Single-screw extrusion as an energy saving preparation step for crushing rapeseed seeds

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Introduction

The carbon footprint of conventional crushing of oilseeds is determined for the largest part by steam consumption. According to the Desmet Ballestra Company[1], 28.4 kWh of electric power and 153 kg of steam are required per ton of seeds during the pre-pressing step of the crushing. If steam is produced by natural gas combustion, approximately 120 kWh of heat are required. These values are corroborated by Kaltschmitt[2] and the Price Waterhouse Coopers report on the French biodiesel production[3]. In the French context where electricity supply is provided for 80 % by nuclear power, shifting source of power toward nuclear energy could reduce the carbon footprint of seeds extraction in large proportion.

The goal of seeds pre-treatment prior to mechanical extraction by mean of screw press is to improve the throughput of these machines and to give to oil-cake the characteristics required to achieve an efficient solvent extraction. Improvement of the throughput is obtained by flaking and a hydro-thermal treatment[4,5]. The seeds are warmed before flaking to increase their plasticity, flaked and cooked at 90-100°C. Flaking plays two important roles in the processing: 1) it facilitates heat exchange and water evaporation during cooking step[6] and 2) it improves oil recovery by increasing oil extractibility[7], i.e., by reducing the proportion of oil which is left in the meal (defect of milling) and by increasing the speed of at which extraction occurs. These effects are obtained by increasing exchange surface, reducing the thickness of particles and by breaking some of cells walls[8]. Cooking leads to important changes at microscopic scale, heat destroying oil bodies by changing the tridimentional conformation of oleosins which are structure proteins located at the interface of hydrophobic lipids and the cellular medium[9]. Another effect of cooking is reducing oil viscosity and water content of flakes. Water plays the role of plasticizing agent in oil cake so that moister cake tends to becomes softer and less able to resist to axial force exerted by screw worm. Consequently, the pressure reached drops and weak pressure gives lower oil yield. Another consequence of low pressure is the production of cakes which lack of solidity and collapse during extraction leading to poor solvent percolation.

Nelson *et al.*[10] proposed single screw extrusion as a pre-treatment for soybean preparation to mechanical extraction. They noticed that extrusion improved greatly the expeller capacity and allowed 70 % yield of oil. Their technique was adopted by numerous small scale oil mill for soybean processing and further studies demonstrated that the oil produced by this way had, in general significantly greater peroxide values than those obtained by solvent extraction and contained less free fatty acid and phosphorus[11]. This study proposed a transposition of this treatment to rapeseed as pre-treatment to replace flaking and traditional cooking.

Material & method

Extruder was a single screw France Extrusion FEX1 powered by a 30 kW motor. The rotating speed was adjustable by mean of a frequency variator from 10 to 620 rpm. The screw has a diameter of 82 mm and a length 720 mm. The extruder had a rated capacity of 200-250 kg/h when using soybean. During the trials, 3 restriction disks were placed between the last screw elements. The die was mounted on a threaded insert allowing adjustment of the gap between the tip of the screw and the die.

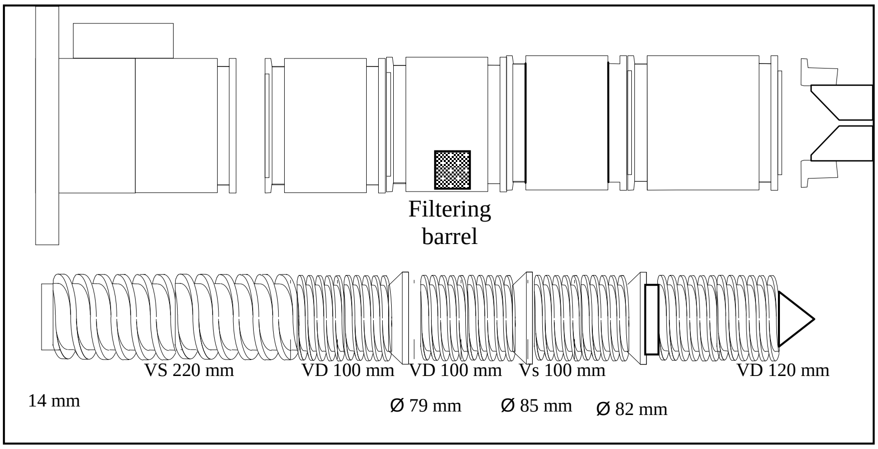

Figure 1: Extruder worm assembly

Pressing of extruded material was carried out in a La Mecanique Moderne MBU75 press. The press screw had a 180 mm diameter in the feed area and 150 mm in high pressure area. The screw length was 1800 mm. The theoretical capacity of the press was given by the volume generated by the revolution of the last screw element which was 0.3 liter. With a rotating speed of 10 rpm and a cake density of 1, the cake capacity was 180 kg/h and approximately 250 kg/h of flakes. The extruded material was transferred to the press by mean of hand held buckets.
The reference processing was carried out by flaking on a Damann Croes flaker having two smooth rolls of 500 mm in diameter and width. The flakes were conveyed to a cooker which was composed of two superposed horizontal cylinders of 900 mm in diameter and 2000 mm in length. Each stage was heated by 4 resistances of 4 kW, the heat being transported by a thermal fluid circulated in cooker jacket. Inside the cooker, flakes were mixed by a helical ribbon. The flakes were dried in the bottom part of the cooker which was connected to a mist extracting fan.
Extraction tests were carried out in a 6 liters batch extractor designed to reproduce conditions encountered in large scale industrial extractors. The cake was placed in a jacketed vertical cylinder (130 mm x 600 mm) and held by a perforated removable plate. The solvent was moved by a pneumatic pump from the 15 L glass vessels located under the extractor through a heat exchanger and directed toward a second vessel located above the extractor. The speed of percolation was measured by counting the time necessary to recover 2 liters of solvent thanks to graduations carved on the bottom vessel.
The initial extrusion study was performed with a modified barrel since previous experiments were showing that rapeseed when extruded was releasing oil in the extruder barrel and that this oil was disturbing the flowing of the seeds by excess of lubrication resulting in insufficient thrust to allow extrusion. During the trials with the filtering barrel, it has been found that in some circumstances the extruder was able to function in interesting fashion. The seeds were flowing out of extruder die in semi-liquid state described by Nelson *et al.*[10] and the temperature was close to 120°C, a level likely to allow the reduction of some enzyme activity. The experience was then reoriented to test this kind of pre-treatment. A comparison of usual processing with extrusion was carried out with the same batch of seeds. In conventional processing, seeds were flaked with a 0.3 mm gap between the cylinders. The cooking was carried out at 100°C with a 40 min dwell.

Results

Filtering barrel: a new barrel was designed with a 40 x 50 mm opening in which several types of filtering devices were tested. The first one was a thick perforated plate which proved to be not close enough of the screw worm allowing the aggregation of some solid material between the barrel and the screw and impeding oil to flow. A second model was designed to be closer to the screw with a thinner perforated plate. This one did not resist to radial pressure of the material. The third one was made of a serial of 6mm thick bars separated by 0.2 mm shims. These bars where orientated perpendicularly to extruder axis. The design was inspired by the observation that oil was able to flow between the barrels elements in spite of their very tight assembly. Once again, this attempt turned out unsuccessful since solid material was pushed between the plates preventing oil flow.

During these failed attempts, it was observed that in some circumstances, extruder could achieve an operating point near the desired result without producing de-oiling. The screw was turning at full speed, several restriction elements were placed between the screw elements and the gap to the die was adjusted to an accurate distance allowing both a sufficient pressure to cause a sharp crushing of the seeds without provoking the presence of oil in the barrel. Table 1 presented typical characteristics of extrusion when successful functioning was achieved.

Table 1: Extrusion parameters

Parameter	Extrusion 1	Extrusion 2
Throughput rate (kg/h)	103	248
Specific mechanical energy (kWh/t)	89	68
Matter temperature (°C)	130	110
Rotation speed (RPM)	620	620
Water content after extrusion (%)	4,25	5,15

Comparison with standard processing.
The regular cooking allowed moisture content of the flakes of 3.9 % while extrusion left 6.7% of water in the extrudat. Both preparations were made at 250 kg/h . The maximal temperature encountered by the reference flakes was 100°C while extruded seeds reached 115°C. The non-extractible oil percentage in flakes was 3.1 % versus 1.7 % in extrudat.

Table 2: Comparison of press performance

Parameter	Flakes	Extrusion
Throughput rate (kg/h)	250	250
Intensity (A)	17,5	14,6
Cage temperature (°C)	77,1	74,1
Rotation speed (RPM)	9,33	9,43
Oil yield (%)	80,7	76,2
Cake oil content (%)	13,2	15,4
Inextractible oil of cake (%)	1,2	1,5

1 : Oil yield: (Os – Oc) / Os x 100, where Os = mass of oil in seeds and Oc = mass of oil in cake.

Table 3: Comparison of extractions

Parameter	Flakes	Extrusion
Percolation speed (L / s)	0,08	0,11
Oil yield [1] (%)	90,7	87,1
Oil residues of the meal (%)	1,4	2,3

1: Oil yield: (Oc – Om) / Oc x 100, where Oc = mass of oil in cake and Om = mass of oil in meal.

The results presented in table 2 show that regular preparation exhibited better oil yield due to lower water content of flakes. This difference explained higher intensity called to the press motor and higher temperature in the cage. The water content had a strong incidence on cake plasticity and on pressure supplied by the worm displacement. This is the reason for the better reduction of non-extractible oil after mechanical extraction. The defect of milling (non-extractible oil) and possibly higher water content caused a lesser oil recovery in the extrusion prepared cake presented in table 3.

Discussion
If these results highlighted the importance of water during mechanical extraction, they demonstrated the feasibility of extrusion pre-treatment with oil rich seeds and opened a possible new approach for reducing energy requirement of mechanical oil extraction by adaptation of presses to moister material.
Drying proved to be the bottleneck of seeds preparation with screw presses. Two approaches could result of this finding: 1) research of greener way to dry seeds, 2) adaptation of presses to cope with moister material.
In geographic areas where the climate is warm and dry during summers, the first approach could lead to use of free dry air to get interesting results but only integrated companies owning both seed storage and oil-mill facilities have advantage to use it. The second approach is more universal but more challenging since it should compensate the natural behavior of seeds.

Conclusion

This preliminary study is promising because it was observed that extrusion of seeds with a high oil content was possible. Despite of middling results for extrusion, compared to flaking-cooking for pressing and extraction performances, the lower consumption of energy makes this process very interesting. Further work is required to determine the quality of extracted oil.

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[1] Van Doosselaere P., Desmet, personal communication (2009)

[2] Kaltschmitt M., Reinhardt G.A., and Steltzer T., Life cylcle analysis of biofuels under different environmental aspects, Biomass and Bioenergy, vol 12:2, pp121-134 (1997)

[3] Ecobilan, Price Waterhouse Coopers, Actualisation du Bilan énergétique et du bilan gaz à effet de serre de l'EMVH en France. Non published study for SOFIPROTEOL (2007)

[4] Singh K.K., Wiesenborn, D.P., Tostenson K. and Kangas N., Influence of moisture content and cooking on screx pressing of Crambe seeds, J.A.O.C.S. vol 79 :2 pp 165-170 (2002).

[5] Zheng YL, Wiesenborn D.P., Tostenson K. and Kangas N., Screw pressing of whole and dehulled Flaxsedd for organic oil, J.A.O.C.S. vol 80 :10, pp1039-1045 (2003)

[6] Laisney J., L'huilerie Moderne, « arts et techniques », Ed. Compagnie Française pour le développement des fibres textiles, Paris (1984).

[7] Heimann M. Flaking mil theory and operation, Oil mill gazeter, nov. 1995, pp32-37 (1995)

[8] Lanoisellé J.L., Bouvier J.M., Contribution à l'étude du pressage hydraulique des graines oléagineuses – mécanismes du pressage et modélisation. PhD thesis, Thèse de l'Université Paris XII Val-de-Marne, 137 p, (1995).

[9] Dickey L.C., Cooke P.H. and Kurantz M.J. Using microwave heating and microscopy to estimate optimal corn germ oil yield with a bench scale press. J.A.O.C.S. 84, pp489-495 (2007)

[10] Nelson A.I. Wijeratne W.B., Yeh S.W., Wei T.M. and Wei L.S. Dry extrusion as an aid to mechanical expellinf of oil from soybeans, J.A.O.C.S. vol 64 :9, pp 1341-1347 (1987)

[11] Wang T. and Johnson L., Survey of soybean oil and meal qualities produced by different processes – JAOCS, vol. 78, n°3, p311-318, 2001