Extrusion-based oilseed processing methods

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Oilseeds occupy an important place in global agriculture by providing vegetable oils and high-protein meals for food, feed and industrial uses. The leading oilseed crops by volume of world production are soya beans, cottonseed, groundnut, sunflower, canola, coconut and palm. Soya beans constitute the largest share of the world oilseed supply, accounting for 57% of global production from 2001 to 2002.

The oil content of oilseeds varies considerably among crop species, cultivars within species, and the agroclimatic conditions under which they are grown. The economic exploitation of oilseeds begins with the primary process of separating oil and protein meal. The technology of oil separation (*Table 1*) has progressed from primitive manual methods to mechanical methods, and to chemical methods using organic solvents. Today, solvent extraction using hexanes is the method of choice for large-scale oil extraction.

Mechanical and hydraulic devices

In the early phases of development, heat was used to condition oilseeds for extraction. Heat conditioning dries the seed, denatures the protein, and reduces the viscosity of the oil. Oilseeds are crushed using mortar and pestle, followed by steaming in open vessels.

The steamed mass was packed while hot into sock-shaped baskets of intricately woven cane. The basket was held inside the borehole of a large log. The oil was pressed out by driving a wedge between the basket and the side of the borehole.

The next development in oilseed extraction technology was hydraulic pressing devices. High-oil bearing seeds were dry heated in open pans or in steam-jacketed vessels. The material was then pressed in perforated baskets by gradually applying hydraulic pressure.

Screw presses

The next development occurred around 1908 with continuous screw pressing, a practice that is still prevalent outside the United States. The screw press consists of a flighted screw rotating within a slotted barrel. It is also often referred to as an 'expeller'.

The barrel is of fixed diameter and the root diameter of the screw increases from the feed end to the discharge end. This design achieves increasing pressure by compensating for volume reduction due to product compaction, thereby achieving oil removal through the slotted barrel while retaining the partially defatted solid mass within the barrel.

Continuous screw presses have been used in two ways in oilseed extraction for over 80 years. The first is full-press operation, where the oilseed, after heat conditioning, is pressed one or more times through the same press or through several presses installed in series. In these cases, the screw press is the sole means of extraction.

Solvent extraction

With solvent extraction, soya beans are prepared by cleaning, drying, tempering, cracking, dehulling, conditioning and flaking. The flakes are extracted using an organic solvent, usually a petroleum distillate high in n-hexane. The advantage of this process is high extraction efficiency, with the residual oil in the meal potentially reduced to 1 to 2%.

Solvent extraction is well suited for extremely large-scale operations with the associated economies of scale. As the cultivation of soya beans expanded tremendously over the past half-century,

Table 1: Quality characteristics of soya bean meals recovered in commercial practice by different oil extraction processes.

	Processing method		
Property	**Extruding-expelling**	**Solvent extraction**	**Screw pressing**
Moisture (% as is)	6,9	11,7	11
Oil (%)[a]	7,2	1,2	5,6
Protein (%)[a]	42,5	48,8	43,2
Urease (ΔpH)	0,07	0,04	0,03
KOH solubility (%)	88,1	89,1	61,6
PDI (%)	18,1	44,5	10,6
Rumen bypass (%)	37,6	36	48,1
Colour (Hunter L)	65,8	69,1	51,5
Trypsin inhibitor (mg/g)	5,52	5,46	0,03
Trypsin inhibitor (TIU/g)	12 250	5 275	2 000

[a]At 12% moisture basis.

solvent extraction technology was able to handle the ever-increasing crop volume.

Traditional extruders

Extruders are mechanical devices in which a feed material is transported by a screw rotating within a closed barrel under varying conditions of heat, shear and pressure, and then discharged through the openings in the optimal geometry for the desired product. These machines are used in processing food, feed and industrial products. Extruders vary widely in design, function, capabilities and cost.

Expanders for solvent extraction

Two types of extruders have found applications in the oilseed processing industry. The first type is the class of extruders called expanders. The general design of the expander consists of an unsegmented barrel housing a worm screw with interrupted flights. Expanders are provided with needle valves at the flight interruptions to inject water or steam into the product stream (usually flakes).

The expander converts flaked materials into porous collets that are much denser than flaked oilseeds and allow more material in the fixed volume solvent extractor. This transformation increases the throughput capacity and efficiency of subsequent solvent extraction.

Interrupted flight expanders are used ahead of solvent extractors in many soya bean processing plants. The original design for expanders was not capable of forming collets from high-oil bearing seeds. This was due to the accumulation of oil within the closed barrel, causing slippage and unsteady mass flow. A new design called the Hivex Expander, which married an expander to a screw press, was developed by Anderson International to remove part of the oil from the expander barrel.

Dry extruders for feed applications

These are high-shear extruders running at screw speeds of about 600r/pm. They fit the needs of small-scale processing operations in remote places where utilities such as steam sources may not be readily available.

Cooking soya beans in dry extruders results in full-energy soya beans as all the original fat is present. Full-energy soya beans have the advantage of being not only a good source of protein, but also a generous source of metabolisable energy from the oil. Proper heat processing denatures protein and inactivates natural soya bean protease inhibitors (trypsin inhibitors), thereby maximising the qualities of protein and energy in soya beans.

Accepting new technologies

Oilseed crushers are facing a delicate balance between control of hexane emissions and containment of energy costs. The 1990 *Clean Air Act* caused much concern regarding hexane emissions. n-Hexane, the main component of the distillate fraction known as "hexanes," is one of 189 hazardous air pollutants listed in the *Clean Air Act*, and hexane is regulated as both a criteria pollutant and a hazardous air pollutant.

The emission limit for hexane as a criteria pollutant is 49,6 tons per year and as a hazardous air pollutant is 4,9 tons per year. Exceeding either limit requires a federal operating permit and an annual fee based on the level of hexane consumption.

The application of extrusion technology in oilseed extraction has received considerable attention during the past 15 years. Much of the development has taken place in the soya bean processing industry. Soya beans have become increasingly important as a food source in meeting acute nutritional needs around the world, especially in developing countries.

In some countries, soya bean production is practiced on small farms over widely scattered areas. The infrastructure for collecting, handling and transporting seed to a central processing facility is unavailable and impractical. Under these circumstances, new technologies for small-scale operations on a decentralised basis has become a necessity.

There has also been a new awakening on the part of consumers with respect to health and organic foods. With the advent of transgenic soya beans (genetically modified organisms, or GMOs) to achieve resistance to certain herbicides, demands for certifiable identity preserved, non-GMO soya beans and their oil and protein products for food and feed, have grown.

Low-linolenic soya beans (<1% linolenic acid) developed at Iowa State University are one example. This oil does not require partial hydrogenation with attendant production of trans-fatty acids to achieve good oxidative stability. Trans-fatty acids will soon have to be labelled as fat.

Large-scale solvent extraction plants find it, in most cases, technically and economically infeasible to preserve the identity of specialty soya beans during processing. Their scale is usually far too great for the available supply and demand for these products. Typical soya bean solvent extraction facilities have crushing capacities exceeding 3 000MT per day.

The high capital costs to control hexane and meet environmental emission and safety requirements require these plants to have large capacities to be competitive. Therefore, technologies to process soya beans without using solvents and to be consistent with identity preservation have become necessary. Processing without solvents is also an attractive proposition based on environmental considerations because of increasing pressures to reduce emissions of organic compounds.

Mechanical oil extraction

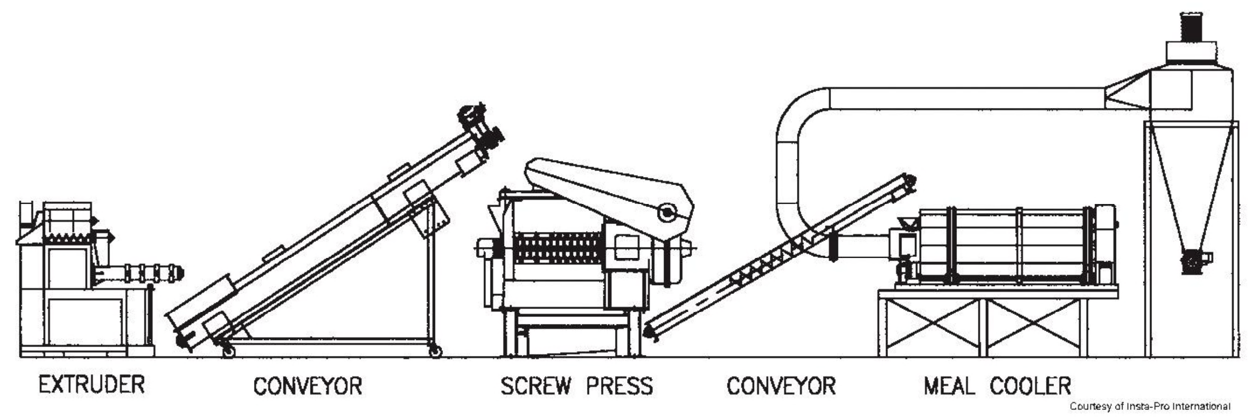
Nelson *et al*. in 1987 reported the use of dry extrusion as an aid to mechanical expelling of soya beans. They reported that when coarsely ground soya beans were processed in a dry extruder, the material discharged was in a semi-fluid state when the extrusion temperature was about 121 to 135°C. They pressed the hot extrudate in a hydraulic press as well as several pilot-plant models of continuous screw presses.

When the extrudate was pressed immediately after exiting the extruder, it was possible to press out the oil easily and efficiently. However, upon cooling, the extrudate turned into a dry meal. Pressing at this stage resulted in drastic reduction of oil yield.

The authors reported 71,8% extraction of oil in a single pass through the extruder and screw press system (*Figure 1*). The residual oil content in resulting press cake was 5,8 to 9,7%. Another significant finding was that the throughput capacity of one of the presses tested was 125 to 135kg/h of extrudate, compared with the manufacturer's rated capacity of 39kg/h for pressing whole soya beans.

Nelson *et al*. postulated that increased throughput capacity was due to the functions of grinding, heating and release

Figure 1: Schematic of an extruder screw press system.



of oil by the extruder before entry into the screw press. In an effort to produce low-fat soya flour suitable for human consumption, they proceeded to extrude and press dehulled soya beans. The trypsin inhibitor activity in raw soya beans was reduced by 91% due to the heat exposure during the extruding and screw-pressing operations.

Scaling up mechanical processing

Nelson and his colleagues collaborated with Insta-Pro International, the manufacturer of dry extruders, to scale up the extruding and screw-pressing process. The process became known in the trade as Express Systems, a registered name of Insta-Pro International. Among academicians, this process is often referred to in the scientific literature as extruding expelling.

Extruding-expelling system

The extruder screw is assembled on a central keyed shaft using several screw segments. The root diameter of the screw is constant. The pitch of the screw segments is variable so that the screw assembly can be configured to exert more or less shear, depending on the material being processed and the shear desired.

Shear locks, also called steam locks, are placed between the screw segments. These are discs that have a straight face on one side and are bevelled on the other side with radial grooves. The shear locks are installed with the bevelled side facing the feed end of the extruder. These locks are made in different diameters and land lengths. They impose restrictions in the path of the material being processed and thus generate mixing and shearing.

The clearance between the land of the shear lock and the internal surface of the barrel can be changed by choosing shear locks with certain diameters. The larger diameter shear locks provide a tight screw configuration resulting in high shearing rates. The screw assembly is held in place by a nose bullet with reverse threads screwed into the end of the shaft. The barrel is assembled in segments over the screw, and these segments are secured with clamps.

Unlike most other extruders, the barrel segments in the dry extruder are not jacketed because all the heat of cooking is generated internally by friction. This reduces manufacturing costs. The internal surface of the barrel is rifled to promote mixing and shearing. The discharge end of the extruder is connected to an end cap, which accepts dies of the desired size and shape. The die, also called the nose cone, is threaded into the end cap. Its inner face is bored in a conical shape to complement the geometry of the nose bullet. The die can be moved toward or away from the nose bullet while the extruder is operating.

The processing temperature profile is controlled by selecting the screw segments, shear locks and dies appropriate to the material being processed. A tight configuration is required to process soya beans because the oil in the beans acts as a lubricant. The die can be moved back and forth to achieve minor adjustments to the process temperature profile while the machine is operating.

Extruding

Whole or dehulled soya beans at normal field moisture content (9 to 13%) are continuously fed to the extruder. The extruder operates at screw speeds of approximately 600r/pm. During passage through the barrel, the material is sheared, compressed and heated. Heat is generated purely by the dissipation of mechanical energy.

The temperature and pressure increase gradually, reach a peak at the die, and drop drastically upon exiting the die. The average residence time of the material within the extruder barrel is less than 30 seconds. The temperature profile can be varied as desired by making equipment changes. The highest temperature at the die end is adjusted to 160°C when the processed soya bean meal is to be used as an end product.

Shearing forces exerted by the dry extrusion system disrupt the cellular structure. Upon exiting the die, the material is suddenly released to the atmospheric pressure environment. This sudden decompression results in explosive disruption of the cell tissue.

Screw pressing

The extrudate exiting the extruder is in a semi-fluid and frothy state, while the oil is free within the matrix. Upon cooling, the oil is absorbed back into the protein matrix and the material becomes a dry and mealy mass. In order to extract the oil, the extrudate must be pressed immediately after extruding. There is a progressive loss of oil extraction efficiency upon cooling of the extrudate. The soya bean extrudate is conveyed immediately and continuously into a screw press, where the oil is pressed out.

The physical properties of the soya bean extrudate coming out of the extruder are very different from those of cracked or whole oilseeds. The particle size of extrudate is also much smaller and the bulk density of the material is lower. Therefore, the pressing worm designed to extract whole or cracked oilseed will not perform well with soya bean extrudate.

It must be modified to provide more aggressive transport and the higher compression demanded by extruded material. With the proper combination of extruder and screw press, soya bean and cottonseed extrudates are pressed in one pass through the press.

It must be realised that both the oil and meal coming out of the extruder-expeller system are at elevated temperature depending on the processing parameters. Both the meal and oil must be cooled to near room temperature before they are sent to storage. The protein-rich meal that comes out of the press in the form of press cake is declumped by using a roller mill and is passed through a meal cooler.

A simple meal cooler design consists of a slowly rotating inclined drum through which a stream of ambient air is drawn at a controlled rate. The meal tumbles as it travels down the inclined drum while air is drawn counter-current to the path of the meal. The air picks up heat from the meal and passes into a cyclone separator, where entrapped fine material is recovered, and the warm air is exhausted.

The oil stream exiting the screw press carries small quantities of protein meal particles known as foots. The coarse particles are removed by passing the oil through continuous screening or settling basins. In large-scale operations, decanter centrifuges may also be used to separate the foots on a continuous basis. The foots can be recycled to the extruder to reclaim oil and meal.

The presence of any foots in the oil imparts a cloudy appearance and forms sediments in storage tanks. The oil stream must be cooled before being placed into storage in order to maintain oil quality. Plate heat exchangers or tubular heat exchangers using water as cooling medium may be used for this purpose.

Future prospects

The future for the extruding-expelling process seems to be bright as a means of processing identity preserved oilseeds into specialty oils and meals. The low cost of constructing plants and the reduced safety issues are additional advantages. There are now over 150 extruding expelling plants around the world and over 65 plants in the United States and Canada, with most processing soya beans.

As soya bean producers recognise opportunities for adding value to their crops and as consumers recognise the enhanced properties of soya products and health advantages of increased soya protein consumption, the extruding-expelling process will likely become more widely used.

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