ASA
American Soybean Association
International Marketing™

feed Technology

Technical Report Series

Published by
American Soybean Association
International Marketing Southeast Asia
541 Orchard Road
#11-03 Liat Towers
Singapore 238881
Tel: (65) 6737 6233
Fax: (65) 6737 5849
Email: asaspore@pacific.net.sg
Website: www.asasea.com

M04GX19403-082005-0500

Technical**Report**Series

feed Technology

American Soybean Association
International Marketing™

TableOfContents

The Art (Science) Of Pelleting

Keith C. Behnke
Kansas State University
USA

Pelleting has been, and continues to be, a popular processing technique in feed manufacturing. In basic terms, pelleting converts a finely ground blend of ingredients into dense, free flowing agglomerates (pellets). There are many reasons used to justify the process, but it may be appropriate to list just a few:

- improved animal performance,
- decreased feed wastage,
- reduced selective feeding,
- improved bulk density,
- better material handling characteristics,
- destruction of deleterious organisms, and
- customer expectations.

Pelleting operations are not without cost. It is a fairly expensive process in terms of both capital and variable costs, but the expense is usually justified in improved plant profit as well as animal performance.

The purpose of this paper is to discuss the pelleting process in terms of operations and to describe how the success or failure of the operation can impact on profits as well as animal performance.

The Process

The formation of the pellet actually occurs at the "nip" between the rolls and the die. All other activities associated with the operation such as conditioning, cooling, etc. really support and augment the action at that point in the system.

In order to understand the process and be in a position to make intelligent decision to improve throughput, quality or appearance, one must have a thorough understanding of what happens at the nip point. Figure 1 is a representation of the die-roll assembly and will help the reader understand the process.

Depending upon the physical characteristics of the feed, a lesser or greater proportion of the work done by the pellet mill is used for compression. For example, if the formula contains a high level of fibrous ingredients such as bagasse, bran, or ground alfalfa, the mill will expend a large amount of energy simply compressing the mash to the density of the subsequent pellet. Conversely, for a relatively dense feed such as high grain and soy meal, the mill will expend a lesser amount of energy for compression and a greater amount for throughput.

The "extrusion area" shown in the figure is the point at which the mash has reached pellet density and begins to flow through the die holes. There are many physical forces that must be dealt with in the pelleting process. Figure 2 is included to familiarize the reader with some of the major forces involved.

Figure 1. Roll And Die Relationships

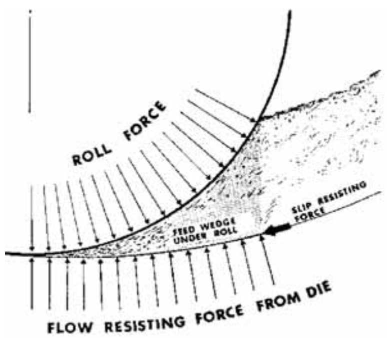
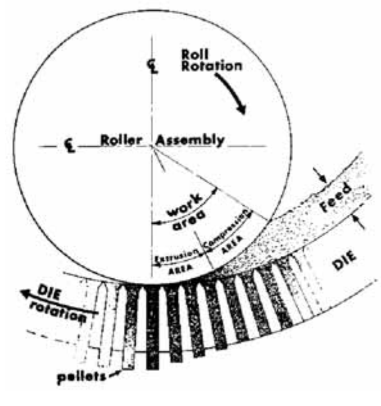


Figure 2. Physical Forces



The primary purpose of the roll is to provide a force on the mash to densify the feed and cause it to flow toward the die. The gap between the roll and the die, the roll surface characteristics and the physical properties of the mash determine how great this potential force might be.

The die provides, not only the final diameter of the pellet, but the resistance force on the feed and has a direct influence on throughput rate and pellet quality. These two forces (roll and die) are apposite each other as shown in the diagram, but must work together to provide quality pellets at an acceptable production rate. The force generated by the roll must be greater than the resistive force provided by the die; if not, throughput is zero.

With a general understanding of the process inside the pellet chamber, it is appropriate to move to a discussion of various factors that affect both throughput and pellet quality.

Pellet Quality

For purposes of this paper, pellet quality will be equated to the ability of pellets to withstand repeated handling without excessive breakage or fines generation. There are many factors that affect pellet quality, but the following will be discussed in some detail:

- formulation
- ingredient particle size
- mash conditioning
- feed rate
- die speed
- die specifications (design)
- other factors

Formulation

There are feedstuff materials that pellet well and produce a durable pellet and others that will not. MacBain (1966) developed a pelletability chart in which he ranked feed ingredients in their pelletability and degree or abrasiveness. Bartikoski (1962) experimented with applying numerical value to each major (feed) ingredient to indicate its "stickiness" or its ability to help form a tough, durable pellet. He called that value a "stick factor" and fed that factor into the computer along with the various nutritive values of each ingredient to provide formulas that meet all nutritional specifications as well as supplying a formula that will produce a quality pellet at least cost.

Those early workers led others to experiment with the effects of various ingredients - grains, milled grain by-products, fats, pellet binders, minerals, etc. - on pellet quality or durability. They also led to the development of a standard method for testing pellet durability perfected in the 1960's by Dr. Harry B. Pfost at Kansas State University and accepted as a standard by the American Association of Agricultural Engineer - ASAE S-269.3 (ASAE, 2003). That method is generally known as the K-State, or tumbling can, durability test; and it provided a means of quantifying the toughness of pellets or their ability to withstand the downstream handling that is typical in feed plants and feed delivery systems. That was a major breakthrough in the technology of pelleting and has served the industry for all these years.

Minerals

Pellet mill performance can be significantly affected by the physical and chemical forms of the calcium and phosphorus sources used in the formula. Sutton (1979) investigated the effect of deflourinated phosphate (two particle sizes) and dicalcium phosphate (18.5%) on pellet mill performance with a broiler grower formula. He found the production rate for the diet containing regular grind deflourinated phosphate to be 68.9% greater than for the diet containing an equal amount of dicalcium phosphate. The finely ground deflourinated phosphate had a 52.5% advantage over dicalcium phosphate.

In a similar study (Behnke, 1981) we also studied the effect of mineral sources on pellet mill performance and pellet quality. Two deflourinated phosphate sources, a fine grind (DPF) and a regular grind (DPR), and an 18.5% dicalcium phosphate (DCP) were used. A practical layer diet was used in which each test mineral source was evaluated at both high (2.5%) and low (1.5%) levels in the diet.

At both levels tested, the production rate for the deflourinated phosphate sources significantly outperformed dicalcium phosphate; while the DCP had a slightly, but not significantly, higher pellet durability index. That would indicate that a physical change - thicker die or reduced feed rate - could be made to improve pellet quality without a substantial loss of system throughput. Behnke (ibid), Verner (1988), and McEllhiney and Zarr (1983) reported similar results comparing phosphorus sources in a variety of pelleted feeds produced under many conditions.

Those studies are cited, not to encourage or discourage the use of any mineral source or any other ingredient - that's the nutritionist's decision - but to indicate that those sources and ingredients can affect pellet quality and production rate and should be considered in the quest for improved pellet quality.

Particle Size

Optimum particle size for best pelleting results has been a matter of controversy for almost as long as feeds have been pelleted. Young (1960) found no significant differences in pellet durability when he experimented with feed rations containing 40, 60, and 70 percent ground corn or grain sorghum when the grain portions were ground coarse, medium, and fine.

Martin (1984) compared pelleting efficiencies and durabilities using a hammermill and a roller mill to grind the corn portion (59.5%) of a pelleted feed. He did not find any differences (P<.05) among the various treatments. The average particle size of the hammer milled corn (3.2mm and 6.4mm screens) ranged from 595 to 876 microns, and the roller milled corn (fine and coarse) ranged from 916 to 1460 microns.

Stevens (1987) conducted similar experiments in which No. 2 yellow corn was used as the grain portion of the typical swine formula. The corn was ground with a hammermill through three screen sizes: 1/16"(1.6mm) (fine); 1/8"(3.2mm) (medium) and 1/4"(6.4mm) (coarse). He then measured the effect of the ground grain particle size on the pelleting production rate, electrical efficiency, and pellet durability.

There were no significant (P<.05) differences in the pelleting production rate or PDI values from different particle sizes of corn mixed into the swine ration; although, the total electricity required to grind the corn and pellet the mash was significantly greater for the fine ground corn.

When ground wheat was used as the grain portion of the swine ration, pellet production rates and PDIs improved as the grain was ground finer; but the finer ground wheat also required substantially more electrical energy.

While the research cited may seem to provide conflicting results, there is overwhelming evidence that the average particle size of the ground grain portion of a ration or of the total ration (mash) affects the pelleting process - throughput and/or pellet quality. The effects, simply, are not the same under all conditions or for all rations. The operators must conduct their own research under their own operating conditions and on the feeds that they produce.

It is common that some portion of a plant's product mix is often in mash or meal form and that grinding the grains more finely in a pre-grind system or the whole mix in a post-grind system causes handling problems in those mash feeds. There are two solutions to that dilemma - either provide two ground grain bins over the mixing system or find a grind (particle size) in the middle somewhere that will produce the better quality pellet and still provide the flowability or angle of repose that is needed for mash feeds. The first option is, of course, the better one but may not be possible, or too expensive, in a given grinding/mixing system situation.

Grind as fine as you must for best pellet quality in your operation and with your operation and with your feed rations, but don't over grind. That is wasteful of energy, reduces production rates, adds to manufacturing costs, and may do more harm than good to the consuming animal.

Mash Conditioning

This is a subject unto itself and will not be addressed in total detail in this paper. Many researchers and practitioners have proven over and over again that pellet durability and pelleting efficiency can be substantially improved by the proper steam conditioning of mash. Steam brings to the surface of pellet mash particles the natural oils which are common to most grains and provides lubrication of the pellet die reducing wear on the die and roller assembly and increasing production rates (Behnke, 1990).

In some instances, thorough conditioning may be counter productive from the standpoint of pellet durability. If the material slips through the die too easily, dwell time in the die hole is reduced causing the pellet to be less durable, and the starch gelatinization caused by the heat and friction in the die may be reduced.

Stevens (1987) conducted extensive research into the phenomenon of starch gelatinization during the feed pelleting process by pelleting corn that was hammermill ground through a 1/8" screen. He used a Perkin-Elmer DSC-23 (Differential Scanning Calorimeter) for gelatinization analysis. Ground corn before pelleting was used as the control. Samples of the pellets were prepared for analysis in the DSC by grinding them in a Braun coffee grinder, then regrinding in the UDY mill. A 2 mm thick outer portion of pellets was scraped with a razor blade from selected samples and ground in the UDY mill.

Table 1. Effect of conditioning and pellet temperatures on starch gelatinization

	Temperature				
	Cond.		Pellet		
Product	C	F	C	F	GEL %
Whole Pellet	23	73	69	156	41.9
Whole Pellet	43	109	76	169	37.1
Whole Pellet	63	145	82	180	33.5
Whole Pellet	80	176	84	183	28.0
Outer Pellet	23	73	69	156	58.3
Outer Pellet	80	176	84	183	25.9

The results of the gelatinization measured in the samples taken immediately after the die are shown in Table 1.

There was a negative relationship between the conditioned meal temperature and degree of gelatinization. As the temperature of the conditioned mash was increased, the degree of gelatinization decreased.

The high degree of gelatinization that occurred in the outer portion of the pellet at a 23°C conditioning temperature indicated that heat and mechanical shear next to the surface of the die hole caused a substantial portion of the gelatinization at all temperatures but, especially, when there were greater temperature differentials between the conditioned meal and the pellet. There is a relationship between that temperature difference and the degree of gelatinization observed. As the temperature differential decreased, the degree of gelatinization decreased.

Stevens (ibid) suggested that the conditioning temperature of 80°C was adequate to gelatinize corn starch; however, the length of time in the pellet mill conditioner at that temperature was probably not adequate for a substantial amount of gelatinization. It would appear, from that research, that most starch gelatinization occurred as the feed material passed through the die.

The temperature of conditioning mash has long been a pelleting criterion and an indication of thorough conditioning, that may, or may not, be a totally viable indicator since time at a given mash temperature will affect the conditioning, may affect the degree of gelatinization, and will certainly affect the pelletability of the mash.

Die Specifications

Behnke (1990) studied the effect of effective die thickness, on length (L), on pellet durability in his experiments reported earlier in this paper. His results indicate, clearly, that durabilities were significantly enhanced with the use of the thicker die; however, production rates were as significantly reduced.

Conclusion

There is no magic. Almost anything that is done to improve pellet quality (durability) will either increase the cost of the ration or reduce the capacity of the pelleting system, or both. Adding to the effective thickness of the die is a perfect example of the sort of trade off that can be expected, and must be recognized, in the search for improved pellet quality.

One of the primary objectives of all commercial feed manufacturers is to economically produce the best pellet quality possible. This is not only important from a customer satisfaction standpoint, but it is becoming apparent that animal performance can be affected by poor quality pellets. Dairy cattle used to consuming pellets, readily reject fines. Even the U.S. broiler integrators are recognizing that poor pellet quality can reduce bird performance.

There are numerous factors that affect pellet quality and many are inter-related. It takes a great deal of effort to determine what changes to make and how other aspects of the system or operation might be affected.

Factors not addressed in this paper but that are currently being investigated include: double pelleting, optimum cooling, automation of the pelleting system, gentler handling of pellets and new binders. This paper has not dealt with issues of water stability of pellet aquatic diets, but that topic is gaining great importance around the world.

As can be seen, pelleting is a very complex issue and one that deserves a good deal of thought and investigation.

References

ASAE, 2003, ASAE Standard: ASAE S 269.3, Wafers Crumbles, and Crumbles - Definitions and Methods for Determining Density, Durability, and Moisture Content, ASAE Standards 2003, The Society of Engineering in Agriculture, St. Joseph, Michigan: 70-72.

Bartikoski, R.G., 1962, The Effect of Steam on Pellet Durability, Cost Reductions Through In-Plant Production Controls, Midwest Feed Manufacturers' Association, Kansas City, Missouri: 42-47.

Behnke, K.C., 1981, Pellet Mill Performance as Affected by Mineral Source, Feedstuffs, Vol. 32, No. 12, Miller Publishing Company, Minneapolis, Minnesota: 34-36.

Behnke, K.C., 1990, (Unpublished) An Evaluation of Wheat as a Pellet Quality Enhancer, Kansas State University, Manhattan, Kansas.

MacBain, R., 1966, Pelleting Animal Feed, American Feed Manufacturers Association, Arlington, Virginia.

Martin, S.A., 1984, Comparison of Hammermill and Roller mill Grinding and the Effect of Particle Size Reduction on Mixing and Pelleting, A Master's Thesis, Kansas State University, Manhattan, Kansas.

McEllhiney, R.R. and R.K. Zarr, 1983, (Unpublished) Results of Fish meal Analog Trials, Kansas State University, Manhattan, Kansas.

Stevens, C.A., 1987, Starch Gelatinization and the Influence of Particle Size, Steam Pressure and Die Speed on the Pelleting Process, A Doctor's Dissertation, Kansas State University, Manhattan, Kansas.

Sutton, L., 1979, (Unpublished), Bordon, Inc., Smith Douglas Div., Elgin, Illinois.

Verner, W.A., 1988, Best Cost vs. Least Cost, Feed Management, Vol. 39, No. 4, Watt Publishing Company, Mount Morris, Illinois: 36, 58.

Young, L.R., 1960, Mechanical Durability of Feed Pellets, A Master's Thesis, Kansas State University, Manhattan, Kansas.

Post-Pelleting Liquid Application: A Practical Guide

Doug Decksheimer
Comco Systems Inc.
Canada

Introduction And Background

In most cases, post-heat liquid application treatment has been limited to fat additions of 1-10 percent. Equipment to apply fat is present in many mills and in some cases can be adapted to apply other liquid ingredients. In the past five years, several hundred pellet lines globally have been retrofitted to dispense enzymes. This increasing trend in Asia has been mostly in high capacity integrated operations. However, today, benefits can be realized in most mills as technology has changed to offer more cost effective solutions.

When determining equipment needs for heat-sensitive liquid ingredients such as enzymes, every effort should be made to ensure that these products are applied with precision and accuracy. Systems to apply liquids post-heat treatment work in a continuous flow setting in most instances. The aim is to apply the liquid after the fines are returned and before the feed goes to the feed truck.

Parameters must be defined to monitor the equipment's efficiency. The installation of a liquid addition system can add a number of requirements to the feed process and existing equipment. These will be discussed in this paper.

The accuracy of a liquid application system should be determined by its ability to consistently deliver precise amounts at the feedmill. It should not be measured by animal or bird performance after consumption of the finished feed.

The Problem

High temperatures are used to satisfy requirements of quality feed and hygiene. Most pelleting mills operate at temperatures between 70 - 80°C. Health issues, such as salmonella have created the need for pelleting temperatures in excess of 90°C. Thermal treatment provides the following advantages:

- Gelatization of starch
- Enhancing the pellet quality
- Enhancing digestibility
- Hygiene treatment

Typically, the pelleting process involves conditioning, pressing and then cooling. Those mills utilizing expanders, process at higher temperatures and pressure. Heat, moisture, pressure and friction, reduction and oxidation reactions and light are stress factors which can negatively influence additives (Schwartz, 1998; Putnam and Taylor, 1997; Perry, 1997; Blair, 1996) Therefore, heat sensitive feed stuffs such as enzymes, vitamins, amino acids, probiotics and antibiotics, may require optional processing equipment.

Getting Started

The application of well-defined feed additives is becoming an indispensable tool for feed producers. There is a constant drive to produce low cost feed with maximum nutritional availability. In fact, post-pelleting application can increase profitability.

As mentioned previously, post-pelleting application is not entirely new to the industry. However, enzymes and other heat-sensitive concentrates have changed the paradigm for post-pelleting addition. Inclusion rates of 40 to 250 grams per ton of finished feed have created the need for precision equipment and have raised some notable concern within the feed industry.

Following are some factors that influence the success of any post-pelleting application system:

1. Coefficient of Variation - the additive must be presented with uniformity to pellets
2. Accuracy - over-dosing or under-dosing is undesirable
3. Precision - the system must provide consistent and repeatable dosing

The answers to the following questions will provide some basic information to consider when making equipment changes and adapting new processes to the mill. The answers will also assist in successfully achieving the above points.

Determining Questions:

1. Where is it possible to add liquid ingredients in the feed process?
   Heat-sensitive ingredients must be added after cooling/sieving and prior to load-out.
2. Where is it possible to measure or calculate the flow of feed pellets or crumbles?
   In order to accurately dose precise amounts of liquids, the rate of dry flow must be accurately determined.
3. How much automation is needed to meet quality control requirements?
   To ensure repeatability and guarantee the application, a means of implementing both robust hardware and controls/software is necessary.

Some Useful Resources in Helping to Evaluate Equipment Needs:

1. The liquid supplier may have feed engineers or technicians available
2. The liquid equipment supplier will have varied experience
3. Consulting or engineering firms may help assess mill needs

Equipment suppliers in conjunction with nutritionists, mill managers and maintenance personnel can all provide input to creating a well-defined system. In short, if you do your homework, your application will be successful.

The Application

Dry Flow Measuring

Achieving the desired accuracy is greatly dependent upon the level of accuracy obtained from the dry-flow measuring device. In general, the steadier the dry flow, the more accurate the liquid can be applied. (Aicher, 1998).

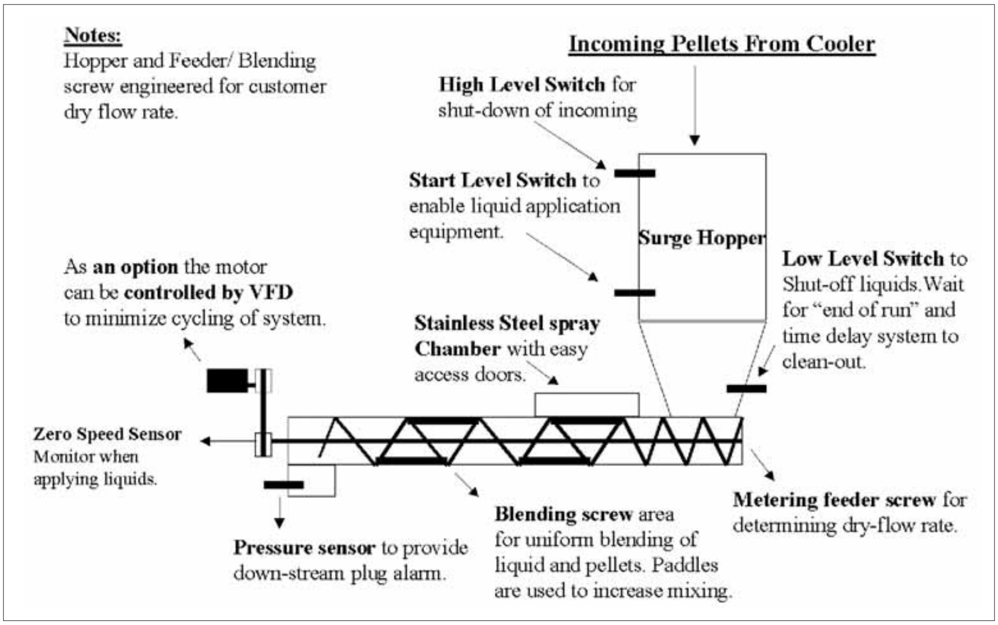
Several options are available for measuring and controlling the dry flow of pellets or crumbles. It is relatively safe to say that the more money spent on dry flow monitoring, the more accurate the system should be, however, one must consider serviceability and ease of calibration within that equation.

For many mills where bulk density of the finished feed is consistent, volumetric measuring (Figure 1) is a proven solution. This cost-effective method uses a surge or buffer hopper with a low and high level switch; the system is calibrated by determining the decreasing amount of pellets over a specified amount of time. Once product reaches the low level switch, a screw auger stops, allowing the bin to fill until product reaches the high level switch and the process then repeats itself.

Several systems employ weigh belts. This method uses a surge bin directly above a belt or mixing screw, which is suspended by a load cell. Weigh belts are not affected by changes in bulk density and can easily be retrofitted into existing mills. They do however, require a high level control system for calibration. Most weight systems are marketed as a package and require a large footprint.

Impact Scales - involve calculating weight by the force of pellets hitting a plate. This method has been widely used in many feedmilling applications. These devices are compact. Impact scales should

Figure 1. Volumetric dry flow control



only be installed in constant flow applications or inconsistency will occur. Bulk density changes may impact the calibration.

Newer yet, is a technology that uses a curved chute resting on a sensing element or load cell. The system determines flow by measuring the sum of forces necessary to re-direct the incoming flow of material from near vertical to near horizontal. Hence, a momentum measurement. Realized accuracy of 99.5% or better is achievable.

In essence, dry flow measuring is the heart of the application, and inaccuracies are compounded through the remainder of the process. Each of the above methods of monitoring pellet flow will work successfully provided the application of the equipment is correct. It is important to ask questions and provide equipment manufacturers with all the relevant data necessary to design an appropriate system.

Liquid Monitoring And Delivery

Currently, there are three methods employed for monitoring the liquid ingredient: measurement can be volumetrically, loss-in-weigh or by flow meter. There are advantages and disadvantages to all;

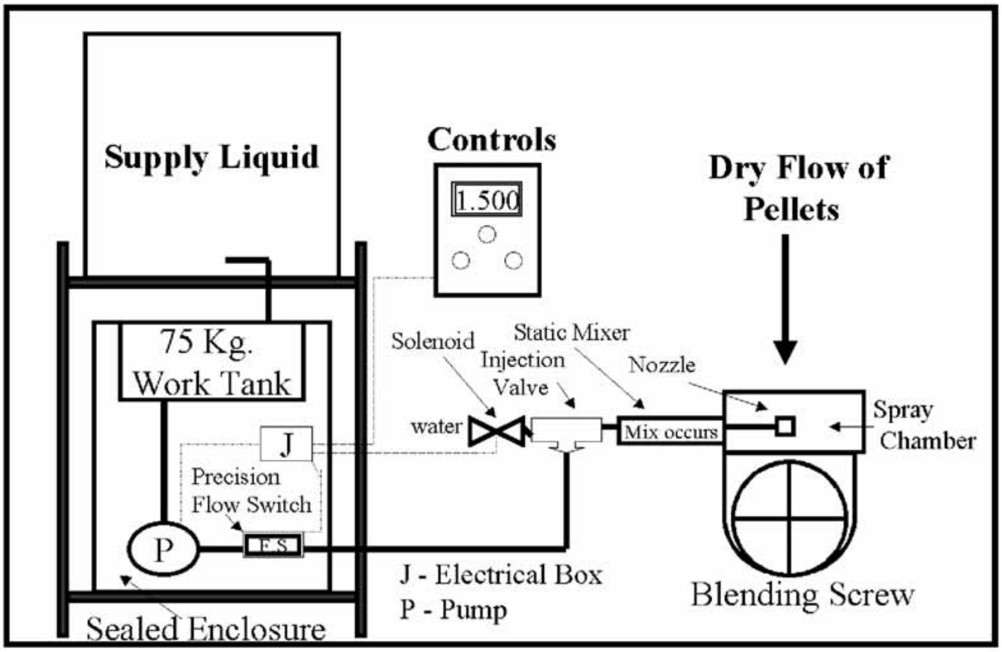
Volumetric (Figure 2) is by far the most cost effective. This system uses a positive displacement pump to dispense precise amount by two methods;

a. time base by calculating the amount of liquid delivered over a specific time and relating that amount in a given minute or hour.
b. Pulse emulation where each stroke of the pump is proportioned to deliver a given amount. The control system then reads the pulses and records the flow rate.

Because volumetric systems do not have true flow knowledge, it is important that these systems have low level detection and in-line no flow monitors or switches to alarm the operator. Volumetric systems installed correctly can provide superior accuracy with a low cost.

Loss-in-weigh is a weight-based system using a positive displacement pump to dispense the precise amount from a day tank. Some advantages of this method are:

Figure 2. Typical volumetric liquid delivery general overview for illustration only.



- Liquid densities do not effect the system
- Real-time weight processing
- Inventory is easier to reconcile by weight

The scale offers further benefits by allowing low level monitoring and re-filling set points.

Flow Meters are the traditional means of monitoring liquid flow. Reliability and accuracy can be proportional to the money spent on the flow meter.

In flow-meter type systems, a positive displacement pump forces liquid into the flow meter producing an electrical out-put to flow. Flow meter based systems require limited space. It is advisable to use a mass flow meter with critical ingredients and those liquids that are subject to density changes with temperature.

Because of the low inclusion (40 - 250 grams per ton) of critical ingredients, it seems logical to dilute additives with water or oil. This will also increase the number of droplets, which will have a positive effect on distribution (Van der Poel and Engelen 1998).

In practice, dilution is simply used to increase the accuracy of the installation. Although the objective is a minimum level of water inclusion, an amount of 500 - 1,000 grams per ton add rate has been proven effective. When it is necessary to mix heat-liable liquids with water, the application system must meet the following criteria:

1. Mixing should take place as close to the spray application as possible.
2. The system should be purged if extended mix times exist
3. A mechanical static mixer should be used

It is possible to spray one or more liquids together in a post-pelleting installation. Compatibility must be determined. Due to contamination and stability concerns, it is recommended that liquids be dosed independently if from varying suppliers.

At times, addition of enzyme or other heat-liable ingredients will take place just before or just after coating the feed pellets with fat. Even if the pellets are coated with fat first, the low levels of enzyme added may be absorbed (Figure 3). The small amount of water added with the enzyme does not alter the humidity of the pellets significantly, primarily because addition rates are well below one litre/ton (Perry, 1997).

Further, information on the effects and interaction with fat can also be seen in Figure 3. The recovery of Xylan LC® was shown to be sufficient irrespective of the fat temperature or the fat level. (Annonier et al., 1998).

Table 3.1 Effect of spraying position and time on the recovery of a liquid enzyme.

Diet[a]	Enzyme Recovery[b]			
	Control	Enzyme sprayed Before fat spraying	Enzyme sprayed immediately after fat spraying	Enzyme sprayed 30 min. after fat spraying
Starter	-	100	90	99
Grower	-	100	104	99

[a] 50% barley based
[b] 2 litres Xylan LC® per tonne of feed
Reference: Annonier et al., 1998.

Table 3.2 Effect of fat level and fat temperature on the recovery of a liquid enzyme.

Fat temperature [°C]	Enzyme recovery [%] in feed with fat level [%][ab]	
	1.5	3.0
64	114	118
80	110	117
88	105	117

[a] 50% barley based
[b] 2 litres Xylan LC® per tonne of feed
Reference: Annonier et al., 1998.

The recovery of Xylan LC® was shown to be sufficient irrespective of the fat temperature or the fat level. Irrespective of the spraying order, feed efficiency was significantly improved by the enzyme in the starting as well as the finishing period: -9 and -4.6% in feed efficiency ratio, respectively. (Annonier et al., 1998)

It is practical to apply the critical ingredients prior or in conjunction with the fat or oil. This application will provide a sealed pellet of the ingredient and reduce the need for penetration if applied after fat or oil coating.

Spraying And Mixing

In practice, it is not feasible to disperse the liquid additive over all the pellets. Homogenous distribution is achievable but only considering the following:

1. Fines must be minimized. Sieving of the fines prior to application increases accuracy
2. Post mixing after application increases distribution lowering the co-efficient of variation
3. The droplets of liquids must be maximized

Liquid droplets are created by using force and properly selected nozzles. Nozzle sizing is very specialized and many factors must be considered. Nozzles that are not sized correctly can produce over or under spraying and negatively impact the installation. A "one size" fits all approach will not work.

Some systems typically used for fat application use a high speed disc which produces a fine atomized mist. This is also an effective method of application and dispersion.

Fines present challenges in post-pelleting systems, particularly in crumb feeds. The wide particle size range and the presence of substantial amounts of fines make the occurrence of segregation practically unavoidable (Barendse,1995). Fine particles that have comparatively large surface/weight ratios will absorb a relatively high percentage of the additive.

Further, fines created or contained in the feed, reduce mixability. In consideration of this, post-pelleting systems should be engineered to minimize pellet degradation during and after spraying.

When spraying or applying liquids, four methods are often used:

1. Mixing Screws - can be retrofitted to allow feed to drop in a flat curtain. A ribbon flight with mixing bars welded at every pitch at 90 degrees apart can produce the needed curtain. A benchmark of 20 seconds retention time will produce excellent mixability.

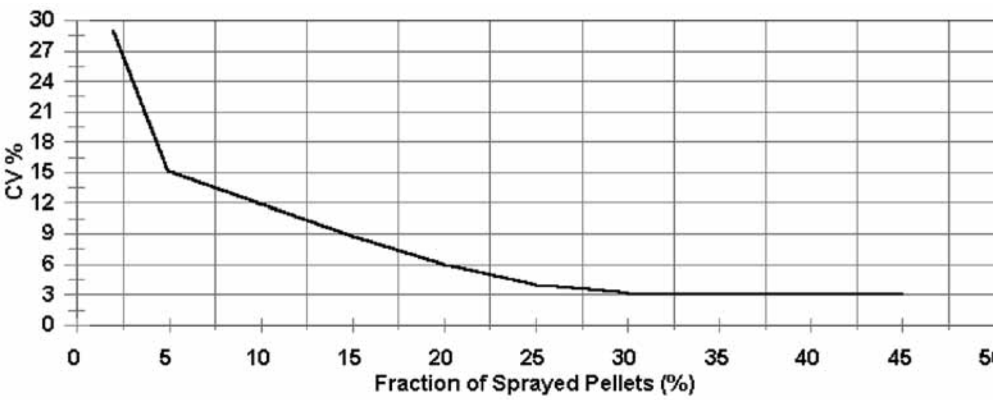
2. A Spray Chamber - is created by use of cones or baffles in a closed compartment. Feed is thinned to a curtain. For areas with limited space, this may be the only option. Care should be taken to avoid overspraying. The chamber should be accessible for regular cleaning.

3. Roto Coater type systems have been developed primarily for the application of fat. The design of these features two discs. Pellets land on the top of a low speed rotating disc which provides a 360 degree curtain around a second disc. Liquid droplets landing on a second high speed rotating disc cause a fine atomized mist, which is forced on to the pellets. Several manufacturers provide similar type systems.

4. Batch mixing - has been used successfully in Europe for adding liquid post-pelleting. The need for a pre-hopper is required and this creates space problems. These mixers are typically paddle type and the weighing of liquid and mixing is completed over a short period. The advantage of this type of system is that it allows for the flexibility of adding both liquid and powder ingredients.

Post mixing after spraying improves uniformity in all application systems. Although some mixing occurs during transportation of the feed, it is expected that the homogeneity will be better when a complete mixing is performed. The object is to have the liquid contact a maximum number of pellets (Aicher, 1998). Sufficient retention time and agitation are necessary to accomplish the desired result (Figure 4).

Figure 4. Effect of spraying accuracy on the coefficient of variation.



Quality Assurance & Automation

Quality control issues are of the utmost importance. The application must tie together into a robust automated system. The control system must fit into the automation objectives of the feed mill.

Today many mills face the challenge of adopting HACCP and “Good Manufacturing Practices” to their day-to-day milling operations. The liquid addition system should fit into this process with routine checks and balances in place. Some high attention detailing includes:

- Recharging of the enzyme day tanks and proper labeling of the tanks itself
- Lot number recording
- Balance the inventory of the liquid sprayed to the feed produced
- Periodic spot calibration
- Periodic finished feed sample taking proving the consistency of the application
- General maintenance of the equipment

No assumptions should be made when applying critical ingredients. Alarms should be included to alert operators of any possible malfunctions. The control loop should include:

- Low or empty tank levels
- Low or no liquid flow

Like all systems, the automation should include the ability to expand enabling the addition of future liquids. Basic reporting will enable the feed mill to reconcile inventory and prove the application.

In short, to obtain accuracy and homogeneity, the flow of liquid and feed must be in close harmony. The use of a process control system to run dependable software is the only way to achieve this goal.

Summary

Liquid application of feed additives may give a solution, in many cases, to making the ready product assortment more flexible. This will cause an extra capital investment that can be earned back by better efficiency and a larger product assortment (Copps, 1997).

Post-pelleting systems can be dependable. In principle, there is a choice between an advanced system that guarantees high accuracy and a cheaper, simpler system, which may always lack accuracy and uniformity. There is a wide range to choose from, and in most cases the best system will be a compromise between the two extremes.

The performance of any post-pelleting system should be judged on the uniformity and accuracy of liquid application, reliability, frequency of maintenance and ease of use (Chemgen, 1999). Some suppliers have underestimated this task, while others have met the demands of today's feed industry.

The use of heat sensitive liquid ingredients in feed manufacturing will continue to increase as more ingredients become available in liquid forms. The challenge will be to successfully and economically adapt application of these liquids to bypass the excessive temperatures of pellet mill conditions and expanders.

References

Aicher, E., 1998. Post Pelleting Liquid System for Enzymes. KC9814. Keeping Current.

Annonier, C., P.A. Geraert, A. Sabatier and T. Julia. 1998. Proceedings 4th Kahl Symposium, Hamburg, Germany.

Barendse, R.C.M., 1995. Technological Aspects of Enzyme Usage. Victam '95 Symposium: From Feed to Food, Utrecht, The Netherlands.

Blair, M., 1996. Liquid or Dry? A Question of Practicalities. Feed Milling International, Nr. Oct. p.13-14.

Coops, M.G., 1997. Bulk Blenders, Mini-symposium Cebeco Ingenieurbureau de Molonaar., Vol 100. p 2-4.

Field Service Group, Chemgen Corp., 1998. Feed & Grain. Oct/Nov, p 16-22.

Putnam, M. and A. Taylor, 1997. Vitamins in Feeds - The Critical Factors. Feed Tech. Vol. 1, Nr. 1.

Document-number 108107, p 39-41, 43.

Schwarz, G., 1998a. Liquid Feed Additives - An Alternative in Modern Animal Nutrition? (Part 1). Feed Management/Kraftfutter, Nr. 10, p. 438-443.

Troubleshooting The Pelleting Process

John D. Payne
Borregaard Ligno Tech
United Kingdom

Introduction

The benefits of producing good quality pellets are well documented and accepted. This paper will deal specifically with production matters and pelleting technique to position the nutritionist and mill manager to meet the ever increasing demand from livestock producers for supply of consistently good quality pellets.

The "Troubleshooting" strategy will be to investigate the major factors which influence pellet quality and production efficiency, i.e., feed formulation, specific power consumption (pellet press) and conditioning, which also includes grinding, as grinding is the first stage of conditioning. In so doing, we will discuss the variability of raw materials, their effect on pellet quality, and learn how to calculate "Feed Quality Factors" such that "Pelletability" of feed formulations can be predicted prior to production. This, together with specific knowledge of your process plant and application of lignin technology, will enable pelleting techniques to be developed so that pellet quality, production rate and profitability can be maximized.

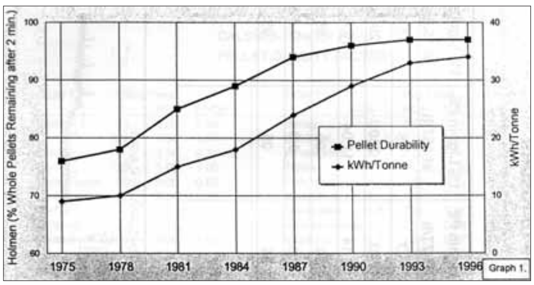
What Is A Pellet Quality/Production Rate Problem?

A pellet quality problem is that which occurs when pellet durability falls below your level of acceptability. A production rate problem is that which occurs when it falls below your level of acceptability relative to pellet quality and design capacity. Level of acceptability varies from country to country, region to region, depending on a number of factors, e.g., technical production ability, feed raw materials and market pressures. However, "Better pellet quality… better overall efficiency" is widely accepted, particularly by integrated feed producers, but on a practical basis, it will probably be the market place which dictates the level of pellet quality for non-integrated companies. Thus, you must first establish your company's level of pellet quality acceptability and aim to maintain it within a close tolerance.

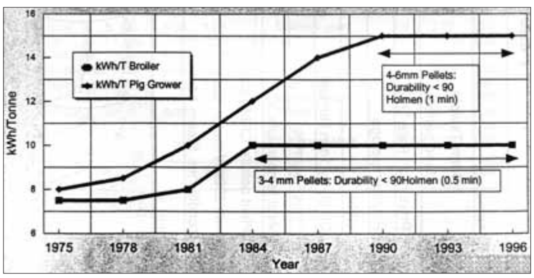
Development Of Pellet Quality

In response to demand for better quality pellets, engineering process technology has responded by applying greater amounts of electrical energy per ton of pelleted feed -- more so for ruminant and pig than for poultry. Graph 1 and 2/3 show, over a 20 year period, how pellet quality has improved in relation to electrical energy input at the pelleting plant (excluding steam, cooler and conveyors). Thus, we can see that pellet quality is relative to energy input and we can use this criteria when trouble shooting.

Graph 1. Relationship between energy input & pellet quality (ruminant feed: 6mm pellets)



Graph 2/3. Electrical energy input.



Fundamental Requirements For Good Pellet Quality And Production Rate

There are just two! That is, assuming adequate grinding and conditioning.

1. A good feed formulation.
2. Sufficient Specific Energy (kWh/ton) used by the pellet press motor.

These are the first two stages of investigation used that are recommended to investigate when troubleshooting either Pellet Quality or Production Rate problems.

Stage 1

Determination Of The Formulation's "Feed Pellet Quality Factor" (FPQF)

The first step to take when trouble shooting is to calculate FPQF. If it is higher than your level of acceptability, then you know the problem is in the feedmill. If it is lower, then discuss it with your nutritionist or feed formulator.

Determination of FPQF can be used:

A. as a formulating tool to predict pellet quality!
B. as a production tool to maximize production rate!

A. Let us first take a look at feed raw materials and their influence on physical pellet quality. Knowing that some raw materials pellet well, wheat for example, and some are very difficult e.g., grain screenings, it should be possible from experience to given each raw material a Pellet Quality Factor; 0 for bad, 10 for good. I say from experience because pelleting each raw material as a "straight" and ascribing a value to it in order to calculate the pelletability of a mixture, does not always work out correctly. There is, without doubt, a synergy between raw materials which we do not yet fully understand.

The values listed for various raw materials are given in the table on page 40 of "The Pelleting Handbook", published by Borregaard Ligno Tech. Clearly, if a feed formulation can be identified as potentially difficult before it gets into production, then a great deal of time and money can be saved. However, it should be stressed that the results from calculations should only be used as guidelines.

As an example, Tables 1, 2, 3 and 4, show the FPQF calculation of a ruminant, pig, duck and Tilapia feed formulation, respectively. The process of calculating the Feed Pellet Quality Factor (FPQF) for any given formulation is straightforward. List the raw materials used in the formulation with their respective % inclusion and Pellet Quality Factor (taken from The Pelleting Handbook or your own modified version). Then, multiply the PQF by the % inclusion of the raw material e.g., Wheat meal: PQF 8: Inclusion 30%. Therefore, its contribution to the overall FPQF = 8 x 30% = 2.4. Add all the FPQF's together and their total represents the Feed Pellet Quality Factor for that particular feed formulation.

Calculation of feed pellet quality factor

Table 1. Dairy feed

	%	PQF	FPQF
Gluton	13	3.00	0.39
Citrus	22.5	7.00	1.57
distillers	6	3.50	0.21
Barley	20	5.00	1.00
Palm Kernal	10	6.00	0.60
oo-Rape	6	6.00	0.36
Tallow		-40.00	
Minerals	2.5	2.00	0.05
Wheat	20	8.00	1.60
Beet Pulp		7.00	
	Total FPQF		**5.78**

Table 2. Pig feed

	%	PQF	FPQF
Barley	23	5.00	1.15
Oat Meal	37.2	2.00	0.74
Wheat Meal	13	8.00	1.04
Tallow	2	-40.00	-0.80
Fish Meal	3	4.00	0.12
Meat Meal	6	5.00	0.30
Grass Meal	1.6	7.00	0.11
Mins on carrier	7	2.00	0.28
Vitamins	2.2	3.00	0.07
Returns	5	5.00	0.25
	Total FPQF		**3.26**

Table 3. Duck feed

	%	PQF	FPQF
Maize Meal	16	5.00	0.80
Rice Broken	35	5.00	1.75
Soya	30	4.00	1.20
Oil	0.5	-40.00	-0.20
Fish Meal	3.5	4.00	0.20
Mins + Vits	10	2.00	0.07
Rice Bran		2.00	0.20
Wheat		8.00	
	Total FPQF		**4.02**

Table 4: Tilapia feed

	%	PQF	FPQF
Feather Meal	3	4.00	0.12
Fish Meal	2	4.00	0.08
Distillers grain	1.9	3.00	1.20
Oil	1.15	-40.00	0.06
Minerals	2.51	2.00	0.13
Rape Meal	5	6.00	0.30
Wheat Pollard	15	5.00	0.75
Wheat	27	8.00	2.16
Soya	25.6	4.00	1.02
Sunflower Meal	16.84	6.00	1.00
	Total FPQF		**6.82**

When using a conventional pelleting line with no expander, if the result is below 5, there could be a pellet quality problem, if it is below 4.7, then the probability of a problem is very high. The tolerance between 4.7 and 5 takes into account the effectiveness and pelleting technique of the feed mill, some mills need to be "5" or over to make good pellets, while others could tolerate a lower level. It is suggested, therefore, that producers of pelleted feeds set their own FPQF level based on nutritional production circumstances and raw materials in relation to the level of pellet quality acceptability. When using an Expander, lower FPQF's can be tolerated.

B. Calculating FPQF also provides a means of deciding production strategy. If FPQF is 5 or over, it generally indicates that the formulation will be easy to condition, therefore more steam can be added. It also indicates that Pellet Quality should be good, therefore, production rate can be maximized.

Stage 2

Determination Of Specific Energy (kWh/T Pellet Press Motor)

If good quality pellets are to be produced, then the pellet press has to impart a given quantity of energy. Graphs 1 and 2 show the amount required -- all things being equal, higher pellet quality requires greater energy input. To produce poultry, pig and ruminant pellets of acceptable durability at an acceptable production rate, then at least 10, 12/15 and 20/25 kWh/T, respectively must be used by the pellet press motor. For fin fish and shrimp feed, around 12 kWh/T is required.

The second stage, therefore, in a trouble shooting effort to solve a pellet quality/production rate problem is to determine the kWh/T of the feed formulation in question. But first check the die to ensure that the holes are not blocked or rolled over. If the kWh/T value is found to be lower than that required, it suggests that the die is not working hard enough. Possibly, it is worn out or simply that its compression length is insufficient. If the value is equal to, or higher than that required, then the fault must lay somewhere else in the plant, such as grinding or conditioning.

To determine kWh/T (units of electrical energy used by the pellet press motor to produce one tone of pellets) the production rate in ton/hour must be known as well as voltage and the average amperage used by the pellet press. To calculate production rate, determine the amount of time it takes to produce a given quantity of feed and calculate tons/hour. Then apply the following formula to calculate power (kW) being taken by the pellet press motor.

$$kW = \frac{\text{Average pellet press motor amperage} \times \text{Voltage} \times 1.73 \times \text{Power Factor}}{1000}$$

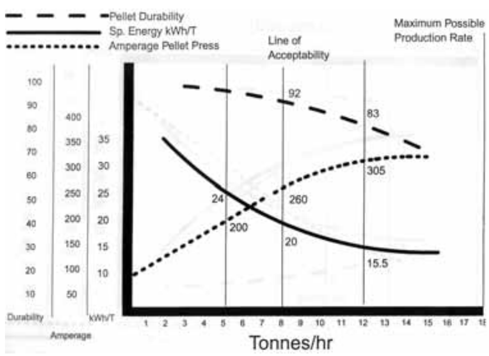
Assume a Power factor of 0.93 unless known.

$$\text{Specific Energy Consumption (kWh/T)} = \frac{kW}{T/h}$$

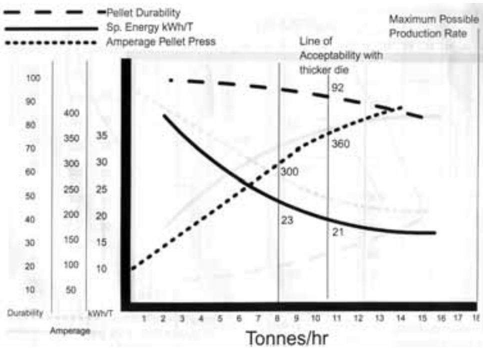
Relationship Between Pellet Press Motor Amperage, Specific Energy Consumption And Pellet Quality

Based on the actual pelleting trial, Graphs 4 to 7 inclusive present an illustrative account of the actual and potential production performance of a pellet press. This scenario is relevant for many pellet presses and different types of feed, particularly so in South East Asia. Graph 4 illustrates how, by controlling production rate, pellet quality, in this case a ruminant feed, can be maintained at a required level of acceptability (92 Holmen). However, with an available motor

Graph 4.

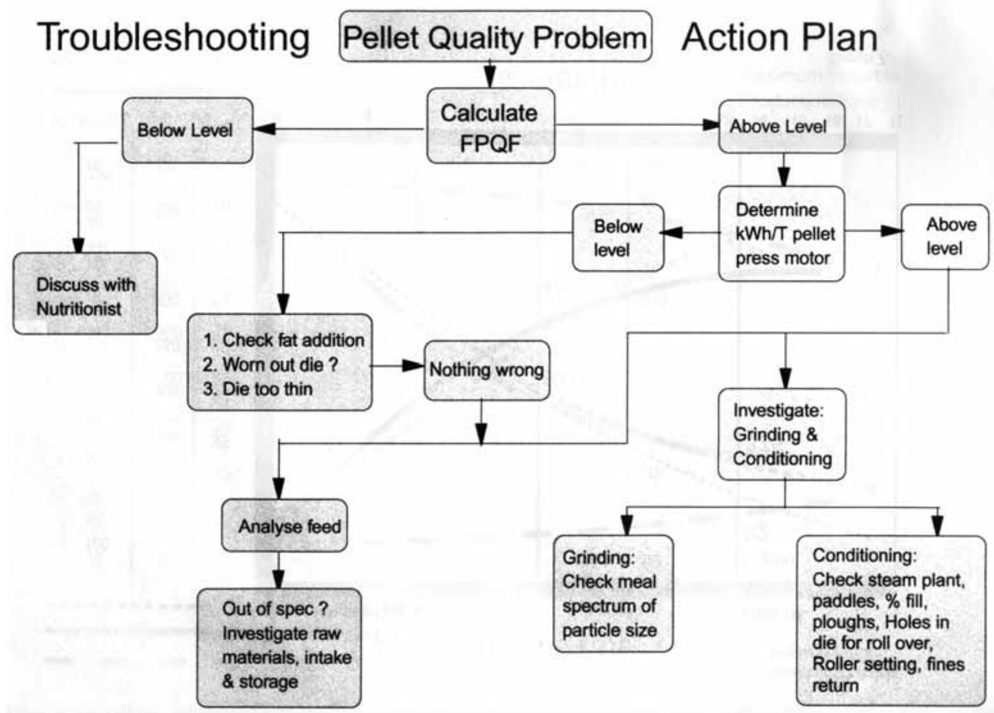


Graph 4.



amperage of over 400, this pellet press, in this example, was working well below its potential -- as are many pellet presses. It indicates that a thicker die could be used in order to increase production rate (see Graph 5). In reality, the same increase in production rate was obtained by adding a Lignin Performance Enhancer (LPE), but as can be seen from Graph 6, the difference in specific energy consumption (kWh/T) is substantial i.e., 16.3 compared to 21 in favor of the LPE. Graph 7 shows how the total potential of the pellet press can be obtained i.e., by combination of a thicker die and the addition of LPE. Without the addition of a LPE, at 13.5 T/h the pellet press motor would have far exceeded its maximum permissible amperage.

Graph 5.



So if the feed formulation and specific energy input are found to be adequate, according to your standards, then it will be necessary to move on to stage 3.

Stage 3

Check Conditioning

Grinding: "Conditioning" starts with grinding the feed raw materials. Grinding finer produces better quality pellets. Measure the "Meal spectrum of particle size" of the meal mixture which is to be pelleted and compare it with the following suggested spectrum:

Meal particles		on a 3.00mm sieve	up to 1%
“	“	on a 2.00mm sieve	up to 5%
“	“	on a 1.00mm sieve	around 20%
“	“	on a .50mm sieve	around 30%
“	“	on a .25mm sieve	around 24%
		Throughs (flour)	Not less than 20%

The sieve analysis not only indicates if the meal is too coarse, it also identifies grinding problems e.g., punctured or badly worn grinder screens. If your meal is much coarser than that suggested or is not as well balanced, the only solution is to fit grinder with screens having smaller perforations or a combination of screen sizes to improve balance. Check meal spectrum of particle size regularly and avoid fitting new beaters and screens together.

Conditioning: Steam/moisture is the critical factor, but if the mixer conditioner is not working effectively, the benefit from producing good quality steam will be wasted. Therefore, ensure that the conditioner is running as full as possible by adjusting the angle of its beaters or possibly reducing the speed. The objective is for the meal, liquids and steam to rub together -- they must be persuaded, not beaten. It is essential that heat and moisture is transferred from steam to meal as fast and as evenly as possible. The factors which influence this are:

1. Quality steam
2. Steam velocity entering the conditioner
3. Location of the steam pipe entering the conditioner
4. Volume of meal in the conditioner

Steam should be “dry” at entry to the conditioner i.e., no water droplets. These should have been taken out by the separator. The pressure of steam should be set to suit requirements -- generally around 4 Bar pressure for ruminant and other fibrous feeds, and around 1 to 2 bar for starchy type of feeds. However, the writer suggests setting your pressure to suit your circumstances depending on the moisture content of your meal prior to conditioning. If your meal is predominantly dry, then use low pressure steam for all types of feed, but ensure the diameter of the steam pipe, after reducing the valve, is big enough to carry the volume at low velocity (20 m/sec) required to optimize meal temperature and moisture. Best results are obtained when steam enters the conditioner via its end plate through a manifold. The steam reducing valve should be at least six meters upstream from entry to the conditioner.

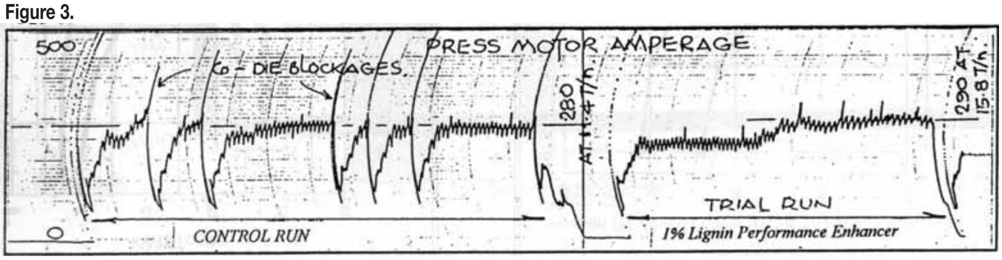
So, if you are satisfied that everything so far meets with requirements, then the last stage has to reveal the problem.

Stage 4

Check out the following main problem areas:

1. Fines return are large pieces or whole pellets returned to the pellet press -- possible hole in sifter screen, See amperage trace Fig. 3 -- recorded in an Israel feedmill.
2. Are you allowing any raw materials to by-pass the grinder e.g., soy or pelleted products? (Sieve analysis will reveal this).

Figure 3.



3. Analyze finished product for oil and protein -- if out of spec., check feed raw materials and storage silos. Possible carry over of one raw material into another.
4. Check temperature and moisture of pellets leaving cooler. These should be at a level which you know the product can be stored without risk of deterioration.
5. Are you adding water? Water doe not disperse well. It creates wet-spots which cause pellets to degrade during storage.
6. Are you adding other liquids e.g., fat, molasses? Check to ensure these are dispersed evenly.
7. Ensure that both (all) rollers in the pelleting machine are positioned correctly and the plough/s are not badly worn/fitted. Uneven pellet length is an indication that something is wrong. Check again to ensure the holes are not rolled over.

Maximizing Pellet Quality/Production Rate

The addition of binders can help solve pellet quality problems or simply lift your pellet quality to a higher plane. Lignin technology has advanced rapidly over the past few years so much so that collectively Lignins have become known as “Lignin Performance Enhancers.” Some have been developed to maximize pellet quality, while others to maximize production of the pellet press without compromising pellet quality.

When used to maximize pellet quality (as well as improving production rate) the glue-like properties of lignin maximize the grip between rollers, meal and die making the action of pelleting more positive i.e., reducing roller slip. As the pellets lose moisture in the cooler, the lignin structure within them toughens and strengthens, resulting in pellets of higher durability.

On the other hand, lignins have been developed to maximize production rate (as well as improving pellet quality) by creating “internal body lubrication” which allows the meal particles to mold together more easily, thereby forming pellets with improved structure. Moreover, lubrication extends to the die allowing for higher production rate without losing pellet quality.

Lignin is a cost effective tool which can be used to overcome production and pellet quality problems or as a means to improve overall efficiency. Fig. 1 and Fig. 2 show a pellet press amperage trace recording when producing a commercial poultry feed. During a three hour production run, the pellet press operator encountered 12 complete chokes and 13 interruptions until a 0.5% addition of a specifically formulated lignin production performance enhancer was made. Amperage was immediately reduced and production ran smoothly from then on. Moreover, production rate increased from 13.2 to 16.1 tons/hour, specific energy consumption was reduced from 11.36 to 10 kWh/T and pellet durability increased from 52 to 62 Holmen. The extra tonnage improved the profitability of this mill by $50 per hour.

Pelleting Trial: commercial broiler feed (corn/soya type)

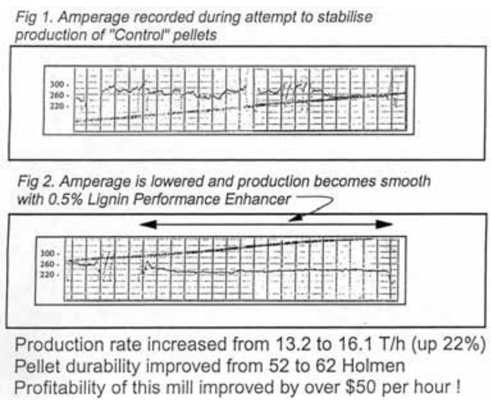


Table 5/Fig 3 show a similar effect when producing 4 mm Tilapia.

Measurement Of Physical Pellet Quality

“Hardness”, “Durability “ and “Appearance” are the main factors associated with the term pellet quality.

Hardness is usually measure by a spring type tester. It is advisable to take the average of several readings because of the variability in results.

Durability is the most important aspect of pellet quality. Durability means the ability of pellets to withstand the rigors of handling and delivery without breaking up. It can be measured in one of two recognized ways:

- Mechanically
  - Tumbling Can Method or Pneumatically
- Holman Tester and Ligno Tester

Pelleting Trial: Table of results

Table 5

4mm Talapia feed pellets	Control	1% Lignin PE at 11.7T/h	1% Lignin PE at 15T/h	1% Lignin PE at 15.8T/h
Production Rate T/h	11.4	11.7	15	15.8
Press Amperage	280	240	280	290
kWh/T	14.53	12.14	11.04	10.86
Durability 1min Holmen	96	98	96	95
Fines Return %	0.7	0.3	0.3	0.4
Meal temperature °C	93	94	95	98

Plant details: CPM 7800 with 200kW motor. Barrel conditioner. Steam 1 bar

Appearance is mainly subjective, color, surface texture etc., pellet length, however, an important aspect when a customer makes a visual assessment of your product, can be measured. The generally accepted guideline for a pellet length is 2.5 times its diameter. Measuring average pellet weight is becoming a common method of monitoring changes in pellet quality, by taking a random sample, weighing and counting the pellets to determine average weight, serves to detect changes in pellet length as well as pellet density.

Conclusion

A “Troubleshooting” route in block form provides a summary to help direct you to a speedy solution of pellet quality/production problems you may encounter.

Measuring/monitoring the performance of your plant will enable you to manage it effectively and provide a means of speedily troubleshooting production or pellet quality problems. Moreover, combining your production knowledge with Lignin Technology will enable you to truly maximize pellet quality and production performance, profitably.

References

Bewley, W., 1991. Countering the myths and “home remedies”. Feed International.

Heimann, M., 1996. Particle size reduction. Feed Computer Compounder.

Kivimae, A. Effects of lignosulphonates on poultry when used as a binder in compound feed. Swedish University of Agricultural Sciences, Uppsala.

Payne, J.D., 1993. How to improve pellet quality. N.L.C.F. Semianr. Seoul, Korea.

Payne, J.D., 1989. Practical experiences from pelleting trials and the use of Lignin binders. The Poultry Association of Symposium. Spain.

Payne, J.D., Rattink, Smith and Winowiski. The Pelleting Handbook. Borregaard Ligno Tech. Sarpsborg, Norway.

Pfost, H.B. 1964. The effect of Lignin bincers, die thickness and temperature on the pelleting process. Kansas State University. Feedstuffs (Vol. 36, No. 22, p.20).

Wetzel, W. 1991. Pellet mills in the Feed Industry. Feed Magazine.

Winowiski, T.S. 1996. Pelleting Aids. American Feed Ingredients Association.

Zatari, I & Schiedler, M. 1990. Effect of pellet integrity, calcium lignosulphate, dietary energy on performance of summer-raised broiler chickens. Poultry Sci. 69:198.

The Lignin Performance Enhancer products referred to in this paper are: Fig 1. PellTech. Other references relate to LignoBond...both produced by Borregaard Ligno Tech. Pellet hardness testers are produced by Amandus Hahl. Tumbling can testers are produced by various pellet press manufacturers. The pneumatic testers -- Holmen Tester and Ligno Tester -- are produced by Borregaard Ligno Tech.

Particle Size Reduction For Animal Feeds

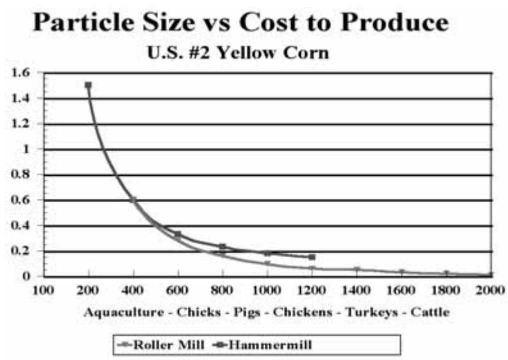
Doug Reuscher
Roskamp Champion
USA

In the feed manufacturing industry, particle size reduction (grinding) is second only to extrusion processes (pelleting, expanders, extruders) in terms of total energy consumption. Any discussion of grinding then must first deal with the question, "Why grind?"

Why process at all? Of course the answer is ultimately feed efficiency, producing the most milk, eggs, meat, or fiber at the lowest possible cost. This first step in the feed manufacturing process works towards the goal of improved feed efficiency by increasing the surface area of the materials being processed. This increases the amount of materials exposed to the animals digestive system, and ultimately leads to more complete digestion, thus better feed efficiency.

Because animal needs vary considerably, the degree of processing for various diets also must vary. Cattle and sheep have rather long, complex digestive tracts and so require a less processed feed material. Swine have a fairly short, simple digestive system (very much like humans) and therefore benefit from a more highly processed feed. Poultry have a short but rather complex digestive system, and depending on the make up of the diet can efficiently utilize feedstuffs less highly processed than swine. The size and age of the animals also affects the dietary requirements so far as particle size is concerned. Generally speaking, younger animals require a finer, more highly processed feed than do older, more developed livestock.

Particle size reduction is also required to prepare the materials for secondary operations such as mixing, pelleting, or extrusion. In general, a finer ground material or mixture will produce a better quality pelleted or extruded feed at a lower cost (energy and maintenance) on the pelleting or extruding machinery. Of course more energy per ton is required to achieve the finer grind and often the capacity of the grinding equipment will be reduced. The fineness of the grind must be matched to both the particle size and capacity requirements of the entire feed manufacturing process.



Due to the wide variety of feed ingredients and compounds, there is no "ideal" particle size for each type and age of animal. The chart presented below is simply an indication of the generally accepted particle size ranges for all types of animals and feeds.

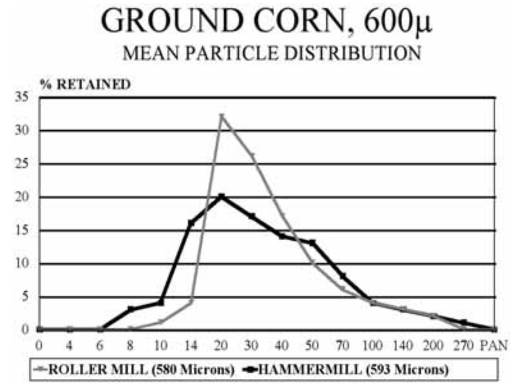
How Fine Do You Grind?

Determining and expressing fineness of grind has been the subject of study as long as feed ingredients have been prepared. While appearances or feel may allow an operator to effectively control a process, subjective evaluation is inaccurate at best, and makes objective measurement and control virtually impossible. Descriptive terms such as coarse, medium, and fine are simply not adequate. What is "fine" in one mill may well be "coarse" in another. Describing the process or equipment is also subject to wide differences in terms of finished particle size(s) produced. Factors such as moisture content of the grain, condition of the hammers and/or screens (hammermill) or the condition of the corrugations (roller mills) can produce widely varying results. In addition, the quality of the grain or other materials being process can have a dramatic impact on the fineness and quality of the finished ground products.

The best measurement of finished particle sizing will be some form of a sieve analysis, expressed in terms of mean particle size, or percentage (ranges) on or passing various test sieves. A complete sieve analysis will not only describe the average particle size, but will also indicate peculiarities in the distribution such as excessive levels of fine or coarse particles, etc. Typical descriptions that lend themselves to objective measurement and control might be: corn ground to 750 Microns, not less than 50% passing 20 mesh, and 85% -10/+40 mesh.

Grinding Equipment

Both roller mills and hammermills have been applied to the task of particle size reduction or grinding in feed milling applications. Hammermills have traditionally been used to produce the finer grinds commonly used for pelleting, and for many mash (meal or non pelleted) feed applications as well. The hammermill is a relatively simple machine and requires a fairly low degree of skill in regards to both the operation and maintenance.



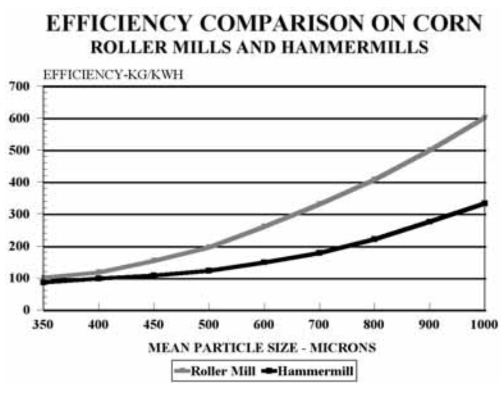
However, recent significant changes in the industry have caused many to reassess their approach to particle size reduction. Increasing energy costs, increasing customer awareness of feed quality, and environmental concerns all challenge the validity of the hammermill as the only alternative for particle size reduction (grinding) applications. In the following discussions, both roller mills and hammermills will discussed in terms of equipment selection, operating conditions and parameters, and relative costs to acquire and to operate.

Roller Mill Grinding

In recent years, more attention has been given to the roller mill set up to function as a grinder. Several important factors have contributed to this including energy costs, product quality concerns, and environmental issues. Each of these will be reviewed in turn below.

Energy costs have escalated dramatically in the last 20 years, and at the same time margins in feed manufacturing have decreased. As a result, cost savings of $0.10 to $0.40 per ton for grinding can mean a significant difference in the bottom line of a feed manufacturing operation. Because of an efficient reduction action, roller mill grinders will produce 15 to 40% more tons/hour at a given horsepower than traditional "full circle" hammermills when producing the same finished particle size. Roller mill energy savings advantages will be even greater when compared to older half screen hammermills with direct connected fans. In many instances the energy savings potential of a roller mill grinder will justify the capital expenditure.

Product quality concerns have always been a part of feed manufacturing, and there are many quantitative methods for measuring feed quality. Nonetheless, the physical traits (appearance, feel, handling characteristics) will always influence the feed buying customer. Because the grind produced by a roller mill is very uniform, the finished product(s) have an excellent physical appearance. The low level of fines and lack of oversize particles make a feedstuff with excellent flow and mixing characteristics. This is especially important for mash or meal type feeds where the flow from bins and feeders can be difficult to regulate, and where segregation and separation



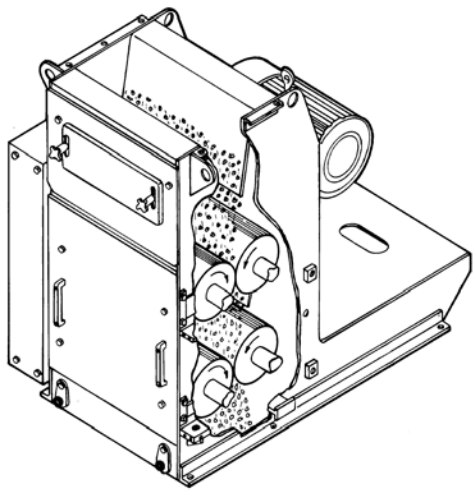
may occur in shipping and handling. Because the product is not heated significantly in the grinding process, less moisture is driven off and the finished product is not prone to hanging up in bins, spoiling in storage, and other maladies related to heat and moisture.

Environmental issues of concern to the feed manufacturer today include particulate emission, employee exposure to noise, and the risk of fire and explosion. Because roller mill grinders create fewer fines, less material is likely to be lost to the atmosphere. Additionally, high efficiency hammermill installations require air assist to achieve the rated performance. Cyclones and bag filters are not 100% effective in removing the particulates from the air streams and so some emissions will occur. Whether or not these emissions are a problem will depend on widely varying local conditions and regulations. Because roller mill grinders operate at lower speeds and with a different kind of reduction action, less noise is generated in the grinding process. In many cases this reduction in noise means a roller mill grinder will not require a separate enclosure to limit employee exposure to high noise levels. Lower operating speeds in roller mill grinders mean less frictional heating and less inertial energy (such as thrown hammers) in a hammermill. This reduction in ignition sources combined with less dust in the product stream greatly reduces the risk of fire in the grinding operation.

The Roller Mill Grinder

Not every make or style of roller mill can be applied to the task of grinding. Essentially, a roller mill grinder will utilize rolls from 9 to 12 inches in diameter operating at differential speeds. Roll speeds will be higher for roller mill grinders than for cracking/crimping and flaking mills. Typical peripheral speeds range from 1,500 feet/minute to more than 3,000 feet/minute for 12" diameter rolls. Due to higher speeds and greater loads, the bearings and shafts of a roller mill grinder experience far more demanding conditions than cracking or crimping mills.

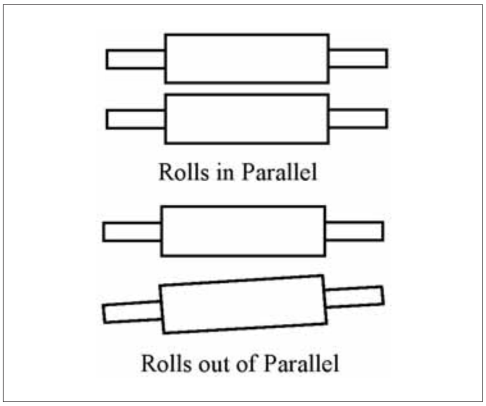
Double Pair Roller Mill

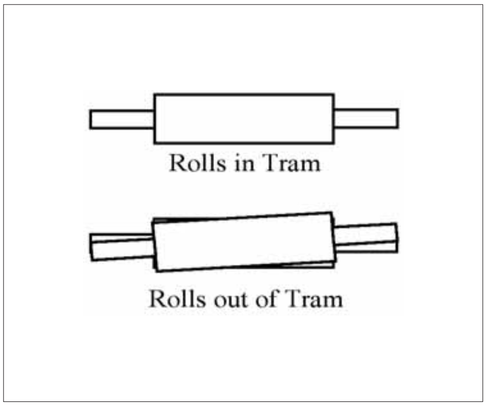


Differential ratios vary from about 1.2:1 up to 2:1 for typical feed milling operations. Lower differential ratios do not permit adequate reduction, while higher ratios can lead to excessive roll wear. It is essential that the roll speed differential be maintained when operating at full motor loads in order to achieve the desired grinding results. Inter roll drives may utilize spur gears, roller chains and sprockets, double sided V belts, toothed belts (timing belts), or shaft mounted gear reducers to achieve this differential action. Each type of drive has its merits and limitations. Generally speaking, the simplest drive that is suitable for the maximum horsepower applied will be the best.

Because the roll clearances need to be maintained under demanding conditions, the mill housing and roll adjustment mechanism of the roller mill grinder must be more robust than for cracking and crimping mills. More precise roll position adjustments must be made, and better control over the feeding is necessary in order to achieve the full benefits of the roller mill grinder through its range of capabilities. Rolls must be operated in parallel and in tram to reliably produce quality finished products. For these reasons, many of the existing cracking and crimping mills cannot be made to function effectively as a roller mill grinder. The figures below depict roll conditions of parallel and tram.

A roll type feeder is generally preferred for a roller mill grinder to insure a uniform feed across the full length of the rolls. While other types of feeders can work, including simple slide gates or more complex vibratory feeders, the roll type feeder covers a wide range of applications very efficiently. Because roller mill grinders do more work and use more horsepower than cracking and crimping mills, roll

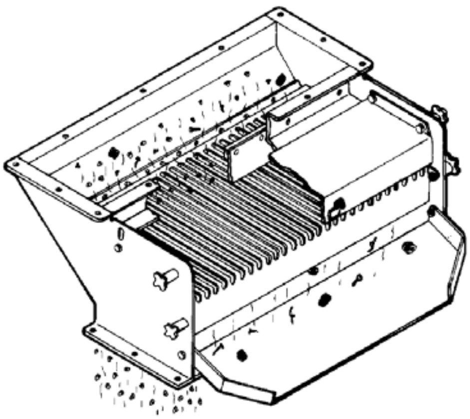




wear rates will be greater. Rolls will require recorrugation when the capacity of the mill drops by 20-30% or when finished product quality is not longer acceptable. Because they do not effectively reduce fibrous materials, roller mill grinders are best applied to grinding friable products such as corn, wheat, milo, soybean meal, and similar products. Roller mill grinders are also commonly applied to feed additive materials and fertilizers where free flowing, granular end products are desired, and when it is desirable to minimize fines.

Cleaning grain ahead of a roller mill can improve the roll life and the quality of the finished product(s). Normally all that is required is some form of scalper to remove gross oversize pieces; stalks, cobs, clods, stones, and the like. Magnetic protection ahead of the mill will insure a minimum amount of tramp metal enters the rolls. While grain for a roller mill grinder does not require any more cleaning than grain going to a hammermill, some objectionable fibrous materials may be passed unprocessed through a roller mill grinder. Rolls tend to be self-limiting in so far as the size of materials that will be pulled into the nip. Rolls cannot get a purchase on large stones, etc. and though roll wear may be accelerated by the presence of such objects, the mill is not likely to suffer acute failures.

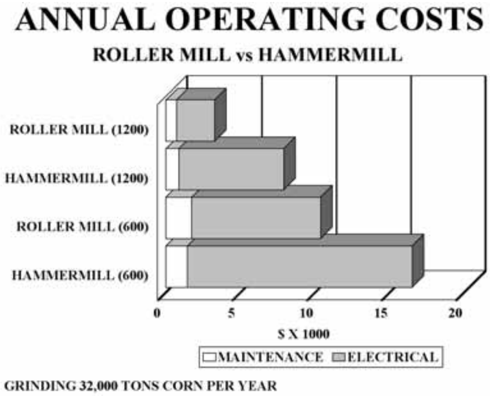
Scalper



The primary claims against roller mill grinders are high initial cost, maintenance hours to change rolls, and the need to carry spare rolls in stock. Roller mills are generally more expensive than hammermills of equal capacity, but total installed costs for the two systems are not so different when all factors are considered. Items such as larger motors, starters, and wiring, air assist systems including fans and cyclones, and additional labor to install the more complex material handling systems of hammermills tend to offset the differences in the basic equipment costs. Because roller mill maintenance (roll change) occurs in a concentrated block the actual time required appears to be significant. In fact, when compared on a "maintenance hours per ton" basis, roller mill grinders are quite competitive with hammermill grinders. Finally, spare rolls may amount to a fair capital investment, but again comparing the actual cost on a "per ton" basis, the maintenance costs of recorrugation and roll replacement are within $0.01 to $0.03 per ton of hammermill maintenance costs.

Hammermill Processing

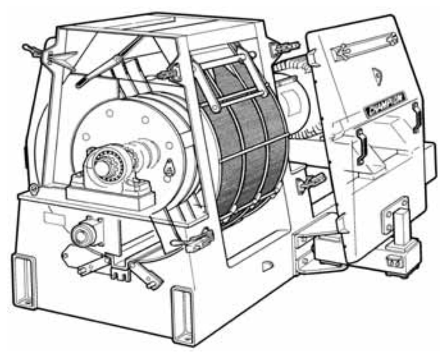
Hammermills have long been used for particle size reduction of materials used in the manufacture of animal feeds. It could be said the hammermill has been the most studied and least understood



piece of equipment in the feed manufacturing plant. Much of this confusion has come about over the years as a result of hit or miss problem solving and by treating symptoms rather than addressing the root causes when treating operational problems.

A well-designed hammermill grinding system will offer good long-term performance and require a minimum amount of attention if a few basic considerations are made at the time the equipment is selected. The following discussion will explore the basic theory of hammermill operation and offer some principles on which systems may be successfully designed.

Equipment Description



A hammermill consists of a rotor assembly, consisting of two or more rotor plates fixed to a main shaft, enclosed in some form of grinding chamber. The actual working mechanisms are the hammers and the screen or grinding plates that encircle the rotor. The rotor may be supported from one end only (overhung) or supported on both ends by the shaft and bearings. For modern, high capacity machines in widths of 12" up to 48", the rotor is normally supported on both ends. This provides a more stable running mill, and reduces the tendency for a rotor shaft to "wind up" or run out under load. The hammers are simply flat metal bars with a hole at one or both ends and usually have some for of hardface treatment on the working end(s). The hammers may be fixed, fastened rigidly to the rotor assembly but much more common is the swinging hammers where the hammers float on pins or rods. This swinging hammer design greatly facilitates changing hammers when the working edges are worn.

Reduction in a hammermill is primarily a result of impact between the rapidly moving hammer and the incoming material. There is some attrition (gradual reduction by particles rubbing) between the particles, and between the hammers and the screen.

The efficiency of the grinding operation will depend on a number of variables including but not limited to: screen area / horsepower ratio, screen (hole) size and open area, tip speed, hammer pattern (number of hammers), hammer position (coarse or fine), uniform feed distribution, and air assist. In addition, the nature and quality of the material(s) being processed will affect the performance of the hammermill.

Basic Machine Characteristics

Hammermills used in feed processing have some common characteristics but equipment manufacturers differ significantly in how they achieve those same characteristics. For the purpose of the discussion, here a number of basic design principles will be reviewed as they apply to maximizing the performance and minimizing the cost of operating a hammermill system.

Full Width Top Feed - the modern hammermill design must include a full width top feed in order to achieve maximum efficiency and minimize the cost of operation. A full width feed insures the entire screen area can be utilized, and that the work being accomplished will be evenly distributed across the full hammer pattern. The top feed permits the direction of rotation to be changed, allowing two corners of the hammer to be utilized before a physical change of the hammer is required.

Tear Shaped Grinding Chamber - a tear shaped grinding chamber is necessary to prevent material from circulating within the grinding chamber. Most well designed modern hammermills have some sort of flow director in the top of the hammermill to properly feed the hammermill and to stop any materials that are circulating within the grinding chamber.

Split Screen / Regrind Chamber - the screen should be split in two pieces, with some device at the bottom of the mill to disrupt the flow of materials within the grinding chamber. This device must be large enough to take products out of rotation but should not be so large as to subtract from the screen area available for grinding. The application of a split screen design will permit the user to adjust the screen sizing on the down side and up side to maximize productivity and product quality.

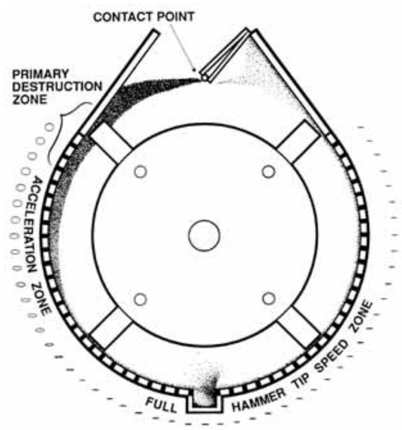
Outboard Supported Rotor – As noted earlier, the rotor should be supported at each end, preferably with standard bearings and bearing housings. This will provide a degree of rigidity not available with an "overhung" rotor design and reduce any problems with rotor shaft "wind up" even if the mill operates with an out of balance rotor. Adequate support for the rotor is particularly important with today's increased capacity demands requiring wider machines..

Rigid Rotor Support - in order to maintain the relative position of the rotor to the grinding chamber the foundation of the mill must be extremely rigid. A rigid structure positively maintains the clearances between the hammer tips and the screen through the full rotation for consistent, efficient processing. This must be accomplished without sacrificing the accessibility to the grinding chamber, as routine maintenance of the hammers and screens will be required.

Replaceable Wear Items - one final rule for a good hammer design is if it can wear, it should be replaceable. Beyond the hammers, screens, and pins, every component within the hammermill will be subject to wear. Accordingly, these components should be fabricated from wear resistant materials, heavy enough to provide good service life, and ultimately should be reasonably simple to replace.

Basic Operational Concepts

Particle size reduction in a hammermill occurs as a result of the impact between a rapidly moving hammer and a relatively slow moving particle. The particle breaks and is accelerated towards the screen. Depending on the particle size and angle of approach, it either passes through the screen or rebounds from the screen into the rapidly moving hammers again. As materials move through the grinding chamber they tend to approach hammer tip speed. Since reduction only occurs when a significant energy is transferred from the hammer to the particle (large difference in velocities), less grinding takes place when the particles approach hammer tip speed. Many manufacturers incorporate devices within their mills to interrupt this product flow, allowing impact and reduction to continue. Tear circle hammermills have a more positive, natural redirection of product at the inlet than "full circle" design machines.

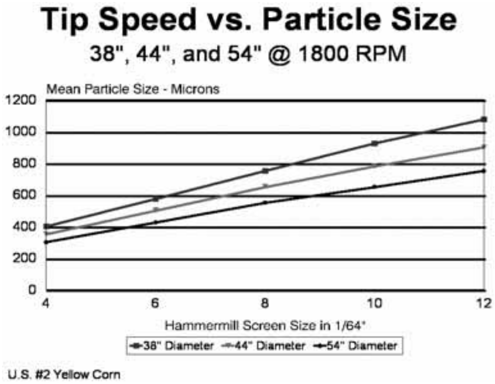


While the basic operational concepts are the same for all hammermills, the actual unit operating conditions change rather dramatically depending on the materials being processed. Grains such as corn, wheat, and sorghum and various soft stocks like soybean meal tend to be friable and easy to grind. Fibrous, oily, or high moisture products like screenings, animal proteins, and grains like oats and barley on the other hand, are very tough and require much more energy to reduce. Consequently, the hammermill set up that works well for one will not necessarily work well for the other. The following discussion covers such factors as tip speeds, hammer patterns and position, horsepower ratios (to hammer and screen area), and air assist systems.

Tip Speed

Tip speed, in addition to screen size has a significant influence on finished particle sizing. High tip speeds (>18,000 Ft/Min) will always grind finer and produce more fines than lower tip speeds. Low tip speeds (<13,000 Ft/Min), on the other hand, produce a coarser granulation with fewer fines. As a rule smaller screen hole sizes should be used with higher tip speeds, and larger screen hole sizes with lower tip speeds.

Tip speed is simply a factor of mill diameter and motor RPM and is not easily changed on direct coupled machines. There are a few V-belt drive hammermills on the market today.



Tip Speed -Friable Products

For producing a uniform granulation with few fines on friable products like corn, wheat, grain sorghum, pelleted ingredients, and solvent extracted meals an intermediate tip speed is normally desirable. Hammermills with a tip speed of 13,000-18,000 Ft/Min will produce a high quality finished product with excellent capacity and efficiency. 38" diameter mills with 1800 RPM motors (17,800 Ft/Min) and 44" mills with 1200 or 1500 RPM motors (13,500 or 17,250 Ft/Min) are both used extensively in the processing of all kinds of feed ingredients.

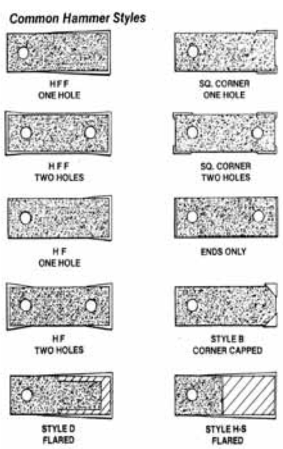
Tip Speed -Feet/Minute

Rotor Diameter x RPM

Diameter	1200 RPM	1800 RPM	3600 RPM
19"	NA	7536	17898
22"	NA	10362	20724
28"	NA	13194	
38"	11938	17670	
42"	13194	19782	
44"	13823	20724	
54"	16964	25434	

Tip Speed - Fine Grinding And Tough To Grind Materials

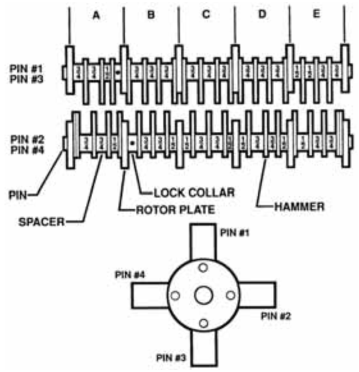
For fine grinding friable products and tough to grind materials like soybean hulls, mill feed, and mixtures with animal protein products, a higher tip speed is indicated. Because more energy is required to grind these kinds of materials a higher tip speed is beneficial. Normal tip speeds for fine grinding and fibrous materials are obtained on 42" and 44" mills operating at 1800 RPM (19,500 and 20,000 Ft/Min), or 28" mills operating at 3000 RPM and 54" mills operating at 1500 RPM (21,000 Ft/Min). Recent developments in hammermill grinding have included the use of 54” diameter mills operating at 1800 RPM. This very high tip speed (>25,000 Ft/Min) is particularly well suited to fine grinding at high capacities and high efficiency. Because a larger screen (hole) sizes can be used while maintaining the fineness of the grind, operating costs are reduced as well.



Hammers

There is an unlimited number of hammer styles available from many suppliers around the world. At the same time, there are distinctly different types of hammers used in different regions of the world. European feed processors tend to favor a plain two-holed hammer, with no hardfacing or edge treatment. North and South American feed millers tend to favor a hammer with a flared hardface end (or ends). Each market tends to find a hammer type that best suits their particular needs.

Hammer patterns and positions have a profound effect on the performance of any hammermill. Because different materials grind differently, the ideal number of hammers and clearance to the screen will need to be adjusted according to each application. At the same time, it is important to make sure the hammer pattern covers the working screen, without having hammers in line.



In most cases, the hammer pattern should include double hammers on the outside rolls of at least two opposing pins. Because the material in the grinding chamber near the sides of the mill moves more slowly (dragging on the sides), the outside rows of hammers must do more work and are subject to more wear. Some manufacturers use thicker or longer hammers on the outside rows.

There is also a relationship between the HP/hammer and the wear on the hammer. Too much HP/hammer will tend to "rock" the hammer each time the hammer swings through a bed of material on the screen, leading to rapid wear of the hammer hole and hammer mounting pin. In extreme cases, the bed may be so deep that the hammer wears above the hardfacing. If this happens the correct solution is not to use a hammer with more hardfacing extending up the hammer, but to reduce the H.P., increase the number of hammers, or reduce the feed rate to the mill. Too little HP/hammer dramatically reduces hammermill efficiency by consuming motor horsepower simply to turn the rotor with its load of hammers. Too little HP/hammer also tends to wear the hammers right on the corner and does not effectively use all the working surface of the hammer.

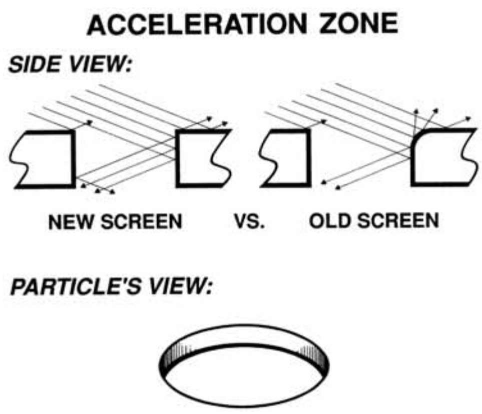
Horsepower / Hammer Ratios

Hammer Size	Easy to Grind	Tough to Grind
6-8"	1 to 1.5 H.P./Hammer	.5 to 1 H.P./Hammer
8-10"	2.5 to 3.5 H.P./Hammer	1 to 2 H.P./Hammer

Screens

More time, effort, and dollars are invested and lost in hammermill processing due to screen application failures than would ever be thought possible. Excessive horsepower per In2 of screen and poor screen configurations steal precious process energy and maintenance dollars. In simplest terms, the best screen for any job is the thinnest material with the most open area. Naturally, some sacrifice in efficiency must be made for the sake of endurance, yet the general rule applies.

It is easy to see how new screens improve capacity and grinding efficiency. While thicker screens will last longer, they significantly reduce the tons/hour that a mill can process. When maintenance costs are typically $0.02-$0.10/ton and electrical costs range from about $0.25/ton, to more than $1.00 per ton, saving money by not changing screens is truly false economy.



Another screen consideration is the amount of open area a particular screen offers. Factors effecting open area include hole size, stagger, angle of stagger, and hole spacing. Screens with fewer holes have less open area, are easier to produce, and generally cost less. Screens with little open area may wear a long time, but the actual grinding cost per ton is greatly exaggerated because of the increased energy cost.

Two rules of thumb apply to hammermill screens in relation to applied horsepower:
1. Never have less than 14 In2 of screen per horsepower (more is always better)
2. Never have less than 4 In2 of open area per horsepower

One very simple way of increasing hammermill capacity without affecting the finished grind or adding expense to the grinding system would be to replace the "up" wide screen with perforations that are 2/64" to 6/64" larger than the "down" side screen. This may add 10-15% to the hammermill capacity and produce no noticeable difference in the finished products. Remember that the screens must be switched when the hammermill rotation is changed to use both corners of the hammer.

Feeders

Proper feeding of a hammermill is absolutely essential if the system is to operate at maximum grinding efficiency, and with the lowest possible cost per ton. Uneven or inconsistent feeding can lead to surges in the motor load. Because the load is constantly changing, the motor cannot operate at peak efficiency and so increases the grinding costs. An additional liability that is often “hidden” is the fact that surges in the feed tend to accelerate wear on the hammers and pins by causing the hammers to “rock” on the pin.

Uneven feeding across the face of the hammermill obviously increases the wear on the working components in the areas of heaviest feeding. Because a part of the mill is being overworked, the rest of the mill is not being fully loaded and grinding efficiency is reduced. Uneven feeding also tends to cause a hammermill to go out of balance more quickly due to uneven wear. This adds to the operating cost of the mill be causing premature replacement of the wear items like hammer and pins.

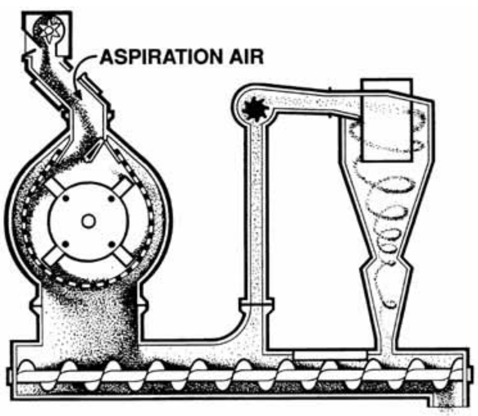
Rotary Pocket Feeder - as the name indicates, rotary pocket feeders utilize a rotor mechanism much like a rotary air lock to evenly distribute the feed to the hammermill. In most cases, the rotor is segmented and the pockets are staggered to improve the distribution of the feed, and to reduce surges in the feed rate. Because the rotary pocket type feeders relies on a free flowing material to fill the pockets, they are best suited to granular materials with a density of 35#/Ft3 or more. Typical applications would be whole grains and coarsely ground meals.

Screw Feeder - screw type feeders are used when processing materials that have poor flow characteristics, or contain large bits of material that would not flow properly with a rotary pocket feeder. Screw feeders impart a surge to the feed, and so have limited applications in high capacity / high efficiency grinding situations. In the past, screw feeders were selected when rotary pocket type feeders lacked sufficient capacity to load a hammermill motor. With the advent of today’s 10” and 12” diameter rotor sections, this is no longer a problem.

Air Assist

The final application topic to be considered is the use of aspiration air to improve mill efficiency and performance. The air assist system controls the environment of the grinding chamber in the hammermill and aids in moving product from the grinding chamber through the screen perforations. A properly designed air assist allows a hammermill to grind more efficiently, producing a more uniform finished product with less heating and controls dusting around the mill. Although hammermill capacity will vary with the type of machine and operational parameters, air assisted grinding systems will out produce non-assisted systems by 15-40%.

A good rule of thumb for the amount of air required to assist product and control dusting is 1.25-1.50 CFM/In2 of screen area. Pressure drop across the mill may range from 2-5" W.C., depending on system operating conditions. In order to make an air assist system work, several items must be considered including the air flow into the mill, paths for the air and product out of the mill, separating the product from the air stream, and controlling the path of the air in the system.



Once the air is through the mill, it is necessary to allow the entrained fines to settle out before sending it along to the cyclone or filter system. To accomplish this, a plenum or settling chamber should be provided between the air/product conveyor and the pickup point. While in the past, such figures as "3-5 times the duct diameter" have been suggested, the bottom line is to reduce the velocity as much as possible to permit the fine material to settle out. If the plenum is designed so the air velocity drops below 15 times the bulk density (15 x 40 or 600 Ft/Min for most feed ingredients) the separation will usually be adequate. Larger plenums will reduce the velocity and improve the air/fines separation. For practical purposes, the plenum cannot be too large.

To make the air assist system work, it is necessary to control the path the air takes through the mill. Normally, the discharge end of the take away conveyor must include some kind of airlock to insure the air is pulled through the hammermill instead of back through the discharge system. This may be as simple as a shroud over the take away screw or as complex as a powered rotary airlock at the discharge of a drag conveyor.

Other Considerations

Magnetic protection is necessary in order to realize the best life of the working components of the mill. Tramp iron that enters a hammermill can knock holes in the screen, break hammers, and create undesirable sources of ignition. Mills that routinely operate with excessively worn or failed hammers will vibrate badly and promote bearing failures. The vibration monitor switch on a hammermill is intended to be used as an emergency shut down measure and not as an indication that lost tools have been found.

Always buy the best possible magnetic protection that is reasonable for a specific system and make sure the magnets are routinely cleaned. Nothing in the process plant is less productive than magnets that are covered with tramp iron.

Many types of feeders can be equipped with VF drives or other means to permit easy adjustment of the feed rate. In many plants these will be integrated with a process control system that automatically adjusts the feed rate to match motor loads or process flow rates. While not as uniform as rotary pocket feeders, variable speed screw feeders can also be employed to regulate the flow of materials into a hammermill grinder. While simple slide gates may be less costly to install initially, the improved service of the mill and working components, lower operational costs, and improved product quality are all good reasons to invest in a quality feeding system.

Handling And Storage Of Soybeans And Soybean Meal

Ulysses A. Acasio
Department of Grain Science and Industry
Kansas State University, USA

Introduction

Soybeans represent the world's most important oilseed as a source of vegetable oil and protein. It is grown extensively in the United States, Brazil, Argentina and China. The beans can be processed into flour for food and meal for feeds. In China, Japan and Southeast Asian countries, soybeans are used primarily in the preparation of various food products. In the U.S. and Europe, soybeans are used mainly for production of oil and meal. There are hundreds of soybean cultivars found in different parts of the world but only dozens are in commercial cultivation.

There are two kinds of soybean meal: full-fat and defatted. Both are used in the feed industry. Defatted soybean meal is a by-product of the oil extraction process and comes in either loose or pelleted form. Brazil and Argentina export their soybean meal in pelleted form while the U.S. exports soybean meal mainly in loose form.

Because of the enormous worldwide economic and nutritional importance of soybean products, it is critical to recognize the various factors contributing to the deterioration of soybeans and soybean meal. Deterioration can occur during handling and storage from harvest until reaching the end-user. The various deteriorative factors and how to minimize the effects on soybeans and soybean meal will be the main focus of the discussion below.

Handling Of Soybeans And Soybean Meal

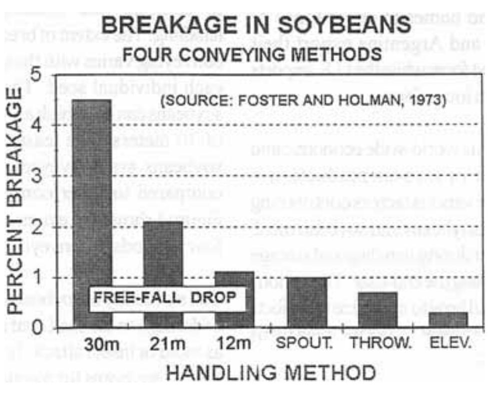
Soybeans and soybean meal are normally handled in bulk form in developed countries, while bag handling is prevalent in developing countries. Some countries are now in a transitional period from bag to bulk handling system. Regardless of the system used, it is important to recognize the advantages and disadvantages of each system to minimize product deterioration and economic losses.

Whole Soybeans

The handling of whole soybeans involves conveying and transporting from the farm to end-user. In the United States, it is possible for soybeans to be handled as many as 15 times from the time they leave the farm until processing into oil and meal. This number may increase to as high as 20 for exported material.

The structure of a soybean seed makes it susceptible to splitting and breakage during mechanical handling. The extent of breakage in soybeans during conveying varies with the impact force imposed on each individual seed. The percentage of broken soybeans can be as high as 4.5% with a free fall drop of 30 meters. The least breakage occurs when soybeans are conveyed in a bucket elevator as compared to other conveying methods studied. Figure 1 shows the extent of soybean breakage with four methods of conveying.

Figure 1. Breakage in soybeans with four conveying methods.



The storability of soybeans is affected by the degree of damage to the seed coat and by other factors such as mold or insect attack. It is therefore important to inspect soybeans for mechanical and other forms of damage prior to storage. If the amount of broken or split soybeans is very high, it may be prudent to separate the broken or split grains by sieving. This material can then be used first as opposed to long-term storage with the original stock.

Soybean Meal

Soybean meal is difficult to handle because of poor flow ability and bridging characteristics. Soybean meal tends to settle or consolidate over time. This phenomenon occurs in most granular materials and becomes more severe with increased moisture, time and small particle size. Because of this, bulk soybean meal is best stored in flat storage buildings instead of vertical silos. Standard conveyors can be used for loading into the building and front-end loadings tractor can be used in combination with standard conveyors for reclamation. New sweep auger designs are now available that effectively reclaim meal products from silos. Various models and capacities are available. One model is designed to reclaim meal products from flat- bottom silos and another for hopper-bottom silos. However, because of their very high initial cost, they have not become a standard equipment yet in the industry.

Addition of calcium carbonate, calcium bentonite, or sodium bentonite at a level between 0.25% to 0.5% is effective in improving the flowability of soybean meal of the additive, and the mixing process may outweigh the potential advantage gained in improving its flowability. Other innovations such as electric vibrators and compressed air to fluidize the meal are available to improve discharge of soybean meal from storage bins.

The flow characteristics of bulk materials are dependent on individual particle shape, density, frictional property, and moisture content. For granular materials like grains, typical flow patterns during discharge from hopper bottom bins are illustrated in Figure 2. Drawing (A) shows a normal discharge pattern. The bridging and funneling problems depicted in drawings (B) and (C) occur in grains containing high content of foreign material or moisture.

Typical flow problems of meal products discharged from storage silos are shown in Figure 3. These are usually due to a combination of factors such poor hopper design, high moisture content and storage time.

Figure 2. Typical flow pattern and problem with bulk granular materials such as grains.

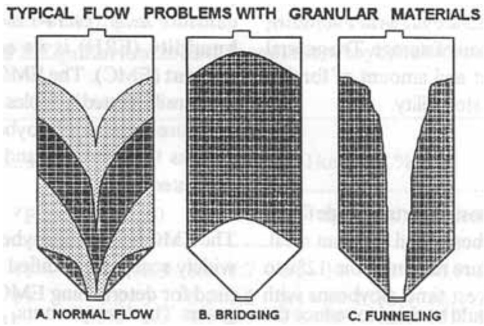
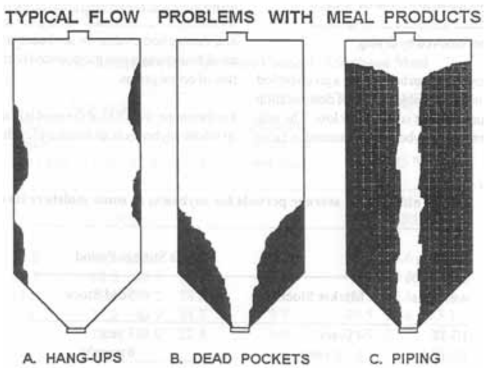


Figure 3. Typical bulk flow problems with meal products during discharge from hopper-bottom silos.



Factors Affecting Safe Product Storage

The three major factors affecting the storability of soybean and soybean meal are moisture content, temperature, and duration of storage. The general condition of the product and amount of foreign materials also affect their storability.

Moisture Content

Moisture is perhaps the most important single factor affecting storage of soybeans and soybean meal. Soybeans contain moisture ranging from 12% to 15% (wet basis) at harvest time. Soybeans with moisture above 13% should be dried to reduce the risk of deterioration due to seed respiration, mold attack, spontaneous heating and reduced germination. It is widely recognized that there are two forms of moisture in cereal grains and oilseeds:

a. free moisture is in vapor form and is removed during drying
b. bound moisture remains "locked" in the molecular structure of the grain and cannot be removed by drying

In general, soybeans can be kept for a given period of time with no appreciable degree of deterioration if the moisture content is relatively low. The safe moisture content of soybeans is presented in Table 1.

Soybeans and soybean meal are hygroscopic materials and will either lose (desorb) or gain (adsorb) moisture from the surrounding air. The moisture level reached by a product at a given constant temperature and equilibrium relative humidity (ERH) is its equilibrium moisture content (EMC). The EMC and ERH of soybean meal are illustrated in Tables 2 and 3. The equilibrium moisture content of soybeans by desorption at various temperatures and relative humidities are presented in Figure 4.

The EMC values for soybeans are based from the widely accepted modified Chung-Pfost equation used for determining EMC and ERH for various grains. The desorption and adsorption EMC curves for soybeans and soybean meal at 25°C (77°F) are shown in Figure 5.

The EMC of soybeans and soybean meal by desorption are higher than that by adsorption under the same set of conditions. This phenomenon is known as hysteresis. It occurs in most agricultural products such as cereal grains, oilseeds, leathers, meats and even vegetables. However, the hysteresis effect in grain diminishes after repeated adsorption and desorption cycles. In soybeans and soybean meal, hysteresis is less pronounced compared with that of cereal grains.

Furthermore, the ERH of the meal is lower than that of whole soybeans at all moisture levels

Table 1. Safe storage periods for soybeans at some moisture levels.

Moisture content, % wet basis	Safe Storage Period: Market Stock	Safe Storage Period: Seed Stock
10-11	4 years	1 year
10-12.5	1 - 3 years	6 months
13-14	6 - 9 months	poor germination
14-15	6 months	poor germination

Source: Barre, 1976

Table 2. Equilibrium moisture content of soybeans (desorption).

Temperature °C	Temperature °F	RH 10	20	30	40	50	60	70	80	90
5	41	5.2	6.3	6.9	7.7	8.6	10.4	12.9	16.9	22.4
15	59	4.3	5.7	6.5	7.2	8.1	10.1	12.4	16.1	21.9
25	77	3.8	5.3	6.1	6.9	7.8	9.7	12.1	15.8	21.3
35	95	3.5	4.8	5.7	6.4	7.6	9.3	11.7	15.4	20.6
45	113	2.9	4.0	5.0	6.0	7.1	8.7	11.1	14.9	-
55	131	2.7	3.6	4.2	5.4	6.5	8.0	10.6	-	-

Source: 1993 American Soc. of Agri. Engineers Standards

Table 3. Equilibrium moisture content of soybean meal.

Desorption: Moisture content,% wet basis	15°C	25°C	35°C	Adsorption: Moisture content,% wet basis	15°C	25°C	35°C
	ERH, %				ERH, %		
35.2	93.5	95.9	93.9	23.5	85.8	86.6	86.9
25.3	88.0	88.9	90.2	17.6	79.0	80.0	80.2
18.2	79.4	79.2	78.6	12.5	66.5	68.1	68.1
7.8	37.2	40.9	44.7	8.9	49.5	51.6	53.1
5.9	18.3	20.0	22.4	6.9	29.9	33.7	36.3

Source: Pixton and Warburton, 1975

Figure 4. The equilibrium moisture content of soybeans by desorption based on the modified Chung-Pfost equation for various grain (Source: ASAE 1993 Standards).

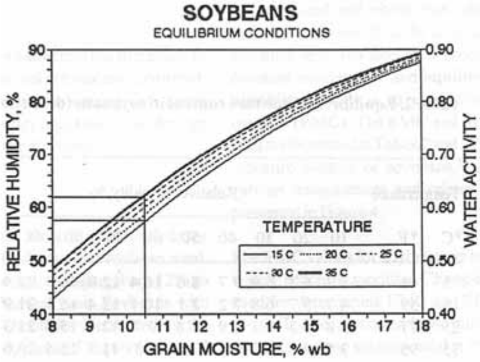
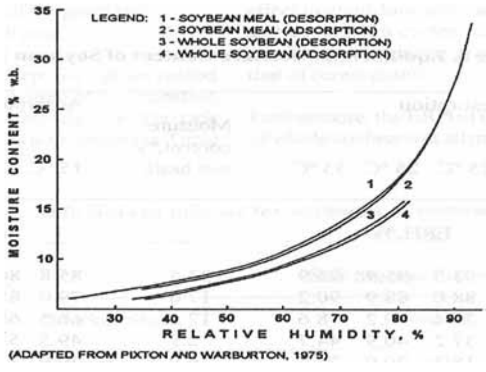


Figure 5. The desorption and absorption equilibrium moisture content of soybeans and soybean meal at 25°C (77°F).



because of its lower oil content. This means that under the same air relative humidity, soybean meal will have higher EMC than whole soybeans.

The rate of moisture adsorption or desorption is directly related to the manner by which a product is exposed to the atmosphere. For example soybeans kept in jute sacks tend to gain or lose moisture more readily than soybeans in bulk form. Hence, bag storage has as self-ventilating and cooling characteristic that makes it the preferred method over bulk system in many developing countries. However, bulk storage of soybeans allows the use of aeration or cooling techniques to maintain its desirable quality in a controlled manner. Aerating soybeans in bags is also possible but is not practical because of the uneven airflow patterns resulting in non-uniform grain temperature.

Temperature

Temperature is another very important factor influencing soybean storage. Growth of fungi and chemical changes such as oxidation increased with temperature in both meal and whole beans. Insects develop and reproduce best between 27 and 35°C (80 to 95°F). Below 16°C (60°F) insects become inactive and die of starvation. Exposure to temperature greater than 600C (140°F) kills most insect species in 10 minutes.

Soybeans with a moisture contents of 14 - 14.3% and maintained at 5- 8°C (41- 46°F) can be stored for over two years without mold damage while soybeans kept at 300C (860F) can be invaded by molds in a few weeks and severely damaged in six months. Recent studies indicate that soybeans can be stored at 10.5% moisture at any temperature without the danger of mold attack (Figure 6). However, at this moisture content, insect infestation may develop unless its temperature is maintained below 20°C (68°F). This is equivalent to a seed wet-bulb temperature of 15°C (59°F) or corresponding relative humidity of 60%.

Temperature also influences moisture migration. The driving force in moisture migration in a grain mass is temperature gradient. This condition causes very small air movements and water vapor translocation in the grain mass. It has been estimated that a grain mass temperature gradient of about 16.7°C (30°F) can induce an inter-seed airflow of 0.06 m / min (0.2 ft / min). Thus, grains stored at moisture contents considered safe, may spoil because of moisture migration associated with inter-seed air currents. The general movement of air in a grain bulk under two climatic conditions characterized by warmer outside air and colder outside air are shown graphically in Figure 7. The air movements in the grain bin is influenced by the outside air temperature that creates temperature gradients in the entire grain mass. This phenomenon affects all types of storage silos whether it is made of concrete or metal. They vary only on the magnitude of air movement.

Figure 6. The relationship between soybean moisture content, mild growth, and insect development as affected by the seed we-bulb temperature.

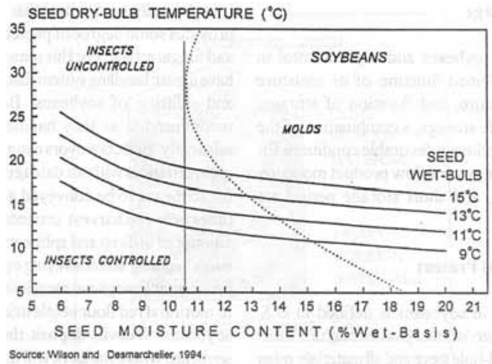
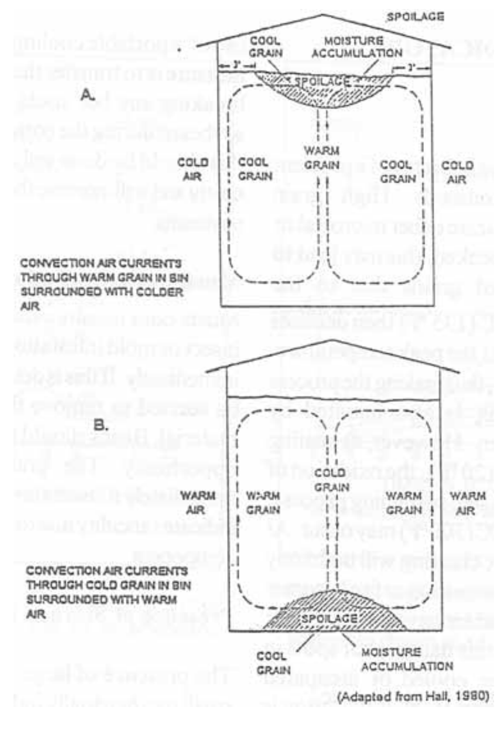


Figure 7. Natural convection currents in stored grain due to temperature gradients.

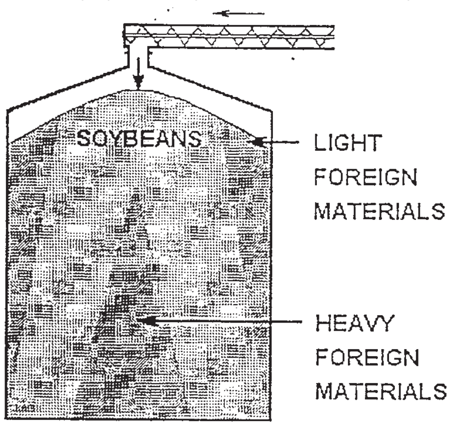


Because of the insulating property of grains, the effect of diurnal temperature changes on the stored grain is minimal but is cumulative. It takes a long time of relatively constant high temperature gradients to initiate the air movements shown in the diagrams to occur. However, experience indicates that under hot and humid tropical conditions, grains stored in metal bins exhibit "sweating" next to the wall. This can be attributed to extreme high temperatures reached at the inner surface of the metal silo on a hot day. At night, rapid cooling of the metal results in moisture condensation as the dew point is reached. Caking and charring in metal silos can be attributed to this phenomenon.

Duration Of Storage

Deterioration of soybeans and soybean meal in storage is a combined function of its moisture content, temperature, and duration of storage. Therefore, for safe storage, a combination of the three factors providing unfavorable conditions for mold development, such as low product moisture, low temperature, and short storage period are desirable.

Figure 8. Schematic diagram of how light and heavy foreign materials segregate when grain is loaded into a storage silo.



(Adapted from Barger, 1981)

Foreign Material Present

Foreign material in soybeans is defined in U.S. Standards as all materials that pass through a 3.2 mm (8 /64-inch) round-hole sieve and all materials other than soybeans remaining on the sieve. Fine foreign materials tend to segregate during bin loading and occupy void spaces in the central region of the grain mass. Meanwhile, the large and lighter materials will accumulate close to the walls of the silo. The process of material segregation inside a storage silo is illustrated in Figure 8.

During aeration, the air will flow around spots with higher concentration of fine foreign materials and through pockets of high concentration of large foreign materials. This condition will create a non-uniform flow of air during aeration, thus, making it an ineffective operation.

Consequently, the non-aerated pockets in the grain mass are potential sites for hot spots that will provide ideal environment for insects to grow and multiply. Hence, cleaning soybeans prior to storage will minimize the risk of spoilage and economic loss. This should be part of an integrated approach to any quality maintenance program of grain processing companies.

Product Condition And History

Sound soybean kernels will store better than kernels damaged by freezing, cracking, splitting, and storage fungi. Split kernels are more susceptible to attack by stored product insects and fungi than whole kernels. It is generally recognized that a sound seed coat provides some degree of protection against insect and fungal attack. For this reason, it is preferred to have a grain handling system that minimizes cracking and splitting of soybeans. Belt conveyors are recommended as they handle grain gently and efficiently. Belt conveyors can also move grains for great distances without damage. It is very common for soybeans to be conveyed as many as 15 to 19 times between harvest processing or export. The amount of broken and split kernels increases with every handling and conveying operation. In terms of insect attack, soybean meal is far more susceptible to moth and red flour beetle infestation than whole soybeans. Weevils deposit their eggs on whole soybeans where the larva will hatch and feed on the bean.

Deterioration Indicators

Heating

Heating is the most common indicator of a problem in stored grains and oilseeds. High grain temperatures normally indicate either microbial or insect activity. If left unchecked, this may lead to heat-damaged or charred grains due to the phenomenon of stack burning. Heating in cereal grains peaks at about 58°C (135°F) then declines to ambient temperature. At the peak temperature, insects and molds are killed, thus making the process self-limiting. In soybeans, is also initiated by microbial and insect activity. However, as heating progresses above 50°C (120°F), the oxidation of oil in soybeans becomes a self-sustaining process. Temperatures above 150°C (300°F) may occur. At this extreme temperature, charring will definitely occur and spontaneous combustion or fire becomes a distinct possibility, if sufficient oxygen is present at the hot spot. Because of this danger, hot spots in stored soybeans must be cooled or dissipated before they reach the critical level. If no action is taken when heating in soybeans occurs, either the product will be lost by stack burning (charring) or at worst, the entire facility will be lost through fire. Aerating soybeans when fire has already started makes the situation worse. A temperature monitoring system in soybean storage silos is essential. Immediate corrective measures for heating cannot be over-emphasized.

Change In Color And General Appearance

In general, sound soybeans are plump with bright uniform tan and not green color and free from unusual spots and shrivelled appearance. Discolored soybeans usually indicate inferior quality and lower market value. The change in color is usually associated with mold invasion accompanied by microbial respiration and subsequent heating. This deterioration process can be detected by periodic drawing of samples from the stored soybeans as part of an integrated approach to quality maintenance. Once detected, appropriate measures can then be taken such as cooling the grain either by aeration or use of a portable cooling unit. Another corrective measure is to transfer the grain to another silo thus breaking any hot spots present and cooling the soybeans during the conveying process. However, this should be done only as a last resort since it is costly and will increase the amount of broken or split soybeans.

Mustiness And Off-odor Condition

Musty odor usually indicates an advanced stage of insect or mold infestation and should be dealt with immediately. If this is detected, the soybeans should be aerated to remove the bad odor and cool the material. Beans should then be used at the earliest opportunity. The grain should be fumigated immediately if insects are present. A sharp odor may indicate rancidity due to chemical changes in the oil component.

Presence Of Storage Insects

The presence of large population of weevils and small moths usually indicate an advanced stage of infestation. Sitophilus granarium (granary weevil) may infest whole soybeans but not soybean meal while Tribolium castaneum (red flour beetle) and Trogoderma granarium (khapra beetle) will infest soybean meal at relative humidities above 75% and temperatures above 30°C (86°F). Ephestia cautela (almond moth) can develop even at 8.8% moisture (wet basis) and temperature of 25°C (77°F) .

Lumping And Caking

Lumping and caking indicate a very advanced stage of fungi invasion in soybeans and soybean meal. In metal bins, caking usually occurs on the bin walls as a result of “sweating” or moisture condensing on the inner surface of the cold bin wall. The condensing moisture is absorbed by the adjacent grains resulting in either sprouting or mold growth. Lumping may also occur in spots where the grain moisture increased due to a leaky roof or moisture migration or translocation by natural convection (see Figure 7). In a bag system of storage, caking of soybeans and soybean meal may also occur as a result of increased moisture content adsorbed from the atmosphere, leaky roof, or due to capillary moisture from the floor. Capillary moisture can be eliminated by putting the bags on pallets. Concrete floors can be made water-proof during construction by installing plastic sheets as moisture barriers before pouring in the floor slab.

Figure 9. The effect of time and temperature on the amount of free fatty acid in the oil of soybeans stored at 37.8°C.

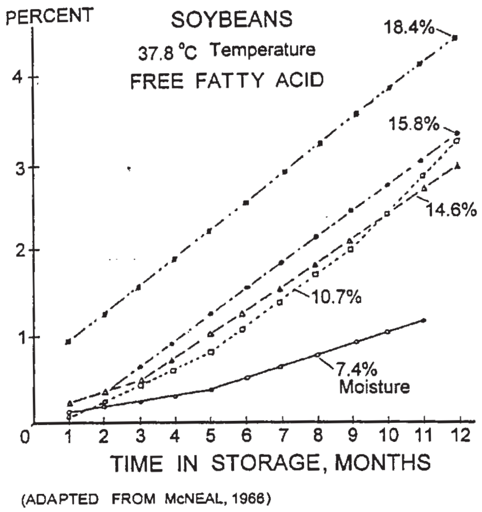
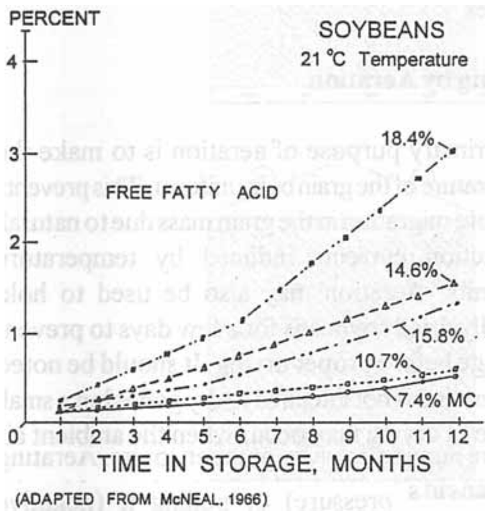


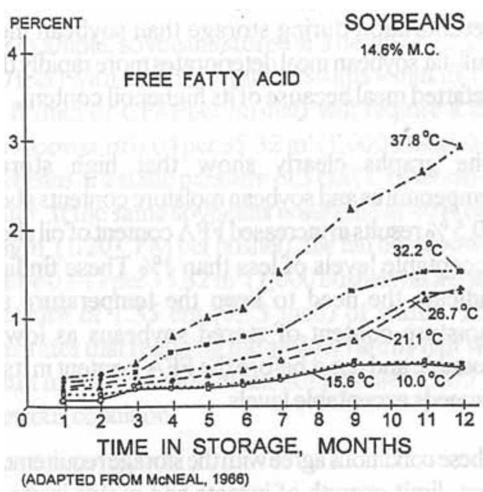
Figure 10. The effect of time and temperature on the free fatty acid content of oil from soybeans stored at 21°C.



Chemical Changes In Storage

Stored soybeans may undergo physical, physiological and chemical changes even under ideal storage conditions. Some of the changes may or may not have a negative effect on the final use of soybeans and soybean meal depending on the degree of change. One common indicator of chemical change in stored soybean is the level of free fatty acid (FFA) present. An increase of FFA above 1% may translate into lower quality of its oil content. The effect of temperature and moisture on FFA content in soybeans is shown in Figures 9, 10 and 11. Other important changes include decline in soybean seed viability, change in the grain color, increase or decrease in its moisture, decomposition of phospholipid, and the denaturation of it protein. Soybean grain is more resistant to deterioration during storage than soybean meal. Full-fat soybean meal deteriorates more rapidly than defatted meal because of its higher oil content.

Figure 11. The effect of soybean moisture content and time on the free fatty acid content of oil from soybeans stored at 14.6%.



The graphs clearly show that high storage temperatures and soybean moisture contents above 10.5% results in increased FFA content of oil above acceptable levels of less than 1%. These findings indicate the need to keep the temperature and moisture content of stored soybeans as low as possible and use it before the FFA content in its oil exceeds acceptable levels.

These conditions agree with the storage requirements that limit growth of insects and molds in stored soybeans (see the mold envelope and seed wet-bulb temperatures in Figure 6). At a moisture level of 10.5% or less, soybeans can be stored at any ambient temperature without molding problem. However, insects may still grow and multiply at relative humidities above 60%.

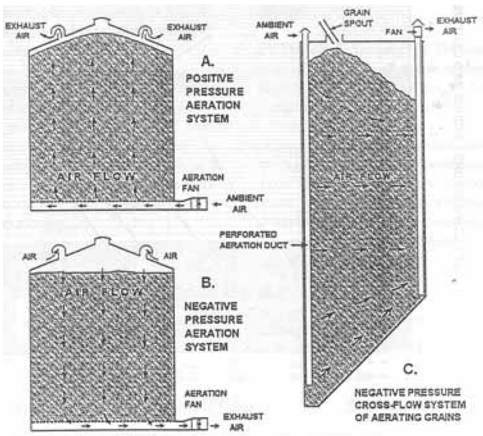
Maintenance Of Quality

Once soybeans reach maturity and are harvested, their inherent quality is fixed and can only be maintained by proper drying, cleaning, and conditioning. Quality maintenance involves various operations that will provide environmental conditions that minimize the combined deteriorative effects of ambient temperature and moisture on both soybeans and soybean meal. It involves slowing down undesirable chemical changes from occurring, inhibiting mold and insect activity. The major elements in achieving this goal consist of a reliable temperature monitoring system, periodic drawing of product samples and accurately testing them, and having a reliable cooling or aeration system.

Temperature Monitoring

The most convenient property of stored grains to measure is temperature. In small farm storage silos, one can use temperature probes to monitor grain temperature and can draw representative samples simultaneously. However, in large commercial silos, the use of thermocouple wires and multi-point potentiometer for remote temperature sensing is standard and essential. Modern grain storage silos are all equipped with temperature monitoring system. Without a remote temperature monitoring system, a storage manager will have to rely on grain probes to measure grain temperatures at various points. This is a very inefficient and cumbersome system that often discourages many storage managers from doing it on a regular basis, and stand the risk of incurring economic loss.

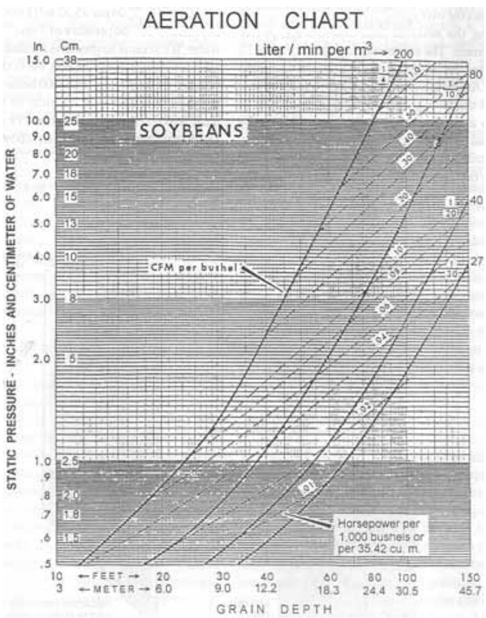
Figure 12. Three systems of aerating grains stored in silos, namely; (a) positive pressure, (b) negative, and (c) negative pressure, cross-flow system.



Product Sampling, Inspection, And Testing

The systematic monitoring of both the environmental and product condition is another essential element in maintaining the quality of stored soybean and soybean meal. This may be accomplished by regularly taking samples of the stored products and analyzing them in the laboratory for signs of deterioration. Signs of deterioration include off-odors, moldy condition, heating, discoloration, and presence of live insects. During the sampling operation, one also should inspect the storage facilities for signs of moisture accumulation or roof leaks and other physical damages to the storage facilities.

Figure 13. A chart used to determine the fan horsepower required in aerating soybeans at different airflow rates and grain depths (Source: US Department of Agriculture, 1960).



Cooling By Aeration

The primary purpose of aeration is to make the temperature of the grain bulk uniform. This prevents moisture migration in the grain mass due to natural convection currents induced by temperature gradients. Aeration may also be used to hold partially dried soybeans for a few days to prevent spoilage before proper drying. It should be noted that aeration is not intended to dry grains but a small degree of drying may occur when the ambient air relative humidity is 40% or much lower. Aerating soybeans in silos can be done either by pushing the air (positive pressure) or pulling it (negative pressure) through the grain mass. Each system has its inherent advantages and disadvantages over the other. For example, a positive pressure system may result in moisture condensation on the underside surface of the silo roof unless sufficient vents are provided. On the other hand, a negative aeration system may initially be pulling hot air from the open space beneath a hot metal roof during the day, thus adding more heat to the grain. A compromise method of aerating soybeans in tall silos would be to use a cross-flow air distribution system. This system eliminates the two problems mentioned above while reducing the aeration time and less fan power requirement. The schematic diagrams in Figure 12 illustrate the three systems of aeration discussed above. An effective aeration system should be able to cool the bulk grain with minimum amount of airflow at the shortest possible time. This can be achieved by selecting the right kind and size of fan, air distribution system, direction of the air, and airflow rate. The relationship between airflow rate, grain depth, horsepower requirement and air pressure are shown graphically in Figure 13.

Table 4. Aeration rates for stored grains.

Airflow rate	liter/min. /m^3 of grain (ft3 /min./bushel of grain)	
Type of Storage	Northern States	Southern States
Flat structure	40 to 80 (1/20 to 1/10)	80 to 160 (1/10 to 1/5)
Upright structure	20 to 40 (1/40 to 1/20)	27 to 80 (1/30 to 1/10)

Source: USDA, 1960

For example, soybeans stored at a depth of 12.2 m (40 feet) with an airflow rate of 80 liters/min/m^3 (1/10 ft3/min or CFM per bushel) will require a fan horsepower of 0.04 per 35.32 m3 (1,000 bushels) of soybeans at a static pressure of 3 cm (1.1 inches) of water. If the same soybeans are aerated at 40 liters/min/m^3 (1/20 CFM per bushel), the fan horsepower will be 0.013 per 35.32 m^3 (1,000 bushels) at a static pressure of 1.85 cm (0.73 inch) of water. This illustrates that reducing the airflow rate by half will result in the reduction of fan horsepower to 1/3 of previous condition.

A general guide in selecting the aeration rate of stored soybeans under warm and temperate climates is given in Table 4.

Summary

The success in the storage and handling of soybeans and soybean meal is dependent upon the understanding of the combined effects of the three most important factors causing spoilage, namely:
1. temperature
2. moisture
3. time

High ambient temperatures and relative humidities above 65% favor both fungi and insect development in stored products. An effective program of monitoring the condition of the stored products and means of maintaining uniform product moisture and temperature, such as by aeration, cooling (chilling) or by proper ventilation are indispensable elements in the successful maintenance of the quality of soybean and soybean meal.

It should be remembered that the original quality of the soybeans and soybean meal cannot be improved upon and that the quality will decline with time. However, deterioration can be reduced to an acceptable level by keeping the products cool and dry during the storage period. This will ensure the availability of good quality product when needed for processing or marketing.

References

Foster, G. H. and L. E. Holman. Grain breakage caused by commercial handling methods. Marketing Res. Report No. 968. Agri. Res. Service, USDA.

Hall, C. W. 1980. Drying and Storage of Agricultural Crops. The AVI Publishing Company, Inc. Westport, CT.

Kaufmann, H. H. 1976. Commercial storage and handling of soybeans. P 731-733 in: Hill, L. D., ed. Proc. World Soybean Res. Conf. The Interstate Printers & Publishers, Inc. Danville, Illinois.

Marketing Research Report No. 178. 1960. Aeration of Grain in Commercial Storage. U.S.D.A.

McNeal, X. 1966. Conditioning and storage of soybeans. Agri. Expt. Sta. Bul. No. 714 University of Arkansas, Fayetville, Arkansas.

Milner, M. and W. F. Geddes. 1945. Grain storage studies I. Influence of localized heating of soybeans on interseed air movements. Cereal Chem. 22(6):477-483. Amer. Asso. of Cereal Chemists. Lancaster, PA.

Nakayama, Y., K. Saio, and M. Kito. 1981. Decomposition of phospholipids in soybeans during

storage. Cereal Chemistry 58(4):260-264. AACC, Inc.
Nicholson, C. J. and M. E. Whitten. 1980. Transportation and handling factors in relation to quality in exporting soybeans. Marketing Res. Report No.1109. USDA.
Pedersen, R. J., R. B. Mills, G. J. Partida, D. A. Wilbur. 1974.Manual of Grain & Cereal Product Insects and their Control. Dept. of Grain Science & Industry, Kansas State University, Manhattan, Kansas.
Pixton, S.W. and S. Warburton. 1975. The moisture content/equilibrium relative humidity relationship of soya meal. J. of Stored Products Res. 11(3/4):249-251. Pergamon Press. Great Britain.
Saio, K., K. Kobayakawa, and M. Kito. 1982. Protein denaturation during model storage studies of soybeans and meals. Cereal Chem. 59(5):408-412.
Scott, W. O. and S. R. Aldrich. 1970. Modern Soybean Production. S. & A. Publications. Champaign, Illinois.
Sirisingh, S. and M. Kogan. 1982. Insect affecting soybeans in storage. P 77-82 in: Sinclair, J.B. and J.A. Jackobs, eds. Proc. Soybean Seed Quality and Stand Establishment Conf. Int. Soybean Program. Univ. of Illinois, Urbana, Illinois.
Stevens, C.,W. Appel, and J. Zhenyu. 1987. Response of soybean meal flowability to selected additives. Kansas Agr.Expt. Sta.Contribution No. 87-72-J. Kansas State U. Manhattan, KS.
Wilson, S. G. and J. M. Desmarchelier. 1993. Aeration according to seed wet-bulb temperature. J. Stored Prod. Res. 30 (1):45-60. Pergamon Press. U.K.

Grain Storage: Considerations To Maintain Quality

Mark A. Myers
Brock Manufacturing
USA

Introduction

The primary tools used to manage grain in bulk storage are Grain Temperature Detection Systems, and Aeration. A temperature detection system is an electronic reading device that is attached to special cables, suspended from the roof of the grain storage. A storage structure may have one, or many cables, depending on the structure diameter. The cables contain temperature sensors at approximately two-meter vertical intervals. Grain temperatures change relatively slowly, and are normally read and recorded once per week. Variations in grain temperature across the grain mass, or localized rising temperatures, can be indications of grain spoilage and the need for managers to take action. But since grain temperature detection is another complete presentation, we will not focus on it today. More importantly, we will focus on Aeration, the process of making changes within a grain mass.

Grain aeration basic principles are divided into four subjects: 1) What is aeration; 2) Why do you aerate grain; 3) When do you aerate grain; and 4) How do you aerate grain. An understanding of these four principles will significantly improve your ability to successfully store grain for an extended period of time.

What Is Aeration?

Aeration is the process of passing large volumes of ambient air through a grain mass, using a fan designed for that purpose, and an air delivery system. There are many designs on the air delivery systems. Most are designed into the concrete foundation of a grain storage structure, using a tunnel and a steel cover perforated with many small holes. Air is forced into the tunnel, through the perforated steel floor, and into the grain. The shape of an aeration system can take many forms, some of which are illustrated here – a double “H”, a “four ‘F’ system, or two rectangular pads. Aeration fans outside are connected to the aeration system inside. The type of system is not as important as the skill and experience of the designer, and the reputation of the manufacturer. Most are designed by the provider of the grain storage system, and meet critical design standards. Each system must be designed to provide adequate volumes and pressures of air for the quantity and depth of the stored grain. The size and type of aeration fan is also critical to successful performance of the system.
Why Do You Aerate Grain?

Grain has enemies, including insects, mold and fungi, heat and moisture. Insects eat and breed in grain, creating damaged grain that will spoil and decay. Mold and fungi create heat and decay. Heat and decay nourish more mold and fungi. Moisture creates spoilage and decay, which creates more heat, spoilage and decay.

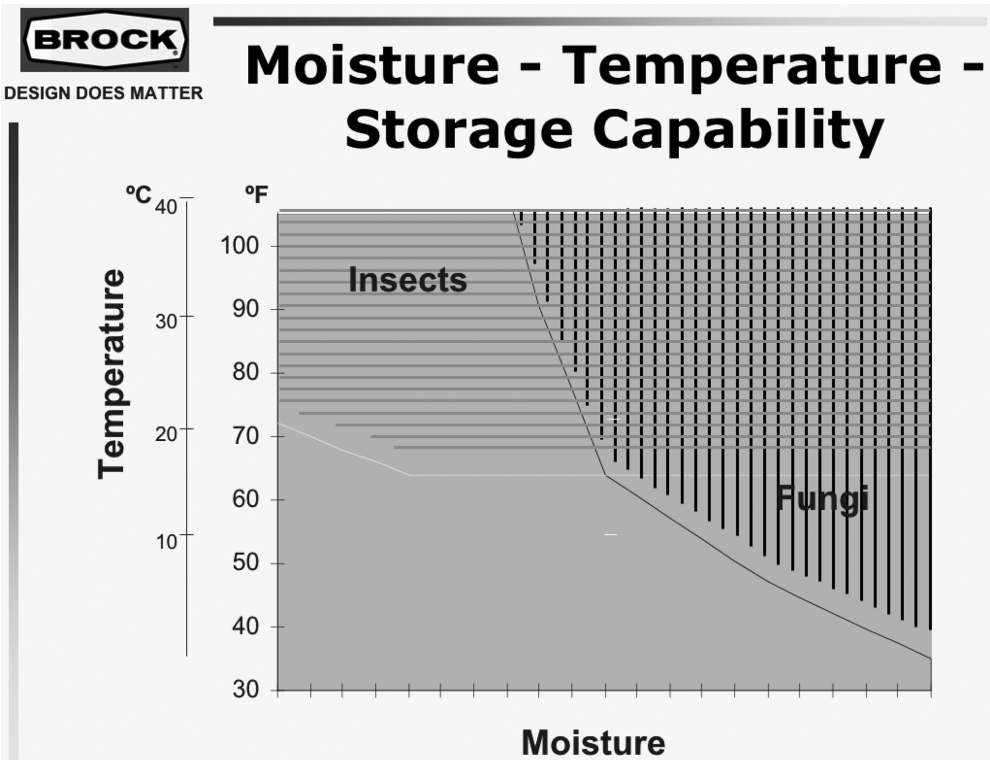
The purpose of aeration is to condition dry grain. It is not for the purpose of drying grain, as air volumes are too low to dry. Aerated, conditioned grain will decrease mold and fungi growth, decrease insect activity, equalize moisture deposits, and equalize heat distribution within the grain mass. Properly managed, aeration will improve your chances of successful storage.

Grain quality and condition can never be improved – it can only be maintained. If spoiled grain is placed in storage, it cannot be retrieved or removed from storage in better condition. It is critically important that only grain in good condition be placed in storage. With good management, good quality grain can be retrieved from storage processing and used.

Consider the food in your home. Many fruits will spoil slowly if left out on the table. If placed in refrigeration, the decay is slowed. If cut open, the decay is accelerated. Grain is the same. In nature, grain has some natural protection. If broken, it decays faster. If kept cool and dry, it decays slower. Why aerate grain? Consider that grain is alive. If it is planted in the ground, it will grow. Like all living organisms, live grain breathes air and releases moisture. When contained in bag or bulk storage, the moisture can accumulate. Changes in temperature can create condensation. Moisture on the surface of grain will start decay and spoilage, which in turn will create heat and accelerate decay. The process of aeration a) equalizes moisture within the grain mass; and b) equalizes heat within the grain mass. Mold and fungi are present in the air and on surfaces wherever you are right now – inside or outside of a building. Mold, fungi, heat, and moisture create spoilage and decay in grain. The process of aeration will equalize heat and moisture, and restrict the opportunity for growth of mold and fungi. The process of aeration will also limit the life cycle activity of insects that require moisture and comfortable temperatures.

Moisture Temperature Storage Capability

On the left side of this chart (Figure 1) is temperature, and at the bottom is moisture (as a percent of content in whole grain). By reducing the available moisture in grain, the growth opportunity for mold and fungi decreases dramatically. Reducing temperature also contributes to the reduction of mold and fungi growth.



Reducing moisture has less effect on insects, but grain temperatures below 22ºC decrease insect life activity (without consideration of moisture content). Temperatures below 18ºC stop most insect life cycle activity. In tropical climates this can be achieved only with mechanical refrigeration, which has proven very effective.

Safe Storage Period (Days – Corn/Maize)

Moisture content and temperature within a stored grain mass have a direct impact upon the number of days that grain can be stored. The worst-case example on this table, grain with a temperature of 27ºC and 30% moisture content can only be stored for 2.6 days before the grain is spoiled. By reducing the moisture content to15%, the total number of possible storage days increases to 87 at 27ºC. At the same time if the temperature were reduced to16ºC. the available storage days will rise to 250.

The day count begins at the time of harvest – not the day that the grain is placed in storage. Lost available storage days can never be recovered. If half of the storage life of grain is lost while the grain is at high temperature or high moisture, those days cannot be restored. Therefore it is important to reduce grain moisture content and temperature as quickly as possible after harvesting.

Safe Storage Period (Days) Temperature & Moisture (Corn)

By examining the safe storage day information in a graph, it becomes apparent how critical the reduction of moisture and temperature become. Notice that grain stored at 13% moisture can be stored in excess of 4000 days at a temperature of 4ºC. On the next slide, we will examine in greater detail the Safe Storage Days in the more common range of 16° to 27°C. and moisture content of 13% to 20%.

By reducing the moisture content to 15%, Safe Storage Days increases to between 100 and 250 days depending upon the temperature of the grain. Managers must determine how dry the grain should be, by deciding how long the grain will be stored before use. Remember that the number of days the grain has been stored before you purchase it will affect the total Safe Storage Days.

When To Aerate Grain?

Because moisture and heat can accumulate in hot spots within the grain mass, aeration should be initiated to distribute or remove concentrations of heat and moisture. Accumulations of moisture cannot be detected, but the rise of temperature associated with moisture and spoilage can be detected with temperature detection systems.

Aeration should be initiated on a regular schedule of preventative maintenance in order to equalize the moisture and temperature within the grain mass. The temperature of the grain mass should be maintained equal to the temperature of the outside air. Because temperature differences greater than 9ºC between the air and the grain mass can create condensation and moisture in the grain, aeration should only begin when the difference between the grain and the outside temperature is less than 9ºC. A regular schedule of aeration maintenance will keep the grain close to the average outside temperature.

The aeration objective is to maintain the grain at a uniform temperature of +/- 2 degrees of the average 30-day daily temperature.

Aeration Rates

How much air is needed to aerate grain in storage? The most common measurement of air is in cubic-feet-per-minute. Typical ratios of air to grain range between 0.05 to 0.20 cubic-feet-per-minute per bushel of grain. This would be the equivalent of 0.054 to 0.222 cubic meters of air per minute for each metric ton of grain. It is most common to design for 0.10 to 0.14 CFM/Bu (0.114 to 0.162 m^3/min/ton). If you receive a proposal for an aeration system designed to Imperial measurements, look for air volumes close to 0.10 (1/10) CFM/BU or higher. Each system manufacturer will try to determine the most efficient system, taking into consideration available equipment, the volume and depth of the grain, and the most cost efficient system to purchase and operate.

How To Aerate Grain

The amount of time required to aeration a grain mass will depend upon the volume of air and the volume of grain. Given 0.10 (1/10) CFM/Bu of grain, the time required to aerate the grain mass is 100 hours. In this time, the temperature of the grain mass will rise or fall to the same temperature as the outside air.

If the volume of air is reduced by one-half to 0-.05 (1/20) CFM/Bu., the time required will double to 200 hours. If the ratio of air to grain remains constant, the size of the grain mass is not important – the amount of time is relatively fixed.

Aeration Front

Understanding how the air moves through a grain mass is important to understanding how aeration works. Typically, air is pushed into the bottom of the grain mass, and exits the top of the grain mass. As the air moves, it creates a "front". Grain temperature below the front is equal to the outside air. The front collects temperature and moisture for transport through the grain mass. When the front completely passes through the grain mass, aeration is complete.

Aeration Problems And Solutions

1. **Aeration Problems** - A common problem that can occur during aeration is a front that stops. If someone stops the aeration fan midway through the aeration process, the moisture and heat-laden front will stall. When the front stalls, it despots the carried moisture and heat in the grain. When aeration is started the second time, the front will again begin at the bottom of the bin, while the heat and moisture deposited above begin to spoil the grain. If the new front does not reach the old front in time spoilage in the old front will create a crust that prevents the movement of air, preventing any additional aeration. The grain must be removed from the storage structure.

   Aeration Solution - After beginning an aeration cycle, do not stop the aeration fan(s) initial the aeration cycle is completed.

2. **Aeration Problem** - Center Fines or Foreign Material (FM). FM is anything that is not whole grain. FM can be broken grain, other organic parts of the grain plant, or weed seeds. Generally, FM has less weight than whole grain. While filling the grain storage structure, the FM will fall into the center of the structure and the heavy good grain will roll or slide to the outside of the structure. The FM in the center of the storage structure can form a column through which air will not pass. This column will spoil very quickly, spreading to the good grain. When the storage structure is unloaded through the bottom, the column will prevent grain from flowing out.

   - **Aeration Solution #1** – During and after filling the storage structure, you should remove a portion of the grain. This will extract the center core. The extracted grain can be processed by cleaning, or by grinding immediately for feed.

   - **Aeration Solution #2** – During filling, you can use a mechanical spreader to distribute the FM in a wider area, preventing the buildup of a center core. The FM will remain in the grain, and can continue to contribute to premature spoilage of the grain.

   - **Aeration Solution #3** – Clean the grain before filling the storage structure. This requires a mechanical cleaner or mechanical screener that will separate good, whole grain from any form of FM. This is the best solution for long-term storage. Whole grain stores much better than FM, and permits easier aeration of better quality.

3. **Aeration Problem** – An obstructed aeration air delivery system will prevent good aeration. Even with the fan running, air cannot pass a dirty obstructed tunnel or perforated floor. Vents that are plugged will prevent air from exiting the storage structure, stopping all aeration.

   Aeration Solution – Before filling the storage structure, inspect in the tunnels under the aeration floor for an accumulation of broken, spoiled grains that obstruct air movement in the tunnels. If necessary, clean and remove all FM. This will also remove insects, insect eggs, and their habitat. Also inspect roof vents for any obstructions, and clean if necessary.

4. **Aeration Problem** – Over filling the storage structure, and grain too close to the roof or touching the roof. When too much grain is put into a storage structure, two problems are created. 1) Not

enough space remains for the movement of air to the exhaust vents during aeration; 2) Grain comes in contact with the roof, where condensation can occur. Condensed moisture will collect at the edge of the roof, and saturate the outside of the grain mass. Spoilage will occur in this area.

Aeration Solution – Do not overfill the storage structure.

5. **Aeration Problems** – Examples of aeration problems. This storage structure has been over filled. Grain has blown out of the vent onto the roof of the silo and spoiled; grain remains stuck in the vent and is obstructing airflow; grain has spoiled and stuck to the walls of the storage structure. The spoiled grain will be difficult to remove, and can affect the new grain when the storage structure is filled again.

Aeration Conclusions

a. Grain should be aerated to

   i. Maintain uniform temperature in the grain mass.

   ii. +/- 2ºC Average Daily Ambient Temperature (day and night).

   iii. Regularly – every 30 days recommended.

   iv. When the difference between the grain temperature and the outside are do not exceed 9º'bcC.

b. When you start an aeration cycle, do not stop the aeration fans until the aeration front passes entirely through the air mass.

   i. You may use the temperature detection system to determine when the aeration cycle is complete.

   ii. Only if necessary, you can aerate by time if you are confidant that you know the aeration rate (0.10 CFM or 1/10 CFM per bushel) and that your aeration system is performing efficiently.

Oilseed Processing Modernization Opportunities

Dan Anderson
Crown Iron Works Co
USA

This paper focusses on some of the basic and also advanced opportunities available to a typical oilseed crusher, primarily on a soybean processor, although many of the concepts discussed are applicable to others in the feed and grains processing industry.

The objectives are to examine some of the cost-reduction opportunities for an existing crushing and refining operation. As the products of these plants are generally sold in the commodity markets, processing plants are generally price-takers as opposed to a price-setter. It is assumed that any modern processor will produce a product of nearly identical quality and quantifiable characteristics, which is the nature of a commodity-based operation. Hence, we will focus on primarily on opportunities to reduce operational costs, although no discussion would be complete without some emphasis on new value-added opportunities. In addition, this paper will touch on some new technologies and market trends that are either already in place or expected to come into force soon.

Opportunities for Cost Reduction

Steam and Process Leaks - as we begin the discussion, we should emphasize the fact that many basic cost-reduction opportunities can be undertaken with little cost. Steam and process leaks are easily identified and in most cases corrected with little effort. For example, while I was recently visiting a major Asian processor, the chief engineer was interested in investing in the latest energy efficient meal desolventizer. This was certainly a good thing and an easily justifiable use of capital. However, when walking through the plant, I noticed several easily correctable problems, including steam leaks, cyclones emitting meal dust, and spilled meal being washed down the drain. Eliminating these losses would have provided as much savings as investing in new equipment, but correcting these maintenance problems was not as fun as considering a new project, so these were neglected. Just a 2 mm steam leak wastes over $1,500 USD per year, and having several of these quickly adds up. Steam trap failures are not as obvious as a leak, but are just as significant in terms of wasting money.

Boiler Efficiency – broilers deserve special mention as opportunities for cost reduction. If the boiler is not operating at least 85% efficiency, a lot of your energy cost is wasted. Recovering heat from blowdown and deaerators, and maximizing the amount of condensate recovery are a few more ways to reduce the operating costs. One of the most significant invoices a company receives is the bill from the electric company, and power factor correction and peak load shedding are ways to maximize efficiencies. There are other electrical demand isssues to be aware of, such as sizing a motor closer to the actual job demand. As a typical example, a conveyor with a 6 kw actual load may be supplied with an 11 kw motor. While there is no doubt the extra reserve power is nice, and may be justified in certain cases. However, during normal operations, this motor will now be loaded at about 50% of its rated capacity, resulting in a lowered efficiency and power factor, and will consume substantially more electricity than a properly sized motor.

Insulation – this is another quick-payback opportunity that never seems to become a priority. Consider assigning a young engineering intern to identify heat losses and if the maintenance department doesn't have time, consider selecting an outside contractor to perform the job. Although this does represent a substantial cash outlay, this is a better option than waiting-payback of insulating of hot equipment usually pays itself back in a matter of months.

Tight control – tight control over process variables is another opportunity for the commodity processor. Products are generally sold on trading rule guidelines-of moisture, fiber, protein, fat, and other quantifiable factors. Tightening control over these parameters is one of the largest revenue-enhancing opportunities available to the processor. For example, a 1000 tpd soybean processor that can tighten control over moisture content by 0.1% will enhance the bottom line by nearly $50,000 USD per year. Clearly investing in process control and instant-results lab equipment is one of the quickest ways to enhance profitability.

In summary, many of these cost reduction opportunities are not very exciting or much fun, but are very real. Identifying these opportunities should be one of the first priorities of the processor seeking to enhance their profitability.

Reducing Operating Costs

Assuming that the bulk of the low cost opportunities have been explored, the next step is to look toward the operation, with an eye on capital investments that provide at least a 3-year payback. The preparation is the obvious first starting point, where there has been considerable interest in producing high protein (hypro) meal. The standard soybean operation cannot increase the amount of protein so our options are to take other things away. Generally, this means removing the hulls, which contain about 35% fiber, which increases the meal protein content. While many of the hulls can be removed after the extracted meal is ground (known as tail-end dehulling), the most common approach is to remove the hulls prior to solvent extraction (front-end dehulling). While the traditional approach has been to dry and temper the bean prior to cold aspirating the soybean cracks, the industry has essentially moved toward the various hot dehulling options because of higher efficiencies and lowered operating and installed costs.

The Dehulling System

There are at least 2 variations on the hot dehulling theme. The full hot dehulling system has become the industry standard, suitable for processing a wide variety of beans, including freshly harvested varieties. A recent variant that has enjoyed substantial attention is known as the warm dehulling system. This system takes advantage of the fact that the hulls on imported beans are not as tightly adhered as fresh harvest beans, and can be removed by a less-intensive separation (and hence the term warm dehulling). In addition to the lowered product costs, the hot dehulling systems provide an improved meal quality and a lowered NOL extracted oil loss. If there is no current demand for hypro, the processor can still enjoy improved qualities and lowered operational costs by use of the combined bean dryer and conditioner system.

Extraction Plant Considerations

The extraction plant is the next area of examination. Probably one of the most significant developments in this area has been implementation of the Schmacher DTDC. With this countercurrent flow unit, hexane recovery is maximized using a minimum of direct-contacting steam. Schumacher DTDCs also provide an optimum toast/PDI control as well, allowing the plant to provide a meal with substantially lowered residual hexane content while simultaneously reducing the overtoasting associated with older designs.

Mineral oil absorption systems are also considered a standard on a modern plant. While some older, smaller capacity designs still rely on refrigerated vent condensers for discharge air hexane recovery, the mineral oil system provides much enhanced hexane recovery, and overall plant safety.

There are many opportunities for excess heat recovery and transfer in the extraction system as well. Mineral oil interchangers, oil to miscella exchangers, vapor contactors, and oil and/or waste water to boiler feedwater exchangers provide very positive economic benefits and these applications should be fully explored.

Improved Refinery Operations

With continuing energy and environmental concerns, refineries have received a great deal of attention toward improving operations. For example, the traditional neutralization system has long depended upon a single, or even double, washing step to remove the soaps from the once-refined oil. New technology has been introduced to eliminate the washing step eliminating oil loss, capital and operating costs of the washing system, and the costs associated with wash water treatment and disposal. The traditional 2-filter bleaching system has been enhanced by addition of a 3rd, pre-bleaching filter, reducing the amount of clay used (and oil lost) by about 30%. The deodorizer, which is one of the most energy intensive operations of the entire crushing system, has enjoyed enhanced heat recovery options. New generations of vacuum systems, which traditionally require 8 kg of steam for every 1 kg of stripping steam are now used extensively to reduce not only energy costs, but also reduce the amount of effluent "dirty" water that the typical refinery must deal with.

Deodorizer System

One of the most significant advancements to the deodorizer system has been development of the various generations of packed column systems. These units generally consist of a high temperature, low residence time packed column stripping section where the volatiles are flashed in a matter of seconds followed by a somewhat lowered temperature heat bleaching section to allow for effective heat bleaching. This design provides an excellent quality finished product while minimizing utility costs and oil losses. As the high temperature exposure time is limited, packed column units minimize the amount of trans-fatty acids generated during processing. Recent packed column designs are equipped with a double shell, eliminating air contact and fire concerns.

Packed column strippers also lend themselves well when retrofitting existing tray type deodorizers. In a typical application, a stripping section is added, with the existing tray unit converted to a heat bleacher. In addition to providing a superior quality oil and reduced operating cost, this approach also allows for a substantial system capacity increase-often exceeding 50% of the original design.

Recent Technological Developments

Now that we've examined some of the "basic" technology improvements that have generally been well integrated into many plants, the next step would be to look toward some of the recent developments that early adaptors have integrated into their operations. We begin with the extraction system, where 3 relatively new systems have experienced substantial success. The first is the zero effluent discharge, or ZED system. In a typical extraction plant, about 50-100 lpm of high BOD wastewater is discharged to a waste treatment system. The ZED system eliminates about 90% of this discharge, with the remaining 10% introduced into the meal, providing a closed-loop evaporation/condensing system for this otherwise wastewater. In addition to essentially eliminating the water discharge, this system also reduces the amount of makeup water that is provided to the plant.

Another innovation is the vapor/solvent interchanger, which replaces the traditional vapor contactor. With this unit, fresh hexane is heated by waste gasses, reducing the load on the solvent/water separator tank and providing a more effective manner for maximizing heat recovery. The third development of great interest is the vapor solvent recovery, or VSR, tray, which is integrated into the DTDC, located immediately under the live steam sparging tray. This system recovers otherwise lost steam vapors and traces of hexane, and can reduce the overall extraction plant steam requirements by as much as 15%.

Recovery System

Refineries have also benefited by some new developments as well. One very interesting developing has been the fatty acid recovery systems developed for seed oils refining operations. During normal processing a low value "acid oil" product is produced, which is sold mostly as technical grade fat. This system is capable of separating out and distilling the high value fatty acids, which typically represent about half of the acid oil volume, leaving the low value "black oil" available for sale as feed fat. Dual temperature deodorizing systems are also of substantial interest. The distillate generated as a co-product of deodorizing contains valuable tocopherols and sterols, and rather than produce a single relatively low value blended product, these systems are capable of removing the higher value materials as a separate product. Bleaching clay oil recovery is another example of new technology to cure an old problem. Spent clay has been historically treated as a troublesome waste, often classified as a hazardous material because of its tendency for spontaneous combustion. By separating and recovering the neutral oil, the clay can be treated as an inert material, and sometimes reused for certain oils.

Value-added Alternatives

Companies such as Crown are continually developing new value-added alternatives, and there are several new innovations out on the horizon. Biodiesel is certainly a growth opportunity and is seen as one of the developing markets for soybean and rapeseed oil. However, economics do not favor production of biodiesel at this time, and the industry is dependent upon government mandates and subsidies, which can change at any time. Edible soy products are growing in popularity especially in Asia, and the prospects for soy protein concentrate (SPC) and soy protein isolate (SPI) are becoming increasingly attractive. One exciting development, with the first commercial operating just now being built in the US, is the use of supercritical fluids (especially carbon dioxide) to extract oil from soybeans. This technology holds several promises, including an all-natural and efficient extraction process, extremely high quality oil produced, and very limited denaturing of the soybean protein. While the economics will probably never allow complete replacement of solvent extraction, this technology will shine for edible and organic soy product markets.

Conclusion

The nature of our business is generally that of a price taker, so the goal is to become the most cost effective producer of quality commodity products. To that end, first take a critical look at existing operations to discover low cost opportunities for reducing costs. The next logical step is to consider the “basic” plant improvements, such as efficient DTDCs, deodorizers, etc. After these have been fully considered, investigate the more cutting edge options, such as the VSR tray and fatty acid systems that early adaptors are currently utilizing. Finally, stay current in the industry as new value-added and evolving technologies are introduced.

Step Grinding For Improved Efficiency Of Grain And Meal Products

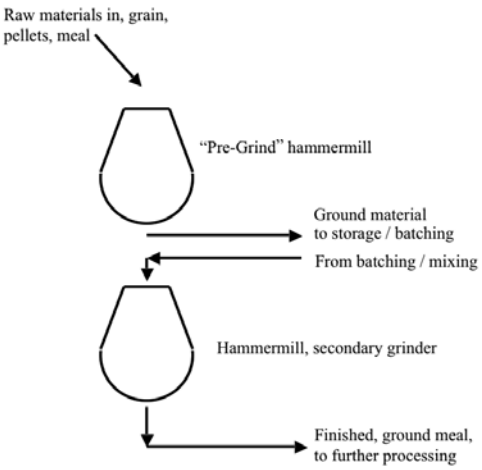
Mark Heimann
Roskamp Champion
USA

In many parts of the world attention is being focused again on a concept known as “Step Grinding”. What is “Step Grinding”, why is there such interest returning, and is this a concept that may hold a benefit for you?

Step grinding in the simplest terms, is size reduction accomplished in steps or stages, usually incorporating two grinding machines (hammermills, roller mills, pulverizers, or some combination thereof). The primary objective of step grinding is to reduce the cost to produce a ton of fine ground finished product. Additional benefits may include improved control of the particle size distribution (more uniform grind with less oversize and fewer fines), reduced product heating and subsequent moisture loss, a reduction in the maintenance cost per ton of ground material, finer finished products, and greater flexibility in the grinding circuit.

As noted above, step grinding may be accomplished in circuits utilizing two machines, though it is certainly possible to “step grind” using a single machine, or more than two machines. With a single machine, a step grind circuit will either involve batch processing (grind a batch coarse, readjust the grinding machine finer and process again) or a continuous operation with a screening stage returning oversize materials for reprocessing (circulation grinding). The potential benefits of circulation grinding were explored in the March 1994 edition of Feed Management in an article authored by William L. Ritchie titled Increasing the efficiency of particle reduction. This type of system does offer the same potential of reducing energy and improving particle size control, but does not significantly add to the flexibility of the grinding system (Figure 1).

Figure 1. Circulation Grinding System.



A second approach, and one that is employed in a number of U.S. feed manufacturing plant is the utilization of two grinders in “series”, one performing a pre-break, and the second grinding the total mixed feed ration. This type of system is commonly referred to as a “post mixer” grinding system, or perhaps just “post grind” system but differs from the European “post grind” concept of batching directly to the grinder.

The advantages of this kind of circuit include lower grinding costs, finer finished products, more uniform particle sizing, more uniform finished product mix (lower C.V.), and greater grinding system capacity. The primary disadvantages of this kind of system are the potential for the destruction of some micro ingredients and vitamins, and the higher capital costs to install the system. In most cases, the cost of additional capital equipment is offset in 6 to 12 months in the energy savings of the grinding circuit alone. Additional benefits such as increased (pellet mill) die and roller or (extruder) die life and increased pelleting or extrusion efficiency are bonuses on top of the energy savings.

This two grinder system may employ two hammermills, one roller mill and one hammermill, or two roller mills. Additionally, sieving between breaks may be added to further enhance the energy efficiency

Figure 2. "Pre grind"/"regrind" system.

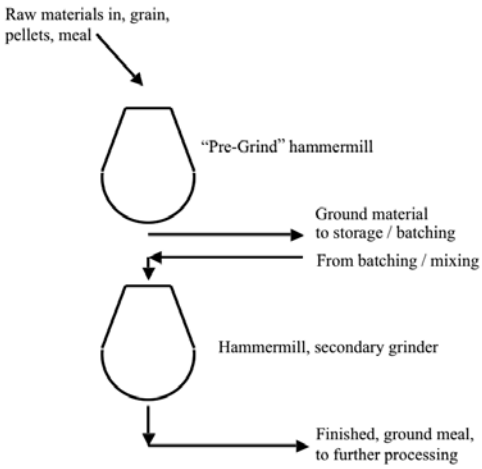
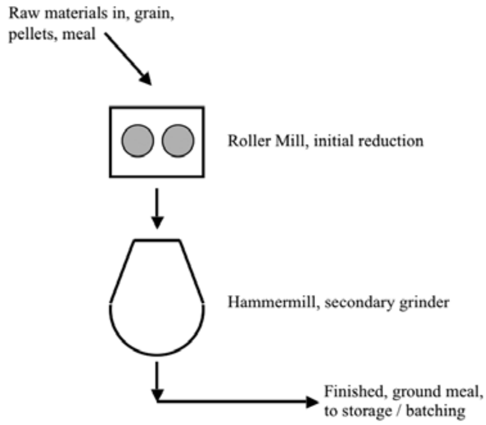


Figure 3. Roller mill hammermill "step grind" system.



of the system and reduce operating costs by removing sized materials before the secondary grinder, or by returning oversize materials to the pre-break machine (Figure 2 and Figure 3).

Step Grinding, The European Approach

More than ten years ago, a step grinding system approach was being presented by European manufacturers of feed milling equipment as a means of reducing operating costs. An integral part of the European approach was sieving before grinding and sieving between grinding stages. Because the European feed manufacturer uses such a wide range of ingredients received in the form of a meal, there is a potential for a high percentage of the raw materials to already be an acceptable particle size for the feed manufacturing process.

By removing these sized materials, the load on the grinding equipment could be reduced considerably. It appears from research and testing in actual applications that the reduction in energy consumption is roughly equal to one half of the amount of the materials removed. In other words, removing 30% of the materials to be ground (as fines) and by-passing the grinder reduces the energy required to grind by about 15% (Figure 4 and Figure 5).

Figure 4. Euro style step grind system.

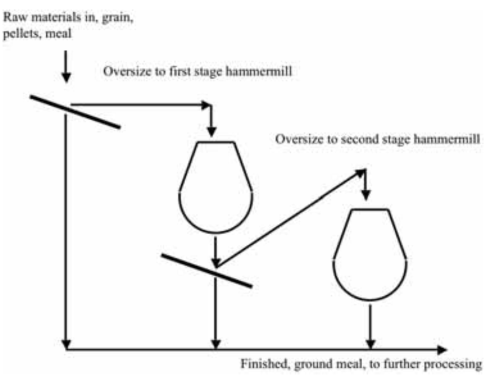
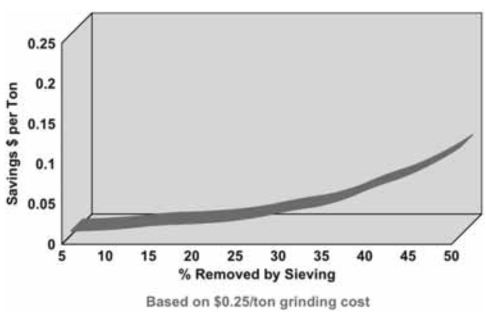


Figure 5. Champion hammermill energy savings by "fines" removal.



Step Grind For Efficiency in the U.S.

Since corn, wheat, sorghum and barley are the basis for most complete feeds in the U.S., the primary economic benefit of step grinding is an actual reduction in the specific energy required to grind feed materials rather than efficiency gains from sifting. As a rule of thumb for a two shift operation, one horsepower costs approximately $1.00 per day. An energy reduction of 50 horsepower will save about $50.00 per day in energy expenditures. Where does this savings come from? Power consumption can be expressed in terms of work accomplished over time.

$$\textbf{POWER} = \frac{\textbf{WORK}}{\textbf{TIME}}$$

The step grind approach yields this energy reduction (less power required) since the materials are reduced more gradually, through a slightly longer period of time. By doing the same amount of work (grinding) over a longer period of time (two or three gradual reductions instead of one instantaneous reduction) the total power requirement is reduced.

Because the roller mill offers such significant energy savings over a hammermill when processing grain in the coarser particle size ranges, the use of the roller mill as a pre-break device can offer substantial savings in a typical grain grinding circuit. By substituting a single pair roller mill in place of the conventional hammermill rotary feeder, the feed rate can be accurately controlled and a significant increase in hammermill capacity can be realized. Because the materials are reduced in size prior to being introduced to the hammermill grinder, larger screens may be employed with no significant increase in finished particle sizing.

This combination of finer feed, increased hammermill efficiency, and the possible use of larger screens not only reduces the energy cost when grinding, but reduces other operating costs (maintenance, parts) as well. Since a rotary feeder is not required the cost of a roller mill for use as a feeder is substantially offset in new installations. In other cases where existing hammermills require a boost in capacity, the application of a roller mill as a feeder can boost hammermill capacity by as much as 40 to 50% with no loss in the fineness of the grind.

Equipment/System	Screen Size	Particle Size	Efficiency*	Capacity
Hammermill	3 Mm	650 Microns	5.8 – 5.1	13.5 Mth
Roller Mill/	Na	3000 Microns	Rm – 0.55	
Hammermill	4 Mm	650 Microns	Hm – 2.7	20 Mth

In this example, the potential capacity increase is roughly 46% by utilizing a roller mill as a pre-break/feeder
** Efficiency expressed in terms of kWh/T (kWh per Ton)*

A Perspective On Mixing And Mix Uniformity

Keith C. Behnke
Kansas State University
USA

The basic premise used by all nutritionists when formulating rations is that each aliquot (mouthful) of the diet is balanced with respect to the known nutrient requirement of the target animal. The diet must contain the necessary nutrients to support maintenance, growth, production, and health. Feed additives should be present to provide the appropriate level of protection from disease and other maladies. In all cases, the levels must be controlled so as to be neither deficient nor toxic. The question that must be addressed is how well do current feed manufacturing techniques provide that level of nutrient uniformity assumed by the nutritionist?

The basic objective of any feed mixing operation is to obtain a uniform, random mixture of the solid and liquid ingredients in the formula. The equipment used is, at least in theory, designed to accomplish that objective without nutrient destruction in a minimum amount of time. A uniform random mixture can only be obtained if there is no favored direction of movement by individual particles and if there are no selective forces (i.e. centrifugal forces) that come into play. In bulk solids mixing, it is logical that motion must be introduced so that particles are displaced relative to one another. That is a complex way of saying that if solids are layered one on top of another and no motion takes place, mixing will not occur. However, if the container is rolled, shaken, or vibrated, particle displacement will occur and random uniformity will eventually be obtained.

There are obviously many factors that influence mixing and feed uniformity. They can be divided into ingredient characteristics and machine characteristics. For the time being, only bulk solids will be discussed – liquids present special circumstances. The purpose of this paper is to provide a discussion of the current situation and provide guidance as to how feed uniformity can be measured.

Current Situation

Mixing is one of the most important operations in the process of feed manufacturing, yet it is frequently given little or no consideration. The objective in mixing is to create a completely homogeneous blend. In other words, every sample taken should be identical in nutrient (attribute) content to any other sample. Needless to say we seldom achieve that goal, however, we do try to manufacture feed that is as uniform as possible.

Too many times too little emphasis is placed on the mixer we use. When we manufacture a feed, we formulate the diet to provide certain nutrients; in fact, we guarantee that many or all of these nutrients are there in the amounts specified. Many thousands of dollars are spent to gather, process, and store ingredients in semi- or fully-automated proportioning systems to feed exact amounts of ingredients to the scale. Yet, if these varied ingredients are not properly mixed, the quality control system prior to that point will lose a great deal of effectiveness.

Value Of Feed Uniformity

Intuitively, the concept of feed uniformity is important and people associated with livestock production realize that if feed ingredients, particularly micro-ingredients such as vitamins, amino acids, trace elements, and drugs, are not properly blended, animal performance will be reduced. Conversely, it is possible to create a toxic situation if some ingredients are not properly incorporated. A recent experience involving urea toxicity comes to mind in which 24 of 25 cattle died because urea segregated from an otherwise safe feed. Most feed additives will fail to provide protection if not properly blended in the feed. Logically, the value of uniformity is greater for the very young animal and animals with a short digestive tract versus older animals that consume large meals less often.

For example, a day-old chick has depleted essentially all nutrient reserves prior to hatching. During his first day on feed, he will consume about ten (10) grams of feed. It is critical that all required nutrients be in that first day's ration. As an interesting exercise, one can calculate how many 10 gram aliquots are in a three ton batch of starter feed and then contemplate the probability of each being precisely right. Conversely feed uniformity is not likely to be as critical to a finishing steer that is consuming 12 Kg of feed and has a 24 to 48 hour retention time in his GI tract.

Regardless of the target animal, good manufacturing practices dictate that we strive to produce as uniform of feed as is possible. To that end, equipment should be selected based upon known compatibility. Operational protocols should be set to insure that maximum uniformity is obtained. Personnel should be trained and educated on the concept of uniformity and appropriate testing should be conducted to ensure that uniformity objectives are met.

Equipment Properties

The range of equipment used to mix feed is at least as diverse as the ingredients. There have been many attempts to reduce mixing concepts to a series of engineering equations thus facilitating equipment design from a theoretical approach. The fact is most contemporary mixing equipment, including horizontal ribbon mixers, vertical screw mixers, and drum mixers, have simply evolved from historically successful designs without benefit of mixing theory input. For example, most horizontal mixers have a length approximately three times their diameter and have a rotational speed of 75-100 meters/minute regardless of the diameter. The inside ribbon is usually 2.5 times the thickness of the outside ribbon to balance the directional forces applied due to ribbon diameter.

Given this discussion, it is easy to appreciate the complexity of the mixing operation in a production facility. Yet, this seems to be an area of little concern to most feed manufacturers – commercial or private. As regulatory pressures for additive uniformity increases and as the need for providing uniform nutrient density to genetically superior livestock becomes necessary, it will be in the best interest of feed manufacturers to ensure uniformity through testing.

Current and Future Aspects

To focus on the regulatory aspect of uniformity, the following excerpt is taken from the 1990 FDA Regulatory Guidelines (FDA, 1990):

> Equipment (225.30) – All equipment used in the manufacture of medicated feed shall have the capacity and capability to produce a homogeneous medicated feed of the intended potency. The capability of the mixing equipment should be demonstrated upon installation and periodically as needed to ensure proper adjustments during operation. Written documentation of the adequacy of the equipment should be available for FDA review.

In January of 1990, the Degussa Corporation introduced a program to monitor uniformity of feeds manufactured by customers using their amino acid and other products (Wicker and Poole, 1991). Their results would indicate that only about half of the feeds tested would be of satisfactory uniformity (C.V. < 10%). About 30% had a C.V. of 10-20% and the remaining 20% of the feed samples had a C.V. of > 30%. It is not known precisely at what level of uniformity animal performance will be affected, but one can certainly assume that at a C.V. of greater than 20%, performance would be decreased.

The samples tested in this study were generally from large, centrally controlled feed mills. To gain a perspective on how well on-farm feed manufacturers do, Stark et al. (1991) conducted a study similar to that of Wicker and Poole except using salt as the tracer rather than synthetic amino acids. The results tended to parallel the Degussa report with about 42% of the samples having a C.V. of < 10%, 46% between a C.V. of 10% and 20%, and 12% having a C.V. of > 20%.

It is apparent that, at least in a significant portion of feed produced, nutrient uniformity criteria is not being met. As regulatory authorities move toward required equipment validation, it is imperative that the feed and livestock industries come to agreement as to what levels of nutrient uniformity is needed and how that uniformity is to be measured. There currently exists a standard (ASAE Standards, 1990) for testing solids-mixing equipment for animal feeds; however, the procedure is complicated and a great deal of the data required is meaningless to either regulators or animal performance.

Mixer Testing

The objectives of mixer testing can be many. The most common reason for testing a mixer is to determine the mixing time at which an adequate or satisfactory blend is obtained. The procedures are relatively simple and involve taking samples at specific time intervals. The assay used and statistical treatment is relatively straightforward.

Result Interpretation And Statistical Evaluation Of Mixing Tests

The standard deviation and coefficient of variation can be used to measure the results of a mixing test. In very simple terms, they help measure the distribution of values and express the value as one number. In order to interpret the results of a test, the variation of the procedure itself should be known. For instance, the coefficient of variation of the Quantab7 method is about 10%; therefore, if the result of the mixer analysis is 10% or less, we assume that a Agood@ mix has been achieved. The same situation applies for other procedures.

One can also use these procedures to isolate points of segregation in the feed mill. If one has a C.V. of 8% at the mixer and a C.V. of 18% after a transfer conveyor, there is a problem between the mixer and that point.

Assay Selection

Numerous assay methods have been used for mixer evaluation. One criteria for selection should be to assay for an ingredient, nutrient, or chemical that comes from a single source. Salt, therefore, is a good selection while protein or nitrogen would be a poor selection.

Sampling is also very important to any mixer evaluation. At least 10 samples should be taken, either from several locations in the mixer or at timed intervals during the mixer discharge. Enough of each sample should be taken each time (approximately 2 lb) to allow for a good test sample. In order to help clarify the requirements for a test procedure to be used for uniformity, the following criteria are offered:

1. The assay principle should be based upon a common ingredient or nutrient that is usually in the formula or can be added without risk.
2. The cost for each assay should be minimal (< $2.00 each).
3. The assay procedure should be simple, fast, accurate, precise, and able to be done on-site.
4. The assay should present no safety hazard to personnel or animals.
5. The assay principle should be supplied from a single source.
6. Sample size required should be reasonable but large enough to reduce or eliminate sampling error.
7. The target mix uniformity (C.V.) should be approximately two (2) times the proven analytical variation for the assay selected but in no case exceed 10%.
8. The statistical procedures required should be easily understood and performed.

As the reader can imagine, there is no "perfect" procedure available.

Mixing Equipment

There are three basic types of mixers used in the feed blending operation: horizontal batch, vertical batch, and continuous. The horizontal batch mixer is by far the most common piece of blending equipment used. The vertical screw mixer is sometimes found in smaller feed mills and is quite frequently used on farms. They are generally slower than a comparably sized horizontal blender.

The continuous blenders vary widely in design and capacity. They are often used to blend liquids into a base mix as well as in the steam conditioning of a pellet mash. Additionally, the continuous mixers are found in plants where continuous rather than batch proportioning is used to arrive at a final homogeneous blend of ingredients.

Horizontal Batch Mixer

This blender is generally equipped with right and left hand ribbon flights which convey material from one end to the other while it is tumbling in the mixer. Other designs include batch paddle mixers in which plows or paddles replace the ribbons. By using paddles, an even higher percentage of liquids may be added at the mixer. The plows are adjustable so that pitch can be set to obtain the desired blending operation.

Horizontal mixers are frequently equipped with multiple discharge openings or with a bottom, which opens along the entire length to facilitate rapid and complete cleanout. They may also be equipped with a surge bin beneath the mixer to reduce emptying and cycle time.

The major advantages of the horizontal mixer over the vertical mixer are the shorter mixing time and the fact that higher percentages of liquid may be added to the blend.

Short-Cycle Mixer

The current generation of mixers are often referred to as Ashort-cycle@ mixers because they are so effective at mixing that a 1.0 minute mixing cycle or less can be obtained. These mixers generally have twin mixing rotors or twin shafts with paddles. Studies conducted at Kansas State on such a mixer (Forberg) found that a simple ration had a CV of less than 5% after only 15 seconds of mix time. A more complex formula with up to 5% liquid addition will mix in less than one minute.

If a short cycle mixer is to be retrofitted into an existing feed mill, caution should be taken to ensure that the batching system is capable of a cycle time less than the anticipated mixing cycle.

These mixers are more expensive than the more typical ribbon mixers but have attributes that are attractive in many situations.

Problem Ingredients

The physical properties of ingredients can affect mixing. If all of the physical properties are relatively the same, then mixing becomes fairly simple. As the physical characteristics of ingredients begin to vary widely, blending and segregation problems are compounded. Some of these factors are:

1. Particle size
2. Particle shape
3. Density, or specific weight
4. Hygroscopicity
5. Static charge
6. Adhesiveness

Of those listed, particle size, shape, and density are the most important. Large and small particles do not mix well. They will mix better if there are particles of varying size in between. High density particles, such as minerals, tend to segregate and go to the bottom of the bin. An illustration would be the blending of cracked corn and fine mixing salt. The corn may have a particle size of 1200-1500 microns (m) and a density of 1.35 g/cc while the salt might have a particle size in the range of 200 m with a density of 2.6 g/cc. While it is not altogether impossible to obtain and maintain a satisfactory blend of these two ingredients, it is difficult.

Hygroscopicity refers to the ability to attract or take-up water. A very hygroscopic material, such as urea, may absorb enough water from the atmosphere to cause caking. Some ingredients, particularly vitamins and drugs, may possess a large static charge making them tend to stick to bin walls and sides of mixers. As the number of ingredients and variations increases, a greater appreciation of the complexity of the mixing operation is formed.

One of the places we can control ingredient variation is ahead of the mixing operation. Are the grinders, either roller mill or hammermill, producing the desired particle sizes? Is the particle size from the grinders ever measured? We may also need to measure the particle size of ingredients that are normally utilized as received. In some cases they may be contributing to poor mixing.

Discharge And Cleanout Of Mixers

There are obvious advantages to the drop-bottom type horizontal mixer in terms of discharge and cleanout. Discharge is nearly instantaneous with the lighter material being discharged within two seconds of the heavier material. There is essentially no carryover from one batch to the next, especially if equipped with air sweep systems.

Liquid Addition

The incorporation of fats, oils, molasses, and other liquids into the vertical mixer is being done today. Many fats and oils are hand-dumped along with the feed ingredients into the dump-in hopper at the base of these mixers. A better way to introduce fats and oils would be through a spray bar installed in the top of the mixer and the liquid metered thereto. The mixes incorporating liquids should be mixed longer than the dry feeds to ensure uniformity and to break up fat or molasses balls that form. To facilitate better mixing and breaking up, a high speed paddle type mixer can be installed in one of the discharge parts and the feed re-elevated to the top of the mixer.

The incorporation of molasses into a vertical mixer is not recommended above 3% if only one mixer is used for all feeds. Even this percentage will require more cleanup maintenance. This requires the installation of access panels in the tub and into the elevating tube to permit cleaning. Molasses builds up on the interior of the tub as well as on the mixing flights and will seriously reduce mixer efficiency. If not kept clean, rejections by the state feed inspection authorities and customer complaints will occur. Teflon lining of the tub and stainless steel screws will reduce maintenance when molasses is being added to the feed mix.

When higher percentages of molasses (3-8%) are going to be mixed continuously in a mixer, then two mixers should be used; one for feed requiring molasses addition and the other for dry feeds.

Liquid addition is best accomplished at the custom mix plant by working on the batch principle. Metering devices can be preset for automatically delivering exact quantities to the mix. The mixers should then operate long enough to properly incorporate or blend the total batch. Attempts to use a continuous, auxiliary mixer for molasses while discharging from the batch mixer can result in headaches. This procedure must be planned very carefully for good results and conditions must be ideal. Getting those conditions ideal is difficult and, for a quantity of molasses (ordered by a customer), the feed man may experience variations in the percentages of molasses applied to the feed as well as a shortage of molasses at the beginning and at the end of the run. If his customers are in the habit of specifying a certain amount, then the feed man should be aware of the continuous system or he may lose customers or give molasses away, thus cutting into his operating profits.

Liquids can be handled equally well in drop-bottom or nondrop-bottom horizontal mixers. About 10% of added liquids are normally considered in the top range of practical use. More than this amount begins to add problems in other areas such as your materials handling equipment. Adding liquids at the batch mixer is a common practice in many feed manufacturing operations. Adding liquids at this point can add to the contamination problem whether they be a drop-bottom or standard discharge type mixer. The addition of liquids (other than molasses) slightly increases horsepower requirements. Regulatory requirements may create a new concept in importance of where and when to add liquids. Where conflicting drug additives follow each other in mixing sequences, contamination is a major problem.

Compliance

Feed manufacturers should not have difficulty meeting requirements established by the regulatory agencies if they adhere to rigid cleaning and operational procedures. When micro-ingredients and premixes are being added, dust collection systems or other air suction systems should be carefully balanced such that a minimum of air is drawn from the mixer. Fortunately, regulations have, in the past, provided a broad range of concentrations in between which the feed manufacturer may operate. However, in light of today's improved detection techniques and consumer concern and awareness of potentially harmful drug residue problems, such allowable variations are being reduced. Most feed producers will not be satisfied with producing a feed having as broad a range as was once permitted.

The mixer should, of course, have good mixing efficiency, and allowing for sufficient time to thoroughly blend the feed is an absolute MUST.

When using antibiotics and other micro-ingredients in mixes which are prepared intermittently for poultry, swine, sheep, and cattle, the manufacturer should be sure:

1. That the mixer internals are clean and that it is cleaned out thoroughly between the mixing of the different rations. This means stopping the mixer and removing excess materials in filler tubes and cut-in hoppers.
2. That the mixer is grounded to bleed off static electricity.
3. That regulatory requirements are followed for:
   a. Cleanout of accessory equipment
   b. Labeling
   c. Recheck of ingredient weight and inclusion
   d. Sampling, etc

Operational Comparison Of Standard Horizontal Batch Mixers And Drop-Bottom Horizontal Batch Mixers

Operational procedures of the drop-bottom unit is very much like the operation of a normal single or multiple discharge mixer, but it has an added advantage in that it discharges most rapidly; as fast as ten seconds for opening, discharging, and closing of doors. The mixer is completely emptied and clean with very little possibility of contamination. This rapid discharge feature reduces the total mixing cycle time, and, since the feed mill capacity is based largely on mixing capacity, can possibly increase plant capacity through savings in discharge time.

Sequence Of Ingredient Addition To Drop-bottom Mixers

We know that there is a decided advantage in following a particular sequence when charging ingredients into the mixer. With the drop-bottom feature you do not have discharge pockets that can possibly catch a few pounds of the first ingredient that is put into the mixer and hold it unmixed. There are no pockets, but a smoothly contoured bottom formed to the contour of the ribbon itself. This further reduces the possibility of segregation and “dead spots”.

Cleaning And Maintenance Requirements

Periodic cleaning of the drop-bottom mixer is no more difficult than the normal periodic cleaning of a standard single or multiple discharge mixer. This can be accomplished through the top or by installing access panels in the side of the catch hopper below the mixer and cleaning it from the bottom with the doors swinging open. Normal cleaning of this unit in dry feed mixing consists of removal of strings that might catch on the ribbon assembly. The only other additional maintenance that would be required would be on the air cylinders themselves and, with proper installation of air supplies with traps and filters, this should be no problem at all.

Noncontamination Feature

The self-cleaning non-contamination feature is a basic point in favor of this particular type of unit. The possibility of contamination must always be considered when using drugs, and we know there are many places in the feed plant where contamination can occur. By eliminating the problem here, one contamination worry is removed.

I might mention, going a bit further, that if you are using bucket elevators to elevate your mixed feed, you can eliminate another source of contamination by equipping your elevator legs with automatic boot cleanout units. These, too, can be integrated into your semi- or fully- automatic batching system to cycle between each batch if desired. Another way to reduce contamination is to use a gravity flow system wherever possible.

With today's high energy specialized feeds, with the necessity for feed mill efficiency, and with contamination being the problem it is, we feel that the drop-bottom mixer will prove more and more important in modern feed manufacturing operations.

Summary

Nutrient uniformity is the common objective of every feed manufacturer. A great deal of emphasis is placed on uniformity because of regulatory compliance, animal performance, and the satisfaction obtained in producing quality feeds. It is surprising how few mixers are actually tested in any manner, let alone on a routine basis. It is hoped that mixer testing will become more commonplace and will be a part of the quality control procedures of every feed producer.

Further research is needed in the design of mixing equipment and additional animal experiments that will result in a better understanding of the value of uniformity and the cost of non-uniformity in livestock production.

References

AAFCO,2004. Analytical Variation (AV) Based on AAFCO Chick Sample Program. Assoc. of Am. Feed Control Officials, Barbara Simms, Treasurer, Texas A.M. Univ., College Station, TX.

ASAE, 1990. Test Procedure for Solids-Mixing Equipment. Standard ASAE S303.2 American Soc. of Agric. Engineers, St. Joseph, MI.

FDA, 1990. Compliance Program Guidance Manual--Medicated Feeds Program No. 7371004. FDA/CVM, Rockville, MD.

Stark, C.R., K.C. Behnke, R.D. Goodband, and J.A. Hansen, 1991. On-Farm Feed Uniformity Survey. Swine Day Report of Progress No. 641, AES, Kansas State University, Manhattan, KS.

Wicker, D.L. and D.R. Poole, 1991. How is Your Mixer Performing? Feed Management, 42(9):40, 43.

Ensuring Optimum Mixability In Feed Manufacturing

Chin Sou Fei
Novus International Pte Ltd
Singapore

Introduction

The daily ration of nutrients that an animal receives from a feed may vary from time to time due to a number of reasons. The sources of variation will probably cause variation in the day-to-day level of nutrition received by an individual animal. Certain nutrients are guaranteed to be present at minimum levels and regulatory officials will be concerned, if guarantees are not met. Certain ingredients may be toxic at very high levels. The nutrient variation in feeds is most likely to occur for the following reasons (Wilcox and Balding, 1976):

a. Variation in the composition or quality of ingredients from batch to batch or from time to time
b. Poor mixing or segregation after mixing
c. Errors during weighing or proportioning

In most cases, a sound quality control program can insure optimum feed preparation. Routine inspection of the mixer, proper mixer "tuning", maintenance of all liquid systems and close attention to ingredient inventories will go a long way to ensure that the nutrient specifications prescribed by the nutritionist, actually reach the bird.

The consequences of nutrient level variation are varied. However, the major disadvantage of variation is normally the effect on animal performance.

Mixing is one of the most essential and critical operations in the process of feed manufacturing, yet it is frequently given little consideration. The objective in mixing is to create a completely homogeneous blend. In other words, every sample taken should be identical in nutrient content. A functional definition of uniform mixing can be summarized in one sentence. "All nutrients will be present in sufficient quantity in the daily feed intake of the target animal to meet its minimum growth requirements".

The literature is filled with classic examples of the impact of inadequate vitamin and mineral consumption on animal performance. However, field examples are rarely "classic" in nature, and are therefore, very difficult to diagnose. Unfortunately, in most cases the effect of inadequately/ improperly mixed feed manifests itself as marginally depressed performance. Typically, birds exhibit slight reductions in growth, feed conversion, feathering and other performance parameters. As a result, the technical staff of a commercial company may incorrectly diagnose a decease condition, and never resolve the underlying problem in the mill.

Effect Of Mixing Uniformity On Animals Performance

Uneven ingredient dispersion feeds may lead to reduced bird performance. In order for birds to reach their genetic potential for growth and meat yield, levels of protein, energy vitamins and minerals must be provided in their proper ratio. Duncan (1989) reported that as protein variation increased in feeds, growth rate and feed conversion were depressed (Table 1). A 10% variation in the feed quality significantly reduced both weight gain and increased feed conversion. When the coefficient of variation (CV) of the feed was increased to 20%, another significant increase was observed in feed/gain (F/G).

Table 1. Chick response to dietary protein variation from 0 to 28 days of age [1, 2]

Treatment	Gain (gm)	F/G
Control	773[a]	1.74[a]
10 % CV	716[a]	1.82[b]
20% CV	703[b]	1.86[c]

[1] *Duncan (1989)*
[2] *Adjacent means within a row with no common superscript differ significantly (P<.05)*

A recent study on the effect of mixing uniformity on day one old broilers was conducted by McCoy et al. (1994). Feed was formulated to meet or exceed NRC requirements for all nutrients for broiler chicks from 0 to 3 week of age. However, in experiment 2, feeds were formulated to 80% of NRC recommendations for crude protein (CP), lysine, methionine, Ca, and P. The purpose of using deficient diet in this study was to accentuate any difference in growth performance that might result from diet nonuniformity.

In experiment 1, feeds were collected from mixer after 20, 40 and 80 revolutions of mixing (20 = highly non-uniformity mixing, 40 = moderate non-uniformity mixing and 80 = uniform mixing). Variability of feed decreased sharply between 20 and 40 revolutions and no further reduction occured between 40 and 80 revolutions (Table 2). The CV values from analyses of salt concentrations were 43, 11 and 13% for 20, 40 and 80 revolutions, respectively. No difference occured among treatment for average daily gain (ADG), average daily feed intake (ADFI), bone strength, bone ash, carcass crude protein, carcass fat, or carcass ash. However, there was a trend for a linear increase in gain:feed (G/F) ratio when mixer revolutions were increased.

In experiment 2, feeds were collected after 5, 20, and 80 revolutions. The salt test CV % decreased from 40.5% to 12.1% when mixing was increased from 5 to 20 revolutions, but there was no further reduction of CV % from 20 to 80 revolutions (Table 3). ADG, ADFI and G/F improved when CV % decreased from 40.5 to 12.1%. However, mortality was not affected by treatment.

The effect of poorly mixed feed on pig performances was reported by Traylor at el. (1994). In this experiment the effect of mix time on diet uniformity and growth performance was evaluated in nursery and finishing pigs on a double-ribbon mixer.

For the nursery experiment, increasing mix time from 0 to 0.5 min decreased the CV % from 106.5 to 28.4% (Table 4). Increasing mix time to 4 min reduced CV value to 12.3%. ADG, F/G and ADFI was increased by 49, 19 and 20 %, respectively as the CV for marker concentration decreased from 106.5 to 12.3%.

For the finishing experiment, increasing mix time reduced the CV for diet uniformity from 54 to less than 10 % (Table 5). The mix time had no statistically

Table 2. Effect of mixing time on diet uniformity and performance, carcass composition, and bone measurements in broiler chicks, experiment 1 [1,2]

	Revolutions			
Item	20	40	80	SE
Salt CV, %	43.0[a]	10.8[b]	13.1[b]	3.7
Red particle CV, %	50.0[a]	14.8[b]	17.1[b]	4.2
Blue particle CV, %	47.6[a]	12.0[b]	14.6[b]	4.2
Chromium CV, %	49.7[a]	15.3[b]	16.7[b]	4.1
Average daily gain, g	31.5	33.4	33.1	1.1
Average daily feed intake, g	47.5	49.0	48.3	1.2
Gain:feed, g:g	.663	.682	.685	.010
Bone breaking strength, kg of force	19.0	19.5	17.6	1.2
Bone ask, %	41.8	41.2	39.4	1.1
Carcass CP, %	53.8	54.4	55.0	.6
Carcass fat, %	29.5	29.3	29.1	.9
Carcass ask, %	7.8	7.7	7.3	.3

[1] *Modified from McCoy et al. (1994)*
[2] *Adjacent means within a row with no common superscript differ significantly (P<.05)*

Table 3. Effect of mixing time on diet uniformity and performance in broiler chicks, experiment 2 [1,2]

	Revolutions			
Item	5	20	80	SE
Salt CV, %2	40.5[a]	12.1[b]	9.7[b]	3.4
Red particle CV, %	53.4[a]	16.6[b]	11.3[b]	4.0
Blue particle CV, %	53.9[a]	17.0[b]	10.6[b]	3.5
Sodium CV, %	44.5[a]	23.2[b]	22.8[b]	3.1
Average daily gain, g	23.6[a]	30.0[b]	30.3[b]	1.7
Average daily feed intake, g	43.1	51.5	52.7	2.9
Gain:feed, g:g	.548[a]	.583[b]	.575[b]	.018
Mortality, %	12.0	0	0	5.8

[1] *Modified from McCoy et al. (1994)*
[2] *Adjacent means within a row with no common superscript differ significantly (P<.05)*

Table 4. Effects of mix time on diet uniformity and growth performance of nursery pigs [1]

	Mix time, min				
Item	0	.5	2	4	CV
CV for Cr, %	106.5	28.4	16.1	12.3	N/A
ADG, lb[2]	.59	.83	.84	.88	12.0
ADFI, lb[3]	1.32	1.57	1.55	1.59	7.9
F/G[4]	2.24	1.89	1.85	1.81	9.1

[1] *Modified from Traylor et al. (1994)*
[2] *Quadratic and cubic effect (P<.02)*
[3] *Quadratic and cubic effect (P<.08)*
[4] *Quadratic and cubic effect (P<.03)*

Table 5. Effects of mix time on diet uniformity and growth performance of finishing pigs [1]

	Mix time, min				
Item	0	.5	2	4	CV
CV for Cr, %	53.8	14.8	12.5	9.6	N/A
ADG, lb	1.71	1.78	1.75	1.73	3.7
ADFI, lb	6.49	6.40	6.36	6.35	3.7
F/G	3.80	3.60	3.63	3.67	3.5
Dressing percentage	73.7	73.3	73.1	73.0	.6
Last rib fat thickness, in	1.20	1.09	1.14	1.18	3.3
Bone breaking strength, strength, kg of peak force	230	236	239	218	16.9

[1] *Modified from Traylor et al. (1994)*

significant effects on ADG, ADFI, F/G and bone strength. However, rate and efficiency of gain had numerical increases of 4 and 5 %, respectively, as mix time increased from 0 to 0.5 min.

They concluded that that increased mix time improved diet uniformity and performance of nursery pigs. Finishing pigs were less sensitive to diet nonuniformity, with growth performance being affected only slightly as mix time was increased from 0 to 4 min. The finishing pigs were quite tolerant of CVs of at least 15% and even up to 54%. However, caution is warranted when using a medicated feed article.

Factors That Affect Mixer Performance

Although insufficient mixing time and filling the mixer beyond the rated capacity are often implicated as common sources of variation in finish feed. Other factors such as particle size and shape of the ingredients, ingredient density, static charge, sequence of ingredient addition, worn, altered, or broken equipment, improper mixer adjustment, poor mixer designed, and cleanliness can affect the mixer performance (Wilcox and Balding, 1986; Wicker and Poole, 1991).

The mixing time necessary to produce a homogenous distribution of feed ingredients should be measured for each mixer. Mixing time is a function of mixer design and the rotational speed of the ribbon, paddle, or auger. Each mixer should be “tuned” to its proper Revolutions Per Minute (RPM) for optimum ingredient dispersion. Different types of ingredients may have a different flow pattern within a mixer at similar RPM’s. Generally, (Wilcox and Unruh, 1986), the higher the RPM, the faster the more efficient the pattern of dispersion (Figure 1). However, optimum RPM can change over the life of the mixer resulting from normal wear, ingredient buildup or structure basis to allow the mill operator to make the adjustments needed to achieve a high level of operational performance.

The size uniformity of the various ingredients that comprise the finished feed can directly impact final ingredient dispersion (Herrman and Behnke, 1994). If all the physical properties are relatively the same, then mixing becomes fairly simple. As the physical characteristics of ingredients begin to vary widely, blending and segregation problems are compounded. Large and small particles do not mix well and subject to directional influence in nearly any type of mechanical mixer. For example, ground grain with a particle size of 1,200-1,500 microns reduced the likelihood of uniform incorporation of microingredients compared to grain ground to an average particle size of 700 microns (Herrman and Behnke, 1994).

Figure1. Effect of paddle/screw RPM on CV in a 2-ton horizontal mixer.

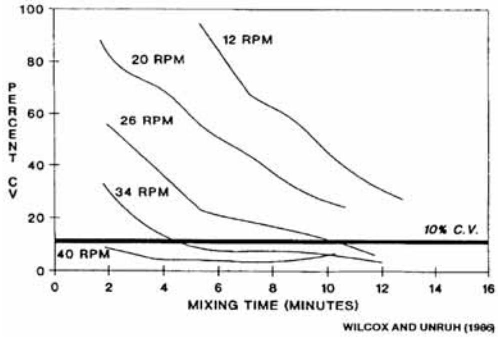


Figure 2. Effect of liquid buildup in a 2-ton horizontal paddle mixer.

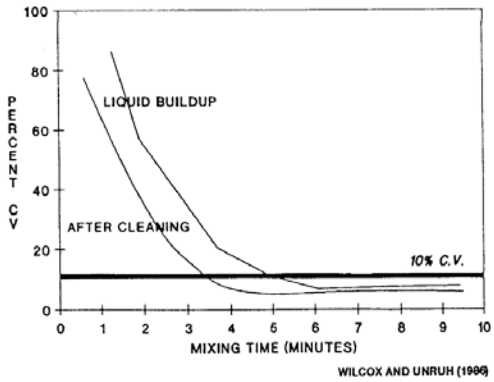
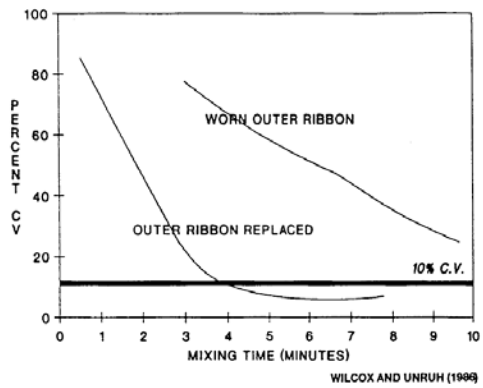


Figure 3. Effect of worn outer ribbon in a 2-ton horizontal ribbon mixer.



The sequence of ingredient addition also determines ingredient dispersion in the mixing process (Herrman and Behnke, 1994). Mixers may have dead spots, where small amounts of ingredients may not be readily incorporated into the feed. This situation is exasperated when mixing ribbons, augers, or paddles become worn. Ground grain or soybean meal should be the first ingredient added into a horizontal mixer. It has been determined that for the quickest distribution of the microingredients within the mass of major ingredients, the microingredients should enter the horizontal mixer early in the dumping order, no later than 10 seconds after the first of the major ingredients begins its entry (Lanz, 1992).

Overfilling or under-filling a mixer can lead to inadequate mixing (Wilcox and Balding, 1976). Overfilling a mixer can inhibit the mixing action of ingredients in horizontal mixers at the top of the mixer. Filling a mixer below 50% of its rated capacity may reduce mixing action and is not recommended.

The incorporation of liquid ingredients (fats, oils, molasses, liquid chlorine chloride, Alimet and other liquids) into the mixer is a common practice in many milling operations. The best way to introduce liquid ingredients are through a spray bar installed at the top of the mixer. Dry ingredients should be adequately mixed prior to the introduction of liquids into the system. Premature liquid addition tends to impede the transport of micronutrients and may even agglomerate the fine particles into “snowballs”.

Most engineers agree that multiple points of application (4-8) are necessary to insure adequate dispersion (Lanz, 1992). The preferred location is such that the manifolds are parallel and located on the “up-turning” side of the rotor. Pressure-loaded check valves and air-purged manifolds help minimize the post-spray dripping that can foul the mixer’s rotor.

Mixer Testing

Routine mixer testing should be an integral part of the quality assurance program and should be conducted quarterly. Procedures for mixer testing are relatively simple and involve taking samples at specific time intervals. The assay used and statistical treatment are relatively straightforward.

Sampling

Good sampling is essential for a mixability study to be worthwhile. An analysis is only as good as the sample. The intent of good sampling is to obtain a small portion of a feed that is representative of the whole. One cannot take only the fines or only large particles and expect to obtain an accurate analysis. The eight factors summarized here are important in order to obtain good samples. These apply to all samples and not just to those taken for mixability studies.

Important factors to obtaining good samples

1. Planning
2. Location
3. Quantity
4. Timing
5. Tools used for sampling
6. Containers
7. Proper labeling
8. Sampling preservative

The number of samples to be taken depends on the accuracy of the results desired. Herrman and Behnke (1994) suggested that 10 samples per batch per mixing time would yield sufficient satisfactory coefficient of variance. Eisenberg and Eisenberg (1992) indicate that the number of samples assayed depends mainly upon the laboratory time and costs.

Ideally, samples should be taken within the mixer either at spaced intervals during the mix or on completion of the mix. Sampling within a mixer may be particularly desirable under these conditions:

1. When a mixer design is being studied, an attempt is made to determine where certain ingredients may concentrate.
2. When the effect of time of mixing is being studied, it is not desirable to discharge the mixer frequently or before mixing is complete.

If one cannot take samples from the mixer, then take them as near the mixer in the production system as possible. Frequently if a mixer discharge is being sampled, it is necessary to sample as rapidly as possible at almost uniform time intervals, which may mean taking samples at 5 to 10 second intervals. If poor mixer or segregation is indicated after preliminary trials, it may be desirable to make a special effort to sample from particular locations or at particular times to locate trouble spots.

Recommended Procedure For Sampling Feeds From The Mixer

1. Decide and make arrangements for the analytical work. Obtain equipment and containers for sampling. The suggested size is 100 to 200 gram and sufficient enough for the planned analyses. Mark sample containers for sample identification.
2. Select a suitable location for taking samples preferably as close to the mixer discharge as possible. The site and sampling procedure should not pose a safety hazard to the person involved in taking the samples.
3. Timing the mixer discharge at 8 to 10 samples per batch are recommended, beginning with initial discharge and ending with samples of the tailings at the final discharge. In between samples will be taken at evenly spaced time intervals between the initial and final discharge.
4. Begin sampling sequence when the mixer is ready to discharge. Record the mixing time; mixing time begins when the last ingredient is added to the mixer and ends when the mixer begins to discharge.

Assay Selection

Numerous assay methods have been used for mixer evaluation. However, there is no “perfect” procedure available. The criteria for the assay selection should be as follows:

1. The assay principals should be based upon a common ingredient, nutrient, or chemical that comes from a single source. Salt, therefore, is a good selection while protein or nitrogen would be a poor selection.
2. The cost of the assay in terms of labor, chemicals, and time should be minimal.
3. The assay procedure should be relatively simple, fast, accurate, precise and should be able to perform in the mill or laboratory, and not require expensive equipment or highly qualified personnel.
4. The assay principle should be supplied from a single source.
5. The sample size required should be reasonable but large enough to reduce or eliminate sampling error.
6. The target mix uniformity (CV values of the tracer) should be about 2 times the proven analytical variation for the assay selected but in no case should it exceed 10%.

Common Mixer Tests

Salt (NaCl) is a common component of most livestock and poultry rations. Therefore, sodium (Na) or chlorine (Cl-) ions are often used as mixer test markers. Assaying samples for salt content may be performed using several techniques.

1. Omnion Sodium Analysis (Omnion, Inc., Rockland, Massachusetts): Use a sodium ion electrode to determine the concentration of Na+ in the samples. The percentage of salt can be calculated from these values. The technique appears to be quite accurate and reliable.
2. Quantab® (Environmental Test Systems, Elkart, Indiana): This method determines the chloride ion concentration of a solution. Salt from the feed samples is extracted in hot water. The titrators consist of a thin strip laminated with a capillary column, impregnated with silver dichromate. The column is a reddish-brown color. When the strips are placed in an aqueous salt solution, the fluid will rise in the column. The indicator across the top turns blue, the reaction is completed. Chloride ion concentration is calculated and variation from the expected concentration is used to determine mixer performance.

Color-coded Tracers

Microtracer™ Rotary detector (Micro Tracers, Inc., San Francisco, CA 94124): Inclusion and subsequent analysis for tracer particles is another method for mixer testing. A sufficient amount of iron filings, colored with a water-soluble die, is added to the mix to result in sixteen counts (particles) per sample, with the sample size ranging between 50 to 100 grams. The iron particles are demagnetized and sprinkled onto a large filter paper. The filter paper is then moistened with ethanol. When spots begin to develop, the paper is transferred to a preheated hot plate or oven and dried. All particles of the same color are counted, noting the total. Variation from the expected number is calculated to determine mixer performance.

As an interim check, other ingredients such as lysine and liquid Alimet feed supplement can be utilized to help determine if the mixer is functioning within an acceptable range of variation. Feed mills routinely assay for Alimet to evaluate mixability due to its relatively low assay CV (3-5%), and the simplicity of the method which uses High Pressure Liquid Chromatography (HPLC).

Data Analysis

The average marker concentration (mean) and variations between samples (standard deviation) are calculated to arrive at a single value described as the coefficient of variation (CV).

SAMPLE ID	Alimet Concentrations (by HPLC analysis)
Feed sample 1	0.174
Feed sample 2	0.174
Feed sample 3	0.180
Feed sample 4	0.180
Feed sample 5	0.179
Feed sample 6	0.184
Feed sample 7	0.173
Feed sample 8	0.175
	Mean = 0.177
	Standard Deviation = 0.004
	CV % = 2.21

Equation to calculate CV %:
CV % = Standard deviation / Mean x 100

Example: A formula calls for 0.175% Alimet. Determine if a good mix has been obtained.

The mean and standard deviation values can be calculated with an inexpensive calculator with the statistical functions. We conclude from this data that the blend was uniform with a CV value of 2.21%.

Interpreting the Results

A CV of less than 10% has somewhat arbitrarily been used as the "cut-off" point for accepting a batch of feed as being properly mixed. The industry standard is a maximum CV of 10% for a feed to be considered adequately mixed. Thus, a desirable CV for a well-mixed feed, using the salt assay method, should be at or below 10%. However, variation in the salt assay procedure may be as high as 5 to 6%, indicating that the actual variation due to mixing is about 5%. Furthermore, when using a limited number of samples (10 - 12), it can be expected that occasionally a CV of more than 10% will occur, which may/may not identify an underlying problem in the mixing process. Thus, these figures may be revised to fit individual mill standards and quality control policy.

Interpretation of mixer tests

% Coefficient of Variation	Rating	Corrective Action
< 10%	Excellent	None
10 - 15%	Good	inspection of mixer
15 - 20 %	Fair	Increase mixing time, look for worn equipment, overfilling, or sequence of ingredient addition
> 20 %	Poor	Possible combination of all the above and consult feed equipment manufacturer

Source: Feed Manufacturing - testing mixer performance. Bulletin MF-1172 Revised, Kansas State University Cooperative Extension Service, Manhattan, KS MF-1172

Conclusion

Feed costs comprise the single most expensive component in producing poultry or other types of meat animals. As a result, effort to reduce nutrient variability within feeds will yield a significant return to commercial operations. Proper ingredient processing and storage, adequate maintenance of mill equipment and routine testing of the final feed are essential to insure optimum animal response to feed nutrients, while controlling feed costs. Nutritionists and feedmill operators should work together to closely monitor feed preparation, and final feed specifications. The bottom-line result will be a reduction in the cost to produce a unit of meat or eggs.

References

Duncan, M.S. 1989. Strategies to deal with nutrient variability In: Recent Advances in Animal Protein Production. Monsanto Latin America Technical Symposium Proceedings. pp. 31-40.

Eisenberg, S and D. Eisenberg, 1992. Markers in mixer testing: closer to perfection. Feed Management. Nov pp 8-20.

Herrman, T. and K. Behnke. 1994. Feed Manufacturing - Testing mixer performance. Bulletin MF-1172 Revised, Kansas State University Cooperative Extension Service, Manhattan, KS.

Lanz, G. T. (1992) Composition of mixing systems. Novus Nutrition Update Vol 2 (1).

McCoy, R.A., K.C. Behnke, J.D. Hancock and R.R. McEllhiney. 1994. Effect of mixing uniformity on broiler chick performance. Poul Sci 73:443.

Traylor, S.L., J.D. Hancock, K.C. Behnke, C.R. Stark, and R.H. Hines. 1994. Mix time affects diet uniformity and growth performance of nursery and finishing pigs. Kansas State Univ. Swine Day 1994, pp 171-175.

Wicker, D.L. and D.R. Poole, 1991. How is your mixer performing? Feed Manage. 42(9):40-44.

Wilcox, R.A. and J.L. Balding, 1976. Feed manufacturing problems - incomplete mixing and segregation. Bulletin C-555 Revised, Kansas State University Cooperative Extension Service, Manhattan, KS.

Wilcox, R. A. and D.L. Unruh. 1986. Feed manufacturing problems - Feed mixing times and feed mixers. Bulletin MF- 829 , Kansas State University Cooperative Extension Service, Manhattan, KS.

High Speed Hammermills For Fine Grinding

Mark Heimann
Roskamp Champion
USA

Hammermills are commonly used for grinding a broad range of materials including those used in the production of pet foods and aquaculture feeds. Since most pets and species of fish, crustaceans, and shellfish have a very short digestive tract, they require a finely ground, highly processed feed in order to realize good feed utilization. Hammermills and air swept pulverizers are the two most common machines used to grind the materials to the fine particle size used in the production of extruded pet foods and aquaculture feeds.

Hammermills vs. Air Swept Pulverizers Compared to most air swept pulverizers hammermills offer high efficiency, low heating, and reduced aspiration requirements. Maintenance costs for hammermills equipped with conventional hardfaced hammers and round hole screens are typically $0.02-$0.10/ton and electrical costs range from about $0.25/ton, to more than $1.00 per ton depending on the feed formulation and fineness of grind. By comparison, air swept pulverizers often consume $2.00 to $4.00 /ton or more for energy, and wear parts costs can exceed $0.25/ton in many instances.

Because there is less heating of the product and lower air flow through a hammermill compared to an air swept pulverizer, materials ground through a hammermill will have less moisture loss than materials ground through air swept pulverizers. Typical moisture loss through a hammermill when fine grinding for aquaculture feeds is 1/2 to 2%. Hammermills are generally less expensive to install and operate than pulverizers, typically costing between $250 and $350 per HP for a complete system including the hammermill, feeder, and appropriate air assist system.

Hammermills are somewhat limited in the finished particle size that can be conveniently achieved. Typical finished ground product from a conventional hammermill set up will be in the range of 90 to 95% less than 30 mesh (0.5 mm) with a mean particle diameter of 200μ to 300μ. Specially equipped hammermills are capable of grinding aquaculture rations as fine as 90 to 95% less than 60 mesh (0.25 mm) with a mean particle diameter of 100μ to 175μ. Air swept pulverizers with built in classifiers can recirculate oversize particles and achieve finished products in the range of 95 to 99% less than 100 mesh (0.15 mm) and a mean particle diameter between 40 and 75μ.

In many instances, "double grinding" systems are employed to obtain the fine finished products needed for efficient aquaculture feed production. Double grinding may be accomplished with a single hammermill, processing the entire batch through the hammermill then with a screen change to improve the fineness of grind, rerunning the same batch back through the same hammermill. A second approach is to use two hammermills in series, grinding through a larger screen first (typically 1 to 3 mm) then regrinding the entire batch through a second hammermill with smaller screens (typically 0.4 to 1 mm). A third double grinding system uses a hammermill for the preliminary grind, and then through an air swept pulverizer for the finished particle sizing. Whatever the system may be, double grinding offers improved efficiency over single grinding operations with a finer, more uniform finished ground product.

Equipment Description

A hammermill consists of a rotor assembly with two or more rotor plates fixed to a main shaft, enclosed in some form of grinding chamber. The actual working mechanisms are the hammers and the screen or grinding plates that encircle the rotor. The hammers are simply flat metal bars with a hole at one or both ends and usually have some for of hardface treatment on the working end(s). The hammers may be fixed, fastened rigidly to the rotor assembly but much more common are swinging hammers where the hammers float on pins or rods. This swinging hammer design greatly facilitates changing hammers when the working edges are worn.

Particle size reduction in a hammermill is primarily a result of impact between the rapidly moving hammers and the incoming material. There is some attrition of the particles (gradual reduction by friction) between the hammers and the screen and as the particles impact the internal components of the hammermill as they are being driven around the machine by the rapidly turning hammers.

The efficiency of the grinding operation will depend on a number of variables including but not limited to: tip speed, screen (hole) size and open area, screen area / horsepower ratio, hammer pattern (number of hammers), hammer position (coarse or fine), uniform feed distribution, and air assist. In addition, the nature and quality of the material(s) being processed will affect the performance of the hammermill.

Basic Machine Characteristics

Hammermills used in aquaculture feed processing have many common characteristics. Here are a few basic design principles as they apply to maximizing the performance and minimizing the cost of operating a hammermill system.

Full Width Top Feed The modern hammermill design must include a full width top feed in order to achieve maximum efficiency and minimize the cost of operation. A full width feed insures the entire screen area can be used effectively, and that the work being accomplished will be evenly distributed across the full hammer pattern. The top feed permits the direction of rotation to be changed, allowing two corners of the hammer and both “edges” of the screen to be utilized before a physical change of the hammer is required.

Tear Shaped Grinding Chamber A tear shaped grinding chamber is necessary to prevent material from circulating within the grinding chamber. Most well designed modern hammermills have some sort of flow director in the top of the hammermill to properly feed incoming materials into the hammer path, and to stop any materials that are circulating within the grinding chamber.

Split Screen / Regrind Chamber Hammermill screens are commonly split in two pieces, with some device at the bottom of the mill to disrupt the flow of materials within the grinding chamber. The application of a split screen design will permit the user to adjust the screen sizing on the down side and up side to maximize productivity and product quality. A “Regrind Chamber” at the bottom of the mill introduces enough turbulence to swirl materials back into the hammer path at the 6:00 position. This regrind chamber must be large enough to take product out of rotation as the hammermill operates, but should not be so large as to reduce the available screen area significantly.

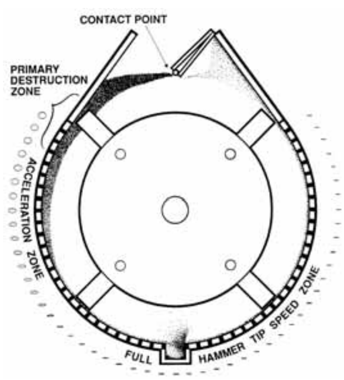
Robust Rotor Support In order to maintain the relative position of the rotor to the grinding chamber the foundation of the mill must be extremely robust. A solid, substantial structure positively maintains the clearances between the hammer tips and the screen through the full rotation for consistent, efficient processing. This stout design must be accomplished without sacrificing the accessibility to the grinding chamber, as routine maintenance of the hammers and screens will be required.

Replaceable Wear Items One final rule for a good hammer design is if it can wear, it should be replaceable. Beyond the hammers, screens, and pins, every component within the hammermill will be subject to wear. Accordingly, these components should be fabricated from wear resistant materials, heavy enough to provide good service life, and ultimately should be reasonably simple to replace.

Basic Operational Concepts

As noted, particle size reduction in a hammermill occurs as a result of the impact between a rapidly moving hammer and a relatively slow moving particle. The particle breaks and is accelerated towards the screen; depending on the particle size and angle of approach, it either passes through the screen or

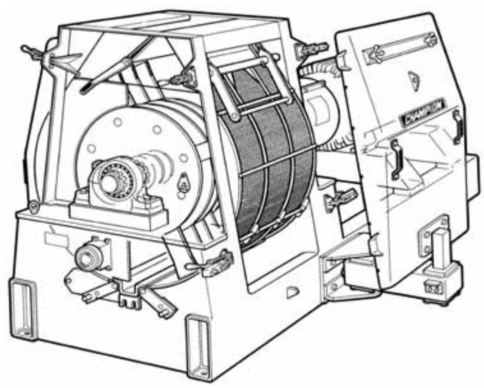
Figure 1.



rebounds from the screen into the rapidly moving hammers again. As materials move through the grinding chamber they tend to approach hammer tip speed. Since reduction only occurs when a significant energy is transferred from the hammer to the particle (large difference in velocities), less grinding takes place as the particles approach full hammer tip speed (Figure 1).

While the basic operational concepts are the same for all hammermills, the actual operating conditions change rather dramatically depending on the materials being processed. Grains such as corn, wheat, and sorghum and various soft stocks like soybean meal tend to be quite friable and easy to grind. Fibrous, oily, or high moisture products like animal derived proteins and wheat bran are tough to grind and will require more energy to reduce. To achieve the best performance, the hammermill must be properly configured for the specific task of fine grinding for aquaculture feeds. The following discussion covers such factors as tip speeds, screen hole size, hammer patterns and position, horsepower ratios (to hammer and screen area), and air assist systems (Figure 2).

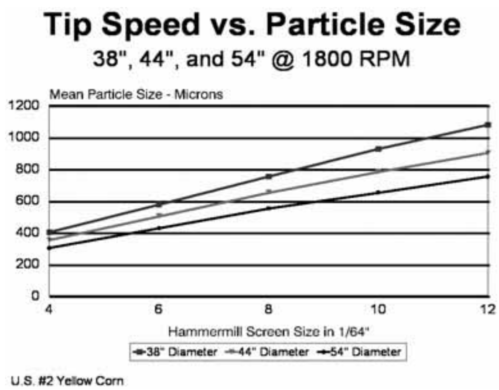
Figure 2.



Tip Speed

Tip speed is simply a factor of mill diameter and motor RPM; ¶ D x RPM = TIP SPEED. Tip speed, in addition to screen size has a significant influence on finished particle sizing. High tip speeds (>100 M/Min) will always grind finer than lower tip speeds. Low tip speeds (<90 M/Min), on the other hand, produce a coarser, more uniform granulation with fewer fines. As a rule, smaller screen hole sizes should be used only with higher tip speeds, and larger screen hole sizes only with lower tip speeds (Figure 3).

Figure 3.



Tip Speed - Fine Grinding and Tough to Grind Materials For fine grinding aquaculture feeds, a high tip speed is required. Normal tip speeds for fine grinding and fibrous materials are obtained on 44" (1.1M) diameter hammermills operating at 1800 RPM and 22" (0.55 M) diameter hammermills operating at 3,600 RPM or 28" hammermills operating at 3000 RPM and 54" hammermills operating at 1500 RPM would be about 110 M/Min Ft/Min). Recent developments in hammermill grinding have included the use of 54" diameter hammermills operating at 1800 RPM. This very high tip speed (>125 M/Min) is particularly well suited to fine grinding at high capacities and high efficiency. Because a larger screen (hole) sizes can be used while maintaining the fineness of the grind, operating costs are reduced as well. High tip speeds also help insure the hammers will not "rock" while the machine is operating with full motor loads, preventing excessive wear on the hammer holes and mounting pins (Figure 4).

Figure 4.

Tip Speed -Feet/Minute

Rotor Diameter x RPM

Diameter	1200 RPM	1800 RPM	3600 RPM
19"	NA	7536	17898
22"	NA	10362	20724
28"	NA	13194	
38"	11938	17670	
42"	13194	19782	
44"	13823	20724	
54"	16964	25434	

Figure 5.

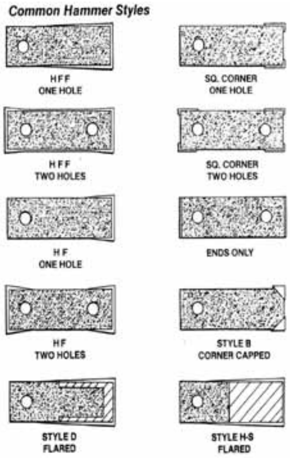


Figure 6.

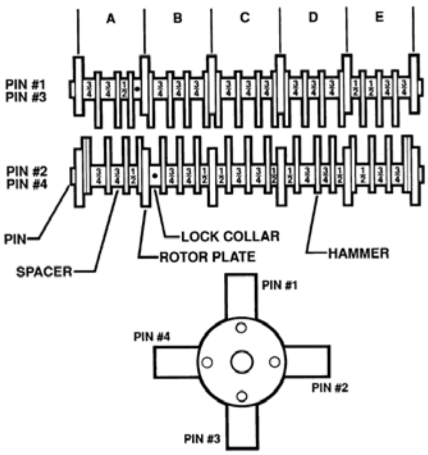
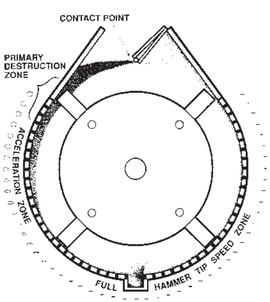


Figure 7. Horsepower/Hammer Ratios

Hammer Size	Easy to Grind	Tough to Grind
6-8"	1 to 1.5 H.P./Hammer	.5 to 1 H.P./Hammer
8-10"	2.5 to 3.5 H.P./Hammer	1 to 2 H.P./Hammer

Figure 8. Hammermill Considerations



12 Pin All Fine Rotor
puts more hammers close to screen for finer grinding

Extra Heavy Pattern
HP/hammer ratio is nearly 1:1 for more hammer contact

High Strength Rotor
Rotor plate material resists elongation and tear out

Forged Rotor Shaft
Alloy steel rotor shaft withstands high loads without deflection

Hammers

There are an unlimited number of hammer styles available from many suppliers around the world. At the same time, there are distinctly different types of hammers used in different regions of the world for a variety of hammermill grinding tasks. For longest hammer life and most efficient operation, a hammer with a flared hardface end (or ends) is preferred. Hammers may be one hole, with one working end (two corners) or two holed, with four corners available for grinding. One hole hammers are generally preferred to maintain balance of the rotor and minimize the potential for catastrophic hammer failure (Figure 5).

Hammer patterns (the number and distribution of the hammers on the rotor) and positions (setting the hammer closer to or further from the screen) have a profound effect on the performance of any hammermill. Because different materials grind differently, the ideal number of hammers and clearance to the screen will need to be adjusted according to each application.

It is important to make sure the hammer pattern covers the working screen, without having hammers trailing hammers in line. In most cases, the hammer pattern should include double hammers on the outside rolls of at least two opposing pins. This is because the material in the grinding chamber near the sides of the mill moves more slowly than material in the middle of the mill due to friction on the sides, consequently the outside rows of hammers must do more work and are subject to more wear (Figure 6).

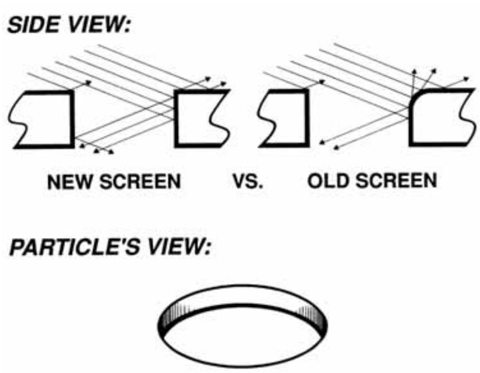
Most general application hammermills today are equipped with a rotor designed for a 4 pin hammer pattern or a 6 pin hammer pattern. Since the rotors are normally drilled for two hammer positions (coarse and fine) the rotors are actually fit with 8 or 12 sets of hammer pins. For fine grinding applications it is often necessary to use an extra heavy hammer pattern to achieve the very fine finished products desired: in many cases, the rotor will be equipped with hammers on all 8 or all 12 sets of hammer pins. This way the total number of hammers is increased significantly, without putting an excessive number of hammers on any individual pin(s), which could lead to high stress and the possible failure of the pins or rotor plates (Figures 7 and 8).

To insure the motor can start a machine with a high inertial load, an electronic soft start may be required.

Screens

In terms of hammermill capacity and efficiency, the best screen for any job is the thinnest material with the most open area. Naturally, some sacrifice in efficiency must be made for the sake of endurance, yet the general rule applies. On the other hand, for many aquaculture applications there is a benefit to using screens with limited open area to promote a finer finished product. Indeed, many hammermills grinding in aquaculture applications are equipped with extended wear liners at the inlet of the machine to increase the impact and grinding that occurs when the product is first struck by the hammers. Some users go so far as to "blank off" a portion of the down side screen by placing a solid sheet metal plate behind the screen to prevent material from passing through the screen openings. This promotes finer finished products, although the production rate will be negatively impacted (Figure 9).

Figure 9. Acceleration Zone



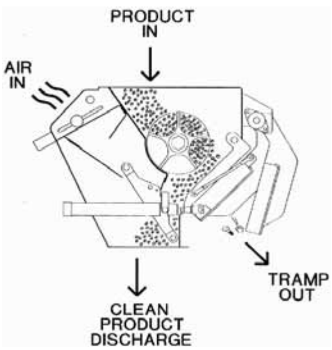
Factors effecting open area include hole size, stagger, angle of stagger, and hole spacing. There are a few specialty screens being used in aquaculture applications to improve the grinding performance. One type of screen material is known as the "Conidur" with the holes punched is such a way that the surface is upset, almost like small louvers or the surface of a cheese grater. This type of screen can work effectively, but is very expensive to purchase and will reduce the machine capacity. One reason the "Conidur" type screen produces a finer finished product is the fact the open area is very low when compared to a conventional round hole screen with a similar opening diameter.

Sealing at the edges of the screen is particularly important when fine grinding for aquaculture feeds. The fit of the screen carriage and the wear liner must be precise to prevent any oversize particles from bypassing around the edges of the screen. At the same time, the screen must be adequately supported, as fine screens do not have the mechanical strength of thicker, heavier screen material. Regular inspections of the screens must be made to monitor the condition of the screens and to catch any worn or failing screens before they fail completely.

Feeders

Proper feeding of a hammermill is absolutely essential if the system is to operate at maximum grinding efficiency, and with the lowest possible cost per ton. Uneven or inconsistent feeding can lead to surges in the motor load. Because the load is constantly changing, the motor cannot operate at peak efficiency and so increases the grinding costs. An additional liability that is often "hidden" is the fact that surges in the feed may tend to accelerate wear on the hammers and pins by causing the hammers to "rock" on the pin.

Figure 10. HRF Rotary Feeder.



Uneven feeding across the face of the hammermill obviously increases the wear on the working components in the areas of heaviest feeding. Because a part of the mill is being overworked, the rest of the mill is not being fully loaded and grinding efficiency is reduced. Uneven feeding also tends to cause a hammermill to go out of balance more quickly due to uneven wear. This adds to the operating cost of the mill by causing premature replacement of the wear items like hammer and pins.

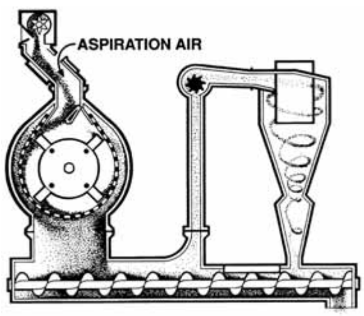
Rotary Pocket Feeder As the name indicates, rotary pocket feeders utilize a rotor mechanism much like a rotary air lock to evenly distribute the feed to the hammermill. In most cases, the rotor is segmented and the pockets are staggered to improve the distribution of the feed, and to reduce surges in the feed rate. Because the rotary pocket type feeders relies on a free flowing material to fill the pockets, they are best suited to granular materials with a density of 30#/Ft3 or more. Typical applications would be whole grains and coarsely ground mixed rations (Figure 10).

Screw Feeder Screw type feeders are used when processing materials that have poor flow characteristics, or contain large bits of material that would not flow properly with a rotary pocket feeder. Screw feeders may impart a surge to the feed, and so have limited applications in high capacity / high efficiency grinding situations. A properly designed screw feeder with multiple screws and double flighting at the discharge end will overcome many of the negative tendencies of screw feeders.

Air Assist

The final application topic to be considered is the use of aspiration air to improve mill efficiency and performance. The air assist system controls the environment of the grinding chamber in the hammermill and aids in moving product from the grinding chamber through the screen perforations. A properly designed air assist allows a hammermill to grind more efficiently, producing a more uniform finished product with less heating and controls dusting around the mill. Although hammermill capacity will vary with the type of machine and operational parameters, air assisted grinding systems will out produce non-assisted systems by 15-40% (Figure 11).

Figure 11.



A good rule of thumb for the amount of air required to assist product and control dusting is 1.25-1.50 CFM/In2 of screen area. Pressure drop across the mill may range from 2-5" W.C., depending on system operating conditions. In order to make an air assist system work, several items must be considered including the air flow into the mill, paths for the air and product out of the mill, separating the product from the air stream, and controlling the path of the air in the system.

Once the air is through the mill, it is necessary to allow the entrained fines to settle out before sending it along to the cyclone or filter system. To accomplish this, a plenum or settling chamber should be provided between the air/product conveyor and the pickup point. The plenum must be designed to reduce the velocity as much as possible to permit the fine material to settle out, and with the air pick up point away from any swirling, turbulent fines material. If the plenum is designed so the air velocity drops below 15 times the bulk density (15 x 35 or 525 Ft/Min for most feed ingredients) the separation will usually be adequate. Larger plenums will reduce the velocity and improve the air/fines separation. For practical purposes, the plenum cannot be too large.

To make the air assist system work, it is necessary to control the path the air takes through the mill. Normally, the discharge end of the take away conveyor must include some kind of air seal to insure the air is pulled through the hammermill instead of back through the discharge system. This may be as simple as a shroud over the take away screw or as complex as a powered rotary airlock at the discharge of a drag conveyor.

Other Considerations

Magnetic protection is necessary in order to realize the best life of the working components of the mill. Tramp iron that enters a hammermill can knock holes in the screen, break hammers, and create undesirable sources of ignition. Mills that routinely operate with excessively worn or failed hammers will vibrate badly and promote bearing failures. The vibration monitor switch on a hammermill is intended to be used as an emergency shut down measure in case of a failure within the hammermill.

Always buy the best possible magnetic protection that is reasonable for a specific system and make sure the magnets are routinely cleaned. Magnets are relatively cheap insurance against damage due to foreign objects, but must be cleaned regularly to insure they continue to operate at maximum performance levels.

Extrusion Equipment Design And Selection

Keith C. Behnke
Kansas State University
USA

The process of extrusion has been around for nearly a century, beginning in the rubber industry to produce items such as hoses and belting. Extrusion has been used nearly that long in the production of pasta by means of a batch extrusion concept. The use of continuous extrusion in food found its first application in the 1940's to produce puffed cereals and snacks from corn meal or grits and pasta from semolina.

Extrusion processing of dietary ingredients and finished feeds for animals began in the 1950's to produce foods for dogs. That industry has grown to nearly a $13 billion industry in the US alone and nearly that large in Europe.

Today, the extrusion process is considered a high-temperature, short time "bioreactor" that can transform any number of raw materials into intermediate or finished products that have high consumer appeal. Food examples of items include an infinite variety of snacks, pasta, textured vegetable protein, breakfast cereals and the like. In terms of tonnage, there is little doubt that pet food reigns at the top. Extrusion allows the continuous cooking of the starch fraction of a formula necessary for the digestive requirements of companion animals and gives the processor the ability to create nearly any shape that might appeal to the pet owner.

A significant application of the extrusion process to animal feeds is in the production of aquafeeds. In some cases, it is desirable or necessary to produce a floating feed to accommodate the feeding habits of the target species. In other cases, extrusion provides a method of agglomerating a variety of ingredients into a sinking food that is water stable and is able to stay in the water column for several hours without disintegrating.

A third widely used application of extrusion to animal feed ingredients is in the processing of raw soy beans into full-fat soybean meal that can be used in non-ruminant feeds without causing digestive upset and that is easily digested. The application of the extrusion to processing raw soybeans expanded dramatically with the availability of low-cost equipment that could adequately heat ground raw soybeans to denature trypsin inhibitors and other anti-nutritional factors. The conditions necessary to warrant the use of extruded soybeans in non-ruminant feeds were reviewed by Hancock (1992), Hancock, (1989) and Hancock, *et al* (1991). Hancock, *et al* (1991) demonstrated improved soybean protein utilization in nursery pigs when dry-roasting of the soybeans was replaced by extrusion processing.

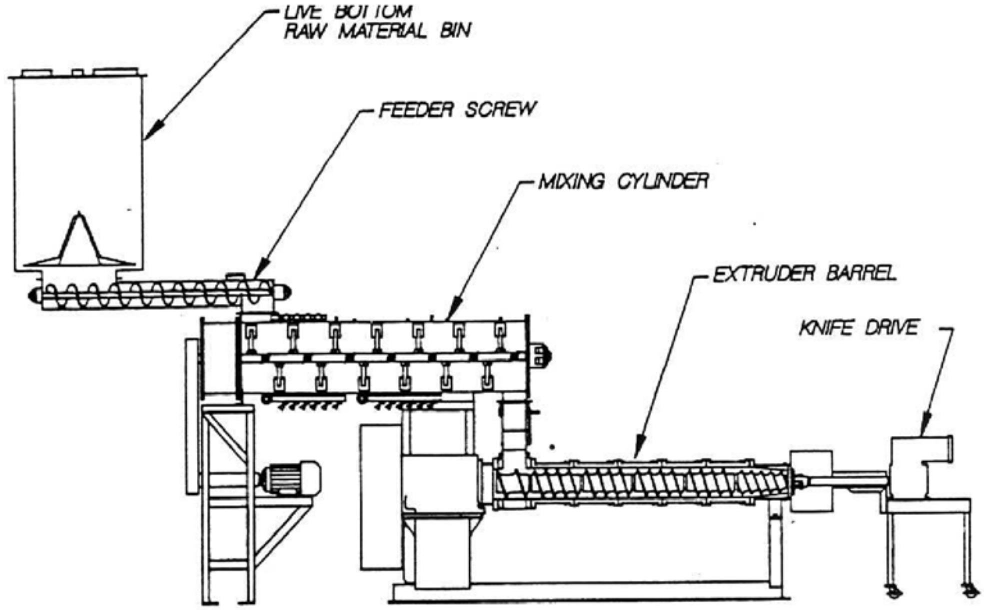
Extrusion Equipment

Extrusion equipment used today to process animal feeds generally fall into two categories: Single screw extruders and twin-screw extruders (Harper, 1989).

Single-Screw Extruders

From an engineering point of view, an extruder is simply a pump that provides the pressure necessary to force the process mash through a restrictive die. During the transport through the barrel, it is common that massive amounts of heat are added to the mash through friction generated between the mash and stationary and rotating components of an extruder. Therefore, an extruder is often considered a "heat exchanger". The pressure and temperature profiles experienced by the process mash can, within limits, be chosen and controlled by variations in screw design and operational conditions. Due to the pressure applied to the barrel, the shape of the final product can be easily controlled through die selection and design.

Figure 1. Common Components of an Extrusion System.
(Courtesy of J.P. Kerns, Wenger International, Inc., Sabetha, KS. USA)



The major features of the single-screw extruder are shown in Figure 1. In most cases, a preconditioner is used in conjunction with the extruder to increase moisture and heat absorption into the process mash, reduce mechanical power requirements and increase capacity. The conditioner normally operates at atmospheric pressure and provides a means in which either water or steam or both are uniformly incorporated into the process mash. In addition, additives such as vitamins, flavors, colors and even meat slurries may be incorporated. The conditioner provides retention time necessary for the mash to absorb the heat and moisture needed before entering the extrusion barrel.

Conceptually, the barrel of a single screw extruder can be divided into three separate zones depending on what is happening to the process mash in that zone. In the feed zone, the conditioned mash is simply received from the conditioner and transported forward in the barrel to a point where the cross-section of the barrel is completely full and an elastic plug is formed. The “transition” zone of the barrel is identified by the fact that the mash changes, rheologically, from a powder to an elastic dough. In the “metering” zone, sometimes referred to as the “cooking zone”, extreme pressure is applied to the mash and high levels of heat are induced by friction causing the temperature of the dough to increase to well above 100°C. From a thermodynamic point of view, 75% or more of the work done in the extruder barrel is done in the metering zone. This is easily seen in maintenance records of any extruder that will show that the final screw and barrel sections require replacement much more often than any other component.

Depending upon the specific design if the extruder, various manufacturers use different screw configurations to create elevated compression in the transition and metering zones. In many cases, either decreasing flight height or decreasing screw diameters are used to create compression rations in the range of 1:2 to 1:5. As compression on the extrudate is increased, the mechanical energy created by the screw turning is dissipated as heat into the extrudate.

In many designs, the surface of the barrel is grooved, either in a spiral or straight, so that the barrel “grips” the extrudate so that the rotating screw can force the material forward toward the die.

Mixing of ingredients within the extruder barrel is limited by laminar flow within the flight channel. To increase mixing potential, it is sometimes advisable to modify the screw profile to include cut-flight sections that allow backward flow of extrudate.

Single screw operations depend on the pressure requirements of the die, the slip at the barrel-extrudate interface and the degree to which the void volume in the barrel id filled. Feed rate, Screw speed and design and the characteristics of the extrudate dictate screw fill. The interaction of all these variables creates the limits in the operating range and flexibility of a single screw extruder.

Twin-Screw Extruders

In order to create a design with greater operating flexibility and with greater operational control, twin-screw machines were developed. Twin-screw extruders can be co-rotating, counter-rotating, intermeshing or non-intermeshing in terms of basic designs. Co-rotating, intermeshing screw designs have dominated that scene as far as these extruders are concerned. This is because of relative ease of design and manufacture compared to counter-rotating designs.

The screw design of twin-screw extruders can dramatically affect operating efficiency and machine capability. Screw components in the feed section of the barrel can be single, double or even triple flight arrangements. With more flights intertwined on the shaft, the conveying capacity of the screw is reduced but the residence time distribution (RTD) is lower. This promotes a first-in, first-out movement of the extrudate. However, double- and triple flighted screws produce more shear across the screw channel and therefore, improved processing uniformity.

Single- verses Twin-Screw Comparison

There is no doubt that twin-screw extruders allow the development and production of a greater array of products but at a significant cost. Twin-screw machines are 1.5 to 2.0 times the cost of a single-screw machine of the same relative cost. The extra expense is due to the relative complexity of the screw design; the complicated drive components and the required heat transfer jackets. This may be somewhat offset by the ability of the twin-screw machine to process drier product thus requiring lower energy for drying. In addition, simply being able to produce a product that is impossible to produce on a single-screw design may justify the additional cost.

A very unique characteristic of a twin-screw machine is the ability to configure a single machine to perform two distinct tasks or functions at the same time. By configuring the first half or so of the machine as a high-shear, high-compression, cooking extruder, providing a vent into the barrel and, then, configuring the last half or the barrel as a low compression, low shear forming extruder, a twin screw can be used to produce high density, cooked products like pre-cooked pasta, sinking aquafeeds or pellets for flaked breakfast cereal. In doing this, a single machine is able to accomplish the functions of two separate single-screw machines producing the same product.

Low-Cost Extruders

As is often the case, entrepreneurs find a way reduce the cost of expensive technology and produce an item (in this case an extruder) that is much lower in cost, has much less flexibility in terms of application but that is capable of producing an acceptable final product. Such is the case with low-cost extruders.

These machines are very simple in design, are constructed of cast, rather than machined, components and perform a specific function reasonably well. In this instance, the application is in the production of full-fat soybean meal. Most of these machines use a simple, interrupted flight arrangement with breaker bolts to create the shear and pressure necessary to heat-denature the anti nutritional factors associated with the use of soybeans in non-ruminant feeds. A manual variable orifice die is used that can be set close to- or away from the end of the screw to increase or decrease operating pressure and process temperature.

While these machine designs usually produce acceptable FFS, they often fail when used to produce other extruded products, such as floating aquafeeds or pet foods, without significant mechanical and system modification. In most cases, a preconditioner is not needed when processing FFS, however, when attempting to produce pet- or aquafeeds, a preconditioner is necessary to precook and hydrate the starch and protein in the formula for successful production. Because of the relative poor fit (tolerance) between the screw sections and the barrel, much higher back flow tends to occur and production efficiency, product quality and nutrient survival tend to be low. However, there is no doubt that low cost extrusion equipment has a place in the feed industry and provides a feasible way to produce products that otherwise would no be cost effective.

Summary

Extrusion has become a common process in the feed industry and allows the production of feed types that simply are not possible with pelleting or any other process we have available. In general, single screw extruders provide adequate operating ranges and are more economical to operate than twin-screw extruders. With the availability of low cost extrusion equipment, processing of oilseeds such as soybeans is feasible. There is no doubt that the application of extrusion to the development of new and novel feed products will continue and will result in increased usage of the technology in the future of the feed industry.

Literature Cited

Hancock, J.D. 1989. Using soybean products in Swing Diets. Proc. 22nd Virginia Pork Industry Conference, Williamsburg, VA. Jan 17-18.

Hancock, J.D., R.H. Hines, G.E. Fitzner and T. L. Gugle 1991. Effects of extrusion processing on the nutritional value of sorghum and soybeans for finishing pigs. Proc 17th Biennial Grain Sorghum Utilization Conf. March 5-7, Lubbock, TX.

Hancock, J.D. 1992. Extrusion Cooking of Dietary Ingredients for Animal Feeds. Proc. Of the Distillers Feed Conference Vol 47:pp33-49. Cincinnati, OH. USA.

Harper, J.M. 1989. Food Extruders and Their Application. In: Extrusion Cooking, Mercier, C., P. Linco, J.M.Harper-editors. Am. Assoc. of Cereal Chemist. St. Paul, MN. Pp 1-15.