EXTRACTION OF SUNFLOWER OIL BY TWIN-SCREW EXTRUDER: SCREW CONFIGURATION AND OPERATING CONDITIONS EFFECTS

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Abstract

An investigation of the screw configuration for oil expression of sunflower seeds on a corotating twin-screw extruder (BC 45, Clextral-France) was carried out in this study. Five screw profiles were examined to define the best performance (oil extraction yield and oil quality) by studying the influence of operating conditions: temperature pressing, screw rotation speed and seed input flow rate. The position and the space between two reversed screw elements affected oil extraction yield. An increase of oil extraction yield was observed when the reversed screw elements were moved with increased spacing between two elements and with smaller pitch elements. Oil extraction yield was increased when pressing temperature, screw rotation speed and seed input flow rate were decreased. The highest oil extraction yield (85%) with the best cake meal quality (the residual oil content lower than 13%) was obtained under the following operating conditions: 75 rpm, 19 kg/h and 120C. Effect of the operating parameters on oil quality was low (mainly on acid and iodine values). In all the experiments tested, the oil quality was very good. The acid value was below 2 mg KOH/g oil and total phosphorus content was very poor, below 100 mg/kg.

Introduction

Industrial oil extraction from oleaginous seeds is commonly realized through mechanical pressing with a hydraulic or single expeller press, followed by solvent extraction. The hydraulic press is comparatively effective, but this process is discontinuous. Recently, the application of a continuous oil extraction process by extrusion technology got some attention from a few researchers (Vadke and Sosulski, 1988; Isobe et al., 1992; Clifford, 2000; Wang and Johnson, 2001; Crowe et. al., 2001; Sing et. al., 2002). Extensive studies on extrusion processing of oil seeds using a twin-screw extruder to generate oil (Guyomard, 1994; Bouvier and Guyomard, 1997; Dufaure et al., 1999a, 1999b; Kartika et al., 2003a, 2003b) have been successfully carried out.

The great capability of twin-screw extruders to conduct diverse functions and processes has a good correlation with advantages of their characteristics. According to Dziezak (1989), those advantages include (i) ability to provide better process control and versatility, especially in pumping efficiency, controlling residence time distribution and uniformity of processing,

(ii) ability to process specialty formulations which the single-screw extruder cannot handle and (iii) flexibility to design a machine which permits self-cleaning and rapid changeover of screw configuration without disassembling the extruder.

The twin-screw extruder is mainly built by elements, namely screws. The arrangement of screw elements with different characteristics (pitch, stagger angle, length) in different positions, and with different spacing determines screw profile/configuration that is the main factor influencing performance (product transformation, residence time distribution, mechanical energy input) during extrusion processing (Gogoi et al., 1996; Gautam and Choudhury, 1999).

During extraction, a significant increase in oil yield was observed as the length and the pitch of reversed screw elements were increased and reduced, respectively (Dufaure et al., 1999a). In addition, oil yield could be made to rise by adding the monolobe paddle screws in module 5 just before the filtration module and by increasing the stagger angle of bilobe paddle screws. Furthermore, an investigation of a continuous oil extraction method using an extruder divided into two zones, (i) the twin-screw zone, which was built from two corotating and copenetrating screws, and (ii) the double single-screw zone, which was constructed from two corotating single-screws, increased oil yield up to 90% with residual oil content in the cake meal lower than 15% (Bouvier and Guyomard, 1997). More systematic studies should be realized to increase oil yield and to reduce residual oil content in the cake meal. Moreover, operating conditions have to be optimized and linked to the quality of the extracted oil.

This study purposed to evaluate the effects of screw configuration and operating parameters such as temperature pressing, screw rotation speed and seed input flow rate on oil extraction of sunflower seeds using a twin-screw extruder. The characterization of extraction performance was observed by the determination of oil extraction yield and oil quality.

Materials and Methods

Materials. All trials were carried out using whole and uncleaned sunflower seeds (3 - 6% of impurity content), which were supplied by La Toulousaine de Cereales (France). The seeds had varied oil and moisture contents from 39 to 46% and from 6 to 8%, respectively. All solvents and chemicals were analytical grade from Sigma-Aldrich, Fluka, Prolabo and ICS (France).

Twin Screw Extruder. Experiments were conducted with a corotating twin-screw extruder (Model BC 45, Clextral, France). It was built with seven modular barrels, each 200 mm long and different twin-screws which had segmental screw elements each 50 and 100 mm long. Three modules were heated by thermal induction and cooled by water circulation. Material was fed into the extruder by a volumetric screw feeder (type 40, Clextral, France). Two filter sections consisting of six hemispherical dishes with perforations of 1-mm in diameter were outfitted on modules 4 and 6 to separate extracted oil. Furthermore, screw rotation speed, seed input flow rate and barrel temperatures were monitored from a control panel.

Screw Configuration Study. Experiments were carried out to evaluate five screw profiles using the sunflower seed rich in oleic acid (average oil content of 39.46% and 7.13% of moisture content). The screw profiles were constructed by placing three reversed screw (CF) elements at different positions and intervals. A reversed screw element was fixed just above the module 4 (1st filter module) while other CF elements were positioned by spacing 0 or 100 mm from the first CF element and by placing them 0 or 100 mm from the left side of module 6 (2nd filter module). Replacing the forward screw element with a smaller pitch developed another configuration (profile 4). For all profiles tested, barrel temperature, screw rotation speed and seed input flow rate were fixed at 80C, 165 rpm and 24 kg/h, respectively. When extraction was under steady state conditions (after 20-25 minutes), filtrate (oil containing the foot) and cake meal samples were collected. The cake meal was further analyzed to determine the residual oil content. The oil extraction yield was calculated by the following relationship: R (% mass) = [100*(Qs*Ts – Qc*Tc)]/(Qs*Ts), where Qs is the inlet flow rate of seeds (kg/h) = Qf + Qc. Qf and Qc are the outlet flow rates of the filtrate (kg/h) and the cake meal (kg/h), respectively. Ts and Tc are the oil content of the seeds (%) and the cake meal (%), respectively.

Operating Conditions Study. The following operating conditions were tested: the barrel temperature (80 – 120C), the screw rotation speed (75–260 rpm) and the seed input flow rate (19 – 48 kg/h). All trials were conducted using profile 2 and conventional type sunflower seeds (average oil content of 45.31% and 6.56% moisture content).

Analysis. The filtrate extracted was centrifuged to separate the foot from the oil. Acid, iodine and saponification values of oil were further evaluated using the French normalized method (NF V03-906), AOCS-Cd 1d-92 and ISO 3657, respectively. The phosphorus content was measured using the AOCS method Ca 12-55. Analyses of moisture and residual oil contents of the cake meal were conducted using NF V03-903 and NF V03-908.

Results and Discussion

Screw Configuration Effect. Figure 1 showed that the screw configuration affected the oil extraction yield. This parameter increased when two reversed screw elements in module 5 were configured in a space of 100 mm, as observed on profiles 1 and 2. Higher oil yield was attained as the reversed screw element in module 7 was positioned just above module 6 (profile 2).

On the contrary, oil extraction could be not realized when the reversed screw elements in module 5 were put together without a space (profile 3) or when a forward screw element in module 6 was replaced by a smaller forward pitch element (profile 4). In both these cases, the torque exceeded the intensity limit and therefore the extruder clogged before reaching a steady state condition and no samples were collected. Using modified profile 3 (profile 5), where a forward screw element in module 5 was replaced by a higher forward pitch element, the oil extraction was successfully realized but the oil yield produced was low.

Effects of screw configuration on oil yield seemed to have been linked to the compression action of the reversed screw elements. The reversed screw element is a very strong flow-restricting/power-consuming element that has a high ability to generate backpressure when placed in a screw profile. A screw configuration with space between the reversed screw elements increases the compression action of reversed screw elements. This is due to high viscosity material in the region where the material encounters the first reversed screw element, giving rise to higher filled volume (Gautam and Choudhury, 1999). Furthermore, the incorporation of reversed screw elements into forward screw elements produces an expanded structure of matter, which breaks easily when shear force is applied. This facilitates diffusion of the lipid droplets released through the fibrous matrix toward the surface of the matter.

The extracted oil had an excellent quality for all the tested profiles. The modification of screw configuration did not change oil quality. The acid value remained stable at less than 2 mg KOH/g oil. The iodine and saponification values were tolerable (84-85 mg iodine/100 g oil and 190-208 mg KOH/g oil, respectively). Also the oil had a very poor phosphorus content (<27 mg/kg). These conditions were favorable to facilitate the refining process. The quality of the cake meal for all configurations tested was not good; the residual oil content was high (>17%), while the moisture content was low (<3%). Higher residual oil and moisture contents were obtained under profile 5.

Operating Conditions Effect. Figures 2 and 3 shows the effects of the screw rotation speed on the oil extraction yield under different seed input flow rate and temperature. The results show that influence of the screw rotation speed on the oil yield greatly depends on seed input flow rate and temperature applied. Under low feed flow rate, reduction in the screw rotation speed linearly increased the oil extraction yield. However, this parameter did not further influence the oil yield when the operation was carried out with a higher feed flow rate. The oil yield thus remained stable either with a decrease in the screw rotation speed or with an increase in the feed flow rate. These phenomena were mainly observed at 100 and 120C. At a lower temperature, the oil extraction yield increased as the screw rotation speed and seed input flow rate decreased.

As well as the screw rotation speed, effects of the temperature on the oil yield are specific. Under low feed flow rate, the oil extraction yield decreased linearly when the barrel temperature increased although the screw rotation speed was decreased. But when the operation was conducted with a high feed flow rate and low screw rotation speed, the oil yield remained stable with increasing barrel temperature. By increasing the screw rotation speed, the oil yield can be improved, but the values obtained were lower than those obtained with low screw rotation speed.

Oil expression at high temperature has a few favorable effects, such as increasing oil fluidity, breaking of the walls of additional oil cells and coagulation of the protein fraction of seed (Karleskind, 1996). Hence, the lipid droplets release easily through the fibrous matrix toward the surface of the matter. On the other hand, this operation increases the residual oil content of cake meal due to reduced plasticity of the seed (Wiesenborn et. al, 2001). In this study, both those phenomena have been evaluated.

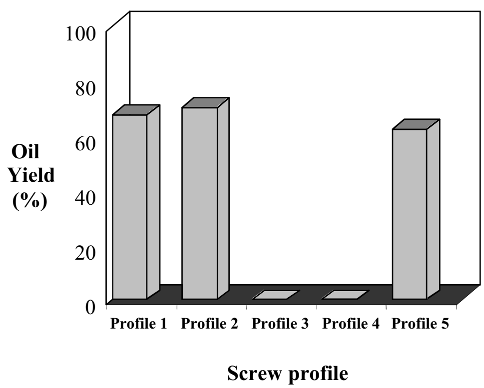

Figure 1. Variation of oil extraction yield from different screw configurations.

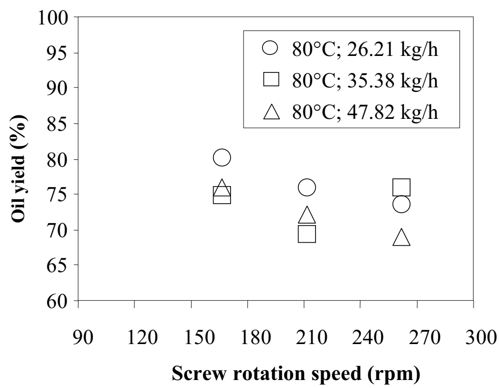

Figure 2. Effect of screw rotation speed on oil yield under different temperatures and seed input flow rates.

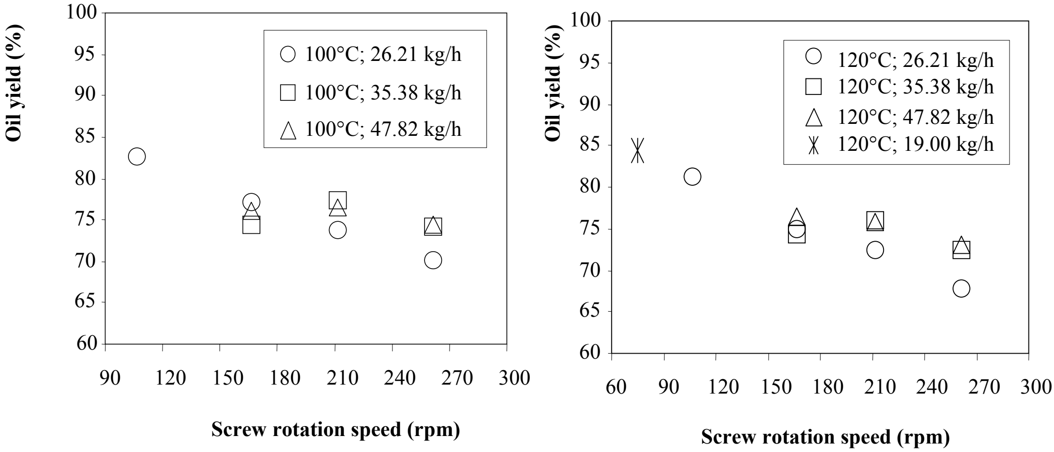

Figure 3. Effect of screw rotation speed on oil yield under different temperatures and seed input flow rates.

The operating conditions generally did not improve the quality of cake meal; they mainly improved the meal residual oil content. The values obtained were high (>16%) for all operating conditions tested, except for operations under screw rotation speeds lower than 165 rpm (<15%). Although these qualities were disadvantageous for direct utilization of cake meal, they facilitate further extraction. Oil extraction by solvent is an adaptable method to treat these kinds of cake meal. In addition, the characteristic of particle size distribution of cake meal, which was dominated by particles smaller than 0.5 mm, facilitates the application of this method.

For all the tested operating conditions, the quality of extracted oil was satisfactory. The acid value remained stable, lower than 2 mg KOH/g of oil. The iodine values indicated that oil oxidation is acceptable (78-88 mg iodine/100 g oil) and the phosphorus content was low (< 97 mg/kg). Operating conditions, particularly temperature, influenced phosphorus content but had a low effect on acid and iodine values. The phosphorus content rose when the barrel temperature increased. Increasing barrel temperature facilitated more effective drying of the seed which lead to a more efficient crushing of the seed, due to the reduction of elasticity. This intense crushing breaks the cell walls and leads to more efficient co-extraction of the membrane phospholipids, as reported by Dufaure et al. (1999a). Higher phosphorus content was observed with high screw rotation speed and low feed rate. However, the highest phosphorus content of 97 mg/kg was obtained under operating conditions 75 rpm, 19 kg/h and 120C.

Conclusions

The screw configuration and the operating conditions played an important role in the oil extraction yield and oil quality during twin-screw oil expression of sunflower seeds. Higher oil extraction yields were reached with increased space between the reversed screw elements and with smaller pitch elements. A systematic increase in oil extraction yield was observed as the barrel temperature, the screw rotation speed and the seed input flow rate were decreased.

The highest oil extraction yield of 85% and the best cake meal quality with the residual oil content lower than 13% were obtained under operating conditions 75 rpm, 19 kg/h and 120C. Moreover, the twin-screw process in different screw configurations and operating conditions lead to production of a good quality of oil.

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