PAUL O. ABBÉ Since 1911

PRINCIPLES OF GRINDING

SPEED OF MILL

Experimental work conducted in our laboratory and supplemented by our pictures in slow motion definitely indicates that the action inside the Mill drum is not a haphazard stirring and throwing of the charge.

There is a specific operating speed for most efficient grinding. At a certain point, controlled by the Mill speed, the load nearest the wall of the cylinder breaks free and it is so quickly followed by other sections in the top curves as to form a cascading, sliding stream containing several layers of balls separated by material of varying thickness. The top layers in the stream travel at a faster speed than the lower layers thus causing a grinding action between them. There is also some action caused by the gyration of individual balls or pebbles and secondary movements having the nature of rubbing or rolling contacts occur inside the main contact line.

It is important to fix the point where the charge, as it is carried upward, breaks away from the periphery of the Mill. We call this the "break point", or "angle of break" because we measure it in degrees. It is measured up the periphery of the Mill from the horizontal.

There are four factors affecting the angle of break:

1. Speed of Mill
2. Amount of grinding media
3. Amount of material
4. In wet grinding, the consistency or viscosity

As this section deals entirely with speeds, we will confine our discussion to this item and cover the other factors in their respective categories.

While, in the old days, operating speeds were determined by trial and error, we have been able to establish practical operating speeds through correlation with the critical speed, which is the speed at which the grinding media, without material, begin to centrifuge. Therefore, to determine the critical speed for any given size Mill, we use the following formula: 54.19 divided by the square root of the radius in feet.

The smaller the Mill the faster in RPM it must run to attain critical speed. Our 4.5" diameter Specimen Jar has a critical speed of 125 RPM, and our size #00 90" diameter Ball Mill 28 RPM.

For most grinding and dispersing problems, we strive to attain the cascading, sliding action described earlier, and to accomplish this we have found that the most desirable angle of break ranges from 50 to 60 degrees from the horizontal.

The lower range is recommended for most wet grinding operations like paints and soft dry materials, and the higher break point (which provides a more severe grinding action) for most dry materials and wet grinding such hard products as enamel frit and glaze.

It is also known that the grinding action in a larger Mill is more severe than in the smaller sizes and, consequently, we are of the opinion that the angle of break should be lower for the larger Mills than for the smaller.

The rule of speed applies regardless of the type of grinding media.

A Pebble Mill the same size as a Ball Mill is expected to run at a slightly faster speed. This is due to the smaller inside diameter of the Pebble Mill with its lining, which is lacking in the Ball Mill.

In the production of bronze and aluminum powders, the Mills are run almost a critical speed so that the balls are drooped to give the same effect as a hammer blow. Without this action the product grinds finely but no flaking of any consequence can be obtained and aluminum or bronze powders are only effective as coatings when they are used in flake form.

QUANTITY OF GRINDING MEDIA

For the most efficient results, the Mill should be at least half filled with grinding media. Some operators prefer to go a little beyond the halfway mark to compensate for wear. There is no objection to this and we have been suggesting a limit of about 5 per cent.

In steel ball grinding, many operators, especially in the paint industry, are satisfied to run with a smaller ball charge ranging as low as one-third the volume of the Mill. They find the smaller charge gives them the required grind within allowable limits of grinding time and the extra space gives them more loading room.

There is no objection to this practice when the grinding cycle falls within the desired working limits. Where speed of grind is of utmost importance, larger ball charges ranging up to the recommended 50% for other types of grinding media are advisable. The logic in this system is best illustrated as follows:

5/8" steel balls are one of the most popular sizes, and there are 36 of these per pound. In a 54" x 60" Steel Ball Mill, for example, the difference between the weight of a one-third and one-half ball charge is 3,970 pounds, or 103,220 balls. The ½" steel ball is another very popular size and, as there 53 of these per pound, the difference would amount to 200,410 balls. It s therefore, reasonable to expect (and experience has proven this to be true) that any addition above the minimum limits prescribed can only result in increased grinding efficiency. This improvement is usually related to the surface area of the media involved.

It is not true that a one-half ball charge consumes proportionately more power than a one-third ball charge. The difference in weight between the tow charges is about 50% but the center of gravity of the larger is nearer the center of rotation of the Mill. Consequently, the power required to turn the larger charge only runs between 15 and 20% more.

The grinding efficiency of the one-half charge is considerably greater than for the one-third and, therefore it ca be expected that power consumption per gallon output will actually be less than with the smaller charge.

Grinding media should be periodically checked. Reduction in the quantity and size of the grinding media will result in poor grinding. We suggest a maximum schedule of once every six months, but any established procedure should be decided by individual experience. In some cases, where abrasive materials are involved, once a month is not too often and, in a few cases, even shorter intervals are indicated.

A simple method for checking is to have a rod cut indication the distance from the top of the grinding media to the underside of the manhole opening and use this for checking the depth of the charge.

When grinding enamel frit, wear to the porcelain balls is quite excessive because to the abrasive nature of the frit. Consequently, many operators have been able to closely determine the ball wear per batch and, when a batch of frit is loaded for grinding, a quantity of new balls is added equaling the weight lost during the previous grind. However, even with this system, we still advise an occasional check with the measuring rod because there is no positive guarantee that all balls will wear the same.

We also advocate dumping the charge once a year, or as often as experience indicates, and removing any grinding media found to be excessively worn or damaged.

TYPE OF GRINDING MEDIA

There are three types of grinding media that are most commonly used:

1. Flint Pebbles
2. Porcelain Balls – regular and high density
3. Steel and other metal Balls

FLINT PEBBLES – These are the oldest type of grinding media in use and they Continue to be extremely popular. They can be used with all types of lining and even in our chrome manganese mills. Among the best known industries in which they are used are paint and enamel products – ceramic slip and glaze – latex compounds – aniline dyes

– graphite and clay mixtures for lead pencils – and hundreds of other products requiring the finest results without contamination. They are exceptionally tough and longwearing and last for many years regardless of the kind of service. The best pebbles are collected along the Normandy Beach in France. They appear to be as plentiful as ever and the quality remains the same as in past years. The pebbles selected for Paul O. Abbé mills are predominantly light colored which have been found to give better service.

PORCELAIN BALLS – This is a pure white ceramic material with a dense, highly vitrified body that will not chip or crack in service. They have been immensely improved in quality in recent years and are used exclusively in many industries.

HIGH DENSITY MEDIA – This is the latest grinding media developed for Ball and Pebble Mills. They are made with a high alumina oxide content and have a density 40 to 50% greater than the regular porcelain balls. They are also fired at higher temperature making them harder and more abrasion resistant.

High density media are available in various shapes including spheres, cylinders and ovals resembling the natural flint pebbles.

Most benefit can be derived from the use of high density grinding media when the product is hard to grind and requires all the energy available to break it down, or where higher viscosities can be developed to advantage – as in the paint industry – through high pigment concentrations which can later be thinned out to make the finished product.

STEEL AND OTHER METAL BALLS – Steel balls are unquestionably doing a faster grinding job than any of the other commercially available media. They have proven especially valuable in the paint industry. This has not always been the case, however. In the early days Mill operators were insistent upon large steel balls, comparable in size to the flint pebbles or porcelain balls in use at the time. Contamination was excessive and they did not appear to grind much faster than the other grinding media. It was not until much smaller sizes were put into use and correct operating techniques were developed that such outstanding results were obtained, in some cases reducing grinding time to one-third that required for other grinding media.

The following types of metal balls are commonly used in Ball Mills:

1. High Carbon – High Manganese Steel with alloying elements or molybdenum, chromium or nickel. These balls especially made for Ball Mills are uniformly through hardened to 60-65 Rockwell C. While they are almost perfect spheres they should not be confused with case hardened ball bearings. They represent the highest quality of all metal balls and most operators insist on using them.

2. Cast Nickel Alloy – This is also very popular and, as it is basically a white metal ball, it causes less metallic staining than the others. Principal objection is its rough outer surface and projecting nubs typical of cast balls. It requires long conditioning periods before being placed into general use.

3. Stainless Steel – because of their high cost they are only being used on special work requiring an acid resistant and non-magnetic ball.

4. Chilled Iron

5. Forged Low Carbon Steel – both 4 and 5 are the cheapest metal balls obtainable. They are only recommended for rough grinding, where metallic contamination is not objectionable.

6. Other, more special types include bronze or brass, aluminum, tungsten carbide, etc.

   Special note: No matter how good the metal ball might be, care must be exercised in the operation of the Mill if excessive wear with its resultant contamination is to be avoided. (See other sections in this chapter; also sections on Cleaning and Discharging.)

The following general rules should be carefully adhered to regardless of the type media used.

1. There should be enough material in the batch to cover the grinding media.

2. Grinding time must be watched carefully to avoid excessive grinding.

3. Excessive buildup of heat should be avoided. In paint grinding, this may lower the operating viscosity beyond the critical point. A reduction in Mill speed may help to avoid overheating, but it is more desirable to circulate a cooling medium around the cylinder. If the Mill is not jacketed, a water spray can be used with satisfaction.

4. The smallest grinding media should be employed. These not only reduce the danger of overheating but, as is well known, the smaller grinding media provide faster and better results.

5. When using extenders, their abrasive nature may cause excessive wear. To avoid this, some operators are able to hold out the extenders until the grinding is almost completed and then add them for the final operation.

SIZE OF GRINDING MEDIA

Probably the most common cause for faulty operation and complaints has been due to the size of grinding media. It is strongly recommended that the smallest feasible grinding media be used in all cases. The optimum size of media should not change with Mill size. If the laboratory Pebble or small Ball successfully grinds a sample batch in a lab Mill, the same size grinding media will do the best job in a production Mill whether the Mill is one foot or eight feet in diameter.

Small grinding media are recommended because:

1. They provide many more grinding contacts per revolution than larger media. This results in much quicker grinding action.

2. They provide smaller voids, limiting the size of particles or agglomerates which can exist there.

3. They do not create excessive energy which cannot be utilized. Oversized grinding media frequently develop more grinding energy than is needed for the job. This excess merely builds up heat and wears down the media and lining, introducing contamination in the batch. Using an extremely large grinding media is somewhat like using a sledgehammer to drive in a carpet tack.

The chief disadvantage of the smallest size grinding media is that discharging takes somewhat longer due to increased surface tension in the smaller voids. Almost invariably, however, the reduced grinding time realized by smaller media more that offsets this disadvantage. Slight air pressure may be used to assist in more rapid discharge.

Using extremely small media, with their greater surface area for the material to adhere to, may yield a smaller initial batch. Subsequent batches will be of normal size, however.

When steel balls are used, the optimum sizes we have usually been recommending have been ½ and 5/8”. However, many operators are now using media as small as ¼” in production mills and find these extremely advantageous where exceptionally fine grinds are required. Generally, the viscosities must be slightly lower for the small size balls than we would recommend for the more popular ½ and 5/8” sizes.

WET GRINDING

The void volume between the grinding media, with the mill half charged, represents approximately 20% of the total volume of the mill – and with a one-third charge of grinding media 13 ½%.

Fastest grinding occurs where there is just sufficient material in a batch to fill all voids and slightly cover the grinding media. This equals approximately 25% of the total volume with a half ball charge and 18% with a one-third ball charge. The material should never be allowed to drop below the surface of the grinding media, because when this happens, excessive wear occurs to the Mill and grinding media and contaminates the material itself. The largest size batches should not exceed 60% of total Mill volume which corresponds with our catalog rating.

There are occasions where additional thinning of the batch after grinding may be done to increase the yield of the Mill. For example: A Paul O. Abbé #3-C lined Pebble Mill has a volume of 450 gallons. A minimum 25% material charge for this Mill would be 112 gallons and the maximum 60% charge 270 gallons. After grinding, if the Mill were loaded to the extreme top with thinner, the yield produced would be 315 gallons, or 70% of the total volume of the Mill.

We find that the most general batch size is about 30% for products that are hard to grind like enamel frit and glazes and 40 t0 45% for products like the average high grade paint and enamel. Larger batches are run where a good mix rather than a grind is involved or where grinding time is not a particularly important factor. A general rule in determining the grinding efficiency for different size batches is to figure that a 40% batch takes twice as long as the 25% and the 60% batch four times as long when a 50% charge of grinding media is used. This is particularly applicable to high grade dispersions. When grinding material such as enamel frit, it is unlikely that the extreme upper limit in batch size will ever grind.

It is a practical plan to establish the batch size consistent with the allowable running time. For example: Assuming that a 25% batch takes 9 hours, this would be too long for an 8 hour shift. Therefore, it is usually advisable to increase the batch size and continue running the Mill to the next working day. Assuming again that 40% batch takes 9 hours, then a slight cutback should make it possible to turn out a batch within an 8 hour working day. It is therefore; always wise to do a little experimenting with the batch size to try to develop a system that will work out best under your particular grinding conditions. The one principal rule to remember is that the grinding media must be covered with material.

CONSISTENCY OR VISCOSITY OF MATERIAL – The most important element in wet grinding is the consistency, or viscosity, of the batch. Low viscosity materials permit the grinding media to move with excessive speed and this combined with the thin protective film around the media, may cause abnormal wear, contamination and heat build-up. If the low viscosities cannot be avoided then it is imperative that small grinding media be used.

With high viscosities free movement of the grinding media is impeded. This can cause a carrying over and “throw” of the media resulting in inefficiencies and contamination.

Based on accepted milling techniques, we have found the following consistencies measured at milling temperature usually work out best:

For flint pebbles and porcelain balls 75 to 90 Kreb Units, 600 to 1100 centipoises

For high density balls 90 to 100 Krebs Units, 1100 to 2100 centipoises

For steel balls 90 to 115 Krebs Units, 1100 to 2400 centipoises

These viscosities are based on using 1 to 1 ½" flint pebbles – 1 to 1 ½" porcelain balls – ½ to ¾" steel balls. The smaller sizes for the lower viscosities and the larger sizes for the higher viscosities.

Some producers of high density media have been recommending a higher viscosity range than the figures we have indicated. In effect, this merely increases the thickness of the film surrounding the media thereby providing more cushion against impact. We find this desirable where a shearing action is only required to obtain results. However, impact is one of the most important advantages of Ball Mill and Pebble Mill operations, consequently, excessive restriction of media movement should be avoided for highest operating efficiency. This same rule also applies where other types of media are used.

Our viscosity readings were made on a Stormer Impeller type Viscometer. We have found this accurate on both high and low shear materials, as well as on products of a thixotropic nature, whether acqueous or non-acqueous mixtures.

WETTING AGENTS -- The use of wetting agents has greatly increased the capacity of Ball Mills and Pebble Mills without altering the viscosity during the grind. A typical example is the case of one operator who, prior to the use of wetting agents, could load no more than 50% solids to retain a suitable working viscosity. By adding the proper wetting agent he was able to increase his solids content to 85%.

It has generally been found that, combined with the increased production, the grinding operation can be performed in a much faster time because the wetting agents aid in breaking down the surface tensions of the aggregated particles and the finished product has greater stability.

DILUTION BEFORE DISCHARGE – Where the product being ground has a heavy consistency which makes it difficult to discharge, it is sometimes advisable to add sufficient additional liquid to thin down the batch. If the mill is equipped with a discharge valve, the liquid is best added to the batch through the valve. The reason for suggesting this is that there is likely to be some unground material packed between the flanges of the manhole frame and cover. To prevent dropping this material into a finished batch, try to avoid disturbing the cover until the ground material has been removed.

If there is any surging of the liquid as it is being loaded into the mill, the brass vent plug on the head of the mill, the brass vent plug on the head of the mill should first be removed. BE SURE TO REPLACE PLUG BEFORE RE-STARTING THE MILL. If the mill is not equipped with a discharge valve, extra liquids must be added through the manhole opening.

The mill should be run form 10 to 15 minutes with the added thinner.

The mill can be completely full after the additional thinner is added. In some cases, the minimum 25% grinding charge of semi-paste material is being ground first and additional liquid to fill the remaining 45% of total volume of the mill is added later to make the finished mix. Where still further thinning is desired, this can only be accomplished by unloading the batch of material and adding the extra thinner in mixing tanks.

Another method is to discharge part of the grinding slurry, mix thinner into the remainder in the mill, discharge this material into the receiver holding the first portion, and finally mix the entire batch with a portable mixer. A variation of this is to be discharge as much of the grinding slurry as possible, and then make the thinner serve the twofold purpose of washing the mill out and finally thinning the entire batch.

COATINGS COMPRISING PAINT, INK AND SIMILAR MATERIALS – While we recognize that actual grinding, i.e. – size reduction of some pigments is not required, the action of Ball and Pebble Mills embodies a combination of impact, shear and attrition. Therefore, it is the utilization of all these forces that insures the best performance of these Mills.

Most desirable applications for Ball and Pebble Mills are on pigments requiring further reduction -- Non-uniform pigments that must be made uniform in the finished product, -- Agglomerated pigments resulting from storage and handling -- Manufactured agglomerates such as carbon beads – Raw materials lacking complete compatibility -- Grinding inexpensive coarse extender pigments in the batch giving more hiding power to expensive pigments, -- Where uniformity and stability of the finished product are essential and must be constant, batch after batch.

On the other hand, simple dispersions can be quickly and easily accomplished in a consistent, productive fashion without the need for elaborate controls or supervision.

One of the most successful techniques employed in the dispersion of pigment in vehicle and solvent is known as low solids grinding. Utilizing this procedure offers two distinct advantages:

1. Dispersion is accomplished in a fraction of the time formerly required. Typical results include a white architectural enamel 8 + grind in one hour with

flint pebbles. Light green trim enamel 6 + grind in one hour with steel balls. Yellow enamel to 7 grind in 2 ½ hours with steel balls.

2. A greater pigment quantity can be dispersed in a mill batch than the ultimate formula requires. The remainder of the formula, i.e.: vehicle and solvent, is then added when the dispersion is complete. Many instances are known where mills have yielded two to four times the actual batch loading in finished product.

Excellent papers covering this subject have been presented to the Federation of Societies for Paint Technology.

The first article presented by Frederick K. Daniel describes the "Flow Point" method of determining the optimum relationship of pigment – binder and solvents.

A second article also presented in October 1950 by R.B. Shurtz gives further data on the "Flow Point" method with tables and graphs showing results on many combinations. If this method of determining pigment concentration or percentage of vehicular solids is used, the danger of seeding or pigment shock is decreased. However, to reduce this danger further it is frequently advantageous to step load the balance of the vehicle solids and solvent with the temperature as close as possible to the mill temperature.

A third paper presented by Frederick K. Daniel in October 1956 discusses the effect on seeding by the solvents utilized in the mill base and let-down phase.

While the use of all forces comprising the action of ball and pebble mills is beneficial on most pigmented products, there are a few pigments on which it is desirable to avoid direct impact and attrition and rely mostly on shear.

For example, one of these is toluidine red. Excessive grinding through impact can destroy the pigment structure thereby reducing its hiding power. To avoid excessive grinding by impact the consistency should be heavier than for normal operation and the size batch should be sufficient to induce spreading of the grinding media in order to prevent direct contact and merely induce a shearing action.

Other operating suggestions of value include the following:

Most operators prefer to first charge the liquids and follow this with the pigment. They find they get faster initial wetting and there is less danger of pigment balls forming

Step loading is more advantageous than tightly packing a bulky pigment to try and get it all in the Mill in one loading. Pigment manufacturers report that excessive packing can cause reaggregation of pigment particles.

Periodic venting of the Mill relieves internal pressures and also helps in grinding.

It is possible to thin out the batch in the Mill without resorting to mixing tanks. This is only recommended, however where the end yield required does not exceed the holding capacity, common in low solids grinding, mixing tanks should be employed.

Wetting or dispersing agents have a definite place in formulating techniques. There are many types on the market and the manufactures of these should be consulted in determining their application.

DRY GRINDING

Whenever there is a choice between grinding a product wet or grinding it dry, wet grinding will generally prove better. However, in many cases, it is impractical to grind wet due to the nature of the process or product.

The void volume between the grinding media, with the mill half charged, represents approximately 20% of the total volume of the mill-and with a one-third charge of grinding media 13 1/3%.

We usually try to limit the size of the batch to 25% of the total Mill volume which is sufficient to fill all voids and slightly cover the grinding media. Any larger batches cause the pebbles to spread out through the mass of solids so they cannot make effective contact with each other, because of the layers of material between them. This greatly reduces the grinding efficiency of the mill and, in some cases, makes it impossible to attain the desired results. The only occasion for larger batches than 25% of total volume, is on products requiring a good mix rather than a grinding action or on products that are soft and easy to grind and the grinding media do not necessarily have to make close contact with each other.

The feed material should preferably be about 8 mesh or smaller, although many operators start with much larger pieces. Having the feed material as fine as possible enable the use of smaller sizes of grinding media, which are always best for fine Uniform grinding and dispersions. For hard material, it is especially advantageous to start with a fairly fine product.

Clogging of material in the Mill makes further operation harmful. This is generally caused by moisture of fat, as in oily seeds. Possible remedies include:

1. Taking the material out and thoroughly drying it.

2. Adding a dry filler to absorb the excessive moisture while the batch is being ground.

3. Adding a few pieces of steel angle, bar, or chain which can slide along the Mill surface and scrape off any materials starting to pack.

4. If the material is packing due to particle size alone, grinding should be stopped prior to this point. The material should then be screened and tailings returned to the mill.