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# PROCESS PARAMETERS AND THE COURSE OF DENSIFICATION OF BULK OIL-BEARING MATERIALS

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## *ABSTRACT*

*Bulk, porous oil-bearing materials acquire various degrees of densification under varying influences of equipment and process parameters with direct bearings on yield during compressive abstraction of oil from such materials. Effects of both aspect ratio and compression cycle on the course of densification were investigated. Mechanical response and oil expression indices were analysed for variances and treatment means were compared using Duncan's multiple range test. All influence factors had significant effects on mechanical response and oil yield. Significant improvements in achievable deformation and specific energy demand were obtained through repeated induction of compressive stress; compression cycle correlated positively with both deformation and energy demand. Margin for the expenditure of energy became wider as pressure ratio at the oil point became lower. This study reveals that performance of compression schemes may be significantly enhanced through careful application of the pressure ratio.*

**Keywords:** *oil yield, densification, pressure ratio, compression*

## INTRODUCTION

The course of abstraction of fluid essence from biological materials using compressive means is indicated in the densification of the processed material. Properties of biological materials and their responses during densification vary depending on different crop keeping, machine and process conditions (Kaliyan and Morey, 2009; Tumuluru, 2014). Understanding these conditions is important in optimizing both mechanical and performance responses

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(Willems *et al.*, 2008a). Forms fitted to these parameters are relevant to the selection and specification of important machine design variables (O'Dogherty and Wheeler, 1984; Savoire *et al.*, 2013). Previous studies (Divišová *et al.*, 2014) tended to focus more on influences of single stand-alone quanta with little consideration for the effects of their interactions with other related influence variables on the processes described. Even in such situations, selection of the variables of interest are limited given logistical constraints of the designs of experiments (Quinn and Keough, 2002). When verified together, the interdependence of these variables indicate influences of a complex nature and of magnitude significant enough to affect design decisions.

Some of the single variables considered in previous studies include depth of products in the compression vessel, size of the compression vessel, product moisture condition before and after processing, thermal conditioning of the products before compression, processing temperature and fractionation of the material to be compressed (Ajibola *et al.*, 1993; Divišová *et al.*, 2014; Faborode and Favier, 1996; Kabutey *et al.*, 2013, 2016; Willems *et al.*, 2008b). The density of the compressed product related to its initial density as compression ratio (Faborode and O'Callaghan, 1986) together with the bulk modulus affects applicable pressure. The ratio of the depth of product in the compression chamber to the vessel's characteristic (in this case, diametric) size constitutes the aspect ratio and may be shown to influence the material's responses under load (Imole *et al.*, 2014; Wiacek *et al.*, 2012). This factor is seldom treated in literature. Thermal treatment is the most adopted technique for optimising recovery of abstracted fluids (Kabutey *et al.*, 2017; Santoso and Inggrid, 2014). However, this approach has been shown to have negative effects on nutrient levels and modifies mechanical properties (Li *et al.*, 2016). A possible route for optimising yield in cold expression is repetitive strain (Akangbe and Herák, 2018). Pressure zone exists within which essence yield commences. For any oleaginous raw biomaterial, the pressure at which the show or flow of oil is occasioned relates to the applied pressure as a pressure ratio and may indicate the applicable pressure for optimal abstraction given the prevailing pressing conditions (Akangbe and Herák, 2017). Although the influence of applied load on the course of densification of oleaginous biomaterials has been investigated for select products, different load magnitudes, vessel configurations and product depths are adopted by authors in manners that make comparison of reported results difficult. Applied pressure provides means for comparative evaluation of observable response trends during densification.

In this study, select machine and process parameters which influence the course of densification of an oleaginous biomaterial were investigated with a view to understanding their effects on the abstraction of oil from materials of this nature.

## MATERIALS AND METHODS

The Bulk seeds of whole and cleaned sesame seeds (*Sesamum indicum* L.) obtained from the Czech Republic were used for this study. At the time of use, the produce had moisture content of approximately 6%, in dry basis.

Two separate tests were conducted to study the effects of the selected influence variables on the mechanical behaviour of the oleaginous material under compression. The first test was run using three different aspect ratios and time rates of deformation. These constituted 9 treatments and were run in three repetitions. The tests were conducted at 26.53 MPa. Subsequently, a second test was performed to study the effect of repetitive induction of stress on the course of densification of the biomaterial. The treatments were six compression cycles implemented in three repetitions leading to 18 experimental runs. This test was also conducted at 26.53 MPa. Each of the two tests corresponds to a completely randomised design, the first incorporating a full factorial concept.

The test apparatus used is that described by (Akangbe and Herák, 2017). The pressing vessel had an internal bore diameter of 60 mm and was fitted with a base plate, 20 mm thick. The plunger was a 60 mm solid steel shaft. Fluid was evacuated from the compression chamber through ten lateral orifices provided approximately 20 mm from the base of the assembly, each 3 mm in diameter, equispaced along the circumference of the pressing vessel. For the first test, a sample of sesame seeds was fed to a depth in the pressing chamber corresponding to the aspect ratio of interest. The produce was then compressed at a predetermined pressing rate. Compression was initiated gradually from zero (0) to full load corresponding to an applied pressure of 26.53 MPa. The three aspect ratios were 0.5, 1.0 and 1.5 while the pressing rates were initiated at 1, 5.5 and 10 mm/min. For the second test seed samples were fed to a depth of 60mm, initially. The course of densification was initiated as described above and ancillary data acquired. Void capacity was reintroduced in the compressed material and compression was carried out again at the new product depth for acquisition of the necessary data. Six compression cycles were carried out in this way and the data acquired. A 50 tonne capacity universal test rig (the ZDM50) made by TEMPOS, spol. s.r.o., Czech Republic was used. The equipment was run on the TIRAtest software written by TIRA GmbH, Germany. Produce moisture contents were determined using oven drying technique as recommended in the ASAE standards S352.2 for moisture determination in unground grains and seeds. A Gallenkamp type hot air oven made by Memmert GmbH, Germany was used for this purpose. Moisture tests were conducted at 103±2°C. The Kern 440–35N top loading type balance manufactured by Kern & Sohn GmbH, Stuttgart, Germany was used for the acquisition of all weight related data. The oil point pressure is the minimum pressure required to occasion the show and flow of oil. Pressure applied at the oil point was measured using an auxiliary device with digital output provided with the ZDM50 and mounted adjacent to the pressing vessel.

Procedure for the determination of the physical parameters described are standard methods described in literature (Mohsenin, 1986). Mechanical parameters were determined as described in existing studies (Herák *et al.*, 2012). Linear deformation refers to the depth of compression attained in the deformed material. The deformed volume may also be similarly obtained. The highest value of deformation attained during a compression is the peak deformation. The strain, $\epsilon$ (–) induced in the process may be computed as the ratio of the peak deformation, $\delta_c$ (mm) to the initial produce depth, $\delta_o$ (mm).

The amount of energy, $E$ (J) required to deform a given quantity of compressed sample may be computed using Eq. 1:

$$E = \sum_{n=0}^{n=i-1} \left[ \left( \frac{F_{n+1} + F_n}{2} \right) \times \left( \delta_{n+1} - \delta_n \right) \right] \tag{1}$$

where, $i$ is the number of subdivisions of the deformation axis, as logged by the test equipment; $F_n$ (N) is the compressive force for a known deformation, $\delta_n$ (mm). Energy demand relative to the volume of material compressed may be evaluated as a function of the initial volume of the compressed oilseed material (Akangbe and Herák, 2017).

The deformation modulus, $M_n$ (MPa) of the compressed oilseed was determined as the slope of the stress and strain or deformation curve at the specified force. This is numerically given by Eq. 2:

$$M_n = \left[ \frac{4 \times \delta_o}{\pi \times D^2} \left( \frac{F_{n+1} - F_n}{\delta_{n+1} - \delta_n} \right) \right]_{n=0}^{n=i-1} \tag{2}$$

The amount of oil, $OY$ (kg/t) recovered from a mass of oil bearing material during compression may be obtained using (Eq. 3):

$$OY = \frac{m_o}{m_{ss}} \times 1000 \tag{3}$$

where, $m_O$ (g) is the mass of oil expressed and $m_{ss}$ is the mass of seed sample compressed. As percentage yield (Ajibola *et al.*, 1993), this may be expressed as (Eq. 4):

$$POY = \frac{m_o}{m_{ss}} \times 100 \tag{4}$$

The performance of the scheme may be obtained in terms of the oil expression efficiency. In order to determine this, it is necessary to determine the actual content of oil in each batch of material used. This was done soxhlet extraction technique, in accordance with the ISO 659: 2009 reference method for oilseeds. Seeds of sesame were milled sufficiently to pass through a size 10 sieve and the samples were defatted in a soxhlet unit using petroleum ether. The solvent was recovered using standard techniques as recommended in the guideline. The test was repeated three times. Oil content, $OC$ (%) was computed using Eq. 5 (International Organization for Standardization, 2009):

$$OC = \frac{m_{OC}}{m_S} \times 100 \tag{5}$$

where, $m_{OC}$ (g) is the mass of oil extracted and $m_S$ (g) is the mass of the defatted sample.

Mechanical oil expression efficiency, $\eta_{OE}$ (%) was computed using Eq. 6. This is the ratio of oil expressed from the seeds to the total quantity of oil contained in them (Ajibola *et al.*, 1993):

$$\eta_{OE} = \frac{POY}{OC} \times 100 \tag{6}$$

For the second test, cumulative effects were computed as sums of the respective values of each parameter obtained to the $i^{th}$ level of repeated induction of compressive stress (or the $i^{th}$ cycle). Cumulative indices were computed using (Eq. 7)

$$Y_{Cj} = \sum_{i=1}^{j} Y_i \tag{7}$$

where, Y is the response variable, $Y_{Cj}$ is the cumulative measure and $j$ is the compression cycle; $j = 1,2,3,\ldots,6$. With each successive cycle, an improvement is obtained in peak deformation. The cumulative magnitude of this deformation ($\delta_{cum}$) may be computed using Eq. 8:

$$\delta_{cum} = H_O - H_P + \delta_i \tag{8}$$

where $\delta_{cum}$ is cumulative deformation, obtained as a function of the original produce depth, $H_O$ the reconstituted product depth, $H_P$ and $i^{th}$ deformation, $\delta_i$. $i = 1,2,3,\ldots,n$ for any $n$ number of compressive strain induction cycles.

Data obtained in the course of this study were subjected to the analysis of variance using the completely randomised design procedure in Genstat. Treatment means were compared using Duncan’s multiple range test. Graphical plots were generated in MS Excel.

## RESULTS AND DISCUSSIONS

When the effects of aspect ratios and the time rate of deformation on the course of densification of the oleaginous material were considered, both factors were observed to have highly significant effects ($p<0.001$) on mechanical response. Although similar amounts of strain were induced at all levels of aspect ratio, strains induced at different rates of deformation differed significantly ($p<0.001$). Significant gains in deformation were recorded as the aspect ratio was increased and the deformation rate was lowered (Fig. 1). Linear deformations of between 15.02 and 54.15mm were achieved, the highest amounts obtaining with the largest aspect ratio and the lowest deformation rate. Since larger aspect ratios will imply bigger initial void capacity in the compressed material, this contributes to the amounts of deformation recorded at these levels of the parameter. The results also agree with findings in related works (Divišová *et al.*, 2014).

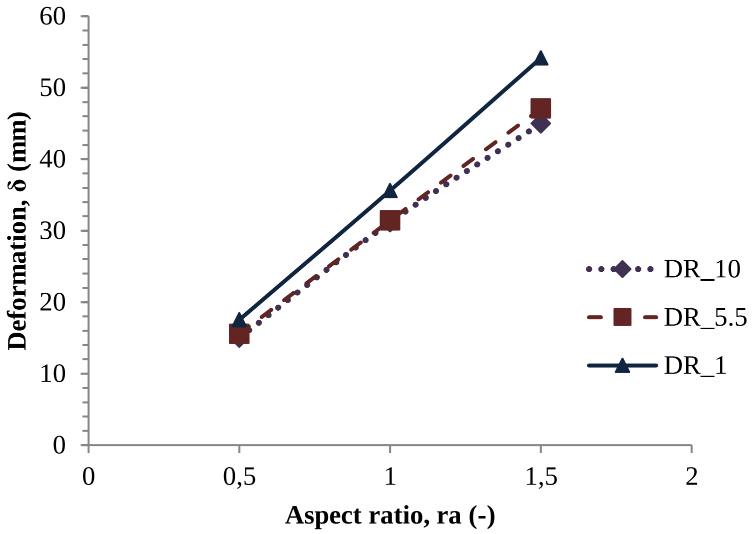

**Figure 1.** Material deformation at different deformation rates (DR) and aspect ratios.

Energy required for the deformation of unit volumes of the compressed material became less as aspect ratio increased (Fig. 2). This means that energy expenditure is more efficient with the larger aspect ratios than with the smaller ones. More energy per volume of compressed material was expended at slower deformation rates than at the quicker rates.

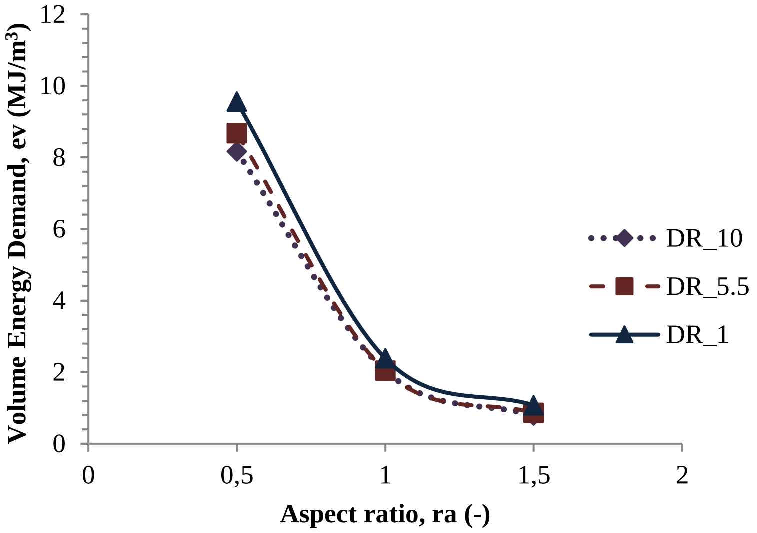

**Figure 2.** Volume specific energy demand for different aspect ratios and deformation rates (DR).

In essence, slowing down the rate of deformation implies sustaining induced strains for much longer durations, hence the higher net expenditure of energy. Deformation rate is also the most important factor influencing the amount of strain induced the material (Fig. 3).

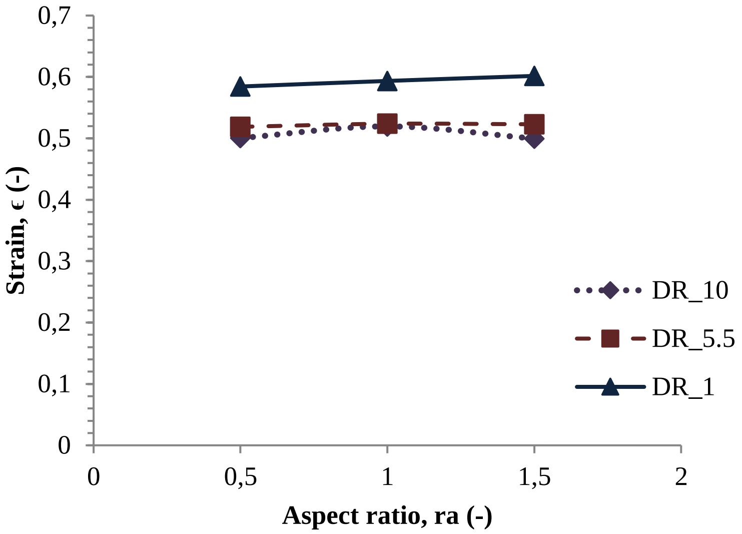

**Figure 3.** Induced strain at different deformation rates (DR) and aspect ratios.

An indication of the materials offer of resistance to further deformation is provided by the deformation modulus. Deformation modulus increased from 330.3 – 410.0 MPa as aspect ratio increased from 0.5 – 1.5. Higher deformation moduli were observed at higher deformation rates. Over the range of treatments investigated, deformation modulus ranged between 322.6 – 458.6 MPa.

Higher oil point pressures were associated with lower aspect ratios and higher deformation rates (Fig. 4). Oil point pressures for this material ranged between 3.06 to 4.96 MPa. Over the range of treatments investigated, oil yields of between 134.4 and 289.8 kg/t of compressed material were recorded. Only deformation rate had significant effect on oil recovery. The most important determinant of recoverable oil was the time rate of deformation; for any aspect ratio, higher yield of oil is indicated at the lower deformation rates (Fig. 5).

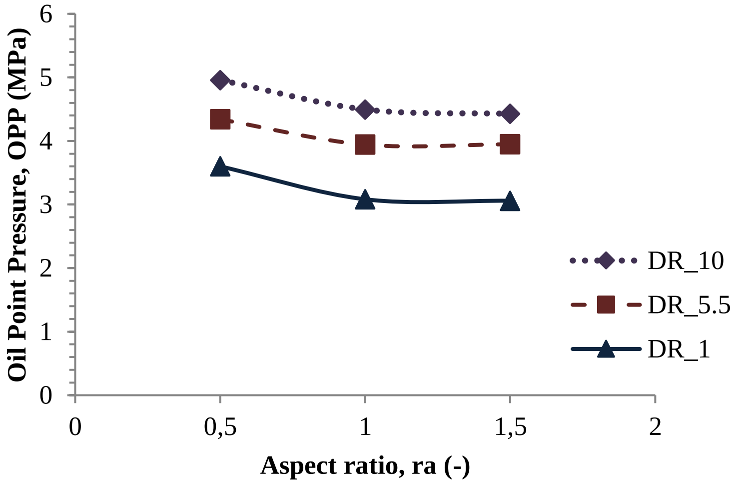

**Figure 4.** Effects of different deformation rates and aspect ratios on the onset of the show and flow of oil.

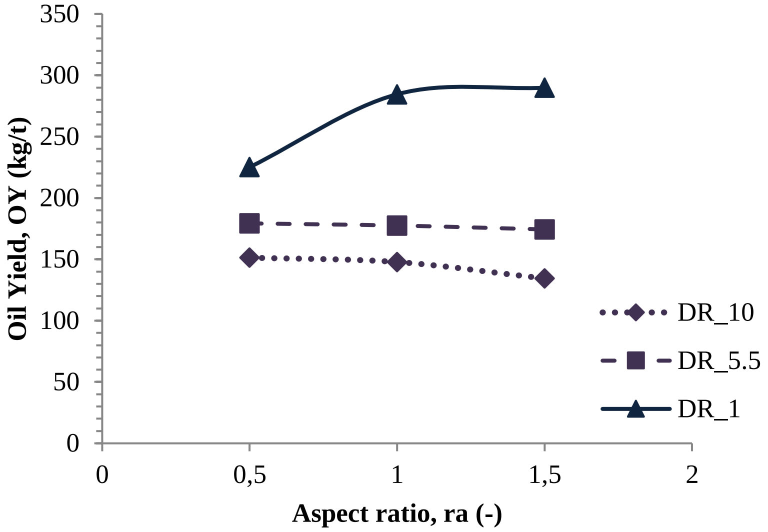

**Figure 5.** Effect of aspect ratios and deformation rates (DR) on the yield of oil.

Results of repeated induction of compressive stress in the oleaginous material are presented in Figures 6 – 9. The number of compression cycle implemented had highly significant effect ($p<0.001$) on mechanical response parameters. Each additional cycle resulted in more deformation of the compressed material than was achieved in the previous cycle (Fig. 6). Cumulatively, deformation improved from 32.7 – 41.2 mm between the 1st and 6th compression cycles.

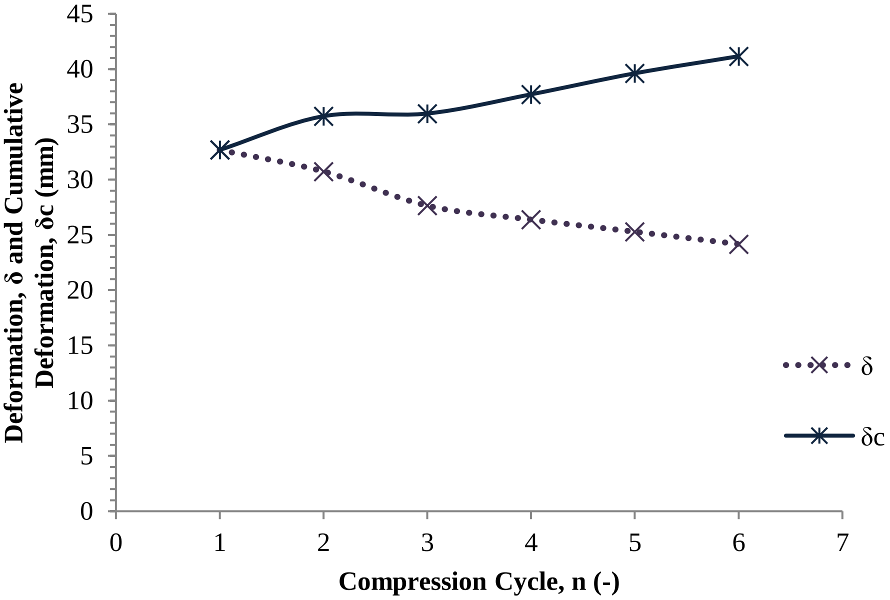

**Figure 6.** Achievable deformation given repeated induction of compressive stress.

Energy requirement for the densification of a unit volume of the oil bearing material increased as the number of compression cycles applied to the material increased (Fig. 7). This implies that more energy is required cumulatively for the net gains in deformation that were achieved. Volume specific energy demand rose cumulatively from 1.9 MJ/m$^3$ to 11.9 MJ/m$^3$ between the 1st and 6th compression cycles. This demand increase correlates positively with desirable mechanical response in the biomaterial and the performance of the scheme, as was evident in the yield of oil.

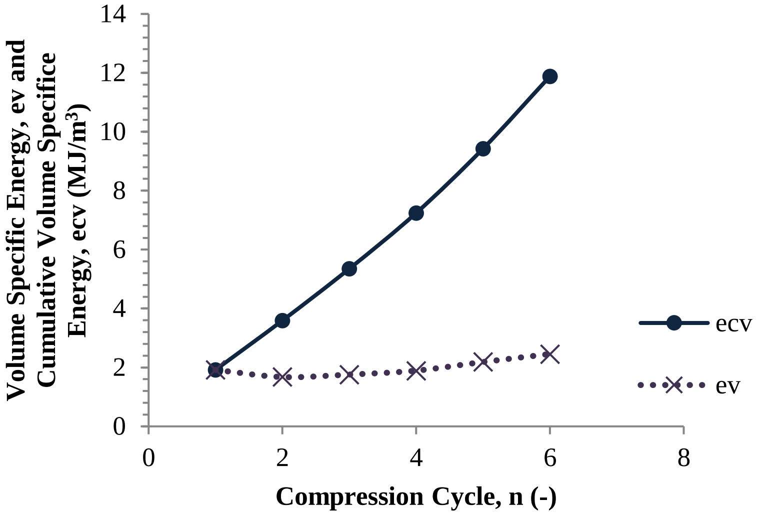

**Figure 7.** Volume specific energy demand for repeated induction of stress in the compressed material.

Cumulative oil yield rose from 173 – 363 kg of oil per tonne of compressed oilseed material, between the 1st and 6th compression cycles. This was also true of pressing performance; oil expression efficiency improved from 38.8%, for single cycle compression schemes to 81.4% for a scheme involving 6 compression cycles (Fig. 8).

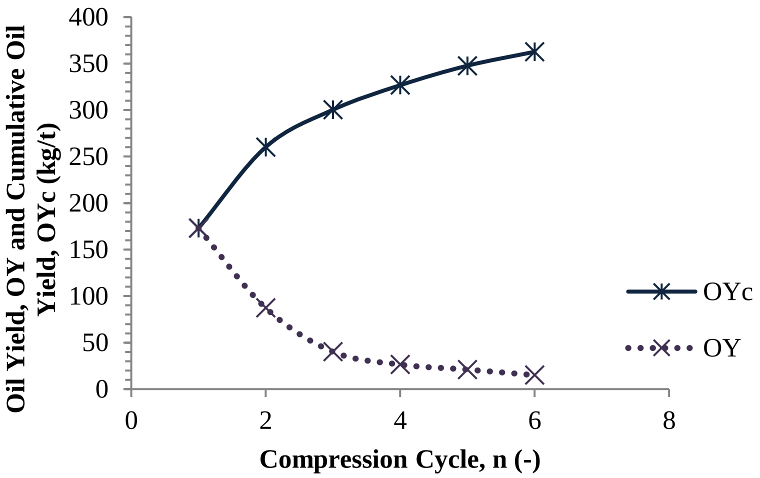

**Figure 8.** Improvements in oil yield over single cycle technique given repeated induction of compressive stress.

Figure 9 is a plot of pressure ratios at the oil point during successive compression cycles. Computed relative to the applied pressure, the pressure ratio at the oil point provides an important indication of the material's capacity for additional compressive load given prevailing pressing conditions. As this ratio increases, the capacity diminishes.

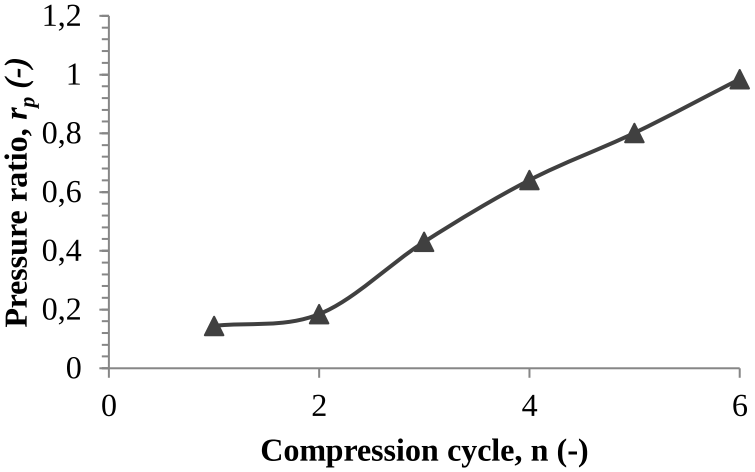

**Figure 9.** Variation of pressure ratio at the oil point with compression cycles.

## CONCLUSIONS

Some parameters involved during the densification of oleaginous materials, namely the time rate of deformation, aspect ratio, repetitive induction of strain and the pressure ratio were investigated with a view to determining their influences on the course of densification. Higher degrees of deformation are favoured at lower rates of induction of densification and higher equipment aspect ratios. This means that large capacity presses are more efficient than those with lower capacities. Repeated induction of strain enhances scheme performance by allowing for thorough working of the processed material. The pressure ratio is an important indicator of the available margin for the expenditure of energy during a compression cycle.

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