (g) | Deformation (mm) | Kernel oil yield (%) | Energy demand (kJ) |
|------------------|----------------------|---------------------------|-------------------|-----------------|---------------------|-------------------|
|                  |                      | Before loading            | Before loading  |                 |                     |                   |
| 1                | *60                  | 305                       | 248.8            | 56.2            | 32.75               | 18.43             | 1.85              |
| 2                | 55                   | 248.8                     | 226.6            | 22.2            | 29.28               | 8.92              | 1.31              |
| 3                | 50                   | 226.6                     | 212.5            | 14.1            | 25.52               | 6.22              | 1.11              |
| 4                | 45                   | 212.5                     | 202.5            | 10              | 26.60               | 4.71              | 0.99              |
| 5                | 40                   | 202.5                     | 194.4            | 8.1             | 24.70               | 4.00              | 0.91              |
| 6                | 38                   | 194.4                     | 192.9            | 1.5             | 26.54               | 0.77              | 0.89              |
| 7                | 36                   | 192.9                     | 189.9            | 3               | 24.40               | 1.56              | 0.81              |
| Total            |                      |                           |                  | 115.1           | 189.79              | 44.60             | 7.87              |

* Initial height of bulk kernels
Figure 1. Kernel oil yield versus repeated loadings in relation to vessel diameters (60, 80 and 100 mm)

Figure 2. Energy demand versus repeated loadings in relation to vessel diameters (60, 80 and 100 mm)

In addition, the smaller space might have provided the maximum impact of the force towards the bulk kernels compared to the bigger space which might have experienced less pressure near the bulk kernels. Higher kernel oil yield was obtained from the continuous pressing (where permanent deformation of the unroasted bulk palm kernels was reached) compared to single or fewer repeated pressings (not reaching permanent deformation) [5,6]. The total amount of kernel oil yield (%) obtained from the repeated loadings for each vessel diameter (60, 80 and 100 mm) at a maximum force of 200 kN and speed of 5 mm min⁻¹ was 58.95, 53.12 and 44.60 respectively. The corresponding energy (kJ) also was 4.85, 6.56 and 7.87. It is important to mention that from the previously published study of unroasted bulk palm kernels at a maximum force of 200 kN and speed of 10 mm min⁻¹ using vessel diameter 60 mm, the total kernel oil yield for the three repeated loadings was 40.55%. The corresponding cumulative energy demand also was 2.48 kJ [7]. Comparing with the present study
results, it was found that at similar loading conditions (force and vessel diameter but at a lower speed of 5 mm min$^{-1}$), the total oil yield and energy were 47.99 % and 2.68 kJ respectively. This suggests that lower speed and more repeated loadings increase oil yield but also increase the energy demand [8,16].

4. Conclusions
For determining the maximum kernel oil yield and total energy of the bulk palm kernels at an initial height of 60 mm, seven repeated loadings were required for each of the pressing vessels used at a maximum force of 200 kN and speed of 5 mm min$^{-1}$. After the seventh test, the kernels were permanently deformed or showed plastic behaviour. The total amount of kernel oil yield (%) obtained from the seven repeated loadings for each vessel diameter (60, 80 and 100 mm) was 58.95, 53.12 and 44.60 and the corresponding energy (kJ) of 4.85, 6.56 and 7.87 respectively. In terms of the output kernel oil yield using the UCTM at a specific force and speed; continuous pressing of the bulk palm kernels until permanent deformation is reached is better than single or fewer repeated pressings. The present and previously published results provide the background information for further studies involving the use of a mechanical screw press Farmer 20 – duo (Farmer 20, Farmet a.s., Ceska Skalice, Czech Republic).

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