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ACARP REPORT

Australian Coal Research Limited

THE HARDGROVE GRINDABILITY INDEX

HGI IS A TECHNICAL DESIGN PARAMETER WHICH HAS BECOME COMMERCIALLY IMPORTANT BECAUSE OF ITS USE IN COAL CONTRACT SPECIFICATIONS. HOWEVER IT IS HIGHLY NON LINEAR AND SHOULD NOT BE USED AS THE SOLE CRITERION FOR JUDGING THE GRINDABILITY OF A COAL. THIS PAPER AIMS TO PLACE THE HGI IN CONTEXT AND TO EXPLAIN ITS LIMITATIONS.

SUMMARY

Efficient combustion in a pulverized coal furnace requires adequate coal with a desired particle size range. The coal characteristic for determining the capacity of a pulverizer to provide this is the Hardgrove Grindability Index (HGI). Like other tests developed at the introduction of pulverized fuel combustion in the 1930s it is empirical but has, with some known limitations, remained effective as an indicator for boiler and ancillary plant design.

More recently it has been used as a factor in contracts for the supply of coal, taking on a commercial role in addition to its technical one. What was a design guide has become a commercial tool, to argue the relative value of a particular coal and in some cases to reject particular coals.

THE HARDGROVE GRINDABILITY TEST

The Hardgrove Grindability test attempts to mimic the operation of a continuous coal pulveriser using a batch process. Hardgrove himself identified this as a limitation and there have been a number of attempts to standardise or improve the original test.

In all cases a 50 gram sample of coal, which has been prepared in a specified manner and which has a limited particle size range, 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 284N. The machine is run for 60 revolutions. The top is removed and the coal recovered. The coal is sized and the quantity less than 75-micron is recorded. This is converted to an HGI value using a calibration graph. Reasonable reproducibility is achieved by conforming to a number of standard test requirements.

The test results in a value for HGI generally between 30 and 100. A high value indicates that a mill using this coal will have a high output while a low value indicates the mill will have a reduced capacity using this coal. The test is highly non-linear such that a change in HGI from 90 to 80 results in a small decrease in mill capacity while a change from 50 to 40 leads to a considerably greater decrease in mill capacity.

In comparing the different standard methods for measuring HGI the main difference lies in the procedures allowed for drying the coal prior to the test.

INTERNATIONAL STANDARDISATION OF THE HGI

The original test, developed by Ralph Hardgrove in 1929, has been the subject of standardisation by a number of national and international bodies to obtain better reliability resulting in slightly different interpretations and different values for the same coal using these standards. This effect is well known and the major difference lies in the way the sample is prepared, leading to the possibility of somewhat higher values when the American ASTM version of the test is used compared with the Australian version. This is well understood in boiler design but has contributed to some confusion when used commercially. The differences can be critical when export grade coals are being offered to prospective overseas clients.

TEST DEFICIENCIES

The most significant deficiency lies in using a batch test process to simulate a continuous pulveriser. The test accumulates fine ground material in the bed of coal over which the balls pass at every revolution. This fine material supports the unground particles better than in an industrial sized mill and results in less overall fine product than would be obtained with a continuous mill.

The most practical deficiency lies in the allowable differences between the standard tests particularly with respect to drying the coal before the test commences. There is significant effect due to moisture and the different procedures can result in the same coal tested under the American ASTM methods being higher than the corresponding Australian standard. This appears to the client to give the coal tested by the US methods a competitive advantage and may even be the difference between acceptance and rejection. The difference is fairly well known and allowed for in the industry.

MOISTURE PLAYS AN IMPORTANT PART IN BOTH THE HGI TEST AND IN FULL-SCALE MILL OPERATION. EXCESSIVE MOISTURE IN EITHER CASE REDUCES MILL PERFORMANCE AND MAY WELL STOP IT COMPLETELY.

Moisture plays an important part in both the HGI test and in full-scale mill operation. Excessive moisture in either case reduces mill performance and may well stop it completely.

When testing blends of coal for HGI anomalous results may arise because HGI is not an additive property of coal. A Waters tested a mixture of coals of different HGI and this did not result in a weighted mean value and generally tended to move towards the lower HGI value.

DETERMINING MILL CAPACITY WITH A SPECIFIC COAL

Tests for pulverizer capacity are listed in order of effectiveness.

TEST AT DESIRED SITE ON INDUSTRIAL MILLS

This is obviously the preferred process as it includes all the local factors in any test. It suffers from the drawback that the operators may not be adept at coping with a new coal type and may not be willing or able to modify the operation of the mill to provide the best performance.

TEST AT A SIMILAR SITE WITH INDUSTRIAL MILLS

Much can be gained from converting tests on the specific coal at other sites with similar types of pulverizer. While not as positive as a test on the intended site, results of a well monitored test can be converted to a different mill and set of operating conditions with a high level of certainty.

PILOT SCALE MILL TEST

If these avenues are not available or there is limited quantity of coal available then tests using a pilot scale mill of the same type is the next best procedure. This involves the need for an effective scale up factor.

HGI TEST

If small quantities of coal are only available the HGI test is the only one available. It is also used in coal contracts as a regular quality check. Some coal specifications limit the properties of coal to be purchased and HGI is a property which has been used in this manner.

EFFECTIVE COAL FIRED BOILER OPERATION

A modern large pulverised coal fired boiler is a device in which coal is reacted with oxygen from the air to provide heat energy input to the water walls, furnace and superheat tubes to raise steam to desired pressure and temperature conditions. The boiler designer selects a furnace volume from knowledge of the coals to be utilised to provide adequate residence time and ensure fairly complete burnout and low loss of carbon in ash.

The effectiveness of combustion in a furnace is a function of the specific coal reactivity and the particle size range of the coal. While the normal range for coal particles is 70% less than 75 microns and 99% less than 300 micron the reactivity of the coal can alter this value and still provide low combustible loss. Low reactivity coal can sometimes be utilised if it is pulverised to a finer value than 70% and high reactivity coals may not need to be as fine as 70% less than 75 microns for effective combustion.

As a consequence of this the pulverisers in service for a large boiler need to grind a specific quantity of coal to a defined particle size range dependent upon coal reactivity and furnace volume.

Coal pulverisers are essentially volumetric devices, but because the density of coal is fairly constant, are rated in mass units of tonnes/hr. A pulveriser accepts a volume of material to be pulverised which is dependent on the physical dimensions of the mill and the ability of coal to pass through the coal pulverising system. The common measure of mass in tonnes enables matching of energy requirements with available coal properties and mill capacity.

Increased combustible loss can occur if the furnace volume or mill capacity is less than desirable for a particular coal. There are a number of possible remedial actions. Manufacturers can correct some deficiencies in the combustion system by biasing the performance of the coal pulverising mills rather than considering changing the furnace volume. It is also possible to place the spare mill usually provided with most pulverised coal systems into service for peak periods to ensure full output.

While the furnace volume and mill capacity in a specific power station may dictate the need to purchase coals which are reactive and which grind easily, commonly there is some degree of flexibility.

HGI IS AN EFFECTIVE MEASURE FOR ALL BUT THE VERY LOW SPEED MILLS FOR WHICH NO EFFECTIVE GRINDABILITY TEST HAS YET BEEN ACCEPTED INTERNATIONALLY.

COAL PULVERISERS

Size reduction is energy intensive and generally very inefficient with regard to energy consumption. In many processes the actual energy used in breakage of particles is less than 5% of the overall energy consumption. Pulverising coal is no exception to this.

There are basically four different types of pulverising mills which are designed to reduce coal with a top particle size of about 50mm to the particle size range necessary for fairly complete combustion in a modern pulverised coal fired boiler. Each type has a different grinding mechanism and different operating characteristics. In three types there are four unit operations going concurrently within the mill body - coal drying, transport, classification and grinding.

For coal pulverisers the capacity of a mill is normally specified as tonnes output when grinding coal with a HGI of 50, with a particle size of 70% less than 75 micron and 1 or 2% greater than 300 micron and with a moisture in coal of less than 10%. A few manufacturers specify 55 instead of 50 with respect to HGI. This standardisation enables selection of an appropriate mill for a specific duty.

From this base value each mill manufacturer provides curves relating the coal properties which affect the mill capacity so that the capacity of the mill coal with specific properties can be calculated. HGI is an effective measure for all but the very low speed mills for which no effective grindability test has yet been accepted internationally. Coal reactivity may require a finer or coarser grind and there is a further curve linking fineness of grind with resultant mill capacity.

TYPES OF COAL PULVERISER

The mill types are best defined in terms of the speed of the operating mechanism.

VERY LOW SPEED MILLS DO NOT EXHIBIT A CONSISTENT RELATIONSHIP BETWEEN HGI AND MILL CAPACITY AND THEREFORE NEED A DIFFERENT FORM OF GRINDABILITY FACTOR.

Very Low Speed Mills

These mills consist of two rollers separated by a small clearance but forced together with high pressure hydraulic rams. Coal is passed between the rolls and is reduced in size in a single pass operation. The size reduction effected is less than in the other mills and the energy consumed is far less. These mills have been used in pressurised fluidised bed combustion (PFBC) units with some success because the product size distribution is close to that required by this technology. Coal properties which affect capacity are specific energy, moisture, top size and density.

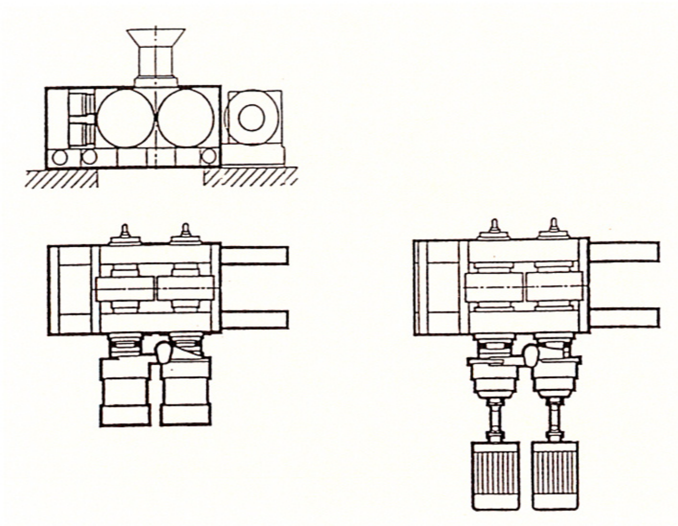

Figure 1
High Pressure Roll Mill

Low Speed Mills

Low speed mills are typically ball mills with a quantity of steel balls inside a horizontal rotating cylinder. When coal is passed through such a mill the coal particles are reduced in size by balls falling under gravity on individual groups of coal particles. This is the least efficient form of grinding but has other benefits with respect to maintenance. Low speed mills are fitted with classifiers which return over-size and some product material for further grinding while allowing a proportion of product material to pass to the boiler burners. Coal properties which affect mill capacity are specific energy, moisture, top size and volatile matter.

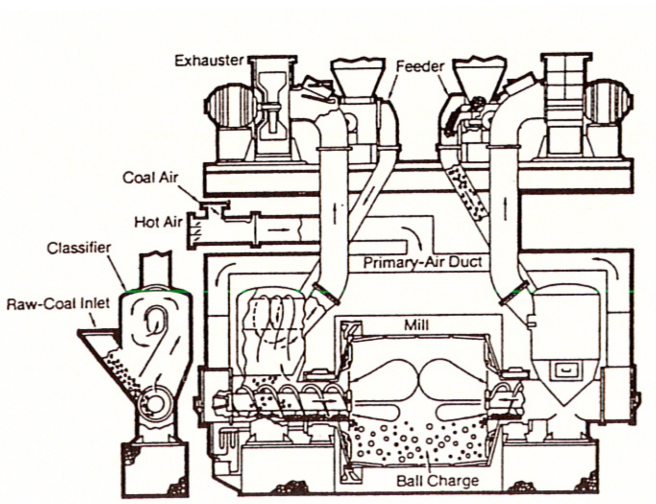

Figure 2
Low Speed Mill, Tube Mill

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Medium Speed Mills

Medium speed mills are generally in the form of a cylindrical body housing a horizontal table rotating at 30-60 rpm with spring or hydraulically loaded rollers or balls close to the table surface. Coal fed to this type of mill is drawn between the rolls and table and compression is used to grind the coal. The mill is relatively inefficient in that about 5% of feed material is reduced to product particle size for every pass under a roll. A number of passes are needed to produce product of adequate fineness. Partly ground coal passes through the mill body with carrier and a series of classification regions allows some of the product material to pass out of the mill, returning oversize and the remaining product for further grinding. Coal properties affecting capacity are specific energy, moisture and volatile content.

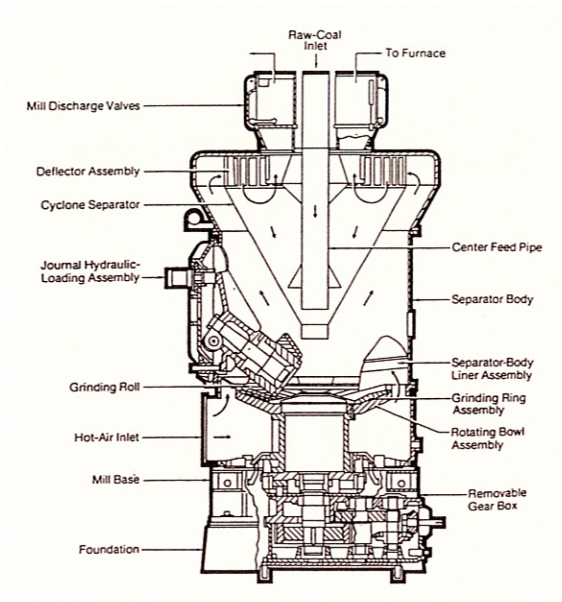

FIGURE 3
MEDIUM SPEED MILL, RAYMOND BOWL MILL

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High Speed Mills

High speed mills are a form of hammer mill with an assembly rotating at about 1000rpm with projections or hammers, which strike and shatter the lump coal entering the body. These units have been developed for small capacity power stations in the range of 30-50 MW units and their use has declined. The main coal properties which affect the capacity of this type of mill are specific energy, moisture and top size.

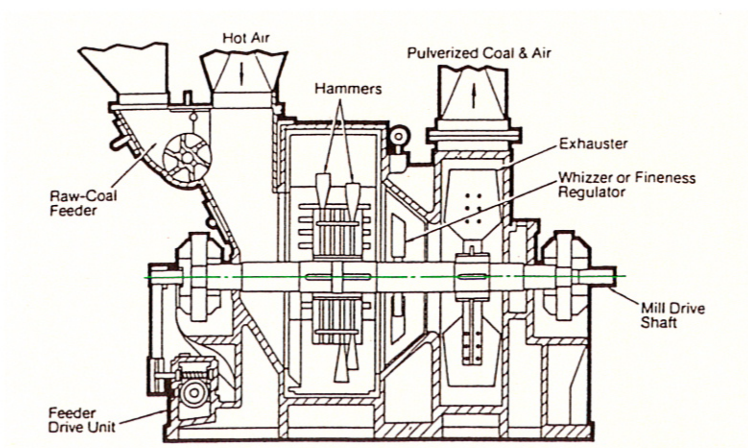

FIGURE 4
HIGH SPEED MILL, HAMMER MILL

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CHARACTERISTIC CURVES LINKING HGI AND MILL CAPACITY

Manufacturers of the last three types of mills provide curves relating mill output with the measured HGI of the coal to be used.

While the curves for mills of one type but from different manufacturers would be expected to be very similar this is not so. Characteristic curves relating mill capacity to HGI can vary from straight lines to curves and cover different ranges of HGI. Just as with HGI these curves form part of commercial contracts concerned with mill performance.

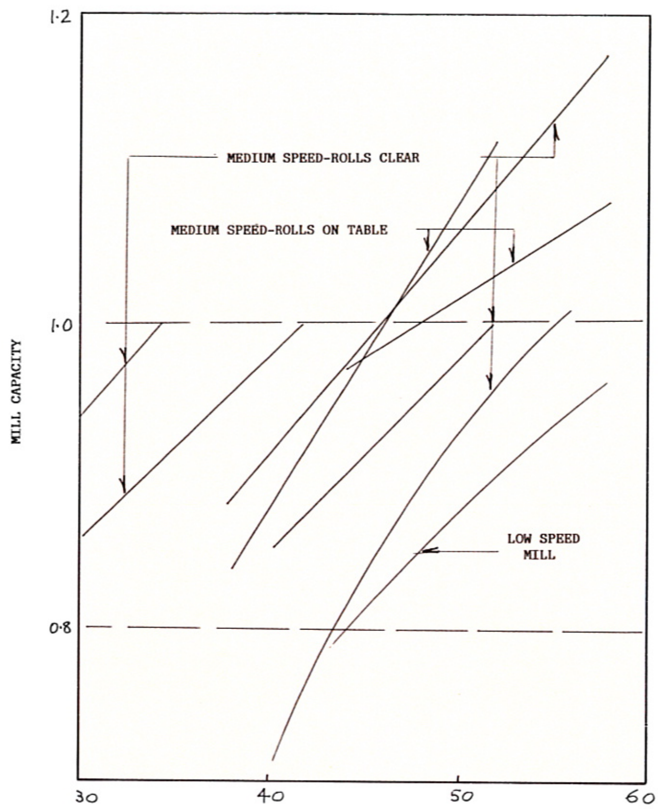

FIGURE 5
HARDGROVE INDEX
TYPICAL MILL CAPACITY
CORRECTION CURVES

PERFORMANCE GUARANTEES FOR COAL PULVERISERS ARE PART OF A TYPICAL BOILER CONTRACT. WHERE COAL PROPERTIES ARE NOT WELL ENOUGH DEFINED, THE CORRECTION CURVES FOR PERFORMANCE, INCLUDING HGI, MAY BE UNNECESSARILY CONSERVATIVE.

COAL PROPERTIES CONTRIBUTING TO PULVERIZER CAPACITY

- Mill manufacturers provides a set of data or curves, as part of the boiler contract, which enable the capacity of a mill to be determined with a coal with specific properties. The properties, which are of concern, are specific energy, HGI, moisture, particle size and reactivity.
- Specific energy is necessary to determine the required nominal maximum mill capacity in tonnes / hour to ensure sufficient coal is delivered to the boiler.
- A curve linking HGI and mill capacity provides information on mill performance with that coal.
- A curve linking moisture content of the coal with mill capacity shows what reduction in capacity will arise if the moisture is excessive. This is particularly important with ball mills.
- The particle size distribution and top size may be of importance. For ball mills there is a curve linking mill capacity with the top size of coal fed to the mill.
- The reactivity of the coal, measured in the first instance by volatile matter is needed to determine if the mill can be set to provide standard 70% less than 75 micron or whether a finer or coarser setting is necessary with corresponding alteration to mill capacity.

HISTORY OF THE HGI GRINDABILITY TEST

With the development of pulverised coal firing for power station boilers about 1930, in the USA, simple tests were needed to define the attributes of coal when applied to this new technology. One of these tests was developed to define the capacity of coal pulverisers, which were needed to grind specific coal to a particle size range suitable for pulverised coal combustion. Previous coal fired power generation had used lump coal and fines were a nuisance.

Ralph Hardgrove of the Fuller Lehigh Company carried out an extensive study examining a mechanically driven mortar and pestle, a bowl and ball device similar to the present standard equipment and a ball mill. After considerable work the predecessor to the present equipment was chosen and tests carried out on many US and Canadian coals. The later versions of this test became standard in the industry and the test produced a value of Hardgrove Grindability Index (HGI) which could be used to compare different coals and to help determine the size and capacity of pulverizing mills needed for a particular application. The test was completely empirical using a batch mode rig which had similarities with one type of mill.

A test developed by Bond was in use in the minerals industry for determining the grindability of ores. This test was a semi batch test based upon a ball mill. It was essentially a set ball milling test and not particularly appropriate for coal pulverisers. Equations linking the Hardgrove and Bond tests have been identified by McIntyre and Plitt and others.

Highnet and Barker in the Central Electricity Generating Board, UK, carried out exhaustive tests using Hardgrove equipment but simulated continuous operation by emptying the machine at regular intervals, sizing the intermediate product, discarding the fines and replacing them with an equivalent quantity of fresh feed material. This apparently gave superior results but was very time consuming and was not developed further.

In the 1970s Agus and Waters in the CSIRO recognised that mills were essentially volumetric devices and modified the Hardgrove equipment to use a volume of coal rather than a mass as the original test required. While all of these developments had advantages over the original rig they were not adopted generally, since by now a body of results had been assembled for the standard test and designers had a good understanding of the inherent limitations of the test.

The physical material property of coal, which may be more appropriate for measuring difficulty to grind, is fracture toughness. However this is difficult to measure because of the friable nature of some coals. Dr Szendi Horvath of CSIRO in Adelaide has done some work with follow up by other Australian organisations. This has not as yet resulted in a superior test.

Conroy presented useful information on the contribution of different components in the coal to the overall HGI result. Bailey and Esterle carried out a project suggesting a revival of a ball mill test for this coal property. They identified positive differences in grindability between components in the coal and suggested that if these fractions could be separated some could be ground with far less energy consumption. There have been a number of reviews by Edwards, Prasher, Sligar and others commenting on various aspects of the test and its application. It needs to be remembered that HGI provides direct information on mill capacity but does not pretend to also provide information on likely wear rates of critical mill components.

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CONCLUSIONS AND IMPLICATIONS FOR AUSTRALIAN COALS

Low HGI value is not a real problem unless it is accompanied by low reactivity.

- The Hardgrove Grindability Index is a tool developed for boiler designers and now used in a commercial manner to specify coals.
- While being developed from the original work of Hardgrove, standards for measurement of HGI, from different countries, differ in detail and result in commercially significant apparent differences in the value for a specific coal. In particular ASTM values can be greater than AS values on the same coal sample.
- HGI is recognized as having some deficiencies, however it is seen to be generally effective for internationally traded coals. It becomes less reliable particularly when the moisture content in the coal is above 10%.
- HGI is a highly non linear measurement, the difference in mill capacity for coals with 40 and 50 values is great while the difference between 90 and 100 is almost negligible.
- Low HGI coal with reasonable reactivity need not be pulverized to as fine a state and will provide fewer operating limitations. Low HGI value is not a real problem unless it is accompanied by low reactivity, needing coal finer than normal industry values.
- The combination of low HGI and low reactivity may limit the market for this coal. A high proportion of Australian coals have HGI values which conform to international coal specification requirements.
- Some international buyers have power stations with insufficient boiler furnace volume and insufficient pulverizer capacity to operate at full load with HGI less than a known value. In these cases full load can still be obtained by putting the spare mill into service.
- Some international power stations are unwilling or unable to adjust the operation of their mills to take advantage of available competitive coals or to compensate for minor deficiencies in coal properties. These utilities prefer to leave their mills at constant settings and purchase coals with a limited range of properties. Other utilities seek to optimize the mill performance at all times and can purchase coals with a broader range of properties at more competitive prices.
- Coal exporters need to be aware of the differences between HGI tests particularly if their coal is close to the acceptable limit for that facility.
- Performance guarantees for coal pulverisers are part of a typical boiler contract. Where coal properties are not well enough defined, the correction curves for performance, including HGI, may be unnecessarily conservative

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