A New Twin-Screw Press Design for Oil Extraction of Dehulled Sunflower Seeds

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Transport of material in a single-screw press depends mainly on friction between the material and the barrel's inner surface and the screw surface during screw rotation. Thus, a solid core component, like seed hulls, is often necessary to produce the fraction. This sometimes causes excess frictional heat, large energy consumption and oil deterioration. Furthermore, if single-screw presses are not configured with breaker bars or other special equipment, they provide inadequate crushing and mixing.

A twin-screw oil press can be expected to solve these problems because of the higher transportation force, similar to a gear pump, and better mixing and crushing at the twin-screw interface. A twin-screw press (screw diameter = 136 mm, length/diameter = 6.5, screw speed 15–100 rpm, feed rate = 50–150 kg/h) was designed with partially intermeshing and counter-rotating screws and was tested on dehulled sunflower seed. The results were compared to a single-screw lab-scale press. Dehulled sunflower seed (wt, 6.0%; oil, 58.6%) without pretreatments (crushing or cooking) gave 93.6% oil recovery with the twin-screw press, in contrast to 20% oil recovery with the single-screw press. The oil expressed with a twin-screw press had less foreign material than the oil from the single-screw press. Other properties of the oil were also good. Energy consumption of the twin-screw press was more efficient. All results suggested that oil production from dehulled sunflower seed with a twin-screw press is highly efficient.

KEY WORDS: **Dehulled sunflower seeds, oil expression, twin-screw press.**

Industrial extraction of edible oil from oilseeds or other oil-rich materials can be carried out through two traditional processes—mechanical expression and solvent extraction. For seeds with high oil content, such as sunflower seeds, groundnuts, palm kernels or rapeseed, both steps are usually involved, whereas materials of lower oil content, such as soybeans, can be directly solvent-extracted (1–6).

Oilseed expelling technology has been developed through semi-empirical methods, mainly by screw press manufacturers, to achieve optimized expression yields and throughputs for all kinds of oil-rich materials (7,8). Optimization of seed pretreatments and expression conditions through response surface analysis also have been reported (9–12). However, until recently little interest has been focused on the principles and theoretical aspects of mechanical expression itself (13,14).

The traditional design for a continuous oilseed screw press is a single-screw of variable pitch and channel depth, slowly rotating in a cage type barrel. Typically, a set of hard-faced bars are separated by lengthwise slit openings (2,4,7). The reduction of displaced volume as the screw rotates (compression ratio) forces the liquid oil through the slits, while the partially defatted presscake is recovered axially at the screw end after passing a choke piece that controls internal pressure from 30 to 70 MPa. In expressing with a single-screw press, the total throughput depends on a carefully designed worm and barrel assembly. The throughput can be controlled in many single-screw presses with a feeder. Size reduction, flaking, cooking and moisture preconditioning of the seeds are also necessary to enhance oil expression by disrupting the seed's cell structure. Only a narrow range of operating conditions (water and hull content of the seeds, particle size and shape, temperatures and minimum and maximum pressures) is thus compatible with both high throughput and high oil recovery at reasonable energy costs.

In addition to several processes with direct solvent extraction, sunflower seed processing usually includes several other steps (1–6,15,16). Sunflower hulls represent 20–30% of seed weight, and contain most of the undesirable waxes and highly abrasive fibers. Seeds are dehulled to 7–12% hulls to reduce wear in the press and to improve meal and oil quality. Although hulls prevent excessive compaction of the cake during expression and further solvent extraction, complete dehulling is somehow detrimental to maximum oil recovery. Dehulled seeds are flaked to 0.35 mm to rupture cell structures and free the oil, steam-cooked and partially dried, then expressed at 80–105°C and 4–7% moisture until 15–18% oil remains. The 3–4 mm thick presscake has to be conditioned at 10–12% moisture and flaked to 0.2–0.3 mm thickness for further solvent extraction. Final defatted meal of about 28–44% protein content, depending on the extent of dehulling, is therefore obtained after desolventizing and optional toasting.

Extrusion cooking technology—high-temperature, short-time cooking under high shear rate and high pressure—is of increasing use in the oil processing industry for the preparation of oilseeds prior to extraction. This enhances pellet porosity, reduces fines, increases the density of flakes and inactivates lipases (17–19). Until now, only single-screw extruders have been used for this purpose. On the other hand, twin-screw extrusion cooking is known as a more versatile technology, displaying the following characteristics (20,21): a positive displacement effect that ensures proper transportation of material of all viscosity; and a high crushing and mixing ability, resulting in effective particle size reduction, material circulation and temperature control during operations. Throughput is thus less dependent on the material itself, and processing parameters can be controlled more broadly and easily.

Because of our ongoing interest in improving food processing and recent domestic interest in sunflower seed as a crop, we have investigated twin-screw expressing of dehulled sunflower seed. In the present paper, the tentative use of a specially designed twin-screw press is described, with almost completely dehulled sunflower seed

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as the raw material to produce both high-quality oil and defatted meal.

MATERIALS AND METHODS

Twin-screw press design. Oil expressing was carried out on a partially intermeshing, counter-rotating twin-screw press made by Suehiro Iron Works (Yokkaichi, Japan). Screw diameter is 136 mm and it has a length/diameter (L/D) ratio of 5.15 (Fig. 1). The two screws turn in opposite directions. Thus, both high pressure and high shear are generated at the upper intermeshing zone of the screws. Two combinations of screw profile, barrel configuration, compression ratio and choke discharge design were used in Experiments 1 and 2, respectively, as shown in Figure 2.

The barrel is formed of 34–50 vertical parallel plates, separated by spacers, allowing a variable ratio of open to total surface area (Fig. 3). Two barrel plates of different thickness were prepared. The wide type (thickness, 15 mm) has a circulation jacket for cooling or heating. The narrow type (thickness, 5 mm) allows an increased slit filter area. The screw temperature was controlled by injection

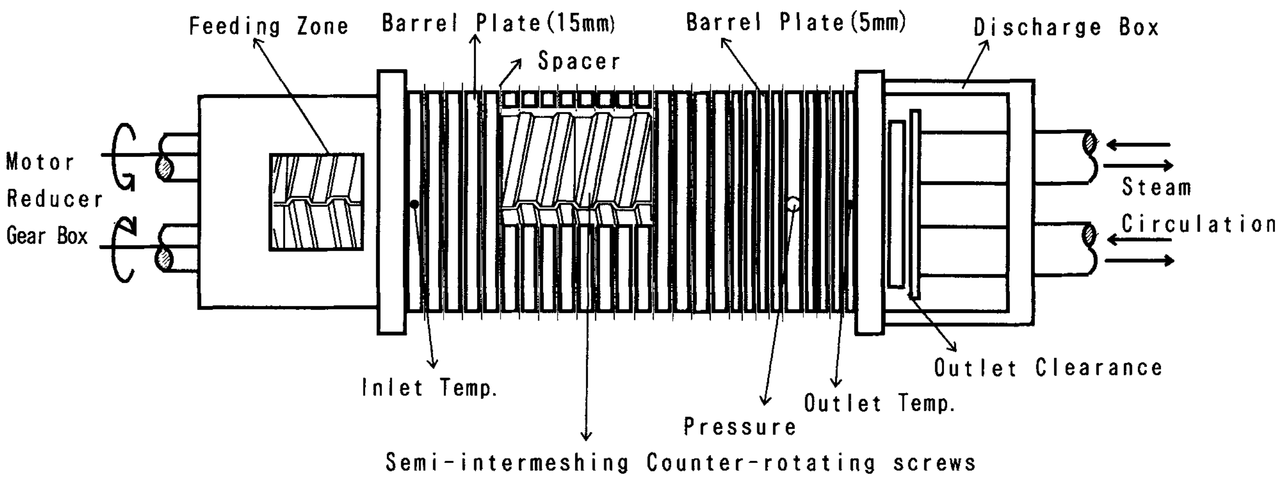

FIG. 1. Twin-screw press.

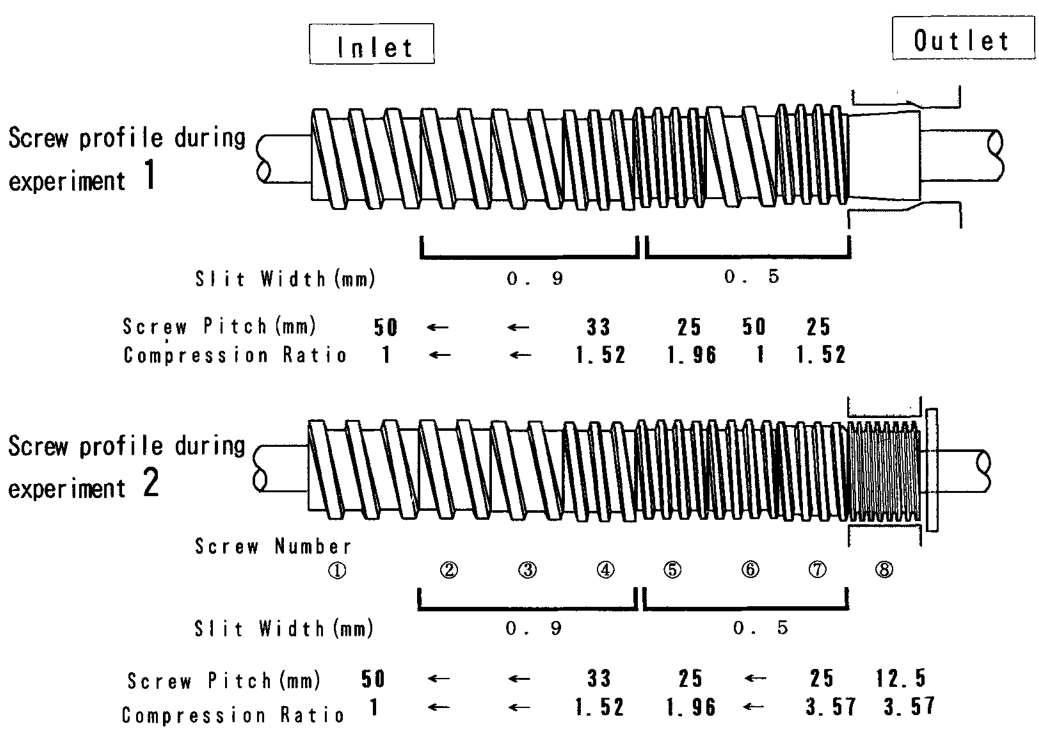

FIG. 2. Screw designs used in Experiments 1 and 2.

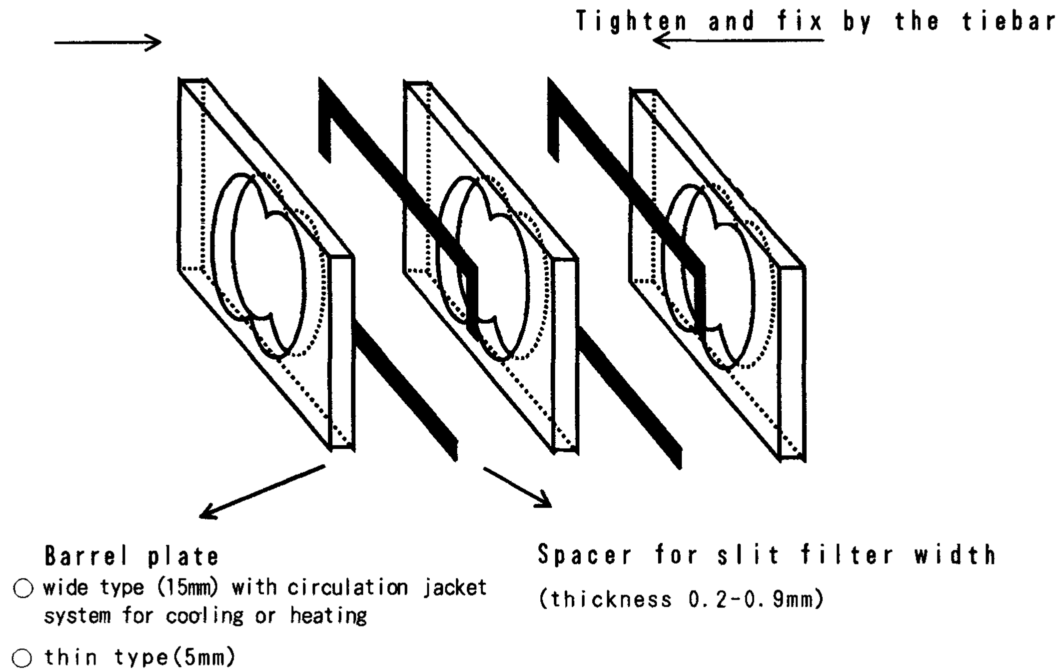

FIG. 3. Barrel and slit design for the twin-screw press.

of steam in both hollow screw shafts, and the whole screw press temperature was allowed to equilibrate for one hour before operating.

A single-screw press also was used for comparison to twin-screw results. This press is a lab-scale single-screw type made by Suehiro Iron Works (screw diameter 56 mm, L/D = 4, screw rotation speed 8–32 rpm, feed rate 5–20 kg/h). This single-screw press has no force feeder or breaker bars.

Raw materials and chemicals. Dehulled sunflower seeds (*Helianthus annuus* L.) of the variety Hybrid 444 (harvested in Minnesota) were supplied by Sumitomo Co. (Tokyo, Japan), and found to contain 3.2% water, 58.6% crude oil, 20.3% crude protein (N × 5.7) and 1.1% chlorogenic acid. The content of hulls was lower than 1% by weight in seeds, and bulk and real densities were found to be 0.61 and 1.09 g/cm^3, respectively. All solvents and other chemicals used were of analytical grade. Sunflower seed with hulls was from the same seeds as above. Hull content was 25%.

Operating conditions. Seeds were mixed with water for moisture conditioning and allowed to stand at room temperature for 10 d before processing. However, sunflower kernels were not submitted to any flaking, rolling or heat treatment before expressing. The screw press was gravity fed, maintaining a slight excess of seed above the screw by hand feeding. At a fixed screw speed of 17 rpm, the total feed rate was 50.2–58.0 kg/h. Expressed oil was recovered at different locations of the barrel and weighed separately. In some cases, a dead stop procedure allowed us to collect partially defatted presscake at different locations in the screw channel for analysis as described below.

During expression, barrel temperatures were measured in three locations with thermocouples, and pressure in the barrel was measured immediately before the outlet discharge. Motor current also was measured to calculate the energy consumption. The only difference between Experiments 1 and 2 was the screw design, as shown in Figure 2. Also, in Experiment 1 we decreased the outlet clearance to test the effect on the nitrogen solubility index (NSI) of the presscake. The single-screw press was gravity fed, and its feed rate was 19.4 to 22.9 kg/h. The screw rotation was 32 rpm, and the temperature and pressure in the barrel were not measured.

Sample analysis. Water, oil, foreign material and chemical analyses of crude oil and presscake were analyzed by standard methods. Samples were analyzed for water content by drying at 105°C for 24 h. Crude oil content in seeds and presscake samples was measured according to the Japanese Oil Chemists' Society method (22). Crushed sample (10 g) was heated 1 h at 105°C, then submitted to Soxhlet extraction with petroleum ether for 8 h. Crude oil is expressed on a dry basis, as the mean of triplicate determinations. Foreign material in expressed oil was measured by Soxhlet extraction after mixing recovered oil with defatted dry sand. Chemical analyses (see Table 1) of the oil and chlorogenic acid measurements were carried out by the Japan Food Research Laboratory (Tokyo, Japan) according to the official methods of the Japanese Oil Chemists' Society (22).

Samples (50 g) of sunflower seeds, final presscake and intermediate presscake taken from the screw channel were suspended and shaken at 25°C for 60 min in 200 mL water on a swing shaker (Taitec R-30, Taiyo Kagaku Kogyo, Tokyo, Japan) at 125 rpm. Then the total slurry was successively filtered on 3, 2, 1 and 0.5 mm opening sieves to separate all particles. All fractions were dried at 105°C, then weighed for measurement of the particle size distribution of the dry matter. The original seed or presscake was crushed and extracted by petroleum ether with no

TABLE 1

Oil Quality, Experiment 1

Screw press	Seed type	Water (%)	α-Tocopherol[a] (mg/100 g oil)	Foreign material (w/w%)	Acid[a] value	Peroxide[a] value (meq/1 kg oil)	Wax[a] (%)	AOM[a] (h)
Twin-screw	Dehulled	0.34	72.0	1.24	1.23	10.8	0.89	7
Single-screw	Nondehulled	0.12	73.2	2.65	1.00	5.3	0.81	7
Single-screw	Dehulled	0.91	70.8	8.39	0.97	7.5	0.67	7
Single-screw[b]	Nondehulled	0.07	84.6	0.01	2.03	14.9	0.69	3

[a] Analyzed by Japan Research Laboratories. AOM, Active Oxygen Method for measuring fat stability on autoxidation, this value is the time (h) to reach a POV value of 100 in the oxidation condition.
[b] Commercial filtered oil from a single-screw press (commercial type).

additional thermal treatment, then pulverized to pass a 500-micrometer sieve. The NSI of defatted seed and presscake powders was measured according to AOCS Methods (23).

RESULTS AND DISCUSSION

Experiment 1. Figure 4 shows the oil recovery from sunflower seeds with and without hulls. Oil recovery means the weight of expressed oil as a percentage of all oil in the starting seeds. The single-screw press used in this experiment could express more than 70% of the oil from seeds with hulls, but almost no oil (less than 20%) from dehulled seeds. On the other hand, with the twin-screw press we could get 93.6% oil recovery from dehulled seeds. This is caused by the screw combination. Intermeshing twin screws have a positive displacement effect, preventing material from rotating with the screw as in the single-screw expressing of dehulled seeds without a force feeder or breaker bars. Figure 4 shows the additional merits of dehulled seeds. Oil content of dehulled seeds is high, 20% more when compared to seeds with hulls. If the feed rates are the same, more oil can be expressed from dehulled seeds. Also, the presscake is higher in protein when dehulled seed is used.

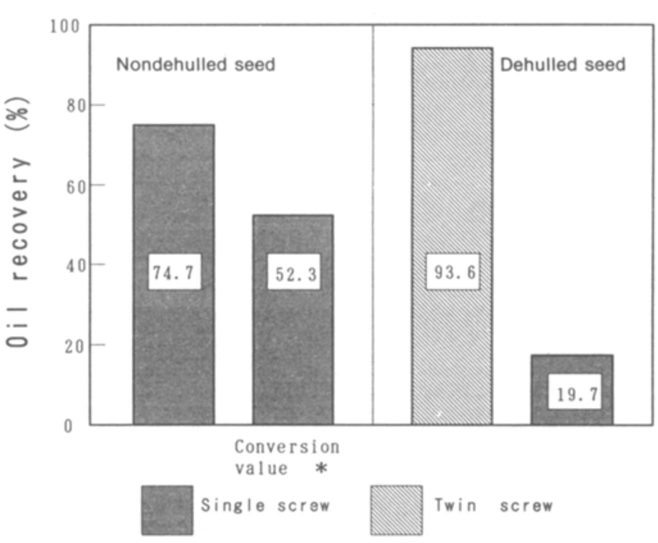

FIG. 4. Oil expression efficiency. Oil recovery is calculated as a percentage of total oil in the starting material. *The converted value was calculated on the basis of dehulled seed weight instead of the nondehulled seed weight.

The quality of the oil expressed with the twin-screw press was better than that expressed with the single-screw in foreign material content (Table 1). Acid values are similar, and are lower than in commercial filtered oil. The higher acid value and peroxide value of twin-screw expressed oil suggest that an oxidizing enzyme did not deactivate under the low temperature conditions of twin-screw expressing, and the opportunity for contact was increased under these mixing conditions. For reference, commercial filtered oil (No. 4) is shown in Table 1. A difference of α-tocopherol between 1–3 and 4 was caused by differences in the sources of the seed.

Table 2 shows the change in NSI of presscakes from single- and twin-screw presses as compared to the original seed value. The decrease in NSI value of single-screw press cake was greater than for the twin-screw's. This NSI decline might be caused by heat generation with shearing in the single-screw press. By reducing the clearance of the outlet in the twin-screw press, we increased the amount of shear that went into the presscake. Thus the protein was less soluble when a smaller clearance was used.

Dehulled sunflower seeds were used "as is" (without any pretreatments) to test the screw press efficiency for replacing each step of the usual pretreatment processes (size reduction, flaking and thermal treatment). During expression, extraction of oil with minimal foreign material and production of high-quality (not overheated) presscake of minimal remaining oil content and high throughput were desired. Energy consumption of oil expression is indicated in Table 3. The twin-screw press was confirmed to be the most energy efficient.

TABLE 2

Protein Change During Oil Expression

	Single-screw presscake	Twin-screw presscake Wide clearance	Twin-screw presscake Narrow clearance
NSI change ratio[a]	34.3	82.0	60.6

[a] This value is the ratio of the NSI value of the presscake to the NSI value of the original seed (%).

TABLE 3

Electrical Energy Consumption, Experiment 1

Screw press	Seed type	Expressed oil (kg/h)	Electricity consumption of motor (kwh)	Unit energy consumption (kwh/kg oil)
Twin-screw	Dehulled	23.45	3.4	0.14
Single-screw	Dehulled	2.86	3.5	1.25
Single-screw	Nondehulled	5.29	3.5	0.67

TABLE 4

Results of Experiment 2

Oil quality				Oil recovery (%)	Expressed oil (kg/h)	Unit energy consumption (kwh/kg oil)
Water (%)	Foreign material (%)	Acid value	Wax (%)			
0.18	0.50	0.93	0.77	93.7	31.9	0.11

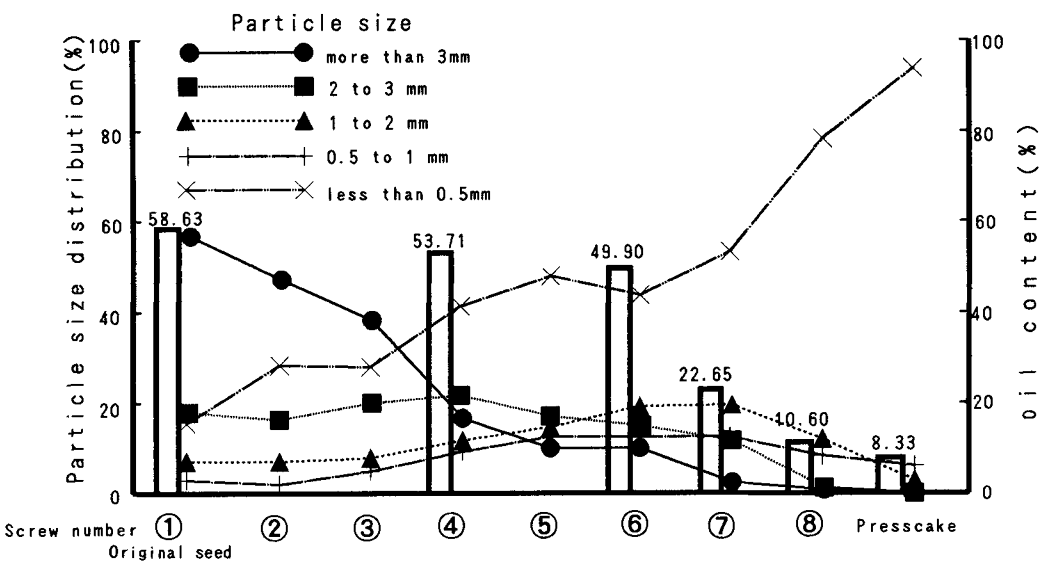

FIG. 5. Particle size distribution and oil content of presscake along the expression path by the dead stop technique (Experiment 2).

Experiment 2. The effect of improving the outlet discharge and adding narrow-pitch screw segments is indicated in Table 4. Foreign material and energy consumption were reduced, and oil recovery was increased a bit in spite of an increase in the feed rate.

Changes in particle size distribution and oil content of material at different points along the twin-screw press are shown in Figure 5 for Experiment 2. By using the dead stop procedure during the experiment, it was possible to disassemble the screw press barrel while still full of material, and to sample partially crushed and expressed seeds at different locations. The total expressing process therefore can be analyzed as a continuous change of the physical properties and chemical composition of the material through the screws.

The total barrel length is divided into two sections for better recovery of the oil. One is a feeding and first-step pressing section, with large slit openings. Then there is a high pressure section with narrower slits, to more completely express oil from the presscake. In the feeding section, sunflower seeds are conveyed by the twin screws, and size reduction begins as seeds are "flaked" in the intermeshing zone between the two screws. The reduction of displaced volume in the next section allows some oil to be evacuated through large slit openings and not flow back to the feeder. Oil mainly comes from later sections where the crushed seeds are actually expressed. The progressive size reduction correlates with the design of large slits in the first section (where mainly large seed particles are processed) for a maximum drainage of almost foreign-material-free oil. A screw section of larger pitch is used to separate the first and second sections and to limit the backflow effect. In the high-pressure section, a drastic reduction of the available volume, the mixing and crushing effect of the screws and the flow limitation due to the choke finally reduce both particle size and oil content of the presscake. The final presscake contains mainly agglomerated fine particles and less than 10% oil.

All results suggest that this new twin-screw press expresses the oil from oilseeds with high efficiency and produces a superior quality oil and meal, especially for material that cannot be expressed by single-screw presses without a force feeder, such as dehulled sunflower seed. Using a twin-screw press also will omit the usual pretreatments of cooking or flaking. The result is that energy consumption for the overall process will be much lower than single-screw processes. And the twin-screw pressing resulted in less protein denaturation as compared to the tested single-screw press. The results from Experiment 2 suggest that this twin-screw press has good crushing ability and, therefore, can be used for oil expression from small seeds, such as rapeseed and sesame seed.

Today, oil milling companies and press manufacturers are trying to improve the screw press to achieve higher oil expressing efficiency and get high-quality oil and meal. The twin-screw press is one possible advance in the oil production process.

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