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Attritor Mills & Media for Chocolate Processing Update

In her book, *Chocolate: The Consuming Passion*, Sandra Boynton says, "Chocolate can do wonderful things for your overall sense of well-being. It can offset disappointments, allay frustrations, provide joy and comfort—even inspire romance."

The centuries old history of chocolate making is replete with a wide variety of devices used to grind and mix the delicious substance. I'd like to tell you about one such device, probably the most efficient comminuting apparatus existing today, the attritor.

Here is a comparison of the effectiveness of various grinding devices for the ultrafine grinding of Pima Chalcopyrite Concentrate—from a study by Herbst and Sepulveda entitled "Fundamentals of Fine and Ultrafine Grinding in a Stirred Ball Mill" presented at the Powder & Bulk Solids Conference, Chicago, Illinois, May 1978. For specific energy input around 100 kwh/t, the median particle size achieved through the use of attritors is nearly one-half smaller than that obtained from conventional ball mills, one-third smaller than vibratory mills. For energy inputs exceeding 200 (kwh/t) attritors continue to grind into the submicron range when size reduction in other devices has almost stopped. In addition, in the micron range, the capacity of the attritor is high relative to the other devices, because of the exceptionally high power input per unit volume of vessel, which gives a much higher grinding potential. As a consequence, time required for grinding in the attritor is shorter than that required to grind in the ball mill for a fixed specific energy input or to a certain desired median particle size.

The attritor (known generically as a "stirred ball mill") is a grinding mill containing internally agitated media.

Power input is used directly for agitating the grinding media, not for rotating or vibrating a large heavy tank in addition to the media.

A useful and simple equation which allows us to see how the attritor fits into the family of mills is M x V, mass times velocity.

For example, ball mills use large media, normally 1/2" or larger, and run at a low 10-50 rpm. Other mills, such as sand, bead, and horizontal, use smaller media from 1/64" to 1/8", but run at a very high 800-1200 rpm. High-speed dispersers without media run even faster, 1200-1800 rpm, with tip speeds of 5000-6000 ft/min.

The attritor falls mid-range between these, using 1/8" to 3/8" media, agitating at moderate speeds from 60 rpm in the largest production size units, to 300 rpm for the laboratory size units, with tip speeds of 600-1000 ft/min.

In attritor grinding, within given limits, the following equation has been developed to relate grinding time to media diameter and agitator speed. In chocolate grinding, "K" will vary depending on viscosity, fat content, moisture percentage, formulation and initial particle size.

$$T = \frac{KD}{\sqrt{N}}$$

T = Grinding time to reach a certain median particle size
K = A constant that varies depending upon the slurry being processed, type of media (especially its density), and model attritor being used
D = Diameter of the media
N = Shaft rpm

In other words, grinding time is directly proportional to ball diameter, and inversely proportional to the square root of the rpm.

Therefore, increasing the rpm decreases the grinding time. Conversely decreasing the rpm increases the grinding time, although one must realize, the higher the

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rpm, the more power required.

This also means that increasing media size increases the grinding time while, as you would expect, decreasing the media size decreases the grinding time.

Since grinding media is an important factor in processing with the attritor, it is worthy of further discussion at this point. As previously mentioned, the media size range is from ⅛" to ⅜". Within this range, the smaller the grinding media used, generally, the faster the grind achievable because, in a given volume, there is more media and therefore more surface contact. However, when the media becomes smaller than ⅛" its mass is considerably less, hence it has less impact force and the grinding times get longer again. If ultrafine grinding is not required, $^3/_{16}$" or ¼" media may be faster because of its greater mass.

Several kinds of grinding media can be used in attritors, such as carbon steel, chrome steel, stainless steel, tungsten carbide, ceramic, zirconium oxide, glass, flintstones, and exotics such as silicon nitride and silicon carbide. The most often used media for chocolate processing are case-hardened carbon steel or chromium steel balls $^3/_{16}$" or ¼" in diameter.

Chrome steel media containing about 1½% chromium is through-hardened and considered to be one of the best steel grinding media. It is about twice as expensive as carbon steel, but ony half as costly as stainless steel. Yet, it has some properties similar to stainless steel. It can tolerate a slight acid or basic slurry, and impart less discoloration than carbon steel. Chrome balls generally wear less than carbon or stainless.

In the attritor, a central rotating shaft equipped with several horizontal arms exerts sufficient stirred action to force the grinding media to tumble randomly throughout the whole tank volume, causing irregular movement instead of group movement.

For efficient fine grinding and dispersing, both impact and shear must be present.

In attritors, impact is produced by the constant impingement of grinding media, shear by the random movement of media spinning in different rotation.

The configuration of the arms on the shaft forces the slurry to constantly move around the tank and in and out of this most active zone. Most of the agitation occurs about two-thirds the radius from the center.

Since grinding does not take place against the tank walls, there is little or no wear on the walls. As a result, the tank lasts longer. Since the walls only act as a container, not a grinding surface, thinner walled vessels are possible, with better heat transfer and temperature control.

Although there are three types of attritors, we generally recommend the continuous or circulation types for chocolate processing because of superior temperature controls and higher yield expectations.

The *continuous attritor* is known as a "C" machine. Currently being used to grind large quantities of compound coatings in the chocolate industry, it is best suited for continuous, large production quantities. It has a tall, narrow, jacketed tank into which a well-premixed slurry is pumped through the bottom of the tank, discharging at the top. Grids located at both the bottom and top of the machine retain the media.

The fineness of the processed material depends on residence or "dwell time", the length of time the material to be processed stays in the grinding chamber. For "C" machines, dwell time is controlled by the pumping rate. The slower the pumping rate, the longer the dwell time. Hence, the finer the grind. The continuous attritor needs a well-mixed, uniform, homogeneous feed and a good metering pump. For compound coatings in the 25-30 final particle micron range, we recommend the "C" machine.

Another type of machine used throughout the chocolate industry in the United States, Canada and South America is the circulation grinding attritor, commonly known as the "Q" machine. This has been developed in the last ten years and patented for chocolate processing in September, 1980.

This unit is a combination of an attritor and a large holding tank generally ten times the size of the attritor. The attritor is filled with media and contains grids which, as in the continuous attritor system, restrain the media while the slurry is allowed to pass through.

One of the essential requirements of the Q attritor is a high circulating rate. The entire contents of the holding tank are pumped through the attritor at least once every 7½ minutes, about 8 times an hour. The material continues to pass through the grinding chamber until the desired particle size is obtained.

This results in a faster grind and a narrower particle size distribution. The fast pumping stream through the agitated media bed makes the Q-machine grinding chamber act as a dynamic sieve or filter, allowing the fines to pass and move quickly while the coarser particles follow a more tortuous path through the same bed. We call this the principle or preferential grinding.

One universal requirement of refined chocolate, whether bitter, plain or milk chocolate, is that it should give no sensation of roughness when eaten. It has been shown that the palate cannot discriminate individual particles below approximately 30 microns in size, so it is essential that the combination of sugar and chocolate solids be ground to this particle size range. Conversely, it is generally critical to chocolate processing, particularly molding, extruding and enrobing, that the viscosity of the chocolate be maintained relatively high, requiring particle size uniformity around 10 microns. These requirements place a premium on the control and maintenance of a small, substantially uniform solid particle size in the chocolate. The circulation attritor, or "Q" machine, is useful in preparing chocolate when small, uniform particle size distribution of the resulting chocolate product is vital, in very fine chocolate candy, for example, in the 10-20 final particle micron size range.

In the past, in the chocolate industry, the micrometer and sieve were the most common means of measuring product size. This was a reasonably reliable, quick and inexpensive way to get the job done—similar to the Hegman gauge for determining pigment particle size in the paint industry.

Where ultrafine particle size and distribution analysis are necessary, many companies employ more sophisticated measuring devices, such as the microtrac, a particle size analyzer which utilizes the theory of low-angle, forward-scattering light from a laser beam and tungsten light beam projected through a stream of particles for accurate readings to as fine as 0.12 microns.

In the "Q" machine, large quantities of material can be handled with smaller investments in grinding media and machinery. For comparison, in a batch 100-S, 60 gallons of media are required to manufacture 60 gallons of product. But in a circulation Q-100 unit, 100 gallons of media will allow you to make 1000 gallons of product. Therefore, the ratio of grinding media to product in the Q-system is significantly better. This translates into substantial savings in capital goods.

In the Q-system, chocolate slurry can be continuously monitored, additional ingredients can be added to the premix tank at any time during the grinding, and processing can be terminated precisely.

Temperature control with the Q-system is easy to monitor:

- The holding tank is also jacketed for cooling or heating and acts as a heat sink and,
- The slurry passes through the grinding chamber very quickly, 20-30 second per pass, with little time for heating-up.

The "Q" system also provides a way to improve the chocolate flavor by allowing undesirable components such as acetic acid to vaporize. The "Q" attritor, with a holding tank in which the slurry is being constantly stirred and heated to the proper temperature, allows some conching to take place while the machine is grinding material.

Since a Q-100 can be hooked up to a 500 to 1,000 gallon tank or multiple, Q-100's can be hooked up to a several-thousand-gallon holding tank. Vastly increased production flexibility at very low cost has become a working reality in the chocolate industry today.

It only remains for Americans to increase their per capita consumption of chocolate from 9 pounds per year, twelfth among nations, to the level of the Swiss, at 22 pounds per year, or even the English, at 17 pounds. To that extent we are, distastefully, a second class power.

Around the world, manufacturers of high quality chocolate have discovered that what Dr. Andrew Szegvari said of the attritor system which he originated over forty years ago, is as true today as it was then: attritors are simple and safe to operate, have excellent temperature controls, yield reproducible results, occupy surprisingly little space, consume minimum energy for operation, and provide fast, efficient grinding and dispersing.

Update on Chocolate Processing Attritor Mills and Media

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Q: What prevents the ball media from rubbing the walls and causing wear of the housing?

A: Although there will be some wear as a result of the ball-shaped grinding media rubbing against the wall of the Attritor grinding chamber, it will be relatively insignificant since the wall is not designed as a grinding surface. The greatest media agitation occurs about ⅔ the radius from the center (see Figure 1). The further out the arm, the more energy transmitted to the balls, but this quickly drops off at the end of the arm.

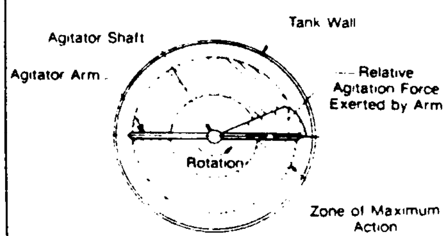

Figure 1

Q: What are advantages and disadvantages of attritor mills vs. other particle size reduction processes?

A: The Attritor, which is referred to as a "stirred ball mill" has several generic advantages over other types of particle size reduction equipment.

1) *Speed.* The Attritor will reduce the size of particles 5 to 10 times faster than conventional ball mills or vibratory mills, according to independent scientific studies.

2) *Efficiency.* Attritors will continue grinding material to submicron size, on a narrow distribution curve, after other types of machines and processes have stopped, because the continuous action of the relatively small media used (⅛" to ¼" dia.) will continue grinding until ultra-fine levels are achieved.

3) *Versatility.* Various types of media including, but not limited to steel, tungsten carbide, ceramic, glass, flintstones, zirconium, alumina, silicon carbide, and silicon nitride can be used in the Attritor, as well as different sizes. The jacketed tank on the Attritor allows the machine to be heated or cooled with water, steam or oil in a wide temperature range, to close tolerances. The Attritor can be operated at many different speed settings.

4) *Simplicity.* Fill the grinding chamber with media and material, grind, discharge, and clean or repeat the process.

5) *Economy.* Since only the contents of the machine are moved, not the machine itself, the Attritor consumes far less energy than other types of mills.

6) *Maintenance.* With so few moving parts, the Attritor is exceptionally easy to maintain online. Many production Attritors operate round-the-clock, year after year, with only cursory inspection procedures involved.

7) *Size.* Surprisingly large quantities of material can be produced on Attritors that will fit into a closet.

8) *Quality of Reproduction.* Results will not vary from one Attritor to another provided material, media and speed remain the same. Uniformity of particle size and shape are inherent.

Q: How does the ball mill compare in fineness and particle size distribution with the triple stone mill?

A: We are not familiar enough with the Triple Stone Mill to compare particle size distribution and fineness with an Attritor.

Q: What is the expected addition of metal to the chocolate in an Attritor compared with other types of mills or refiners? On the Attritor, is contamination from the media a problem in chocolate or compounds?

A: Since Chocolate processing Attritors are equipped with a magnetic separator in the pumping line, most of the metal contamination is eliminated.

Q: What are the higher yields expected with a continuous machine? Is there greater recovery, less loss or what?

A: Both continuous and circulation Attritors use small amounts of the media to process large quantities of the product, therefore, there is less loss and greater recovery.

Q: Must chocolate nibs undergo pre-grinding before an Attritor mill can be used?

A: 1) The batch Attritor can be used to process chocolate nibs into chocolate liquor stage but there is other, more economical equipment available for this process.

2) The continuous or circulation Attritors are used mainly for refining the chocolate liquor. These two types of Attritors can process material only in liquid or semi-liquid form.

Q: You say that Chrome Steel Media can tolerate a "slight acid or basic slurry". Can you be more specific, i.e. by giving a pH range?
A: pH of 5.5 to 8.5.

Q: How does the particle distribution and shape compare with (a) roller mills and (b) other ball mills with ½" or larger, and media mills with ⅛" or smaller?
A: Whereas we have little data from roller mills, I do know from our customers that Attritors give much sharper distribution than ball mills. Also, in terms of the mini-media mills, which are generally continuous machines with a single pass or throughput, the Attritor and especially the Q-machine give narrower particle size distribution because of little chance of short circuiting (bypassing the active grinding zone).

Q: How does one assess when the ball media must be replaced? What affect does ball wear have on the finished products? What hazards do the ball media present and how do you defend against their getting into the product?
A: Specially designed and manufactured bar grids in the grinding chamber of Attritors hold the grinding media in the tank while the material is being discharged. When the media begin to clog the openings in the bar grid, it is time to consider reclassifying or replacing the media. The effect of ball (media) wear on the finished product, if any, varies widely depending on the type of material and media and tolerance levels. Laboratory tests and analysis generally indicate how best to overcome or eliminate contamination, which is the effect of wear, if it is a problem.

Q: When one grinds a mixture of materials on an Attritor mill, how well does it grind coarse, low density particles or flakes when contrasted to coarse, high density particles?
A: A batch Attritor could handle these types of mixtures without any difficulty. But, if one wishes to process them with a circulation Attritor, a sufficient premix tank is most important.

Q: On Microtrac, what type of percent distribution of particles is obtained?
A: Percent by volume.

Q: How does the iron content of product change with your circulating system?
A: Since chocolate processing Attritors are equipped with a magnetic separator in the pumping line, most of the metal contamination is eliminated. However, one paint industry manufacturer, not utilizing a magnetic separator, after 2,000 hours of use found 20 times less metal loss from a 50 HP Q-Attritor with steel media than from a 60 HP sandmill with zirconium silicate media. The steel contamination came only from the mill and its agitating disks.

Q: For a circulating system with chrome media, what service life in hours can be expected?
A: Although very little data are available on the subject of media service life, perhaps because there are so many variables, one of our customers in the paint pigment industry informs us that he "tops off" his chrome steel media with 3% of the original charge every 10,000 hours. He disposes of the entire amount of media every 37,000 hours.

Q: Attritor keeps grinding when others have stopped. Is this good? Would it increase the proportion of superfines particularly in the Q machine?
A: Although Attritors will keep grinding when others have stopped, *if the need arises,* which we believe is good, the machine should be turned off when particle size reduction has been achieved.
The Q-machine which gives a very sharp particle size reduces the entire curve with time, therefore, would not produce a high proportion of superfines. Only if allowed to process long enough would the entire batch end up superfine.