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Hammermills and Roller mills

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Ingredients come to the feed processor from a variety of sources. Many of these, particularly the coarse cereal grains, require some degree of processing before they are ready to be blended into an animal ration. The process of particle size reduction improves ingredient performance during mixing and, in most cases, the nutritive value of an ingredient can be improved or more nearly realized.

There are many ways to reduce the particle size of feed ingredients. Two of the most common pieces of equipment used are the hammermill and the roller mill. The choice of which to use depends upon the unique requirements of every individual situation. Either piece of equipment is capable of producing what is often termed in the industry as a "satisfactory grind." However, excessive size reduction can result in wasted electrical energy, unnecessary wear on mechanical equipment, and possible digestive problems in livestock and poultry.

The information provided in this bulletin will help feed processors decide which mill (roller or hammer) is best suited for their grinding needs. This bulletin also contains information pertaining to the general design and operating parameters of roller mills and hammermills, an explanation of how these mills reduce ingredient particle size, and an economic comparison of these two mills.

Size Reduction

The initial reduction of cereal grains begins by disrupting the outer protective layer of the seed (hull), exposing the interior (Figure 1). Continued size reduction increases both the number of particles and the amount of surface area per unit of volume. It is this increased surface area that is of primary importance. A greater portion of the grain's interior is exposed to digestive enzymes, allowing increased access to nutritional components such as starch and protein. The enhanced breakdown of these nutritional components improves absorption in the digestive tract. The overall effect is increased animal performance (MF-2050).

Size reduction is also used to modify the physical characteristics of ingredients resulting in improved mixing, pelleting, and, in some instances, handling or transport.

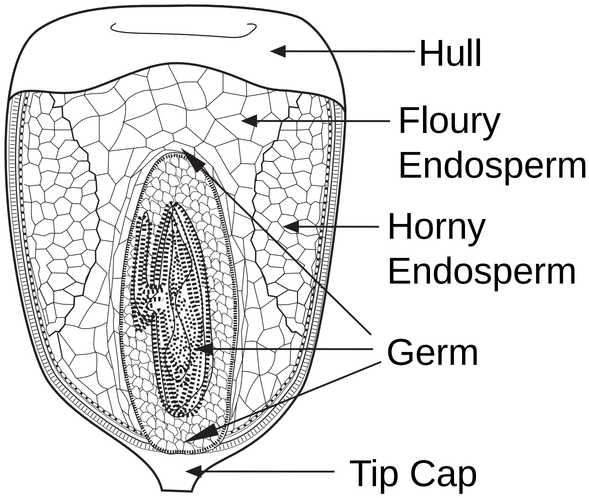
Hammermills accomplish size reduction by impacting a slow moving target, such as a cereal grain, with a rapidly moving hammer. The target has little or no momentum (low kinetic energy), whereas the hammer tip is travelling at a minimum of 16,000 feet per minute (4,880 m/min) and perhaps in excess of 23,000 feet per minute (7,015 m/min) (high kinetic energy). The transfer of energy that results from this collision fractures the grain into many pieces. Sizing is a function of hammer-tip speed; hammer design and placement; screen design and hole size; and whether or not air assist is used.

Because impact is the primary force used in a hammermill to reduce particle size, anything that: increases the chance of a collision between a hammer and a target, increases the magnitude of the collision, or improves material take-away, would be advantageous to particle size reduction. The magnitude of the collisions can be escalated by increasing the speed of the hammers. Anderson (1994) stated that when drive speed and screen size were kept constant, the increased hammer-tip speed obtained from increased rotor diameter produced particles of smaller mean geometric size.

Particles produced using a hammermill will generally be spherical in shape with a surface that appears polished. The distribution of particle sizes will vary widely around the geometric mean such that there will be some large-sized and many small-sized particles.

Roller mills accomplish size reduction through a combination of forces and design features. If the rolls rotate at the same speed, compression is the primary

Figure 1. Corn Kernel



force used. If the rolls rotate at different speeds, shearing and compression are the primary forces used. If the rolls are grooved, a tearing or grinding component is introduced. Coarse grooves provide less size reduction than fine grooves do.

There is little noise or dust pollution associated with properly designed and maintained roller mills. Their slower operating speeds do not generate heat, and there is very little moisture loss.

Particles produced tend to be uniform in size; that is, very little fine material is generated. The shape of the particles tends to be irregular, more cubic or rectangular than spherical. The irregular shape of the particles means they do not pack as well. For similar-sized particles, bulk density of material ground on a roller mill will be about 5 to 15 percent less than material ground by a hammermill.

Hammermills

Advantages:

- produce a wide range of particle sizes
- work with any friable material and fiber
- less initial purchase cost compared to hammermill
- offer minimal expense for maintenance
- generally feature uncomplicated operation

Disadvantages:

- provide less efficient use of energy compared to the roller mill
- may generate heat (source of energy loss)
- may create noise and dust pollution
- produce greater particle size variability (less uniform)

General Design

The major components of these hammermills, shown in Figure 2, include the following:

- a delivery device to introduce material into the path of the hammers; a rotor comprised of a series of machined disks mounted on the horizontal shaft
- free-swinging hammers that are suspended from rods running parallel to the shaft and through the rotor disks
- a perforated screen and either gravity- or air-assisted removal of ground product

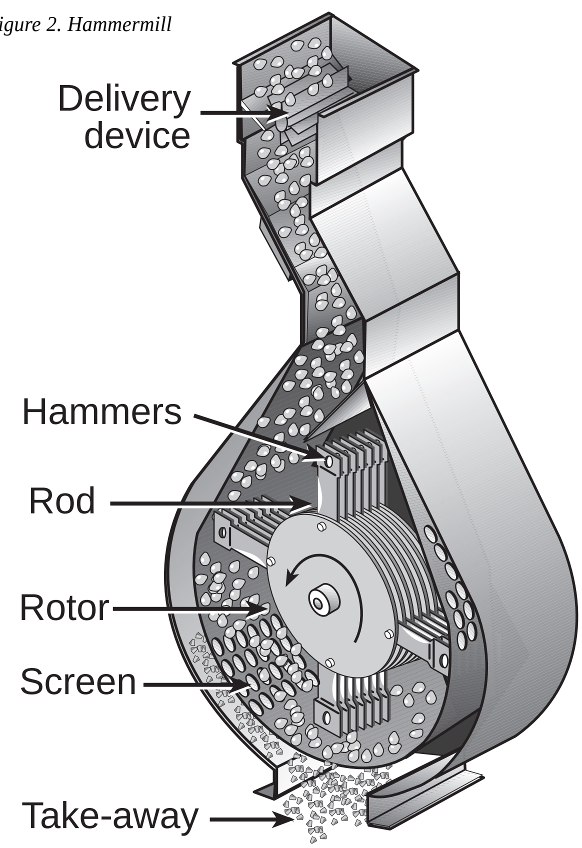
Feeder Design

Material is introduced into the paths of the hammers by a variable speed vein feeder. This type of feeder can have its motor slaved by a programmable controller to the main drive motor of the hammermill. The operational speed of the feeder is controlled to maintain optimum amperage loading of the main motor.

Hammer Design

The design and placement of hammers is determined by operating parameters such as rotor speed, motor horsepower, and open area in the screen. Optimal hammer design and placement will provide maximum contact with the feed ingredient.

Figure 2. Hammermill



Mills in which the rotor speed is approximately 1,800 rpm, hammers should be about 10 inches (≈ 25 cm) long, 2.5 inches (≈ 6.35 cm) across, and .25 inches (≈ 6.4 mm) thick. For a rotor speed about 3,600 rpm, hammers should be 6 to 8 inches (≈ 15 to 20 cm) long, 2 inches (≈ 5 cm) across, and 0.25 inches (≈ 6.4 mm) thick. The number of hammers used for 1,800 rpm should be 1 for every 2.5 to 3.5 horsepower, and for 3,600, rpm 1 for every 1 to 2 horsepower. Hammers should be balanced and arranged on the rods so that they do not trail one another. The distance between hammer and screen should be 0.5 inches (≈ 12 to 14 mm) for size reduction of cereal grains.

The velocity or tip speed of the hammers is critical for proper size reduction. Tip speed is calculated by multiplying the rotational speed of the drive source (shaft rpm) by the circumference of the hammer tip arc (Formula 1).

Formula 1:

$$\text{feet per minute} = \frac{\pi D \times \text{rpm}}{12 \text{ in/ft}}$$

π = 3.14
D = inches diameter
rpm = revolutions per minute

Tip speeds commonly range between 16,000 and 23,000 feet per minute (5,000 and 7,000 m/min). When tip speeds exceed 23,000 feet per minute, careful consideration must be given to the design of the hammermill, the materials used in its construction, and the fabrication of all the components. Simply changing the rotational speed of the drive source is not a recommended method of increasing hammer speed in excess of 23,000 feet per minute.

Screen Design

The amount of open area in a hammermill screen determines the particle size and grinding efficiency. The screen must be designed to maintain its integrity and provide the greatest amount of open area. Screen openings (holes) that are aligned in a 60-degree staggered pattern optimize open area while maintaining screen strength. This method will result in a 40 percent open area using $^1/_8$ inch (3.2 mm) holes aligned on $^3/_{16}$ inch (4.8 mm) centers.

The reader is urged to pay particular attention to the ratio of open screen area to horsepower. Recommended ratio for grains would be 8 to 9 square inch (≈ 55 cm^2) per horsepower (Bliss, 1990). Not enough open area per horsepower results in the generation of heat. When the heat generated exceeds 120°F to 125°F (44°C to 46°C) capacity may be decreased as much as 50 percent.

The removal of sized material from a hammermill is a critical design feature. Proper take-away affects not only the efficiency of operation, but also particle size. When the correct ratio of screen area to horsepower is used and proper distance between hammers and screen face is maintained, most of the correctly sized particles will exit the screen in a timely manner.

Anderson (1994) stated the particles that do not pass through the screen holes become part of a fluidized bed of material swept along the face of the screen by the high-speed rotation of the hammers. As these particles rub against the screen and each other their size is continually reduced by attrition. This excessive size reduction is counterproductive. Energy is wasted in the production of heat, throughput is restricted, and particles become too small.

Most newer hammermills are equipped with an air-assist system that draws air into the hammermill with the product to be ground. Systems are designed to provide reduced pressure on the exit side of the screen to disrupt the fluidized bed of material on the face of the screen, thus allowing particles to exit through screen holes. Some full-circle hammermills are designed so the screen is in two pieces. It is possible to use a larger hole size on the upward arc of the hammers to further reduce the amount of material on the face of the screen.

Roller mills

Advantages:

- energy efficient
- uniform particle-size distribution
- little noise and dust generation

Disadvantages:

- little or no effect on fiber
- particles tend to be irregular in shape and dimension
- may have high initial cost (depends on system design)
- when required, maintenance can be expensive

General Design

There are many manufacturers of roller mills, but they all share the following design features shown in Figure 3:

- a delivery device to supply a constant and uniform amount of the material to be ground
- a pair of rolls mounted horizontally in a rigid frame
- one roll is fixed in position and the other can be moved closer to or further from the fixed roll
- the rolls counter rotate either at the same speed or one may rotate faster; roll surface may be smooth or have various grooves or corrugations
- pairs of rolls may be placed on top of one another in a frame.

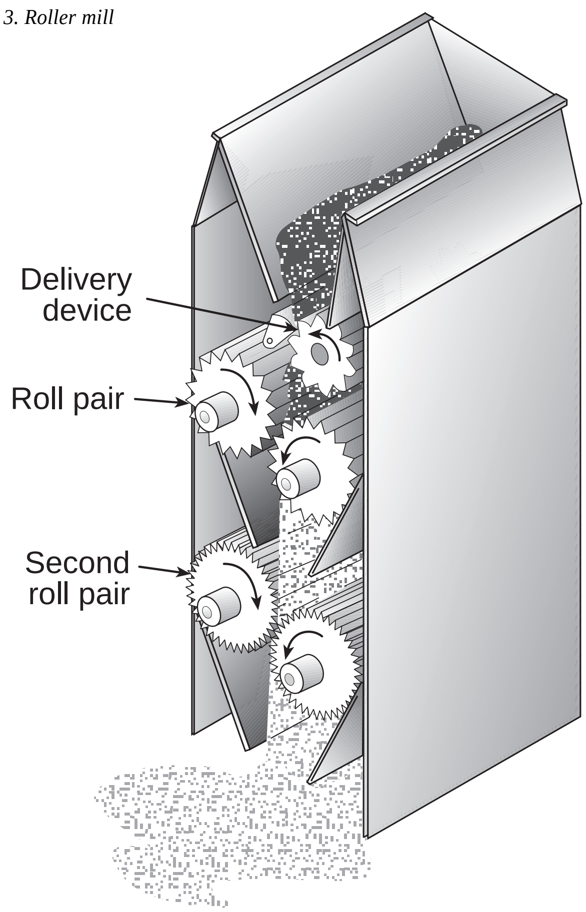
To ensure optimum operation, material must be introduced between the rolls in a uniform and constant manner. The simplest feeder is a bin hopper with an agitator located inside it and a manually set discharge gate. This type of feeder is best suited for coarse processing. For grinding operations, a roll feeder is suggested. In this type of feeder, the roll is located below the bin hopper and has a manually set or automatic adjustable discharge gate. If the gate is adjusted automatically, it will be slaved to the amperage load of the main motor of the roller mill.

The rolls that make up a pair will be 9 to 12 inches (23 to 30.5 cm) in diameter, and their ratio of length to diameter can be as great as 4:1. It is very important to maintain the alignment between the roll pairs. Sizing of the material is dependent upon the gap between the rolls along their length. If this gap is not uniform, mill performance will suffer, leading to increased maintenance costs, reduced throughput, and overall increased operation costs. The gap may be adjusted manually or automatically through the use of pneumatic or hydraulic cylinders operated through a computer or programmable controller.

Each pair of rolls is counter rotating. For improved size reduction one of the rolls rotates faster. This results in a differential in speed between the roll pair. Typical differentials range from 1.2:1 to 2.0:1 (fast to slow). Typical roll speeds would be 1,300 feet per minute (≈ 395 m/min) for a 9 inch (≈ 23 cm) roll to 3,140 feet per minute (≈ 957 m/min) for a 12 inch (≈ 30.5 cm) roll. Usually a single motor is used to power a two high roll pair, with either belt or chain reduction supplying the differential. In a three high roll pair, the bottom pair will have a separate drive motor. In addition, the roll faces can be grooved to further take advantage of the speed differential and improve size reduction.

By placing (stacking) pairs of rolls on top of one another, two or three high, it is possible to reduce particle sizes down to 500 microns, duplicating the size-reducing capability of a hammermill for grain. For coarse reduction of grain, a roller mill may have a significant advantage (perhaps as high as 85 percent) over a hammermill in terms of throughput/kwh of energy. For cereal grains processed to typical sizes (600 to 900 microns) for the feed industry, the advantage is about 30 to 50 percent. This translates into reduced operating expense.

Figure 3. Roller mill



Economic Comparison

Feed manufacturers are in general agreement that particle size reduction is a necessary, although energy intense process. The amount of electricity used in particle size reduction is second only to the amounts used in either the pelleting or extrusion operations. The costs of electrical energy for particle size reduction are being subjected to increased scrutiny from feed mill operators as they search for ways to reduce production costs.

A Hypothetical Scenario:

The following summary of information was supplied by Roskamp Champion (1992). The scenario was created so comparisons could be made between hammermill and roller mill systems in meeting the demands of typically sized feed manufacturing facilities.

Assumptions:

The following assumptions were made:
1. product to be processed is #2 yellow dent corn
2. work week is 5 days, 24 hrs/day, 52 weeks/yr
3. labor cost is $15.00/hr
4. electricity is $0.07/kwh

Systems and Equipment:

The systems were designed to provide a mean geometric particle size of 600 to 700 microns.
1. 13 ton/hr whole corn, 75 hp hammermill-50 hp roller mill and necessary auxiliary equipment
2. 20 ton/hr whole corn, 150 hp hammermill-75 hp roller mill and necessary auxiliary equipment

3. 90 to 100 ton/hr whole corn, 2 × 400 hp hammermills-2 × 200 hp roller mill and necessary auxiliary equipment
4. 200 ton/hr whole corn, 4 × 350 hp hammermills-4 × 200 hp roller mill and necessary auxiliary equipment

Comparisons:

Capital costs for each system are displayed in Table 1 and include:

- the purchase price of all equipment needed for each system,
- the approximate cost of labor needed to install the equipment, and
- the cost of electrical work.

Comparisons of the capital costs are made in Table 1a. With the exception of system 1, costs for only the size reducing equipment are the highest for the roller mill systems. The costs for auxiliary equipment, installation labor, and electrical work are higher for the hammermill systems (explained by the need for plenum chambers on the conveyors, the need for a dust control system, and the greater horsepower requirements). Comparisons of total capital cost expenditures reveal the following:

- in system 1, a savings in excess of 33 percent is achieved by purchasing the roller mill;
- in system 2, the purchase of the hammermill saves about 16.5 percent;
- in system 3, the purchase of the roller mills saves about 2.4 percent; and
- in system 4, the purchase of the hammermills saves almost 6 percent.

Comparisons such as these are useful when a feed manufacturer is designing a new facility or is upgrading an existing one.

Maintenance costs are presented in Table 2. Hammer, screen, and roll life are dependent upon the quality of the material being processed. This scenario assumed all inbound grain had been cleaned of all foreign material prior to processing. The cost of labor is greater for the roller mill systems and so are the costs of replacement parts. Comparisons of maintenance costs are found in Table 2a. On an annual basis there is a very slight advantage for the use of a roller mill in systems 1 and 3, with systems 2 and 4 showing a slightly greater advantage for the use of hammermills. When the systems are compared on a per ton basis the costs range from $.022 to $.058. System 1 shows a $.013 advantage for the roller mill. System 2 with a hammermill has a $.022 per ton advantage over the roller mill. System 3 has a $.001 advantage for the roller mill. System 4 has a $.003 advantage for the hammermill.

Yearly electrical costs have been broken down in Table 3. Comparisons of annual electricity costs are given in Table 3a. Roller mill systems require much less electricity to process the same number of tons as a hammermill, as evidenced by the large differences in electrical costs. On a per ton basis, roller mills provided a minimum savings of $.18 per ton in system 4 and a maximum of $.23 per ton in system 1.

Overall annual operating costs are reported in Table 4 and represent the cost of: maintenance; electricity; and long term costs for roller mills. System comparisons are made in Table 4a and they show annual savings of $.14 to $.21 per ton for roller mill systems.

System comparisons are shown in Table 5. Initial capital expenses favor the use of a roller mill in systems 1 and 3, but a hammermill in system 2 and 4. A similar pattern is followed with regard to annual maintenance costs. However, the advantage for the roller mill in system 3 is very small, as is the advantage for the hammermills in system 4. Roller mills have a very clear advantage in efficient use of electrical power, with annual savings from 44 to 52 percent of the cost of using hammermills. This advantage is more than enough to offset the small disparity in maintenance costs giving roller mills a clear advantage in annual costs.

Conclusions:

In the hypothetical scenario presented, the use of a roller mill system is justified when annual cost per ton of processed material is used as the determining factor. When cereal grains are used as the major carbohydrate source it would be difficult for any feed mill operator to ignore the savings in processing charges offered by roller mills. This scenario was constructed around a mean geometric particle size of 600 to 700 microns. If this could be increased to 1,000 to 1,200 microns, the demonstrated advantage of the roller mill in regard to electricity used per ton of material processed would be even greater. The roller mill also produces a more uniform product and provides a more worker friendly environment.

Summary

The advantages and disadvantages of hammermills and roller mills are considered, as well as an economic comparison between these two types of grinders. While the capital expense of a hammermill is less than a roller mill, this difference is offset by a lower operating cost for the roller mill. The modes of action involved in particle size reduction for each mill are discussed.

Table 1. *Capital Costs*

	Hammermill				Roller mill			
	1	2	3	4	1	2	3	4
Hammermill Equipment ($)	27,004	27,817	118,906	229,512				
Roller Equipment ($)					21,450	68,984	214,820	428,372
Conveyors ($)	4,000	4,000	8,000	18,870	3,000	3,000	6,000	12,000
Dust System ($)	10,759	10,759	29,796	55,000				
Total Material & Equipment ($)	**41,763**	**42,576**	**156,702**	**303,382**	**24,450**	**71,984**	**220,820**	**440,372**
Labor ($)	8,301	8,301	16,600	33,192	5,999	5,999	11,996	23,992
	50,064	**53,877**	**173,302**	**336,574**	**30,440**	**77,983**	**232,816**	**464,364**
Electricity ($150/Hp) ($)	16,500	24,000	127,500	216,000	7,950	11,700	60,900	121,800
Total Capital ($)	**66,564**	**74,877**	**300,802**	**552,574**	**38,399**	**89,683**	**293,716**	**586,164**

Table 1a. *Summary: Capital Costs*

	System 1 hammermill-roller	System 2 hammermill-roller	System 3 hammermill-roller	System 4 hammermill-roller
Tons/Yr	27,040	124,800	273,000	1,123,200
Grinding Equipment ($)	27,004-21,450	27,817-68,984	118,906-214,820	229,512-428,372
Difference	**5,554**	**41,167**	**95,914**	**198,860**
Other Equipment ($)	14,759-3,000	14,759-3,000	37,796-6,000	73,870-12,000
Difference	**11,759**	**11,759**	**31,796**	**61,870**
Labor ($)	8,301-5,999	8,301-5,999	16,600-11,996	33,192-23,992
Difference	**2,302**	**2,302**	**4,604**	**9,200**
Electricity Install ($)	16,500-7,950	24,000-11,700	127,500-60,900	216,000-121,800
Difference	**8,550**	**12,300**	**66,600**	**94,200**
Total Capital ($)	66,564-38,399	74,877-89,683	300,802-293,716	552,574-586,164
Difference	**28,165**	**14,806**	**7,086**	**33,590**

Table 2. *Annual Maintenance Costs*

	Hammermill				Roller mill			
	1	2	3	4	1	2	3	4
Tons/Yr	27,040	124,800	273,000	1,123,200	27,040	124,800	273,000	1,123,200
Tons/Hammer Set	40,000	40,000	40,000	40,000				
# Hammer Sets	.68	3.12	6.825	28				
$/Hammer Set	221	294	693	704				
Hammer Cost($)	**150**	**917.3**	**4,730**	**19,712**				
Tons/Screen Set	10,000	10,000	10,000	10,000				
# Screen Sets	2.7	12.48	27.3	112				
$/Screen Set	27	27	214	214				
Screen Cost	**73**	**337**	**5,842**	**24,032**				
Ton/Corrugation					35,000	50,000	80,000	80,000
# Recorrugations					.77	2.5	1.7	3.51
# Pairs					2	2	4	8
Recorr. Cost/Pair ($)					402	748	1,262	1,262
Recorr. Cost ($)					**619**	**3,740**	**8,581**	**35,437**
Belt Cost					316	1,021	2,222	9,140
Misc. Cost	1,322	1,322	2,643	2,643	100	100	1,452	1,452
Labor Cost	30	140	307	1,264	185	599	1,024	4,212
Cost/Year ($)	**1,575**	**2,716**	**13,522**	**47,651**	**1,220**	**5,460**	**13,280**	**50,241**
Cost/Ton ($)	**.058**	**.022**	**.05**	**.042**	**.045**	**.044**	**.049**	**.045**

Table 2a. *Summary: Annual Maintenance Costs*

	System 1 hammermill-roller	System 2 hammermill-roller	System 3 hammermill-roller	System 4 hammermill-roller
Tons/Yr	27,040	124,800	273,000	1,123,200
Cost/Yr ($)	1,575-1,220	2,716-5,460	13,522-13,280	47,651-50,241
Difference ($)	**355**	**2,744**	**242**	**2,590**
Cost/Ton ($)	.058-.045	.022-.044	.050-.049	.042-.045
Difference ($)	**.013**	**.022**	**.001**	**.003**

Table 3. *Annual Electrical Costs*

	Hammermill				Roller mill			
	1	2	3	4	1	2	3	4
Tons/Yr	27,040	124,800	273,000	1,123,200	27,040	124,800	273,000	1,123,200
System Hp	100	150	800	1,400	50	75	400	800
Conveyor Hp	3	3	6	12	3	3	6	12
Dust Sys. Hp	7	7	44	28				
Total Hp	110	160	850	1,440	53	78	406	812
Total Kw	82	119.3	633.7	1,073.6	39.5	58	302.7	605.3
Hr/Week	40	120	50	120	40	120	50	120
Kwh/Yr	170,560	744,432	1,647,620	6,699,264	82,160	361,920	787,020	3,777,072
$/Kwh	.07	.07	.07	.07	.07	.07	.07	.07
$/Yr	**11,939**	**52,110**	**115,333**	**468,948**	**5,751**	**25,334**	**55,091**	**264,395**
$/Ton	**.442**	**.418**	**.422**	**.418**	**.212**	**.203**	**.202**	**.235**

Table 3a. *Summary: Annual Electrical Costs*

	System 1 hammermill-roller	System 2 hammermill-roller	System 3 hammermill-roller	System 4 hammermill-roller
Tons/Yr	27,040	124,800	273,000	1,123,200
$/Yr	11,939-5,751	52,110-25,334	115,333-55,091	468,949-264,395
Difference	**6,188**	**26,776**	**60,242**	**204,554**
$/Ton	.442-.213	.418-.209	.422-.202	.418-.235
Difference($)	**.23**	**.21**	**.22**	**.183**

Table 4. *Annual Costs*

	Hammermill				Roller mill			
	1	2	3	4	1	2	3	4
Tons/Yr	27,040	124,800	273,000	1,123,200	27,040	124,800	273,000	1,123,200
Maintenance Cost ($)	1,575	2,716	13,522	47,651	1,220	5,460	13,280	50,241
Maintenance Cost/Ton($)	.058	.022	.050	.042	.045	.044	.049	.045
Electricity Cost ($)	11,939	52,110	115,333	468,949	5,751	25,334	55,091	264,395
Electricity Cost/Ton ($)	.442	.418	.422	.418	.212	.203	.202	.235
Long Term Cost/Ton ($)					.029	.020	.042	.042
Long Term ($)					784.16	2,496	11,466	47,174
Total	**13,513**	**54,826**	**128,855**	**516,600**	**7,755**	**33,290**	**79,837**	**361,969**
Cost/Ton ($)	**.50**	**.44**	**.47**	**.46**	**.29**	**.27**	**.29**	**.32**

Long term costs were figured only for the roller mill systems and reflect the costs of recorrugating the rolls (each pair had the initial 80,000 tons plus 80,000 × 6 recorrigations prior to roll retirement).

Table 4a. *Summary: Annual Costs*

	System 1 hammermill-roller	System 2 hammermill-roller	System 3 hammermill-roller	System 4 hammermill-roller
Tons/Yr	27,040	124,800	273,000	1,123,200
Maintenance ($)	1,575-1,220	2,716-5,460	13,522-13,280	47,651-50,241
Difference ($)	**355**	**2,744**	**242**	**2,590**
Electricity ($)	11,939-5,751	52,110-25,334	115,333-55,091	468,948-264,395
Difference ($)	**6,188**	**26,776**	**60,242**	**204,553**
Long Term ($)	784	2,496	11,466	47,174
Total ($)	13,514-7,755	54,826-33,290	128,855-79,837	516,600-361,969
Difference ($)	**5,759**	**21,536**	**49,018**	**154,631**
$/Ton	.50-.29	.44-.27	.47-.29	.46-.32
Difference($)	**.21**	**.17**	**.18**	**.14**

Table 5. *Summary: System Cost Comparisons*

	System 1 hammermill-roller	System 2 hammermill-roller	System 3 hammermill-roller	System 4 hammermill-roller
Tons/Yr	27,040	124,800	273,000	1,123,200
Capital ($)	66,564-38,399	74,877-89,683	300,802-293,716	552,574-586,164
Difference ($)	**28,165**	**14,806**	**7,086**	**33,590**
Maintenance ($)	1,575-1,220	2,716-5,460	13,522-13,280	47,651-50,241
Difference($)	**355**	**2,744**	**242**	**2,590**
Maintenance/Ton ($)	.058-.045	.022-.044	.050-.049	.042-.045
Difference ($)	**.013**	**.022**	**.001**	**.003**
Electricity ($)	11,939-5,751	52,110-25,334	115,333-55,091	468,949-264,395
Difference ($)	**6,188**	**26,776**	**60,242**	**204,554**
Electricity/Ton ($)	.442-.213	.418-.203	422-.202	.418-.235
Difference ($)	**.23**	**.21**	**.22**	**.183**
Cost/Yr ($)	13,514-7,755	54,826-33,290	128,855-79,837	516,600-361,969
Difference ($)	**5,759**	**21,536**	**49,018**	**154,631**
Cost/Ton ($)	.50-.29	.44-.27	.47-.29	.46-.32
Difference ($)	**.21**	**.17**	**.18**	**.14**

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