ACARP HARDGROVE GRINDABILITY INDEX

The Hardgrove Grindability Index was developed as an empirical test to indicate how difficult it would be to grind a specific coal to the particle size necessary for effective combustion in a pulverized coal fired boiler.

Its use has been extended to cover the preparation of pulverized coal for the cement, steel and chemical production industries.

It has also been used more recently as one of the key properties included in specifications for the supply of coal for the above applications.

UNIT 1 HARDGROVE GRINDABILITY INDEX

OVERVIEW

The economic size of large industrial plant using coal is defined by the particle size range of the coal so that it can react effectively with oxygen in air in a gas stream. If the coal particles are larger than this the industrial plant needs to be larger to obtain reasonable burnout of particles.

This applies whether the reaction is:

- pulverized coal combustion in a boiler to generate electric power
- pulverized coal injection in a cement kiln to make cement clinker
- pulverized coal injection in a blast furnace to assist economic iron making
- entrained particle gasification to make syngas for electric power generation
- entrained particle gasification to make syngas for chemical production.

The comments below on equipment to produce this particle size range economically apply to all these applications in a general manner.

Grinding coal produces a range of particle sizes. The preferred particle size range for any of the above applications is nominally 70% of particles less than 75 (μms) microns in diameter and 99.5% of particles less than 300 microns in diameter. In general, particles less than 75 microns react in the volume of gas surrounding them. Particles between 75 and 300 microns require some combination of turbulence at a specific temperature for a defined time for relatively complete combustion. Particles larger than 300 microns do not burn out completely in the time available in the reactor and result in unburned carbon.

The coal property concerned with producing this desired particle size by grinding coal in a pulverizer is the Hardgrove Grindability Index (HGI)

HARDGROVE GRINDABILITY INDEX (HGI)

The HGI was developed in the 1930s to measure empirically the relative difficulty of grinding coal to the particle size necessary for relatively complete combustion in the then newly developed pulverized coal boiler furnace.

Its use has been extended to grinding coal for the iron making, cement and chemical industries utilizing coal.

More recently it has another role as one of the properties in a specification when purchasing coal from different potential suppliers. The specification usually lists a range of values for every property within which the plant is known to function efficiently. These values may arise from the original design or from practical experience with specific plant.

HGI test procedure

The HGI test tries to mimic the operation of a ball and track type of industrial coal pulverizer manufactured by Babcock. It does this using a batch mode of operation compared with a dynamic situation in an industrial coal pulverizer. It is derived directly from the original experimental work of R Hardgrove.

A 50 gm sample of coal, which has been prepared in a specific manner and which has a limited particle size range, 1.18 x 0.6 mm, is placed in a stationary grinding bowl in which eight steel balls can run in a circular path. A loaded ring is placed on top of the set of balls with a gravity load of 284 N. The machine is run for 50 revolutions. The top is removed and the ground coal removed. This coal is sized and the quantity less than 75 microns recorded. This is converted to a HGI value using a calibration graph.

International standardisation of HGI

This test has been incorporated into the Standards of different countries. The major standards are listed in the references. These standards differ in detail and result in **commercially significant differences** in the value of HGI for a specific coal. The most significant of these differences is that values using ASTM procedure can be higher than values using AS procedure on the same coal sample.

The differences generally lie in the allowed method of preparing the sample before testing. These differences are well understood by boiler and coal pulverizer designers but have led to some confusion when used commercially for coal trading.

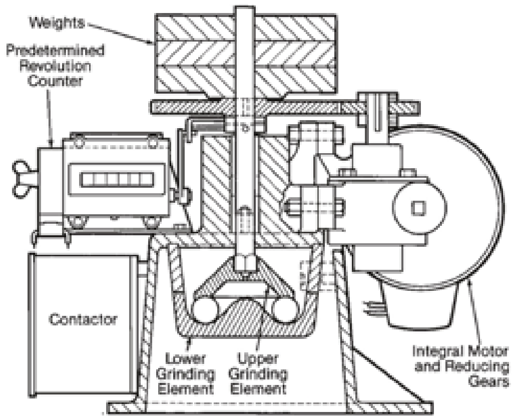


FIGURE 1 Cross section of HGI test apparatus. *Reproduced with permission from SAI Global under Licence 0803-C045.*

FIGURE 2 Typical HGI Commercial Test Equipment. *Photo courtesy of Wallerby Mining Products*

Characteristics of HGI

HGI has a number of important characteristics, the first of these is that it is an **empirical test** not linked with a known physical property of coal. The empirical test has been refined over time but still has a relatively low reproducibility and repeatability which can lead to ambiguity in evaluating mill performance and coal properties. Improvements in an empirical test are extremely difficult as there is no goal to aim for as would be the case for a known physical property.

The second characteristic of HGI is that it exhibits a **non linear change in difficulty to grind**. Coals with low values of HGI are more difficult to grind and high values are much easier to grind. For instance the change in difficulty from 30 to 40 is greater than a change from 60 to 70. It should be noted that this change in difficulty is gradual and continuous and certainly does not imply any step change in grindability at a specific HGI value. This change in difficulty is reflected in an increase in the rate of production of a constant fineness product as the HGI increases. Conversely the mill capacity falls when grinding coal with a lower HGI. The curve shows variation in mill capacity with HGI with 100% capacity being nominally set at HGI of 50.

Note that the three curves shown below show the general shape and direction of a mill response to a change in HGI but would be somewhat different for mills from different manufacturers to whom reference should be made for specific curves.

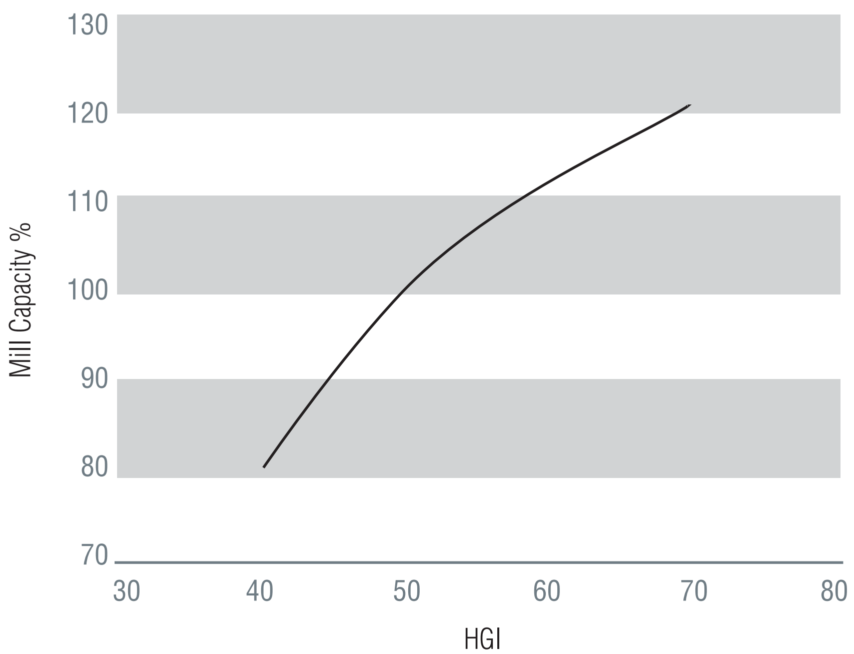


FIGURE 3 Mill capacity vs HGI

Conversely at a constant HGI the fineness of the product varies with mill capacity. Below rated capacity the mill produces coal with a higher proportion less than 75 microns and above rated capacity it produces coal with a lower proportion less than 75 microns.

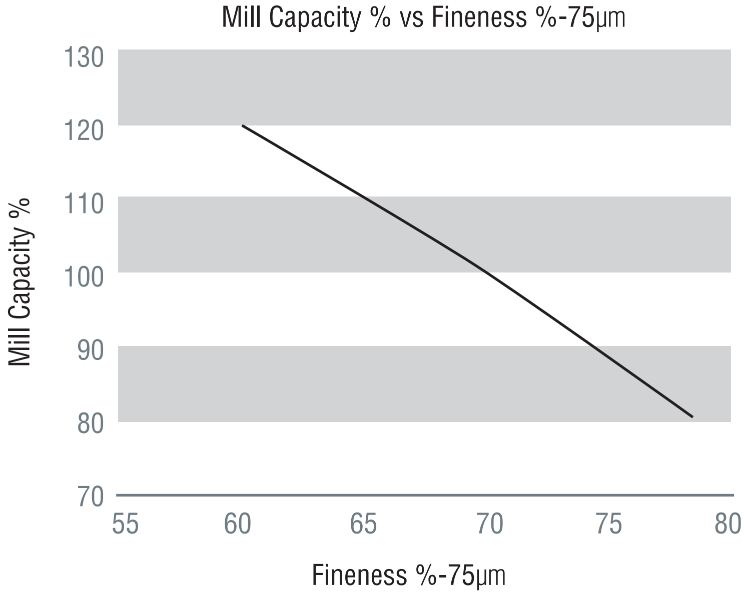


FIGURE 4 Product fineness vs mill capacity at constant HGI

It should be noted that coals with lower HGI's need more power to drive the pulverizer than coals with higher HGI's to produce product of the same fineness.

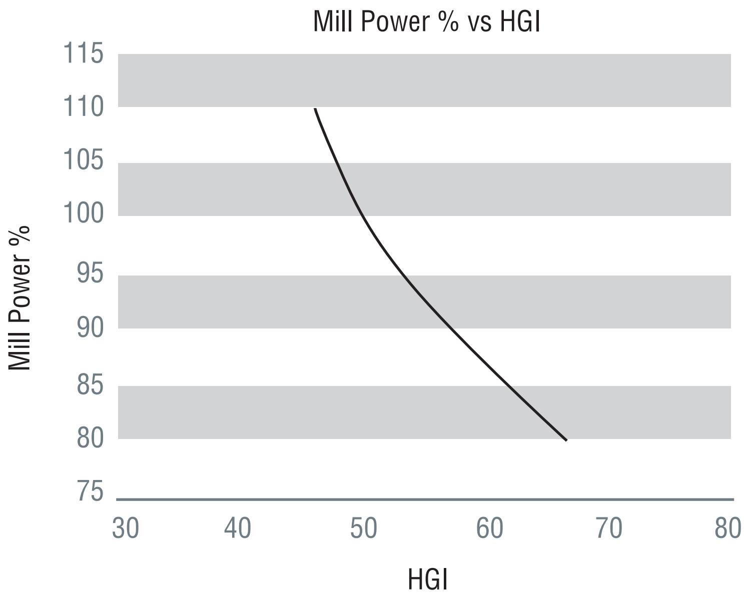


FIGURE 5 Mill power demand vs HGI at constant product fineness

The third characteristic of HGI is that the **HGI of a blend is not necessarily the weighted sum of the component coals** in the blend. With a blend of coals with similar HGI's the difference is small. When a blend of coals with quite different HGI's are mixed the resulting HGI is farther from the weighted average of the coals in the blend.

The fourth characteristic of HGI is its ability, when combined with coal reactivity or volatile matter, to **provide guidance on likely combustion/reaction performance** in conventional industrial equipment. This is described in more detail below.

HGI is seen as a good measure of the difficulty of grinding coal for coals with fairly standard properties.

It is seen to be less effective as a measure of difficulty to grind as coal properties move away from normal. For instance coals with a moisture content of less than about 10% behave in an expected manner. However as moisture content increases the HGI becomes les effective as a predictor.

Essentially there is an envelope of coal properties within which HGI is reliable. This envelope is not well defined. There are known instances of coal pulverizer capacity being inadequate when using some coals with rather unusual properties. This factor has become more important as the range of internationally traded coals increases.

It should be noted that HGI does not provide direct information on the likely wear rates of critical mill grinding components.

HGI test limitations

Hardgrove himself identified some deficiencies when proposing the test. The HGI test has been reviewed many times since then and various shortcomings identified.

The **primary shortcoming is the use of a batch process** to try and represent a continuous milling process. Fine ground coal accumulates in the bed of material under the balls as they rotate. This has a cushioning effect which supports partly ground particles more than would be the case in an industrial pulverizer and results in less fine product than would be expected.

Moisture content of the coal sample is important for both the test and industrial pulverizer operation. Increased moisture content reduces performance and at the limit will trip the mill.

The test uses sample **feed with a limited range of particle sizes**, 1.18 x 0.6 mm, rather than a complete range of sizes. There is the possibility that the method of preparing the coal sample may result in this providing a different result compared with using a complete range of particle sizes.

When testing **blends of different coals the result may not be the weighted average** of the component coals, possibly linked with the limited range mentioned above. This deviation becomes greater as the difference between the component coal HGI's becomes greater.

Because of these and other limitations the **standard test is not highly precise**, repeatability between successive samples on the same test machine being 2 units and reproducibility between laboratories being 4 units.

Notwithstanding these limitations HGI is seen to be generally effective for internationally traded coals, becoming less precise as the moisture content of the coal increases above about 10%.

Other measures of coal grindability

The primary measure of grindability of minerals in general is the Bond Work Index which uses a pilot scale wet ball mill. This covered a very wide range of values but was apparently not precise enough for use with coal. It also used a slurry sample which was inappropriate for coal for pulverized combustion.

Numerous other grindability tests have been proposed but have failed to win acceptance. These have tended to be modifications to make the Hardgrove test mimic more closely an industrial coal pulverizer.

The closest standard material physical property to HGI is fracture toughness. This is difficult to measure reliably because of the friability and heterogeneity of coal lumps. Micro indentation equipment has been refined close to the point where it may be precise enough to supersede the HGI test.

HGI Test Unit. *Image courtesy of Wallerby Mining Products*

UNIT 2 ROLE OF HGI IN COAL PULVERIZER PERFORMANCE

Coal pulverizers produce an output quantity of coal particles with a range of particle sizes. When operating at less than their nominal capacity the coal particles are finer and when operating at more than their nominal capacity the coal particles are coarser. It is normal to define the output of a coal pulverizer in terms of the rate of coal produced and the particle size distribution of this product.

The accepted standard for defining the output of an industrial coal pulverizer is output quantity in tonnes/hour with a particle size defined by 70% less than 75 microns and 99.5% less than 300 microns when grinding coal with a HGI of known value. For most mills this is a value of 50 with one manufacturer using 55. This value has no critical importance other than to provide a value against which mill capacity is defined.

Coal pulverizer manufacturers provide sets of curves linking actual performance of the mill with coal with different properties such as HGI, moisture content % and feed particle top size. These curves enable results of a test on a particular coal to be referenced back to the standard conditions to monitor the performance of the pulverizer. It should be noted that the shape of these curves is generally similar within a type of mill but may be quite different for different types of mill.

Evaluation of pulverizer performance with a new coal

How a particular coal is likely to perform with a proposed type of coal pulverizer can be determined in a number of ways depending on the amount of coal available. This question may arise when designing a new application or when a new coal is being considered for an existing application. The accuracy of the estimate increases with greater quantity of coal and larger test equipment closer to industrial capacity.

Where a small amount of coal is available measurement of the HGI and using the mill manufacturer's curves will provide a first estimate of the performance of a mill with the coal in question.

If a larger amount of coal is available then carrying out a performance test in a pilot scale mill of the same type as the preferred mill provides a greater level of certainty in the likely performance of the coal. It may be necessary to use a scale up factor to industrial size mills.

Where significant quantities of coal are available for testing in a full scale industrial mill of the proposed type will provide more accurate information. This is not as effective as at the desired site but a test to the requirements of ASME Power Test Code 4.2 can be converted to the proposed mill site fairly effectively.

Where coal is to be supplied to an existing power station testing on the actual mills that will be used provides the most accurate performance indication allowing for any local differences. This can be reinforced by testing the coal on a mill recently overhauled and on a mill considered worn out. It should be noted that this may require the mill to be operated in a somewhat different manner to the existing coal for best performance.

Coal pulverizer manufacturers have detailed records of how their particular mill performs with internationally traded coals.

ROLE OF HGI IN COAL SPECIFICATIONS

A coal specification consists of a list of properties considered of importance in the efficient performance of the application, whether a combustion or gasification plant. These various properties may be shown as ranges or as properties with limited values. HGI may be specified in either way.

There is no logical basis for specifying a lower HGI limit unless other coal properties are taken into consideration at the same time. Reference to the section on complementary coal properties explains why this is so.

A lesser problem when using HGI in a coal specification is the precision of measurement possible. The repeatability of consecutive determinations on the same sample in the same laboratory should not differ by more than two points. The reproducibility of mean values of duplicate determinations carried out by different laboratories should not differ by more than three points. This lack of precision in the test has been known to cause friction between buyer and seller of coal.

Coal properties complementary to HGI

Coal calorific value, moisture content and volatile matter content/reactivity can be complementary properties to HGI in modifying the effect of coal particle size distribution on boiler or other plant performance.

In order to provide a simple reference point for the industry pulverized coal with 70% less than 75 microns and 99.5% less than 300 microns was recognized as being appropriate for normal conditions, based upon coal with a medium volatile matter content or reactivity, which results in reasonable burnout of coal particles, 98–99%, in a well designed boiler furnace.

If the volatile matter content or reactivity is higher than normal, then coal particles somewhat larger will burn out successfully in the normal furnace volume. This coarser product requirement allows the mill to provide more output. Alternatively it allows the use of coal with a lower HGI with effective particle burnout.

Thus a combination of coal properties is necessary to ensure relatively complete combustion/reaction in normal boiler furnaces.

The moisture content of the coal can also limit the performance of a mill, irrespective of HGI, if it is such that the drying or thermal limit of the mill is approached.

UNIT 3 COMBUSTION AND GASIFICATION OF COAL

While the reaction rates are significantly different, both combustion and gasification of coal particles in suspension requires particles to be within well defined particle size limits. Particles less than 75 microns in diameter tend to react with the volume of air or oxygen surrounding them with only ash remaining. Particles between 75 and 300 microns in diameter require the classical time, temperature and turbulence regime for long enough to burn out effectively. Particles greater than 300 microns tend to not burn completely leaving a residual particle with some carbon not consumed.

Taking a large coal fired boiler as an example of the different applications, pulverized coal particles are reacted with oxygen in the air to provide heat energy to the water-walls in the furnace and superheater to raise steam to the desired pressure and temperature. The furnace volume is designed to allow adequate residence time for this to occur based upon the properties of the coal.

The pulverizers for this application need to grind the necessary quantity of coal to the desired particle size range. Pulverizers are essentially volumetric devices passing a volume of material to be pulverized through the pulverizer body but rated in tonnes/hour because the density of coal is fairly constant.

Incomplete burnout of coal particles can occur if the furnace volume is insufficient or if the pulverizer capacity is too small or pulverizer grinding elements are worn or the reactivity of the coal is less than designed for. The specific furnace volume or pulverizer capacity at an installation may dictate the need to purchase coals which are more reactive or which grind more easily for effective operation.

These nominal particle size ranges are the basic starting point for monitoring and improving plant performance. They presume a nominal volatile matter content or coal reactivity which contributes to fairly complete burnout under these conditions. However if the volatile matter content is higher or the coal has a measured higher reactivity then particles somewhat larger will react effectively with fairly complete burnout.

Conversely coal with less volatile matter content or lower reactivity will require more particles to be less than 75 microns for fairly complete reaction. This applies whether the reaction is:

- combustion in a boiler to generate power
- pulverized coal injection in a cement kiln to make cement clinker
- pulverized coal injection in a blast furnace to assist economic iron making
- entrained particle gasification to make syngas for power generation
- entrained particle gasification to make syngas for chemical production.

It is accepted that size reduction is energy intensive and that the efficiency of grinding is low with the energy used to break particles being about 5% of the overall energy input. Coal needs to be ground from about 50 mm in diameter to 70% less than 75 microns for most applications. All mills have four unit operations going on concurrently within the mill body. These are drying the coal, transporting the coal within the mill, classifying the particles into those that can pass out as product and those which must be returned to the grinding zone for further grinding and grinding itself.

There are two conditions controlling the performance of coal pulverizers. The first of these is the capacity of a mill providing the desired particle fineness. As the output of a mill increases the particles produced become coarser so more difficult to achieve effective burnout. The second limitation is the thermal limit of the mill. When coal with moisture content above the capability of the hot air supply to dry the coal the mill reaches its thermal limit, bogs down with wet coal and trips on motor overload.

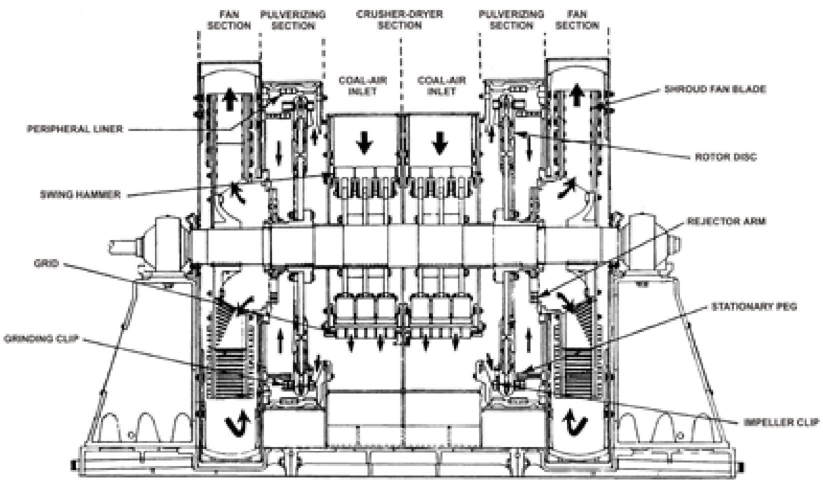
There are four types of coal pulverizing mill generally characterized by the speed of rotation of the main grinding component. Within these general types there are significant differences from different manufacturers, depending on what key patents are used. HGI provides adequate information on the capacity of the first three types of mill with different coals. It does not provide adequate information for very low speed mills and other capacity tests are required for this type of mill.

It should be noted that there is no "best" mill; one or more of the four types of mill is most suited to the suite of coals likely to be utilized at the site. The basic characteristics of the four types are set out below.

High speed mill

In a high speed mill a horizontal shaft rotates at about 1000 rpm. This has a series of hammers or wear bars attached. Coal particles fall on to the rotating assembly and the lumps of coal are ground by impact with the rotating hammers. All feed material is not reduced to product size in a single pass and multiple hammers are used to reduce all particles to product size. Coal properties concerned with mill capacity are calorific value, HGI, moisture content and top particle size.

The mill is primarily used for grinding brown coal and lignite where the mill capacities are high. A few black coal fired power stations use a smaller mill to produce conventional feed to a pulverized coal fired boiler. About one third of the coal pulverizers in Australia are of this type. This type of mill handles high moisture content well but excessive wear takes place with high abrasiveness coals.



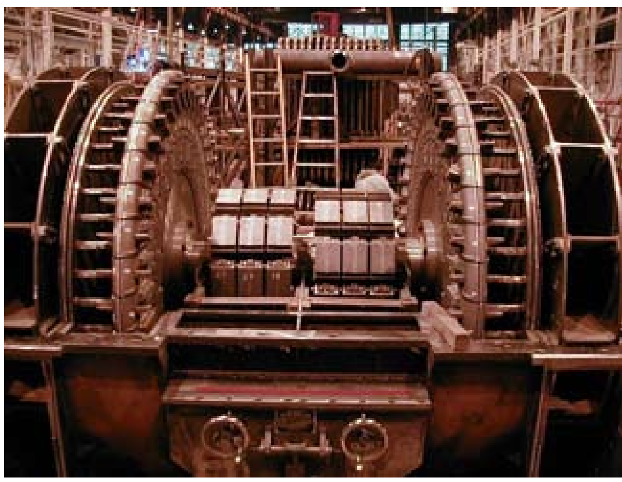


FIGURE 6 A&B High Speed Mill.
Images courtesy of Riley Power Inc., a Babcock Power Inc. company

Medium speed mill or vertical spindle mill

In a medium speed mill a horizontal table rotates at about 50 rpm. A number of rolls or balls lie in a track on the table and are compressed down on to a bed of coal on the table by spring or hydraulic force. As the table rotates it draws coal under a roll or ball where grinding takes place. About 5% of the material is reduced to product size per pass under a roll or ball so that the oversize needs to be recycled to be ground further. Partly ground coal passes up through the mill body with carrier air, passing through a series of classification zones, product passing out of the mill and oversize being returned to the grinding zone. Coal properties concerned with mill capacity are calorific value, HGI, moisture content, and volatile matter. The mill is primarily used for grinding black coal and mill capacity can be up to 100 tph. About one third of coal pulverizers in Australia are of this type. This type of mill can handle medium moisture content well and medium abrasiveness coals.

There are two versions of this mill with quite different characteristics. One type has rolls or balls sitting in a track and needs to use coal as a lubricant to minimize component wear.

The other type has the rolls set a small clearance above the table so that the mill can run empty with no serious wear problem. As coal is fed to the mill in builds up a bed of coal and starts grinding.

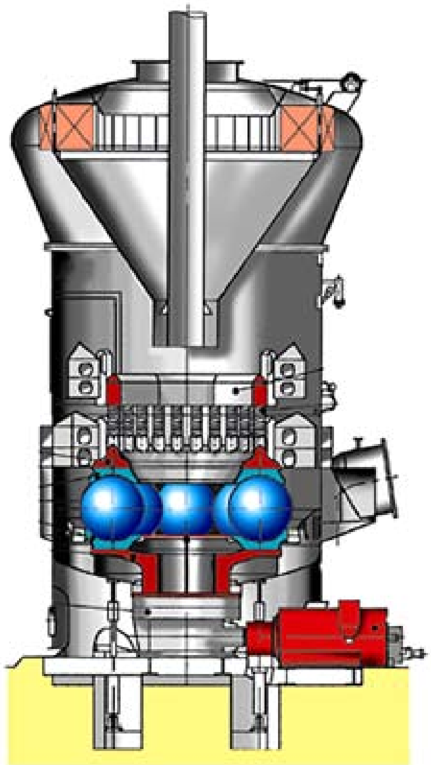


FIGURE 7 Medium speed mill – cross section
Courtesy of Claudis Peters

Low speed mill

In a low speed mill a horizontal cylindrical drum rotates at about 17 rpm. Within this drum there is a charge of balls from 50 to 20 mm in diameter. Coal lumps are fed to the mill and a cascade of balls from the mill rotation breaks up the lumps. This process is not complete in a single pass and oversize material is returned to the mill via a classifier for further grinding to achieve product particle size for reaction. The mills may be double ended to increase capacity. Coal properties concerned with mill capacity are calorific value, HGI, moisture content, particle top size and volatile matter content. This mill is excellent for highly abrasive coal as the wearing component, the balls, can be added with the coal feed as they wear. The mill does not handle high moisture content coal well and capacity falls about 3% for every 1% increase in moisture content.

FIGURE 8 Low Speed Mill.
Image courtesy of Metso Minerals

Very low speed mill

Very low speed mills or high pressure roll mills consist of two large rolls with horizontal shafts rotating close to each other at about 5 rpm. Coal lumps pass down into the space between the rolls and are ground as they pass in a choking condition between the rolls. The product from this mill is rather larger than normal pulverized coal particle size and this mill has been used specifically for preparing coal for pressurized bed fluidized combustion (PFBC). This mill usually depends on a single pass with no classification or recycling. Coal properties concerned with mill capacity are calorific value, moisture content, top particle size and coal density.

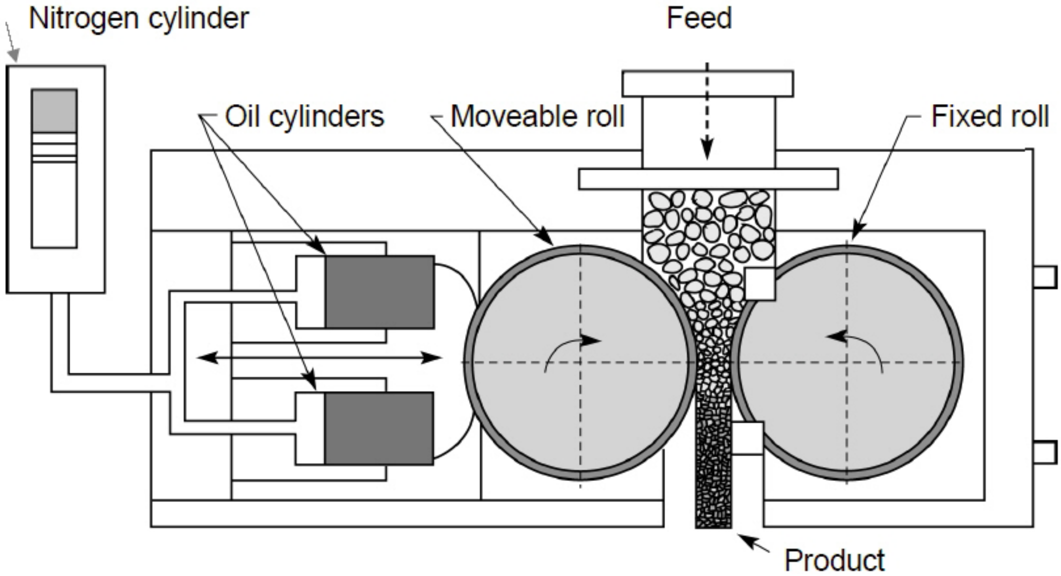


FIGURE 9 Very low speed mill-high pressure roll mill.
Image courtesy of Julius Kruttschnitt Mineral Research Centre

COMMON MILL CHARACTERISTICS

Mill capacity

A mill can provide a range of capacities at different particle fineness. Mill capacity and the fineness of the particle product are complementary in that at lesser capacities the particles are much finer whereas at high capacity the particles are much coarser.

The industry convention is to specify the capacity of mills in tonnes per hour with a fineness of 70% less than 75 microns and 99.5% less than 300 microns when grinding coal with a HGI of 50. One mill manufacturer uses a figure of 55 in place of 50 for HGI.

The capacity of a mill may also be limited by the moisture in the coal and the available drying or thermal capacity of the mill. If the thermal capacity of the mill is approached or exceeded the mill outlet temperature falls, the motor current rises and in the limit trips the mill which is full of coal. This capacity limit is not linked with the HGI of the coal being pulverized.

Mill correction curves

All mills have a set of curves to determine the capacity of the mill when fed with coal with properties different from the standard ones. Different types of mill react differently to different coal properties. Correction curves may be drawn conservatively to provide some extra commercial protection.

The primary correction curve is that for HGI. This shows mill capacity increasing with increasing HGI in a non linear manner. The change in output is slow to change at low values of HGI and increases with higher HGI values. The complementary curve shows change in fineness of product with change in HGI at constant mill capacity.

The next most important curve relates mill output to moisture content in the coal This curve shows a steady decrease in mill capacity as moisture content % rises culminating in a sudden reduction as the mill is tripped out of service when the moisture content reaches the thermal limit of the mill and there is insufficient hot air capacity to dry the incoming coal.

Generally mill capacity falls as the top size of the feed coal increases. This curve shows a continuous reduction with increase in feed top size to a limit where the larger lumps will not pass into the mill.

Mill classifiers

Most mills do not reduce feed to product particle size in a single pass. There is a need for a classifier to separate potential product from oversize and return the oversize for further grinding. Thus a mill has two regions, a grinding region where feed and recycle particles are further ground and a classifier region where ground particles are separated into product size and oversize.

The classifiers on most mills grinding coal have height limitations brought about by other equipment requirements and as a consequence the classifiers are not high efficiency and return a significant proportion of potential product to be reground. This, in turn, tends to support larger particles in medium and low speed mills, reducing their grinding efficiency.

Classifiers may be static or dynamic. Static classifiers are generally of the cyclone type located directly above the grinding zone. Dynamic classifiers have a horizontal rotating element with slots which allow potential product material to pass but reject the larger particles because they are traveling at a lower velocity. Dynamic classifiers are more efficient but entail more auxiliary power and maintenance.

If the mill classifier is not functioning correctly the mill produces coal particles which are far too large for effective burnout.

With the development of pulverized fuel firing into larger boilers in the 1930s in the USA there was a need to develop a set of tests capable of characterizing coal for this new technology. Where previously lump coal was preferred the new technology required coal to be ground to a desired fineness for combustion in suspension in air.

Ralph Hardgrove of the Fuller Lehigh Company carried out an extensive set of tests with different grinding mechanisms. Five mechanisms tested included a mechanical mortar and pestle, the predecessor of the present test and a small ball tube mill. From these tests the predecessor to the present equipment was selected and tests carried out on more than one hundred US and Canadian coals with resulting grindability values of 21 to 113. The variation in coal quality included ash content ranging from 3 to 57%, volatile matter from 5 to 58% and fixed carbon content from 31 to 84%. This is obviously a broad range of coal properties and a sound basis for a test method.

This test became the standard for the industry, the Hardgrove Grindability Index (HGI). This test could be used to compare different coals to determine the necessary capacity and size of coal pulverizer for a particular application. It could be part of a suite of tests to examine the differences between two or more coals.

The test was completely empirical and not designed to measure a known physical property, such as fracture toughness, of the coal. It used a batch mode of operation to mimic the operation of one type of coal pulverizer operating in a dynamic mode. The original test has been standardised and now forms the basis for Australia, US and ISO Standards set out in the references below.

The remainder of the mining industry tended to use the Bond Work Index test to determine the grindability of other minerals. This was based upon a small ball mill, similar to one of the initial trials of Hardgrove. However, this test was carried out with the material in wet slurry which was inappropriate for coal. Equations linking the Hardgrove and Bond tests have been identified by McIntyre, Plitt and others.

Over the intervening years the HGI test has been investigated numerous times to try and minimize some of the limitations which have become apparent. These limitations included a lesser level of reproducibility and a lack of knowledge of the extent of the envelope of other coal properties within which the test was valid.

A number of experiments were used to try and convert the batch test into a dynamic test similar to the Babcock E type mill. The first of these was Highnet and Barker of the Central Electricity Generating Board in the UK who simulated continuous operation by stopping and emptying the machine at regular intervals, sizing the intermediate product, discarding the fine product and adding an equivalent quantity of new feed. This was deemed to be superior but it was significantly more expensive to execute.

Further experiments with modified equipment which are variations on the original test equipment have been proposed by Scieszka, Tora, Sanders and others.

In the 1970s Agus and Waters in the CSIRO, Australia recognized that mills were essentially volumetric devices and modified the Hardgrove equipment to use a volume of coal rather than a mass of coal required by the original test.

Other research groups attempted to predict the HGI from consideration of the other chemical and physical properties of a coal sample, trying to eliminate the actual test. Both multiple regression and artificial neural networks were used with varying success. These predictions were generally good over a group of like coals but less effective as the coal properties varied from normal expectations.

While all of these developments had advantages they were not adopted generally, possibly because a large body of results had been assembled for the original test and plant designers understood the limitations of this test.

HGI as a predictor of coal pulverizer performance

Relatively little investigation has been carried out in trying to measure how well HGI actually can be used to predict the performance of a pulverizer with coals which have a less common range of properties.

The range of properties of coals traded internationally was quite limited but there are an increasing proportion of coals offered internationally with a broader range of critical properties. This is important when an existing power station or other facility is considering purchasing coal with different properties to that for which it was designed and this broader range of coals with less usual properties is available for consideration.

HGI as a reliable criterion included in a coal specification

Most of the investigations of HGI have been centered on trying to provide a more reliable commercial measure for inclusion in a coal specification. The repeatability of the HGI test is poor and the spread between testing stations is also relatively high to the extent that there are significant legal cases on the real HGI of delivered coal.

Research has taken the form of trying to tighten the conditions surrounding the execution of the test and developing new variations of the test which may result in higher precision. Other approaches have sought to infer HGI from consideration of other properties of coal including chemical and petrographic measurements.

A different direction has been to try and measure standard physical properties which are closely linked with grindability. The nearest of these is the fracture toughness of coal. It is relatively easy to achieve precision when testing fracture toughness of metals, but because coal is so heterogeneous the precision of measurement is not better than of HGI at present.

Future direction of HGI research and investigation

There is a case to develop an envelope of the coal properties, such as moisture content, within which HGI provides a reliable guide to the capacity of a coal pulverizer. This would require examining the many acceptance and performance tests carried out on coal pulverizers in Australian power stations in the first instance during plant commissioning and later.

There is also a case to improve the standard HGI test or replace it with a more reproducible test with a tighter level of repeatability and reproducibility.

REFERENCES

This small select group of references covers existing HGI Standards, original and early research work, reviews, recent work and relevant ACARP Research Reports.

STANDARDS

The main standards for measurement of HGI are set out below:

AS 1038 Part 20:2002, Hardgrove Grindability of coal

ASTM D 409-2006, Grindability of coal by the Hardgrove machine method

ASTM D5003-06a, Hardgrove Grindability for petcoke

BS 1016-1981 Part 20, Hardgrove Grindability

DIN 51742-2001, Determination of HGI of hard coal

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GLOSSARY

ACARP	Australian Coal Association Research Program
AS	Australian Standard
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing Materials
BS	British Standard
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DIN	German Standard
GOST	Russian Standard
HGI	Hardgrove Grindability Index
HPRM	High Pressure Roll Mill
ISO	International Standards Organization
JIS	Japanese Standard
PFBC	Pressurised Fluidised Bed Combustion
tph	tonnes per hour capacity
UK	United Kingdom

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Report published September 2008

www.acarp.com.au

The Australian coal industry's research program