A Unique Approach to Micronization

BY JEFF GWIRTZ | KANSAS STATE UNIVERSITY, R. CARL HOSENEY | R&R RESEARCH SERVICES INC., F. DOWELL | USDA/ARS GRAIN MARKETING AND PRODUCTION RESEARCH CENTER, R. HUBBARD | PULSEWAVE LLC

Introduction to Resonance Destruction

Resonance destruction occurs when the vibration of a certain material exceeds its natural resonance frequency. Objects have a natural frequency in which they will move in oscillation and vibration. When working within that frequency, things move along pretty smoothly. However, problems can arise when the natural frequency is accelerated or changed.

Consider when a child is pushed on a swing set – there is a certain natural frequency that occurs which is based on the length of the chain or weight of child. If there is a change to that natural frequency the kid will either fly out of his/her seat, or smash into the pusher and knock him/her over. When something is pushed beyond its natural frequency it will absorb as much energy as possible; releasing what it can't absorb. That energy loss occurs as heat, sound or light – and the object breaks apart.

Another important example of resonance frequency is the failure of the Tacoma Narrows Bridge – the third longest suspension bridge at the time it was built. In 1940, within 4 months of its opening, the bridge vibrated into pieces when a 42-mile-per-hour wind pushed it at just the right frequency. The bridge absorbed energy and began to vibrate in order to dissipate the excess energy. Continued energy input exceeding the ability of the bridge to oscillate at its natural frequency resulted in the bridge breaking apart or self-destructing. Video clips and discussion of the Tacoma Narrows Bridge failure can be found online at: http://www.pbs.org/wgbh/nova/bridge/meetsusp.html#clips.

Resonance destruction is not a new technology or phenomenon but is a new technology to be applied to grain processing. The Pulsewave™ Technology machine uses resonance destruction as a major component of force in processing material. In the Pulsewave Technology, material is not being impinged on another surface or processed between moving surfaces as in a conventional mill, rather entrained air is manipulated in such a way as to cause the material to achieve and exceed certain natural vibration frequencies. With a roller mill, compression and shear are the main forces imposed on the particle as it moves between the rotating surfaces of the roll chills. In a stone mill this action is friction and abrasion. Particle failure or reduction under compression, shear, abrasion and friction does not appear to follow natural lines of fissure. This observation may result from our ability to control and stop these processes once initial particle breakage has occurred. The unique benefits of achieving and exceeding natural vibration frequencies is that product breaks along natural lines of fissure offers an opportunity to enhance control of particle size reduction.

How do resonance frequencies and destruction relate to milling? Soft wheat millers obtain very fine particle size flour in large part because the protein matrix tends to cleave very small particles away from starch granules quite easily. Hard wheat millers find that the protein matrix tends to hold itself to the starch granules with more tenacity. As a result, we can observe slightly higher starch damage in hard wheat milling than in soft wheat milling. In order to increase starch damage of hard wheat flours some millers intentionally flake endosperm, creating starch damage. They then break that flake down through other types of destructive processes as the material moves toward the sifter. Particle size reduction along these natural lines occurs in typical roller milling processes. Through controlled resonance destruction it might be possible to facilitate separation more readily along anatomical structures such as aleurone, bran, germ and endosperm. Such ability would allow for improved flour extraction and better control of contamination of endosperm/flour with bran and other fractions.

The Pulsewave™ Technology Machine

Table 1 shows some basic information about the Pulsewave unit. It has a capacity range of 500-8,000 pounds per hour depending on the type of material being processed. The maximum particle size that can be fed into the unit is limited to three inches by three inches. The machine is reported to have cryogenic capabilities, which would be particularly useful in spice processing where volatile oil retention would be critically important. The footprint is fairly small: four feet by eight feet. The installation in Centennial, Colo., is 17 feet tall. Other forms of the machine are being developed so size will likely change.

Raw material throughput	500-8000 lbs/hr (varies by material)
Max raw material size	3 inches by 3 inches
Cold processing	YES
Extraction capability	YES
Generate stable emulsions	YES
Footprint	4 feet by 8 feet
Particle size	<1µ for many materials
Particle consistency	tight bell curve for homogenous materials

Pulsewave Processed Whole Grain Cereals and Oil Seeds

Three important points of interest shown on the volume-frequency distribution curve for whole brown rice (Figure 1) are $D_{0.50}$, $D_{0.90}$ and $D_{0.10}$. $D_{0.50}$ is the particle size diameter at which half the particles are above and half are below the stated size, and $D_{0.50}$=94.242 microns (µm) in this sample. $D_{0.10}$ is the micron size at which 10 percent of the particles are smaller than this diameter, and is 7.761 µm for this sample. Likewise, 90 percent of the particles are smaller than $D_{0.90}$, which is 694.894 µm for this sample. Rice is very hard and difficult to grind into flour with the same particle size distribution as wheat flour. The Pulsewave Technology process used here accomplished this considerable particle size reduction in a single pass.

A change in speed and other operational parameters appears to allow for production of light rye, medium or dark rye flour in a single pass (Figure 2). The proportion of the various types of rye flour could be easily managed using Pulsewave Technology. This could simplify the gradual reduction system used to produce these various grades of rye flour.

Pulsewave Technology is also capable of processing high oil products, such as raw soybeans (Figure 3). As suggested earlier, the machine breaks material at natural lines of fissure. In the case of oil seeds, improved separation of oil-containing bodies may help in oil recovery. If grain has oil packets or oil cells in it, Pulsewave Technology tends to break apart and not disrupt that oil cell, thus preventing oil or fat from leaching into other parts of the product. Samples of Pulsewave Technology processed grains under magnification show fluorescent cells containing the oil intact, which

Figure 1. Particle size distribution of whole brown rice processed using Pulsewave Technology

Figure 2. Particle size distribution of rye processed using Pulsewave Technology

Figure 3. Particle size distribution of soybeans processed using Pulsewave Technology

Figure 4. Particle size distribution of whole kernel corn processed using Pulsewave Technology

Figure 5. Particle size distribution of hard red winter wheat processed using Pulsewave Technology.

suggests that oil did not leach into other parts of the product. This phenomenon would enhance product stability and the functionality of both cereal grain and oil seed based products in some cases.

Whole-kernel corn processed using Pulsewave™ Technology results in an interesting bi-modal curve (Figure 4). It is clear that some portions of the corn kernel are less easily broken down than others. As observed in rye processing, Pulsewave™ Technology can make a wide distribution of products from corn by changing speed and other operational parameters. The ability to alter granulation and limit disruption of germ may be useful in producing whole-corn products favored in some markets.

Wheat processed using this technology is shown in Figure 5. The larger particle size material shown in the frequency distribution is bran. The impact of two different speeds of the processing of hard red winter wheat is shown in Figure 6. The top curve shows the frequency distribution obtained at 4,000 RPM and the bottom curve at 4,500 RPM. The greater speed shifts the curve to the left and lowers the height due to the finer particle size distribution. The curve obtained at the faster speed is showing bi-modal tendency with bran material making up the material in the far right peak.

Figure 7 compares the cumulative granulation curves for commercial flour, and flour produced using Pulsewave Technology after one and two passes. The red line in Figure 7 is commercially available fine ground whole hard red winter flour. The green line is whole wheat flour produced using Pulsewave Technology at 4,500 RPM. The blue line is the cumulative frequency distribution for hard red winter wheat passed through the machine multiple times. The first pass was at 4,000 RPM while the second pass was at 5,500 RPM. Repetitive passes reduce particle size considerably.

Using multiple passes of Pulsewave Technology can result in generating a variety of products from the same material with distinctly different particle size distributions and functional properties. For example, multiple passes using Pulsewave Technology on wheat bran reduces the particle size to the point that a bit of processed bran on your tongue feels as if it dissolves. Figure 8 shows that a single pass using Pulsewave Technology can produce a very fine whole wheat flour product.

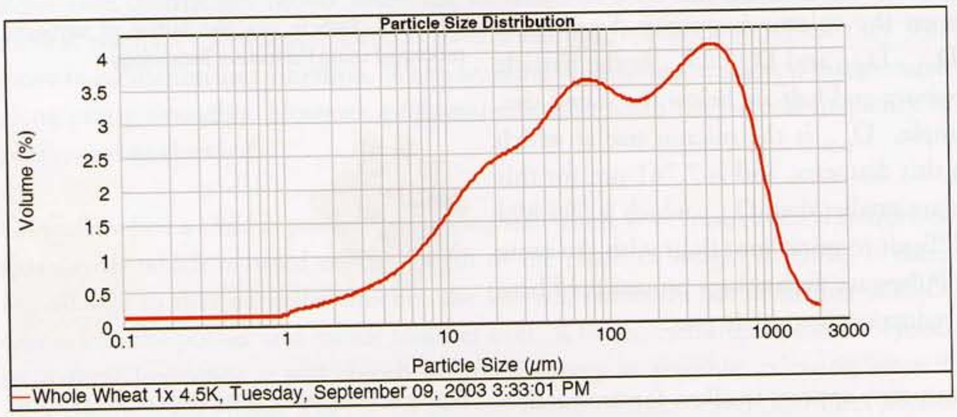
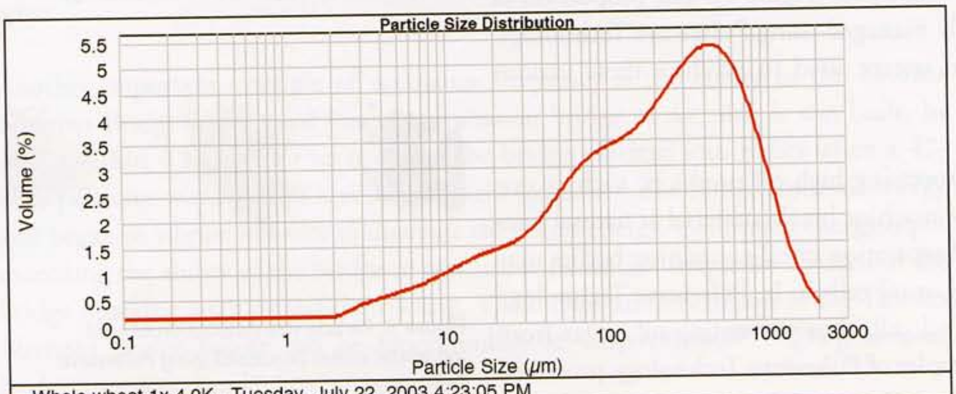


Figure 6. Particle size distribution of hard red winter wheat processed using Pulsewave Technology at two different speeds.



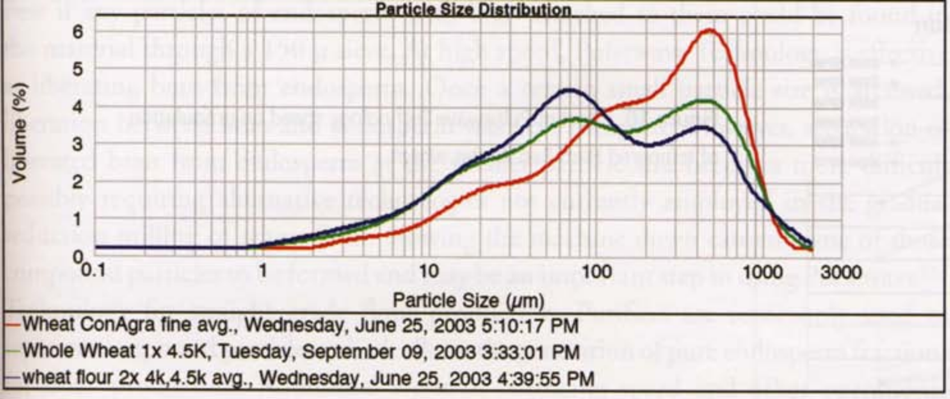
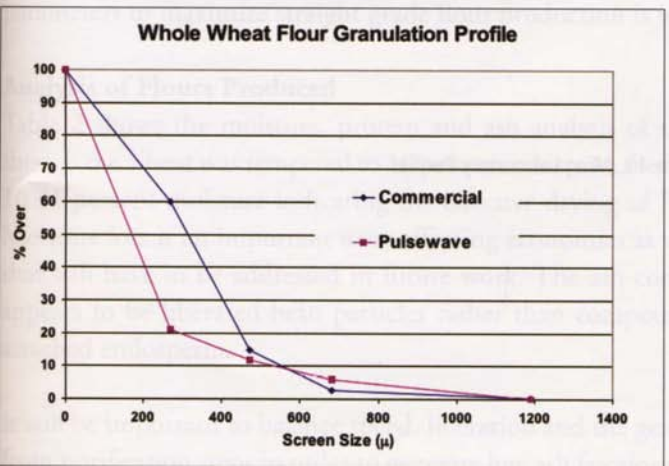


Figure 7. Cumulative granulation curves comparing commercial and Pulsewave™ Technology whole wheat flour.



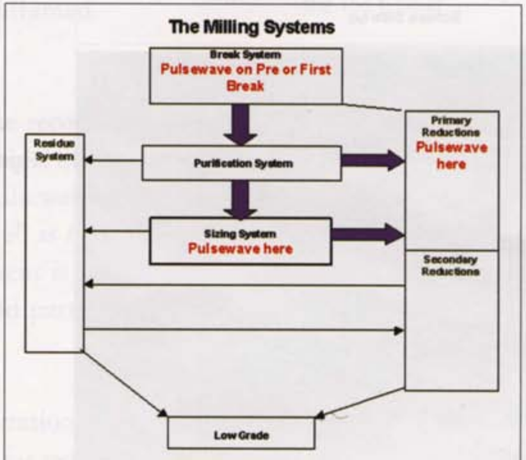


Figure 8. (left). Cumulative granulation curves comparing commercial and Pulsewave Technology whole wheat flour.

Figure 9 (right). Pulsewave Technology potential applications in the gradual reduction milling process for wheat

Applications in a Conventional Milling Process

Figure 9 shows locations where Pulsewave Technology might fit into the gradual reduction system for wheat flour production. The operational parameters of Pulsewave Technology can be adjusted to replace a portion of the primary break system as well as in the sizings operations. Pulsewave Technology has the ability to reduce a very high percentage of clean endosperm into flour in a single pass. This could eliminate reduction passages in the gradual reduction system. Pulsewave Technology experiments to remove endosperm from the bran have shown some promise and would replace bran dusters and reduce or eliminate low grade and secondary reduction grinding and sifting operations. With the correct vibration frequency and speed for each product it might be possible to increase flour extraction from wheat to more closely match the available endosperm.

Controlled Breaking

The first exposure to Pulsewave Technology was in the production of whole wheat products. As shown earlier, this was accomplished with relative ease. However, in order to use the technology successfully in the production of wheat flour it was important to determine capability to control particle size and ability to differentiate between the basic anatomical components (bran, germ and endosperm) in the wheat kernel. The granulation curves (Figure 10) indicate the extent speed change has on product granulation. One estimate indicates the Pulsewave Technology replaces the first three breaks and sizings in a single pass.

Straight Grade Flour Production

The objective of this study was to produce straight grade flour from cleaned tempered wheat using Pulsewave Technology as the principle method of particle size reduction.

Clean hard white wheat was tempered in Centennial, Colo., and processed using Pulsewave Technology. The processed material was sent to the Grain Science Department in Manhattan, Kan., where it was separated using the Great Western Tru-Balance Sifter in the Kansas State University pilot flour mill. Flour through the 153 micron screen was identified as "Initial PW" flour. The material over the 153 micron screen consisting of bran and endosperm particles was divided in half. One half was returned to Colorado and processed again using Pulsewave™ Technology and returned to K-State for sifting though a 132 micron flour

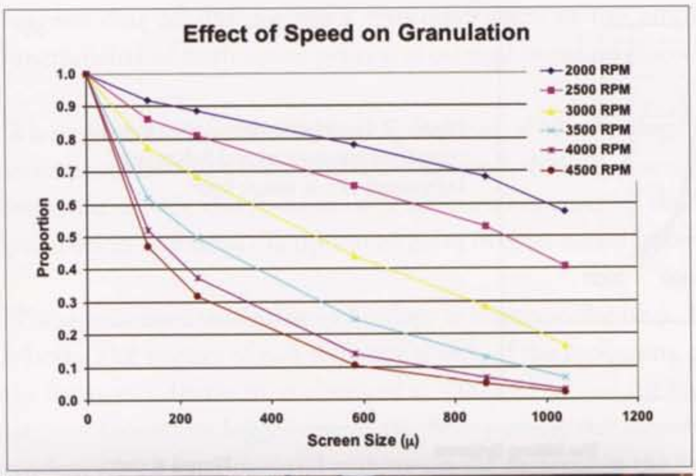


Figure 10. Effect of Pulsewave Technology speed on granulation of tempered Hard Red Winter wheat.

Figure 11. Miag Laboratory Purifier

cloth producing a flour identified as "Initial Overs" flour. The second half of the sample taken from over the 153 micron screen was purified using a Miag Laboratory Purifier (Figure 11) equipped with a single deck of screens producing two fractions (head and tail) through the screen deck and tail over stock in addition to aspirated stock. The two stocks through the screen deck and the tailings were returned to Colorado for additional processing using Pulsewave Technology. Following processing, the materials were returned to K-State for additional separation on a 132 micron opening flour cloth. The flours were identified as "Thu Head," "Thu Tail," and "Tail" flours.

Scanning Electron Microscopic View of Various Milled Fractions

Two samples of Pulsewave Technology milled wheat were viewed with a scanning electron microscope (SEM). After milling, the ground wheat samples were separated on a set of 153 μ sieves. The two samples used in this study were material that passed through a 153 μ sieve and material that passed through a 300 μ sieve but was retained on the 153 μ sieve. Visually the sample through the 153 μ sieve appeared to be mainly flour contaminated with small bran fragments. Material that passed through a 300 μ sieve but was retained on the 153 μ sieve appeared to be about an even mixture of bran particles and pieces of endosperm.

The SEM was used to determine if Pulsewave Technology generated separate bran and endosperm particles, or if compound particles containing both bran and endosperm would be found during conventional milling. Bran observed in previous Pulsewave Technology work was very clean (no or little adhering endosperm). During previous work it also appeared possible to separate manually pure pieces of endosperm from bran. However, observations and data were never convincing enough to conclude that Pulsewave Technology essentially completely separated the bran from the endosperm.

Figure 15 presents a 150X magnification of particles through a 150 μ sieve. There are two bran pieces (top and right in photo). The top piece has starch granules resting on the bran. They do not, however, appear to be bound to the bran.

Figure 19 shows an 80X magnification of a bran and endosperm particle mixture through a 150 μ sieve. The more spherical particles are endosperm and the thin flat sheets are bran. No compound particles with both bran and endosperm are observed.

Few if any particles of endosperm with bran attached to them could be found in the material through a 150 μ sieve. At high speed, Pulsewave Technology is effective at liberating bran from endosperm. Once a certain small particle size is attained, liberation between bran and endosperm was very complete. However, separation of liberated bran from endosperm at the smaller particle size becomes more difficult possibly requiring alternative technologies not currently employed in the gradual reduction milling of wheat flour. Slowing the machine down caused some of those compound particles to be formed and may be an important step in using Pulsewave™ Technology for straight grade flour production. Purifiers are commonly used to separate compound particles, which allows the generation of pure endosperm fractions for flour production. Additional work in balancing speed and other operational parameters to maximize straight grade flour production is warranted.

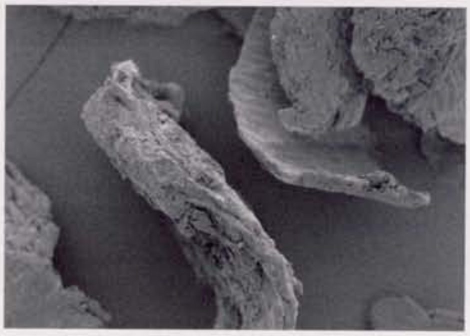


Figure 12. 180X magnification of two bran particles through a 300 μ sieve but retained on the 153 μ sieve

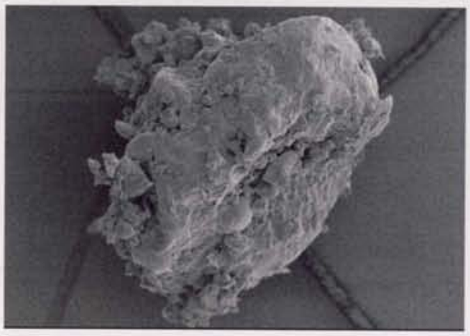


Figure 13. 500X magnification of an endosperm particle through a 150 μ sieve

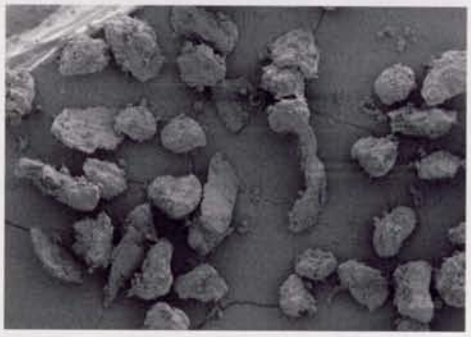


Figure 14. 80X magnification of a bran and endosperm particle mixture through a 150 μ sieve.

Analysis of Flours Produced

Table 2 shows the moisture, protein and ash analysis of the recovered flour. Even though the wheat was tempered to 16 percent moisture, the initial flour generated was 10.31 percent moisture indicating the effective drying of Pulsewave™ Technology. Moisture loss is an important issue affecting economics as well as flour performance that will have to be addressed in future work. The ash content is high; however, it appears to be liberated bran particles rather than compound particles of bran and attached endosperm.

It will be important to balance speed, liberation and the generation of clean material from purification steps in order to generate low ash fractions for reduction into flour. Products processed several times through Pulsewave Technology had approximately five percent moisture. The low moisture may contribute to bran liberation and bran particle size reduction.

Adding the moisture back in this machine or preventing its loss from the product will be very helpful in producing low ash flour. Pulsewave Technology has processed 30 percent moisture wheat, and produced whole wheat flour at about 15 percent moisture. In fact, 16 percent moisture wheat (with water added to bring it to 30 percent moisture) was processed using Pulsewave Technology and resulted in a 15 percent moisture product. Pulsewave Technology does a tremendous job of grinding and drying. Undoubtedly control of moisture loss and condensation will be important issues to resolve as the technology develops.

Test Baking Results

Dr. Carl Hoseney conducted bake tests with the samples (Table 3). The most important comparison is between the initial sample of flour and the blend. There was no control flour from the same wheat milled on a conventional mill. Flour ash

Flour Sample ID	Moisture %	As Is M.B.	Protein % (14% M.B.)	Ash % (14% M.B.)
Initial PW	10.13	13.35	12.78	0.87
Initial Overs	7.33	13.95	12.95	1.46
Tail	5.8	15.71	14.34	2.8
Thru Tail	5.62	13.66	12.45	1.53
Thru Head	7.25	11.68	10.83	0.66

Table 2. Flour analysis from Pulsewave Technology processing study.

Flour	Protein (14% M.B.)	Volume (cc)	Notes
Initial Overs	12.95	647	Thick cells; poor; third darkest crumb color
Tail	14.34	522	Thick cells; poor; darkest crumb color
Thru Tail	12.45	555	Thick cells; poor; second darkest crumb color
Thru Head	10.83	760	Good grain; light crumb color
Initial PW	12.78	887	Good grain; sl dark crumb color
Blend		849	Good grain

Table 3. Baking test results from Pulsewave Technology processing study.

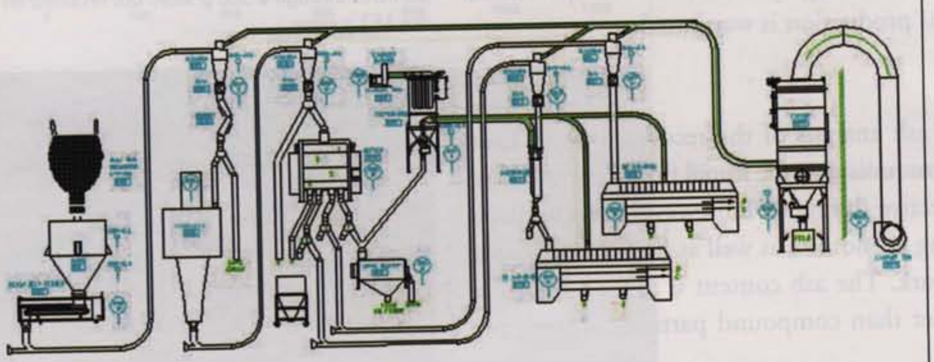


Figure 15. Experimental flour mill flow using Pulsewave Technology.

content levels are around 0.8-0.9 percent from a straight grade; extraction levels can be as high as 88 percent. Obviously the flour gets darker…and could be useful for generating that type of flour for the appropriate market.

Conclusions

Pulsewave Technology processing of tempered wheat causes a separation to occur at the bran-endosperm interface. This should be ideal to separate the material into pure or relatively pure bran and endosperm fractions. Sieving alone does not lead to complete separation of small bran particles from endosperm.

Additional Research

Additional research needs for resonance destruction in cereal and oil seed processing:

1. The capacity and energy consumption of a sustained run time must be more accurately quantified. Energy consumption must be known in order to determine its competitiveness as a grain processing alternative.
2. Identify method of controlling moisture content.
3. Balance a processing system using resonance destruction by controlling liberation and particle reduction to facilitate effective separation.
4. Develop a continuous process to determine footprint size, energy consumption, yield, and maintain moisture content.

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Background

Dr. Bob Hubbard (Pulsewave LLC) approached Dr. Floyd Dowell at the USDA/ARS Grain Marketing and Production Research Center about the resonance destruction machine and possibilities for cooperation. Dr. Hubbard's initial presentation evoked questions of how this might fit into the milling process, including capacity and energy consumption issues. USDA/ARS requested Dr. Gwirtz to evaluate the technology for milling applications under a Specific Cooperative Agreement (SCA). Pulsewave LLC had already established a working relationship with Dr. R. Carl Hoseney. These events brought the four authors together on this exploratory evaluation project.

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