DETERMINING PRESSURE RELATIONS OF VEGETABLE OIL PRESS USING DISCRETE ELEMENT METHOD SIMULATION

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Abstract

The plant oil extraction is a process with high energy consumption. During the process major part of the kinetic energy transforms into thermal energy. The material receives a very significant amount of heat, which is able to modify the quality of the plant oil. This is why the precise determination of the thermal relations is important to recognize disadvantageous constructions. With the support of discrete element method it is possible to examine the mechanical and thermal relations plus deduce the extracted oil chemical attributions.

Introduction

In case of an oil press with worm shaft from the temperature aspect we determine two basic methods; the cold and hot pressing method. Using cold pressing procedure over the clarity of oil seeds there is no need for any further treating. According to experiences cold pressing provides good quality, in case of canola it is possible to get oil with low phosphor content, which does not require any further processing to produce biodiesel. If during the extraction the temperature of the oil increases too high, then it is necessary to perform additional treatment because of the high phosphor level.

Materials and methods

DEM (discrete element method) is a discontinuous numerical method based on molecular dynamics. It was developed and applied for analyzing rock mechanics by Cundall in 1971 It is the most proper way to simulate the behaviour of materials consisting of seeds.

The examined OKB-1 oil press machine has a complex geometry. On the shaft there are three different worms with different shapes. After the worm shaft the solid material leaves through a tight slot and the oil leaks through the press basket.

It is important to differentiate those sections where the geometry of the seeds would deform significantly, because the elements in the simulation cannot be deformed (Cundall, Hart 1992). In this model every seed is simulated as a ball, so we cannot study them at their highly deformed state with this material model.

The simulation develops from the simple built model into a more complex one. This method is reasoned because it is important to make sure of the realistic properties and effects of the simulated processes. The examination of the realistic behaviour is only possible with evolutionary developments (Donzé 1999).

First model:

The first model is simple and one sectioned screw geometry which contains the surface models of the casing, the shaft, the closing covers at the two ends and the helicoids (Figure 1.).

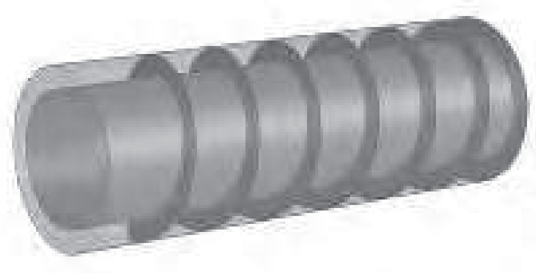


Figure 1. The model for the first simulation

The built model has nearly the same dimensions like the first section of the real machine. The size of the balls which simulate the seeds, was chosen to ensure that at least two balls positioned into radiant direction without overlapping each other (Bojtár, I., and K. Bagi 1989). The size of the particles matches the seeds in reality (Table 1.). Because of the chosen diameter it is possible to run the simulation with fewer elements but still being accurate. During the pressing process the slot at the end of the machine causes the highest resistance on the material. This generates reacting pressure against the flow of the material (Ugural, A. C., and S. K. Fenster 1987). This pressure in this simplified model is replaced by a static closing cover at the end.

Table 1. Model parameters

Property	Value
Gravitational acceleration	9.81 ms^{-2}
Angular velocity (shaft and worm)	π rad•s^{-1}
Angular velocity (closing cover)	π•2^{-1} rad•s^{-1}
Ball diameter	7 mm
Material density	500 kgm^{-3}
Damping coefficient	0.14
Normal stiffness (ball-ball and wall-ball)	2•10^3 Nm^{-1}
Shear stiffness (ball-ball and wall-ball)	2•10^3 Nm^{-1}
Global friction coefficient	0.1

The aim of our analysis is to get data about the longitudinal distribution of pressure by rotating the shaft and the helicoid parts of the model.

Second model:

The second model could simulate the continuous material flow. In this model the closing plate effects constant dynamical resistance (servo wall). The function of this wall is to ensure the constant particle flowing, additionally produce the constant pressure to the particles.

The model with servo mechanism opens the door to the research of the constant material stream. The difference between the previous model and this one is the data of material stream. The resulted speed of the servo wall is $v_{sw} = 5.7 \cdot 10^{-3}$ ms^{-1} , that means $\dot{V}$= 28.2 cm^3s^{-1} material stream. Because the displacement of the servo wall in one second is less than 1 percent compared to the longitudinal dimension could be static. It means that the results of these two models are very similar.

Third model:

The third model geometry was improved by giving thickness to the worm. This model contains the surface models of the casing, the shaft, the closing covers at the two ends, the worm modelled by two helicoids and a small surface to close the end of the worm (Figure 2.).

Figure 2. The geometry of the second simulation

The closing cover at the end of the model has to resist the pressure. This surface was set to be dynamic and have a constant resistance against the material. So it allows the particles to have volumetric flow. This servo wall keeps the given pressure value with 5% inaccuracy.

The second model has nearly also the same dimensions like the real machine. But the material properties are not the exact properties of the real seed. The same test material parameters were used as by the first and second simulation (Table 1).

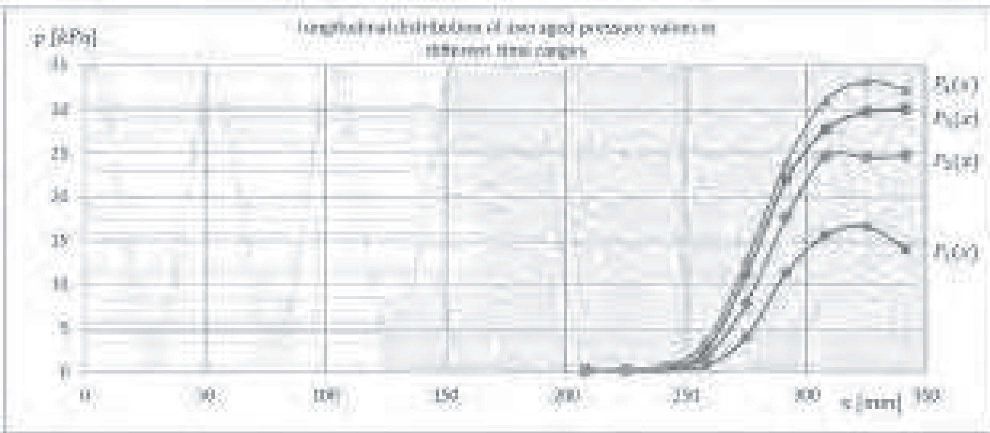
Basically the simulations were set to calculate the longitudinal distribution of pressure on the casing and evolved heat by friction in the material. But because of unexpected results the analysis focused on the pressure values.

Result and discussion

First simulation:

The value of pressure which effects on a surface is calculated from the sum of the normal forces at the contacts between the surface and the walls. During the simulation the software checks all of the contacts in the model in every time step and selects those which contact the surface. Then it is able to determine selected section by summarising the normal forces then dividing with the size of the area. The pressure was determined on the surface of sections. Because of the fluctuating behaviour of these values the final data were determined by averaging for 5000 time steps. To get detailed view of the process, the data were measured in four different time ranges. The time range of the averaging process cannot be comparable with the temporal difference between the starts.

By analysing the pressure we can see that the significant increase starts just at the beginning of the last thread. The increase continues monotonous to the end of the thread. The pressure between the worm and the closing cover in spite of expectations is not constant (Figure 3.). It fluctuates around a value which was calculated at the end of the worm.



Figurte 3. The longitudinal distribution of the averaged pressure in different time ranges

Besides this fluctuation is small enough to adduct with constant longitudinal distribution. At the last thread the bordered pressure increment is caused by the property of the discontinuous material. At fluids the longitudinal distribution is more uniform because their press transmitting attribute is better. Moreover the fluids can induce flow at the slot between the worm and the casing. According to the longitudinal distribution of the pressure we can realize that the most loaded part of the model. Probably the biggest quantity of heat is evolved in this section. But we can see that the compressed material fills only three threads of the helicoid(Figure 3.). Firstly it makes unsure that the same characteristic would be seen at a totally filled model but as the pressure highly increases at the last thread and it does not have a significant effect on the other two threads we can safely declare that similar characteristic would be formed by a totally filled model.

Second simulation:

To compare longitudinal pressure in the first and the second model we present these on Figure 4. It shows that the similarity is significant, because the distributions are the same, but on the second function the values of the pressure are higher. Due to the inaccuracy of the second simulation we are not able to draw a conclusion.

Third simulation:

New simulation was started with the new geometry but using the same properties like in the previous simulations included the pressure of the servo wall (closing cover) which was 25,46 [kPa]. After the accumulation process the volumetric flow rate could not increase and started fluctuating about zero. Because of the thickness of the worm it was expected to gain lower values in the volumetric flow but not zero. To examine this extreme decrease, different worm thicknesses were set with static closing cover. Basically the thickness is defined by an angle which gives the degree of rotation of the second helicoid from the first one. This theory is illustrated in Figure 6. at the cross-section. The summary of the results are seen in Figure 5.

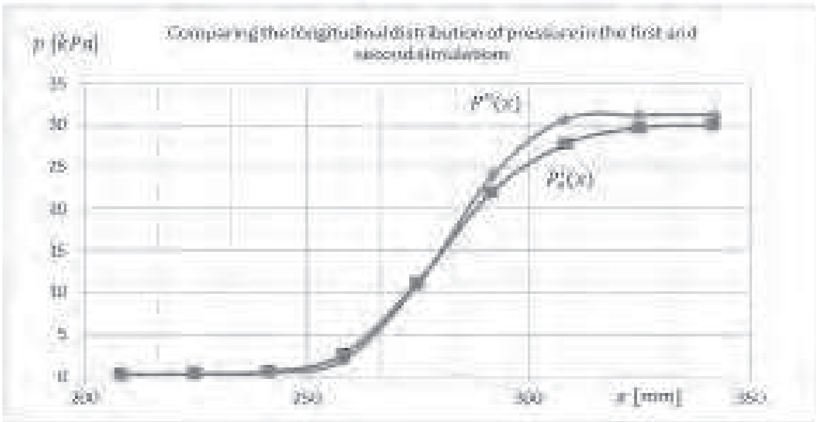


Figure 4. The longitudinal distribution of pressure simulations

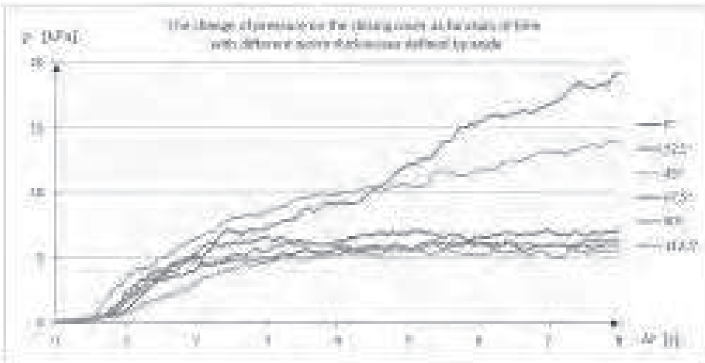


Figure 5. The change of pressure as function of time with different worm thicknesses defined by angle

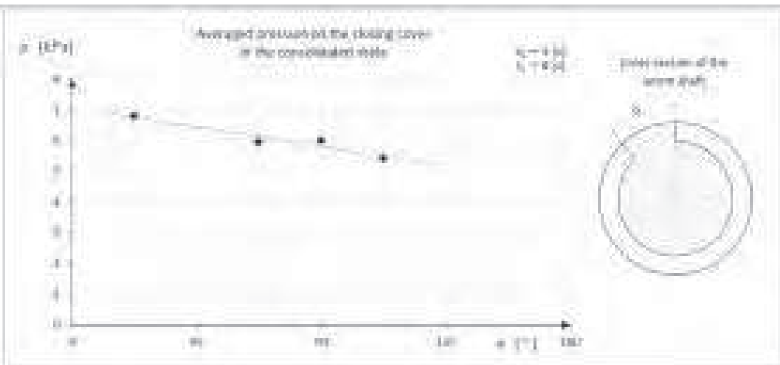


Figure 6. Averaged pressure on the closing cover in the consolidated state

At Figure 5. it can be clearly seen that two angle values; the 0° and the 45° have salient curves. At these angels the pressure does not consolidate in this time range about a value like the other graphs. Probably these false values were caused by the special relation of the geometrical dimensions including the diameter of the balls. At these setups the particles can stretch extremely instead of bouncing back because of their undeformable attribute. So it can result in very high pressure. The curve of 22,5° proves this idea because it is not located between the two salient curves but at the other ones. Examining the correct curves, the averaged pressure values show the expected relation (Figure 6).

The averaging was done in the consolidated state which started at t_0=4 [s] and ended at t_1=8 [s]. The scale of the simulated angles is tight. At first the size of the particles delimits the angle values using in the simulation because at higher degrees the small amount of material in the model could not effect significant pressure. Secondly the detailed analysis using more values would not lead to more precise graph. There are angles where the same amount of material would be caused by the generating method. It would lead to inaccurate values. Thirdly changing the size of the particles would highly increase the duration of the simulations.

Conclusions

In this paper, granular material behaviour is investigated by the numerical approach. The discrete element method (DEM) seems to be a promising approach for making an elaborated model to describe the thermal processes of the oil press. Former research has shown that virtual DEM simulations were developed in correspondence with the real tests (Tamás, Jóri 2011). It is important to simulate the behaviour of a synthetic material whose microproperties can be chosen to reproduce the relevant behaviors of a particular solid.

The simplified geometry of the pressing machine was built in the discrete element software to model the basic phenomenon under the pressing process. The results of the longitudinal distribution increasing quickly in the last round of the helical and the highest values were generated in this space.

As we experienced there are special geometrical setups which could lead to false calculations. Probably it happens when the size of the elements is relatively big and the stiffness values are relatively low so enables the material to stretch extremely. As a result of this when using similar setups to decrease the duration of the simulation it is suggested to make further analyses to be sure the setup does not give false values.

Basically the first aim at this stage of the research is to make sure about the suitability of the model for further simulations and developments. So the deep analysis of the special geometric relations is not needed. It is enough to ascertain the model is correct. The dimensions of the new model with worm thickness are equal the dimensions of $\alpha=90°$ model version. Based on this analysis the determined model looks suitable for further analysis and developments.

The simulations open the door to develop new models that are very similar to the real oil press machines. It can be concluded that the discrete element method can be used for simulating the thermal processes of the oil presses also. The model can be used in development procedures of pressing, reducing the number of real tests.

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