Processing with ultrasonic energy

The following article reviews research on the possible use of ultrasonic energy to improve or enhance agricultural processing. It was written by Karl J. Moulton Sr., retired chemical engineer, Vegetable Oil Research, U.S. Department of Agriculture's Northern Regional Research Center, Peoria, Illinois.

In today's world, we all have heard and used the terms "sonic," "ultrasonic," "ultrasound" or "ultrasonic energy." In the past 20 years, we've come to recognize everyday applications of ultrasonic energy, such as imaging a baby in the mother's womb, exciting fluids to clean jewelry, welding plastics to form bags and containers, and degassing liquids. Scientists in the late 19th century little realized the industrial potential of their discovery that very fine particles could be agglomerated into larger particles by applying ultrasonic energy.

In the 1960s, scientific applications of ultrasound were reconsidered practical after several processes—such as dust precipitators—failed because they were carried out mostly in the audible range. Sound generators since then have improved and today we have more powerful and more efficient piezoelectric transducers. Now, an ultrasonic power supply transforms conventional line voltage to 20 kHz high-frequency electrical energy, and offers variable power control, automatic amplitude compensation and automatic frequency control.

The scientist can optimize a desired reaction by establishing limits of ultrasonic power input, temperature, pressure and flow rate in a reaction vessel. Ultrasonic action is the result of a phenomenon known as cavitation, the making and breaking of microscopic bubbles. The collapse of these minute bubbles produces localized shock waves, reported to be up to 20,000 atmospheres, sufficient to do useful work. Forces are great enough to literally tear molecules from the surface of hard materials. Localized heat also is generated which can initiate some reactions.

With very little imagination, one can visualize applications that can be improved by using ultrasonic energy. This article reviews research which used ultrasonic sound to extract protein or oil and to degum or hydrogenate oil. Several unreported, potentially feasible oil processes are suggested.

Oil extraction

In 1967, Schurig and Sole (1) reported the use of ultrasonic energy to extract cottonseed oil with ethyl alcohol. The authors studied one batch and four configurations of a stationary seedbed continuous system. The batch system was unsuccessful. A surface-mounted transducer in the continuous system improved mixing of the miscella and oil within the seed and gave high rates of extraction. However, the ultrasonic action was hindered in one configuration in which the stationary seedbed was resting on the transducer.

Soybean protein extraction

Isolated soy protein (ISP) usually is produced commercially from defatted soy flakes in batch-stirred tanks. Sixty percent of the total protein in the defatted flakes is recovered after 40-50 minutes' batch extraction of flakes with an aqueous solvent. In 1982, Moulton and Wang reported continuous ultrasonic extraction of soy protein as an alternative process to produce ISP from defatted soybean flakes (2).

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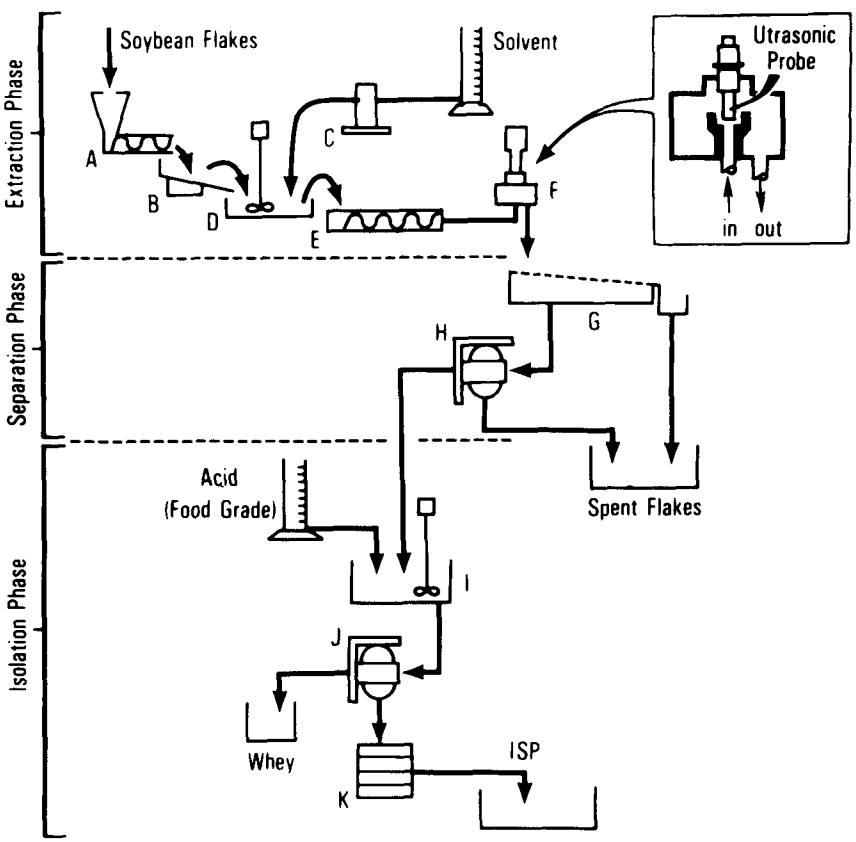

FIG. 1. Pilot-plant production of isolated soy protein (ISP) from defatted, low-temperature desolventized soybean flakes.

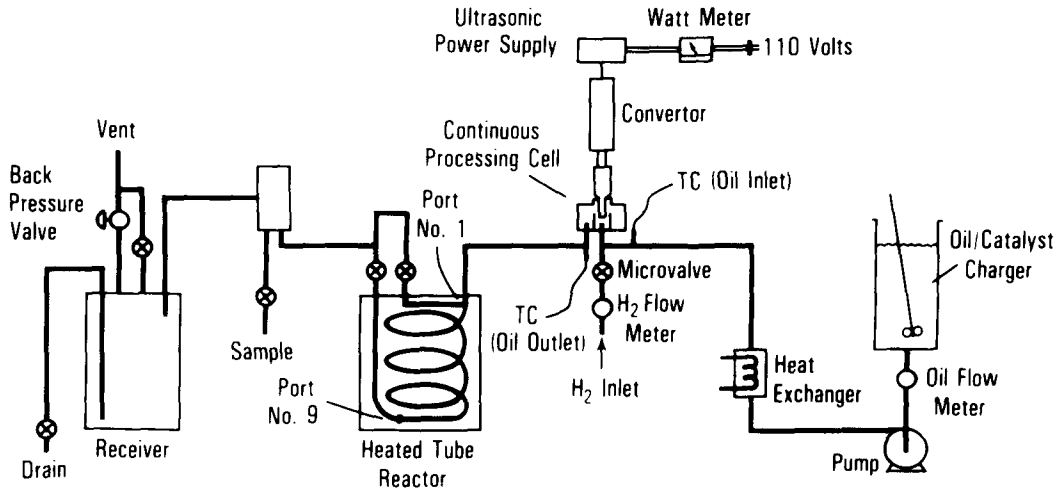

FIG. 2. Flow diagram for slurry hydrogenation of soybean oil with and without the use of ultrasonic power.

In the continuous process (Fig. 1), defatted soy flakes were metered (A and B) to combine with solvent (water or aqueous alkali) and pumped (C) into a small, stirred vessel (D). The flake/solvent slurry was then pumped (E) through the ultrasonic processing cell (F) and discharged onto a vibrating screen (G). Filtrate, containing peptized protein, passed through the screen and flowed to a centrifuge (H). The supernatant was sent to a stirred vessel (I) where foodgrade acid was added to precipitate the ISP, which was then separated (J) from the whey and freeze-dried (K). Ultrasonic energy was applied to the flake/solvent slurry in the processing cell using a 550-watt, 20 kHz power supply (Branson Ultrasonics Corp., Danbury, CT). A 1:1.5 booster horn between the converter and the 1-inch diameter titanium processing horn increased the longitudinal mechanical vibrations of the horn by 50%.

A batch 800-watt sonic cleaning tank was charged and operated with 50 grams (dry basis) of defatted flakes and 500 grams of tap water for comparison with the continuous ultrasonic process. Samples were withdrawn from the tank after sonicating for 2.5, 5 and 60 minutes. The batch ultrasonic extraction for 60 minutes required 250 times more energy than the continuous ultrasonic process to extract an equivalent amount of protein in 2.5 minutes. The flakes/solvent slurry was pumped in continuous flow through the ultrasonic processing cell without separating, foaming or biodegrading—which sometimes occur in conventional long-term batch reactions.

Oil hydrogenation

For the past 70 years, vegetable oils have been hydrogenated commercially in batch converters requiring extensive heat, power and manpower. Continuous systems, either constant flow or in stages, generally have been unsuccessful because of back-mixing and low selectivity.

In 1983, Moulton and colleagues (3) reported the continuous hydrogenation of soybean oil using an ultrasonic processing cell with an exposed transducer within the cell. A slurry of copper chromite catalyst (1%) or nickel catalyst (0.01%) and refined and bleached soybean oil was pumped through a preheater and ultrasonic processing cell to a receiver (Fig. 2). Ultrasonic energy was produced by a 550-watt, 20 kHz power supply to a 1-inch diameter titanium processing horn inserted in the stainless steel high-pressure processing cell. Although a search of the literature indicated chemical reactions could be enhanced with the application of ultrasonic energy, water or a low vapor-pressure solvent was required. The authors found that soybean oil could be hydrogenated rapidly with ultrasonic energy in a three-phase (liquid oil/H_2 gas/solid catalyst) nonaqueous system. The catalyst activity did not significantly improve at hydrogenation pressures of 200 psig and greater. However, with copper chromite catalyst at 115 psig and 181°C, soybean oil was selectively reduced to an oil with 1.0% triene in nine seconds. Although the linolenate selectivity by the process was lower (5 to 7), compared with that by a conventional batch hydrogenation (10), it was considerably better than the selectivity (1 to 2) by commercial hydrogenation of soybean oil with nickel catalyst.

In 1987, Moulton and colleagues (4) reported on the parameters of continuous ultrasonic hydrogenation that influence the quality of the resulting products. The effects of varying ultrasonic power, temperature, pressure and concentration of nickel catalyst were studied. Test oils were compared with each other and with commercially hydrogenated soybean oil by an experienced taste panel. The process-

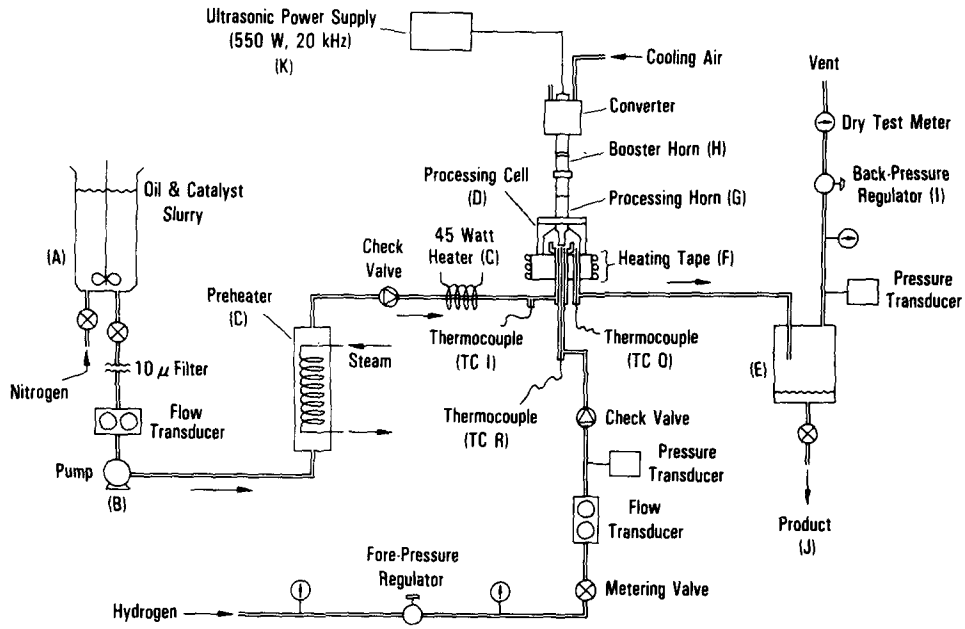

FIG. 3. Flowsheet for the continuous ultrasonic hydrogenation of soybean oil.

ing system (Fig. 3) was similar to the system previously reported, with modifications to permit better temperature control and measurement. The same ultrasonic power supply and processing cell were used. An amplitude-decreasing (1:0.4) booster horn was used and thermocouples were inserted in the inlet line (TC I) directly under the processing horn (TC R) and in the outlet line (TC O). As before, hydrogen and catalyst/oil slurry was introduced coaxially beneath the processing horn (G). Continuous ultrasonic hydrogenated test oils were prepared by varying temperature (270 and 290°C), pressure (65 and 106 psig), catalyst concentration (40, 80, 120 and 150 ppm Ni) and ultrasonic power level (100, 40 and 0% of full power). Residence time in the reactor was nine seconds. Also, the same lot of refined and bleached soybean oil was batch-hydrogenated in a stirred autoclave at the same temperature and pressure for nine seconds and 480 seconds to produce oils to compare with continuous ultrasonic hydrogenated oils. By accurate measurement of reaction temperatures, the authors were able to attain reproducible hydrogenation conditions and determine the effect of only the ultrasonic action on the hydrogenation rate. It was surprising to observe lower specific power (watts/IV) when the ultrasonic power was lowered from full power to 40% of full power.

The flavor of post-bleached and deodorized oils of similar composition, hydrogenated continuously with and without ultrasonic energy, batch hydrogenated and commercially hydrogenated, were evaluated by an experienced taste panel. Initially all oils were rated as good quality. After storage for eight days at 60°C, however, flavor scores of commercially hydrogenated oils were significantly lower than oils hydrogenated continuously with ultrasound.

In 1988, Covey and colleagues (5) successfully hydrogenated refined and bleached soybean oil with ultrasonic energy produced by a 375-watt power supply in a specially designed batch reactor. The bottom of the reactor could be moved to change the reactor volume, thus changing the distance ultrasonic waves traveled in the oil. The reactor was heated by immersion in a temperature-controlled oil bath. The hydrogenation rate in the smaller volume reactor was about five times faster in the presence of ultrasonic energy at 170°C and 0.02% nickel catalyst, depending on the hydrogen pressure, than in a conventional stirred-batch reactor.

Crude oil degumming

Phospholipids are difficult to remove from crude soybean oil without prior chemical treatment or pretreatment and without causing environmental problems. Figure 4 compares current acceptable methods to refining crude oil with a proposed continuous ultrasonic method.

Chemical refining involves treating the crude oil with NaOH to remove free fatty acids and phosphatides. The refined oil must be washed and dried; the soapstock must be treated further and washed. Usually a batch process, chemical refining is energy- and labor-intensive. Treatment of the waste caustic water, waste acid and waste acid water must be done to minimize environmental pollution.

Physical refining eliminates some of the problems resulting from the chemical refining process. However, to be effective, crude soy-

bean oil must be pretreated with H_3PO_4 to condition the phosphatides in the crude oil so that they are effectively hydrated with water later. Degummed oil from the physical refining process must be washed to rid the oil of residual H_3PO_4, which causes a "melon" flavor in the final product. Like chemical refining, physical refining is usually a batch process and is energy- and labor-intensive.

Continuous ultrasonic degumming, as described by Moulton and Mounts (6), eliminates the problems resulting in the chemical and physical refining processes. Simply, crude soybean oil was continuously combined with nearly stoichiometric amount of water just prior to contacting the ultrasonic processing horn. Heating the crude oil was not required. Alkali or acid treatment of the crude oil was not required. The oil-hydrated gums were then centrifuged, without cooling or drying, to separate degummed oil from the gums. The ultrasonic degummed oil was ready for bleaching without drying (since the water used was combined with the gums). The gums were ready for processing into lecithin products.

The continuous ultrasonic degumming process equipment (Fig. 5) consisted of a 750-watt, 20 kHz power supply (Branson Ultrasonics Corp., Danbury, CT), converter, 1:0.5 booster horn, 1-inch diameter titanium processing horn and stainless steel high-pressure processing cell. A diagram of the processing cell (Fig. 6) shows the design of the processing cell and the flow of oil/water through it. As with the continuous ultrasonic hydrogenation process described above, thermocouples were located strategically to measure temperatures of the inlet oil, oil in the reaction zone and the exit oil. With a good (low phosphorus) crude oil, 99% of the original phosphorus was removed at 40°C in 0.8 of a second. Degumming continuously with ultrasonic sound was five times faster than batch degumming to achieve the same degree of phosphorous removal. Furthermore, batch degumming also requires time to charge and discharge the

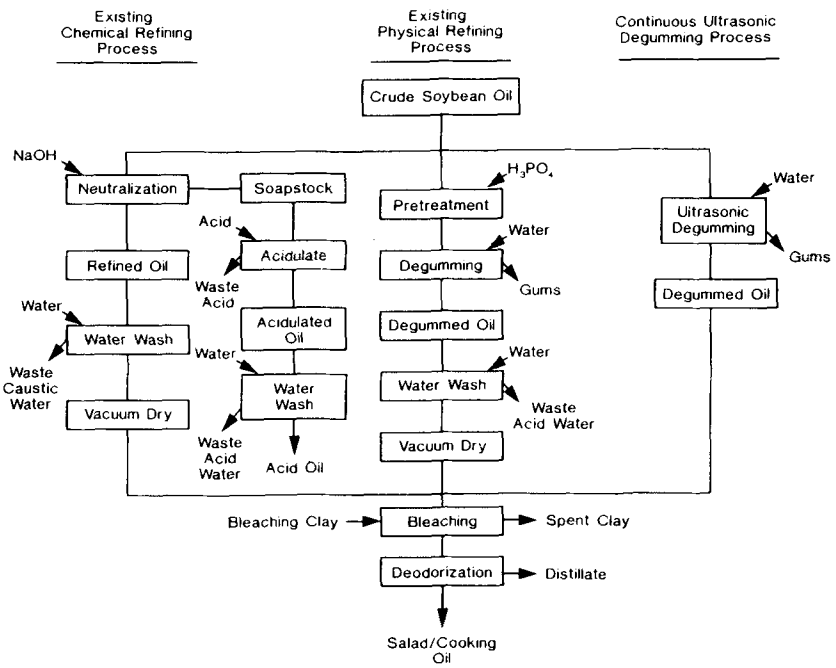

FIG. 4. Comparison of existing chemical refining process, existing physical refining process and proposed continuous ultrasonic degumming process.

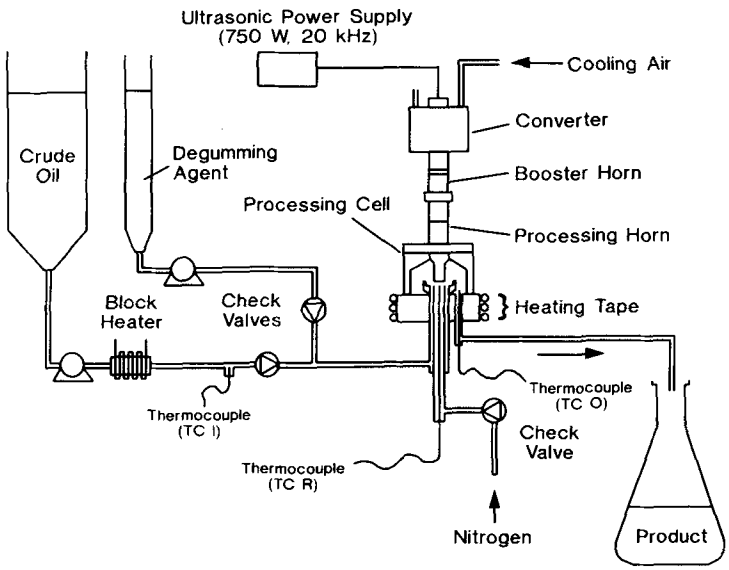

FIG. 5. Flow diagram showing equipment used for continuous ultrasonic degumming of soybean oil.

vessel, to heat the oil to degumming temperature and to cool the product.

Of course, for complete satisfaction, the final deodorized oil from continuous ultrasonic degumming must be as good or better than an oil produced by chemical or physical refining methods. In this study, freshly deodorized ultrasonic and batch degummed oils and the same oils stored four days at 60°C showed no significant flavor difference. *(Continued)*

Potential use in agricultural processes

Ultrasound use may offer an improved or more efficient solution to inherent and sometimes mounting problems encountered in processing agricultural products. For instance, continuous ultrasonic extraction of oil from oilseeds, incorporating the new ultrasonic piezoelectric transducer, appears to be feasible in much the same manner as that used to extract protein from soy flakes. Perhaps different and safer solvents can be successful. Since alkali or H_3PO_4 in conventional refining of oils must be washed from the oil product, continuous ultrasonic washing offers a practical solution.

Ultrasonic cavitation may improve contact of oil with bleaching earth and the adsorptive ability of the earth. By choosing the proper flow rate, temperature, ultrasonic power and amplitude (booster horn selection), continuous rapid decolorization and removal of peroxides from the oil should be possible. Also, ultrasound may assist the reclamation of spent catalysts and spent bleaching clay.

Cavitation occurs when a sound wave, transmitted through a liquid, reduces the absolute pressure below the vapor pressure of the liquid. Static pressure in a reactor is the most important factor because it is the difference between static pressure and the vapor pressure that determines the peak force of the shock waves. For this reason, it seems difficult to achieve deacidification/deodorization with ultrasound at the same reduced pressure currently used. However, if deodorization could be achieved continuously, quickly and at low temperature, it would be worth the research effort.

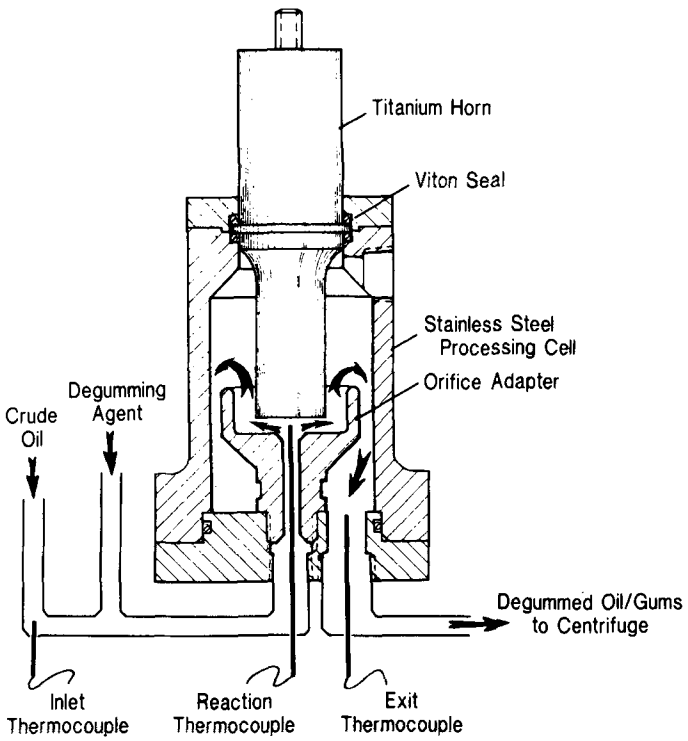

FIG. 6. Schematic of ultrasonic processing cell.

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