ATTRITOR GRINDING AND DISPERSING EQUIPMENT

by
A. Szegvari and M. Yang
UNION PROCESS INC.
Akron, Ohio

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KENT STATE UNIVERSITY
Department of Rheology

Kent, Ohio
by
Arno Szegvari

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The Szegvari Attritor[1], commonly known as the Attritor, is the most efficient comminuting equipment existing today.

In this talk, we will discuss the principle of the Attritor along with its applications. The Attritor is a grinding mill containing internally agitated media. It has been generically referred to as a "stirred ball mill."

A useful and simple equation describing the grinding momentum is M x V (mass x velocity), which enables us to see how the Attritor fits into the family of mills.

For example, ball mills use large media, normally 1/2" or larger, and run at a low (10-50) rpm. The other mills, such as sand, bead, and horizontal, use smaller media (from 1/64" to 1/8"), but run at a very high rpm (roughly 800-1200). High-speed dispersers with no media run even faster (1200-1800) rpm, with tip speeds of 5000-6000 fpm. *(See chart, Comparison of Grinding Mills, below).*

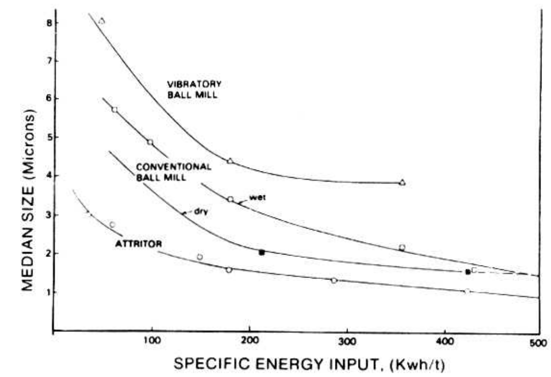
The Attritor falls mid-range between these, using 1/8" to 3/8" media, agitating at moderate speeds from 60 rpm in the largest production size units, to 300 rpm for the laboratory size units (with tip speeds of 600-1000 fpm).

Along with this same principal, the lately developed and patented High Speed Attritor for dry grinding uses smaller media and has higher tip speeds.

Within a similar RPM range, rotor/stator dispersers have lower tip speeds than regular dispersers because the diameter of the rotor is less since it functions against a stationary piece.

The most important concept in the Attritor is that the power input is used directly for agitating the media to achieve grinding and is not used for rotating or vibrating a large, heavy tank in addition to the media.

Let's now turn to the efficiency of the Attritor. *Figure 1* shows the comparison of the effectiveness of various grinding devices for the ultra-fine grinding of pima chalcopyrite concentrate.[2]



Comparison of the effectiveness of various grinding devices for the ultrafine grinding of Pima chalcopyrite concentrate. Herbst and Sepulveda, "Fundamentals of Fine and Ultrafine Grinding in a Stirred Ball Mill," Proc. Powder & Bulk Solids Conf., Chicago, IL, May 1978.

Figure 1

The top curve represents data from the vibratory ball mill; the middle two curves are obtained from conventional ball mills; the bottom curve is obtained from the Attritor. As you can see, for specific energy input around 100 kwh/T, the median particle size achieved through the use of Attritors is nearly 1/2 smaller than that obtained from conventional ball mills, and is about 1/3 smaller than that obtained from vibratory mills.

Moreover, for specific energy input exceeding 200 kwh/T, Attritors continue to grind into the submicron range, while other grinding machines can no longer effectively produce any smaller particles. Consequently, the time required in the Attritor is much shorter.

COMPARISON OF GRINDING MILLS

TYPE OF MILL	MEDIA SIZE	R.P.M.	TIP SPEED (fpm)
Ball Mill	1/2" and larger	10-50	–
Attritor	1/8"-3/8"	60-350	600-1000
High Speed Attritor	0.5-3.00MM	320-1700	2500-3000
Sand Mill (Horizontal Mill)	0.25-2.00MM	800-3800	2000-3000
Rotor Stator	–	1000-3600	2000-4200
High Speed Disperser	–	1200-3600	5000-6000

(1) Dr. Andrew Szegvari, renowned chemist and inventor of the Szegvari Attritor, b-June 5, 1897 – d-August 9, 1980.

(2) Herbst and Sepulveda, "Fundamentals of Fine and Ultrafine Grinding in a Stirred Ball Mill," Proc. Powder & Bulk Solids.

The Attritor's efficiency can be explained as follows.

The central rotating shaft, equipped with several horizontal arms, exerts sufficient stirring action to force the grinding media to tumble randomly throughout the whole tank volume, causing irregular movement instead of group movement. *See Figure 2.*

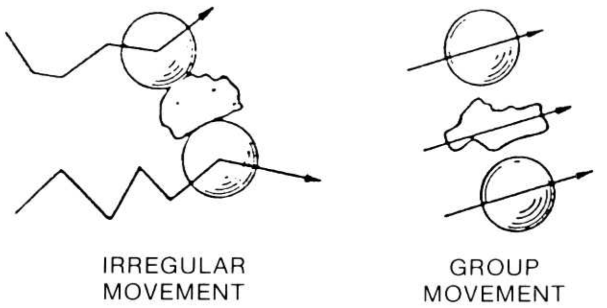


Figure 2

This irregular movement results in impact action of the media.

The arm causes this irregular movement by exerting a combination of: *(see Figure 3)*

1. Impact action on the media which later collide with other media;
2. Rotational force on the media; and
3. Tumbling force as media fall into the void left by the arm.

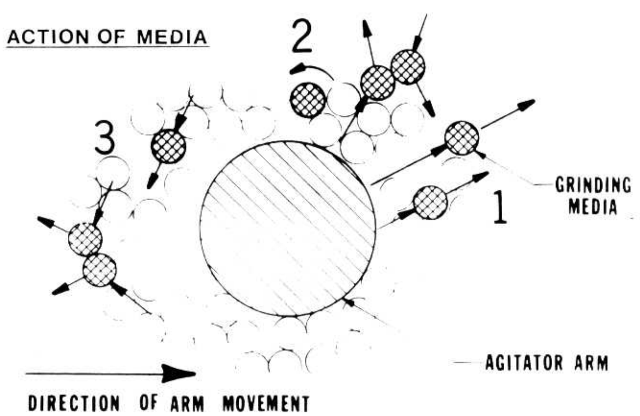


Figure 3

For efficient fine grinding, both impact action and shearing force must be present. *See Figure 4.* In the Attritor, impact action is present by the constant impinging of the grinding media due to its irregular movement.

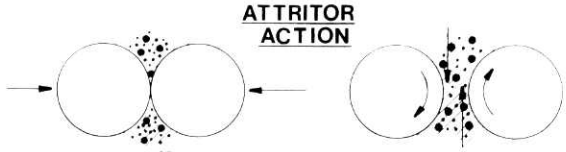


Figure 4

Shearing action is present in the Attritor in that the balls (media) in their random movement are spinning in different rotation and, therefore, exerting shearing forces on the adjacent slurry. As a result, both liquid shearing force and impact force are present. Such combined shearing and impact results in size reduction as well as good dispersion.

The same principle makes the Attritor useful for micromixing by breaking up agglomerates of different material particles and dispersing them.

See Figure 5 to help visualize the relative size between a 40 micron particle (approximately 400 mesh) and a 3/16" diameter grinding media which as a 120 times larger diameter that translates into 1.72 million times greater mass.

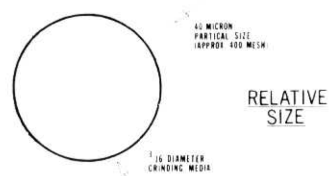


Figure 5

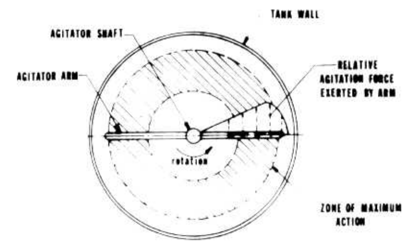


Figure 6

In the Attritor, the greatest media agitation, as described above, occurs about 2/3 the radius from center. *See Figure 6.* As you can see, the further out the arm, the more energy transmitted to the balls, but this quickly drops off at the end of the arm.

Due to the configuration of the arms, the slurry is constantly moving around the tank and in and out of this most active zone. In large model machines, this movement is enhanced by adding a circulating system.

This explains another advantage of the Attritor. Grinding does not take place against the tank walls so there is little or no wear of the walls, resulting in longer service life of the vessel. Also, as the walls act as a container and not a grinding surface, thinner walled vessels are possible and enable better heat transfer and temperature control.

In the terms of tank and steel parts wear, one leading paint manufacturer compared a 50 hp, Q-50 Attritor with a 60 HP sand mill. He weighed all steel parts before and after to get weight loss – Q-50: shaft, arms, tank, grinding media; sand mill: shaft, arms, tank. After 6,000 hours of processing in the Attritor with all steel parts and steel media there was only 10 lbs. of wear contributing to slurry contamination. In the sand mill, after only 2,000 hours of processing with all steel parts but with zirconium media, there was 75 lbs. of steel weight loss.

In Attritor grinding, within given limits, the following equation has been developed to relate grinding time to media diameter and agitator speed:

$$T=\frac{KD}{\sqrt{N}}$$ [3]

T = grinding time to reach a certain median particle size

K = a constant that varies depending upon the slurry being processed, type of media, 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, and conversely decreasing the rpm increases the grinding time. But one must realize, the higher the rpm the more power required.

This also means that increasing media size increases the grinding time and conversely, decreasing the media size decreases the grinding time.

Since the grinding media are another important factor in processing with the Attritor, it is worthwhile discussing it in more detail at this point. As previously mentioned, the media size range is from 1/8" to 3/8". Within this range, the smaller the grinding media used, generally the faster the grind achievable; because, in a given volume, there are more media and therefore more surface contact. However, when the media becomes smaller than 1/8" its mass is considerably less, hence it has less impact force and the grinding times get longer again. Also note that if ultrafine grinding is not required, using the larger ball may be faster because its mass is greater. *See Figure 7.*

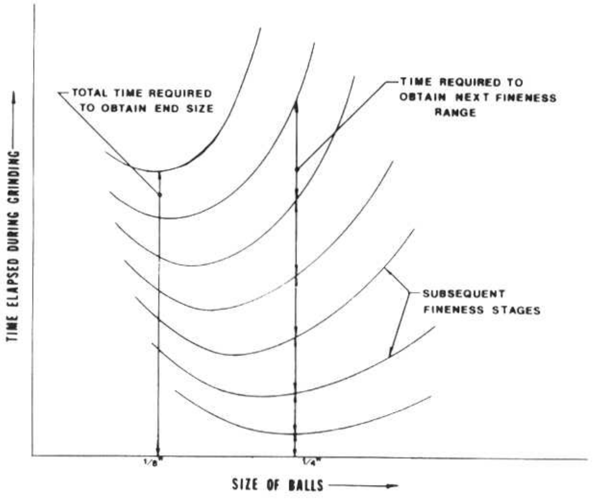


Figure 7

Selection of grinding media depends upon several factors, some of which are interrelated.

1. **Specific gravity** – In general, high density media give better results. The media should be more dense than the material to be ground. Also, highly viscous materials require media with higher density to prevent floating.
2. **Initial feed size** – Smaller media cannot easily break up large particles.
3. **Final particle size** – Smaller media are more efficient when ultrafine particles are desired.
4. **Hardness** – The harder the media, the better the grinding efficiency and, consequently, the longer the wear.
5. **pH** – Some strong acid or basic slurries may react with certain metallic media.
6. **Discoloration** – For instance, white coatings should remain white.
7. **Contamination** – The material resulting from the wear of the media does not affect the product or can be removed by a magnetic separator, chemically, or in a sintering process.
8. **Availability** – Some of the special ceramic media are manufactured to order and have very long lead times, as do very large orders of stainless steel media, depending of course on conditions.
9. **Costs** – Media that may be 2-3 times more expensive may wear better, sometimes 5-6 times longer, therefore well worth their extra cost over the long run.
10. **Consistency in Size** – Although more important with mini media, ideally one wants all the same size (say 1mm or 0.5mm). In these small sizes, there are ranges as due to the manufacturing process, the media must be classified or screened. The tighter the range, the better. For example, .9 to 1.1 is better than .8 to 1.2. Also, it is very important that the media is free from any fragments or broken pieces. Always inspect and/or screen mini media before loading it into mill.

There are several types of grinding media generally used in the Attritor. They are, to name a few, carbon steel, chrome steel, stainless steel, tungsten carbide, ceramic, zirconium, glass, flintstones, and exotics such as silicone nitride and silicon carbide.

The carbon steel grinding media (Sp.gr. 7.8) is most commonly used. It is hard, dense, relatively inexpensive, and readily available. Typically, case hardened is used.

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

The stainless steel media, containing about 16-18% chromium, is about 5 times more expensive than carbon steel media, and is used mainly for aqueous dispersions

[3] Temple C. Patton, "Paint Flow and Pigment Dispersion," Second Edition, Wiley – Interscience, New York, 1979.

with high or low pH. When maintaining the light color of a product is an important factor, stainless steel is used as it imparts less discoloration than carbon steel grinding media. We recommend the through-hardened 440-C which is magnetic, so a magnetic separator can be used to reduce iron contamination. The 300 series stainless steel media, although more corrosive- and rust-resistant, cannot be hardened, therefore, it wears poorly. Because of the expense of stainless steel balls, the less expensive stainless steel "diagonals" can be used, although they generally cause a longer grinding time.

Tungsten carbide (Sp.gr. 15) is hard and dense, but it is very expensive. It is used mainly for grinding hard materials such as tungsten carbide, cobalt, or hard metals.

Ceramic media such as steatite (Sp.gr. 2.7), which is mainly 64% silica combined with 26% magnesium oxide and 6% alumina, and mullite, which is mainly 74% alumina and a combination of silica and magnesium oxide, is used with metallic contamination and discoloration must be kept to a minimum. Of the nonmetallic ceramic media, steatite wears very well, but obviously is no comparison to the steel media. However, because of its low density, the grinding time is usually longer.

Aluminum oxide media (Sp.gr. 3.4) are available at four grades: 87%, 90%, 96% and 99%. They are more dense, but we have found that all grades wear a great deal, although our testing has shown the 87% to wear the best.

Another new type of media, referred to as zirconia toughened alumina, is 70% alumina and 30% zirconia. This media does wear well, but its cost is comparable to that of a middle grade zirconia media.

With the "ceramic" media the grain size is important when grinding down to 1-2μ or less. Whereas good steel media wear with much less than micron particles, the ceramic wears in the grain size of which they are composed. These grains may interfere with the particle size reading of your sample.

For the same type of media, there can be much difference in quality from one manufacturer to another.

It is when trying to achieve a grind of 1μ that one may find it has leveled off at 2-3μ but the reading is actually the wear from the media.

There are now various zirconium oxide media available in the Sp.gr. range of 5.4-5.8. They are stabilized with either magnesia, yttria, or rare earth. The magnesia stabilized media, although less expensive, do not wear well. The yttria stabilized media wear quite well. The zirconium oxide media vary in color from yellow ochre to white, depending on the manufacturer.

Zirconium silicate medial (Sp.gr. 3.9) are about 69% ZrO_2 and 31% SiO_2, but presently available only in small sizes.

Glass media (soda lime) – (Sp.gr. 2.5) are lead-free and can be used in Attritors but do not wear well.

Flintstones are inexpensive and last a long time. Their density and properties are similar to steatite. However, because of their irregular shapes, a longer grinding time is required and they can be used only in batch Attritors.

Specials (exotics) such as silicone nitride and silicon carbide are now being manufactured. They are very expensive and used mainly for grinding like materials or for research.

NOTE: Most mills are loaded by volume, not weight, but most media is sold by weight. For example, a batch Attritor is loaded with media to the top arm; therefore, an Attritor filled with steel media will take almost three times the weight as that filled with ceramic (Steatite) media. A 100-S Attritor required 75 gallons of media, and this equals 3,000 lbs. of steel media, but only 1,050 lbs. of Steatite media. The media loading requirement is the same, whether it is 1/8", 1/4" or 3/8", but the cost per pound does vary per size.

There are three types of Attritors:

1. **Batch**
2. **Continuous**
3. **Circulation**

The **batch Attritor** *(see Figure 8)* consists of a jacketed vessel filled with grinding media. Either hot or cold water or low pressure steam is run through the specially designed jacket for temperature control. Pressurized jackets can be made for ASCM-coded vessels for use with either high pressure cooling systems or steam. The vessel material is generally constructed of 304 stainless steel but it can also be made from AR (abrasive-resistant) steel, or coated with ceramic, plastic, or rubber.

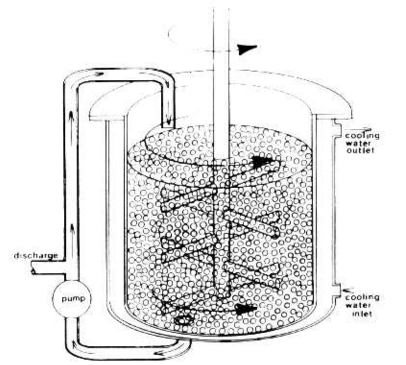


Figure 8

Production size Attritors *(see Figure 9)* are equipped with a built-in pumping system which maintains circulation during grinding for accelerated attrition and uniformity. The pump can also be used for discharging.

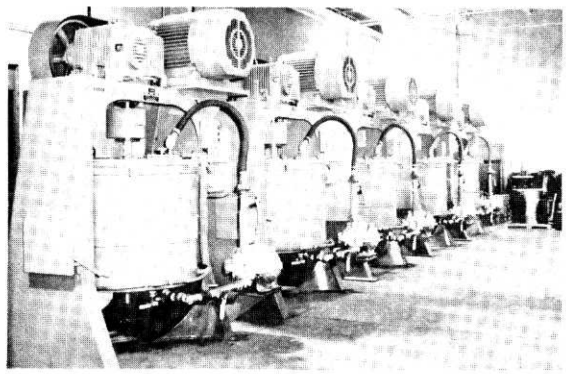


Figure 9

In the batch Attritor, the material is fed into the jacketed tank and is ground until the dispersion and desired particle size are achieved. No premix is necessary as it is accomplished in the grinding chamber. Ingredients can be added at any time. Inspection and formula corrections can be made during the grinding process without stopping the machine.

Batch Attritors can process high density material such as tungsten carbide and very viscous materials. Slurries with a 30,000 cps can be processed easily. High viscosity thixotropic mixtures can be handled because the machine discharges through the bottom valve while still running at slow speed.

The Attritor is versatile. It can be used for grinding high temperature slurry (500°F) or for cryogenic grinding, or equipped with an O-ring or mechanical seal for grinding under a blanket of inert gas. Water-colored covers with condenser are available for controlling solvent evaporation.

Also, a torque meter can be equipped on both the laboratory and production models. The torque meter on the laboratory model gives precise energy input being expended in the grinding chamber. This can be valuable information for scale-up. It may indicate viscosity changes which can be related with particle size reduction.

On production size equipment the torque meter can be used for both quality control and as a means of determining grinding time. Generally a grinding time is established for a particular product and the same time is used repeatedly, but conditions in the mill are gradually changing (media wear, arm wear) which would necessitate slightly longer grinding times. Since these same conditions result in less torque, if one converts the total grinding time to total energy expended into the grinding vessel, then the batch process can be timed more reliably.

Closed-system Attritors with cover seals are available for grinding under inert gases with special discharge into a closed vessel. These can be used for grinding materials such as rare earth magnets.

Batch Attritors come in many sizes – from a research model 750 cc tank (or 125 cc mini tank), to the lab model ($1\frac{1}{2}$ or $2\frac{1}{2}$ gallon tank), to the large production units (600 gallon tank).

The Model 01 Attritor is a very useful research tool for testing various formulations and grinding conditions. The lab model 1-S can used for an accurate scale-up test machine. The most important factor is to keep the peripheral tip speed constant and the media:slurry ratio about the same. Generally in the 1-S, the media:slurry ratio is 1:3/4, but in the production unit it is 1:1, therefore grinding times are somewhat longer in the larger machines, such as the 200-S and 400-S.

For metal-free grinding our laboratory size Attritors are available with tanks lined with ceramic (alumina), zirconium oxide, silicon nitride, silicon carbide, polyurethane, good grade rubber and tefzel.

Our large production Attritor tanks can be lined with ceramic (alumina), food grade rubber or polyurethane (the later two being insulating materials so a heat exchanger is added to the circulation line for temperature control).

Attritors have been used to grind hard and soft ferrites, tungsten carbide, cobalt, aluminum and other metal powders, ceramic materials, hard-to-grind and disperse pigments such as iron oxides, phthalo blues and carbon blacks, printing inks, paper coatings, coal, coke, graphite resins, sulfur, pharmaceuticals, plastics, and confections, to name a few.

The batch Attritor has been used successfully in the dry grinding area. The dry grinding effect is achieved in the Attritor wherein the shaft and arms agitate the media into an expanded condition in which the media is in a random state of internal porosity called kinematic porosity. In this expanded condition, the media and particles are free to move and collide and impinge upon each other. *See Figures 10 and 11.*

Dry grinding Attritors have been used in both the batch and continuous processes. In the continuous process the material is fed into the vessel at the top, falls through the agitating media bed, and is discharged through the grids at the bottom.

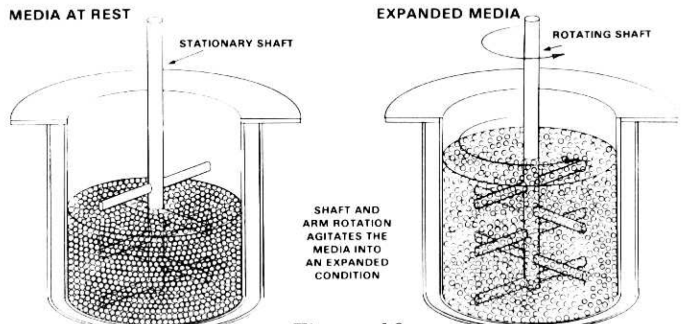


Figure 10

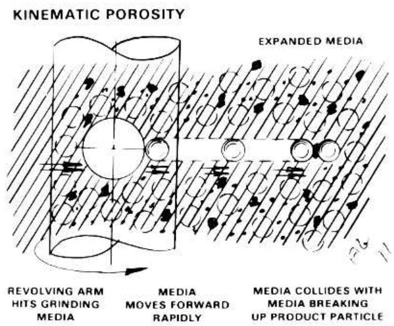


Figure 11

The dry grinding Attritor is also being used in the processing of DSM (dispersion strengthened metal), also called cold welding or mechanical alloying. In this process the kinematic porosity results in breaking the material into small particles, then beating them together to form agglomerates. By repeating the process, the various metals are evenly mixed and dispersed to form a new alloy (DSM).

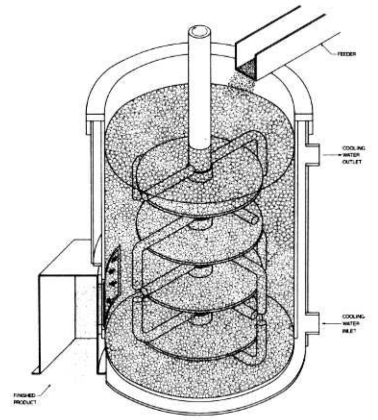


Figure 12

In the 90s, the HSA (High Speed Attritor) has been developed and patented. It runs at much higher speeds than the above-mentioned dry grinding Attritor, but it is used with much smaller media. *(See Figure 12)* Generally used for continuous dry grinding, material is fed through the top of the machine and is reduced in size as it passes through the agitated media bed. It is discharged at the lower portion of the tank through a side discharge screen. Feed material is generally under 40 mesh. The SDG and HSA Attritors are sometimes set-up in a two-stage process. Using larger media, the SDG Attritor is used to pregrind the course feed material, then the HSA is run to achieve a fine product in the single microns.

(Figures 13 and 14). Another system is the **continuous Attritor** (C or H machine) which is best-suited for continuous, large production quantities. The continuous Attritor has a tall, narrow, jacketed tank into which a well premixed slurry is pumped in through the bottom and discharged at the top. Grids located at both the bottom and top of the machine retain the media.

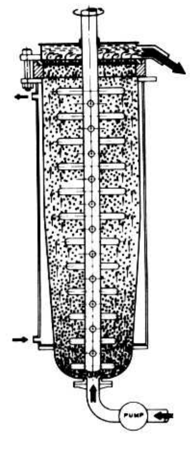


Figure 13

Figure 14

The fineness of the processed material depends on the residence or "dwell time," which is defined as the length of time the material to be processed stays in the grinding chamber.

The dwell time is controlled by the pumping rate. The slower the pumping rate, the longer the dwell time, and hence the finer the grind.

The dwell time is calculated by dividing the void volume by the pumping rate. Void volume is the entire volume of the tank minus the media and the agitator shaft and arms. Therefore, scale-up for a "C" machine is determined by calculating the dwell time of a particular product and dividing this into the void volume of the larger unit. (This is assuming the same tip speeds for both units.) For quick scale-up, one can ration the gross tank capacities.

One prerequisite of the continuous Attritor is that it needs a well mixed, uniform, homogeneous feed. Also a good metering pump is required, such as a gear or Moyno pump.

The continuous Attritor can be set up in series. By using larger media in the first unit, which is equipped with grids having larger openings, the system can accept a coarser feed size. The subsequent units can have smaller media, resulting in a finer grind.

Continuous Attritors are currently being used for grinding calcium carbonate and clay slurries in the paper industry, as well as large quantities of chemical materials, various coal slurries, and compound coatings in the confectionery industry.

Special models of continuous Attritors, called the CL or CLS, have also been recently developed and patented for grinding minerals (limestone) and for lime slaking. In these machines, the dry powder and liquid are introduced at the top of the machine and also exit at the top. These are often used with settling tanks in which the oversize is piped back in the mill for regrinding. These machines can produce tons (dry) of material per hour.

(Figures 15 and 16). The third system is called the **circulation grinding Attritor** (Q machine) and has been developed in the last few years. This system is a combination of an Attritor and a large holding tank which is generally 10 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.

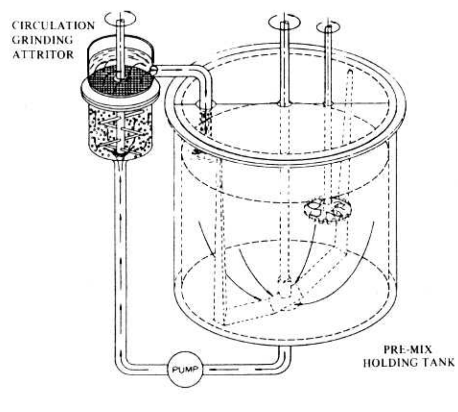


Figure 15

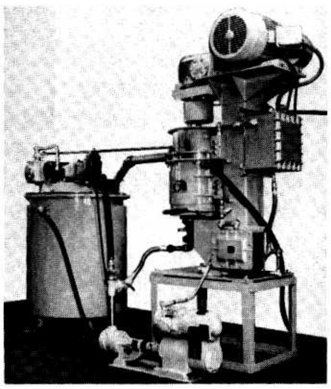


Figure 16

One of the essential requirements of the Q Attritor is the high circulating (pumping) rate. The entire contents of the holding tank are passed through the Attritor at least once every 7½ minutes, or about 8 times per hour.

This high pumping rate results in a faster grind and a narrower particle size distribution. This phenomenon is explained by the principle of preferential grinding *(See Figure 17)* The fast pumping stream through the agitated media bed makes the Q-machine grinding chamber act as

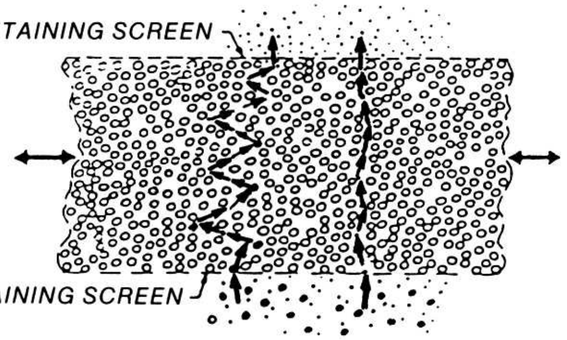


Figure 17

a dynamic sieve or filter, allowing the fines to pass and move quickly through, while the coarser particles follow a more tortuous path through the media bed.

With the circulation process, unlike the continuous Attritor with the slurry making a single pass, the material makes many passes through the grinding chamber until the desired particle size is obtained.

Generally a gear pump is used which is a good metering pump. However, for abrasive and high viscosity slurries, a diaphragm air pump is used.

One advantage of the circulation system is that large quantities of material can be handled with a smaller investment of grinding media and Attritor equipment. The slurry can be continuously monitored, additional ingredients can be added to the premix tank at any time during the grinding, and the processing can be terminated precisely.

Another advantage of the Q Attritor is better temperature control, which is achievable for two reasons:

1. The holding tank is jacketed for cooling or heating and acts as a heat sink.
2. The slurry passes through the grinding chamber very quickly (20-30 seconds per pass), therefore having less time to be heated up.

These advantages are very important when one lines the grinding chamber with plastic or rubber for metal contamination-free processing.

It is fairly reliable to scale up from the laboratory Q-2 which processes 3½ to 5 gallons, to the Q-100 which can process 1,000 gallons at once. First, one should determine "Q-time" for a certain product. Q-time means the total time the slurry spends in the grinding chamber. It is calculated by dividing the total grinding time by the dilution ratio. The dilution ratio is determined by dividing the slurry volume in the holding tank by the void volume of the grinding tank.

After the Q-time is determined, the production rate of a large Q-machine can be obtained by dividing its void volume with Q-time.

Q-Attritor scale-up is directly proportional to the ratio of void volumes between different size machines, providing all the other conditions are kept the same.

The process batch sizes of the "Q-system" have great versatility, for example, a Q-100 can be hooked up with a 500 to 1,000 gallon tank, or multiple Q-100s can be hooked up to a several thousand-gallon holding tank.

The circulation Attritor has been used successfully in the following applications: industrial coatings, paints, inks, sulphur dispersions, agricultural flowables, paper coatings, chocolate liquor, confectionery products, metal oxides, coal dispersions, and ceramic dispersions.

All three types of Attritors are easily maintained. The media can be rinsed and discharged separately through an opening at the bottom of the tank. When necessary, the shaft is easily disconnected and the tank can be tilted forward 90° (batch and continuous Attritors) or rotated 90° (circulation Attritors). The arms are easily removed for cleaning or replacement by taking out a pin.

In conclusion, the features of the Attritor equipment can best be summed up as follows:

- Fast and efficient grinding
- Simple and safe to operate
- Low power consumption
- Excellent temperature control
- Low maintenance