Investigation of factors influencing the attrition breakage of coal

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Journal Paper

Synopsis

The presence of fines (particles smaller than 6 mm in diameter) causes hydrodynamic problems in gasifiers and therefore it is of great importance to minimize the amount of fine coal in the feed. This serves as motivation for understanding coal's breakage mechanisms, which could lead to the ability to predict the generation of fines.

The aim of this project was to simulate the pulsating effect of the conveyor belt in order to investigate factors influencing the breakage.

Results indicated that an increased initial particle size had an increasing effect in the amount of fines generated. Weathering had an insignificant effect on the breakage of coal. To conclude, a breakage model was developed to describe the rate of breakage out of the top size when a combination of two breakage modes is present.

Introduction

Coal is transported on conveyor belts several kilometres long from neighbouring mines to be fed into power stations, steam generators and gasifiers. The coal fed to gasifiers needs to be of a high quality for optimum conversion. To explain these requirements, a brief description of a gasifier is given.

Approximately 8 tons of coal at a time is fed into a compartment at the top of the colossal steel construction (known as a coal lock) from a conveyor belt. After loading the coal, the lid is closed tightly and before the bottom of the lock is opened to feed coal to the body of the gasifier, a gas is fed into the lock. The gas helps to maintain the high pressure that has been built up by feeding high pressure and high temperature steam and oxygen into the gasifier. Raw synthesis gas, produced by gasifying the coal, is fed to reactors for further treatment.

To have all that happening in a reliable and stable fashion demands several things of the coal. The foremost important property is the particle size: the lumps must be between 5 and 100 mm. If the particles are smaller than 5 mm, they could get carried upwards in the rising gas and are very difficult to remove. Once these fines coalesce in the fire bed, they create areas of greater resistance to the flow of the gas. Particles greater than the suggested top size of 100 mm tend to roll towards the periphery of the gasifier, which creates inconsistencies in the bed's overall resistance to gas flow. Furthermore, fine coal is difficult to transport, expensive to clean and dewater, and therefore leads to higher costs.

In the recent years utilization of mechanized mining methods had an increasing effect on the amount of fines produced. A significant amount of coal is lost during handling and it is therefore important to understand the breakage mechanisms of coal. With a good understanding of the breakage mechanisms of coal, it can be possible to predict the generation of fines. This can in turn lead to the development of process conditions and precautions to minimize the generation of fines and optimum usage towards the gasifiers.

During transportation, the idler rollers of the conveyor belts cause the coal to experience a pulsating effect. It is assumed that these pulses lead to breakage through attrition. Previous studies have shown that the tumbling test allows unique opportunities for understanding the breakage mechanism of coal, especially breakage by attrition (Sahoo and Roach, 2005). It is suggested that the experimental results from this project will display similar characteristics.

Mechanisms of breakage

If a stress applied to a particle is bigger than the fracture strength of the particle, the particle will fracture. The nature of the particle and the manner in which the force is applied to the

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particle, determines the way the particle breaks. The size of a lump of coal can be reduced by two main mechanisms, i.e. impact and attrition.

Figure 1 depicts impact breakage where the energy applied to the particle was greater than the fracture energy of the particle. The particle fractures along the line of weakness to produce a large number of fragments with a wide spectrum of sizes.

When insufficient energy to cause significant fracture is applied, attrition or abrasion occurs. Attrition occurs when two hard surfaces rub against each other and slowly grind away the surfaces. This is also known as shear force or localized stressing. Abrasion results in a distribution of very fine and very coarse products. Figure 2 indicates the smooth edges of particle that was subjected to attrition.

Experimental

The pseudo conveyor apparatus consists of a deep container mounted on a sieve shaker, displayed in Figure 3. The container consists of a cylindrical barrel with a diameter of 45 cm. It is made out of mild steel with a 3 mm rubber lining, replicating a conveyor belt. A mild steel lid with a rubber gasket seals the barrel by means of six bolts in radial order.

Madison test sieves were employed to determine the particle size distribution. The sieve series is based on the international series having a ratio of √2 as recommended by the International Standards Organization. The sieves used can be seen in Figure 4. Hand sieving was resorted to, since using a sieve shaker will cause only more undesired breakage.

The sample was initially sorted into different sizes by passing it through a series of 8 screens with aperture sizes ranging from 75 mm to 6.7 mm, as listed in Table I. Size fractions were carried over to containers and sealed airtight for storage.

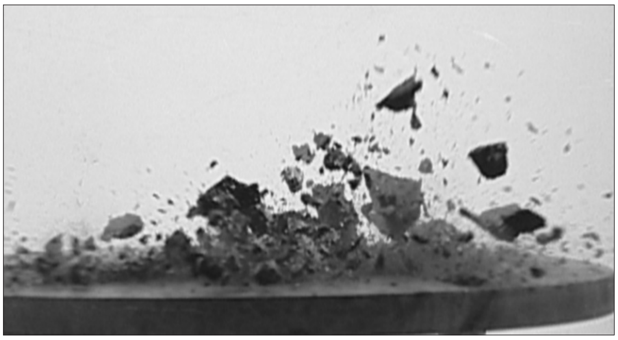

Figure 1—Impact breakage

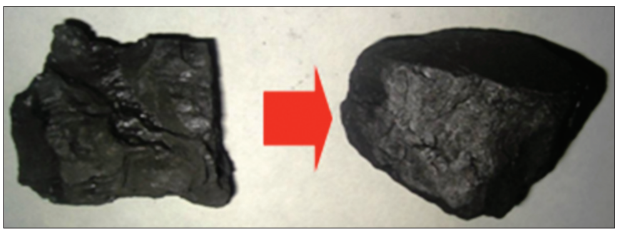

Figure 2—Smooth edges of particle subjected to attrition breakage

Figure 3—Pseudo conveyor apparatus

Figure 4—Sieve series

Table I

Sieve series

Size ranges (mm)		Bed depth
-9.5	+ 6.7	20.1 mm
-13.2	+ 9.5	28.5 mm
-19	+ 13.2	39.6 mm
-26.5	+ 19	57 mm
-37.5	+ 26.5	79.5 mm
-53	+ 37.5	112.5 mm
-75	+ 53	159 mm

One day prior to the experiment, the samples were wet sieved using tap water. Wet sieving was employed because of the adherence of very fine particles to larger particles as a result of surface tension arising from small amounts of moisture.

After overnight drying, the samples were screened again to remove the fines generated by washing. The required amount of coal from a specific size range was weighed and put into the steel drum.

Experiments were done to investigate the effect of the initial particle size of the coal, as well as the effect of weathering on the breakage of the coal.

The experimental duration was established in 2007 by Wiese and Louw who conducted similar experiments. They found that the amount of fines increase rapidly after 1 minute and from there on breakage is less abrupt. It takes approximately 20 minutes to reach steady state attrition fracture and if attrition keeps on taking place, all the oversize particles will degrade completely.

Effect of initial particle size on breakage

In order to determine the rate of breakage out of a specific top size, the one-size-fraction technique, as described by Austin *et al.* (1984, p. 63), was employed. Coal from a specific size interval was weighed and placed in the steel drum until the specific bed depth for that size interval was reached. The drum was enclosed by a lid and six bolts in radial order to prevent loss of coal fines. The sample was pulsed at a constant frequency and stopped after each predetermined time interval (3, 5, 10, 15 and 20 minutes). After each time interval, the material was removed from the drum and carefully screened to prevent further breakage. The material was removed from the drum by means of hands, a dustpan and brush and a handheld vacuum cleaner. Different screen fractions of coal were weighed to determine the new particle size distribution after each time interval. After weighing, the total sample, including fines, was returned to the drum for the next time interval.

Effect of weathering on breakage

In order to determine the effect of weathering on coal, four samples from the -53 mm to +37,5 mm size interval was prepared. The samples were weighed and stored in an oxidative environment for different time intervals (24 hours, 1 week and 1 month). At each time interval, an attrition test was conducted in a similar manner as described previously.

Results

The size interval -9.5 mm +6.7 mm produces 14% fines (particles smaller than 6.7 mm) and the percentage fines produced by the other size intervals range, from 3% to 4.5% as can be seen from Figure 5. Smaller particles have a larger surface available for attrition breakage, thus they will produce more fines.

Effect of initial particle size on breakage

In using the one-size-fraction to isolate the breakage out the top size, initial particle size from seven intervals, ranging between -53 mm and +6.7 mm, were used. The mean fractions were computed for each size interval and plotted on a graph in Figure 6. (The lines were added for readability.)

The breakage out of the initial size increases with increasing size, as noted by Figure 6. A 20% difference was noted between the smallest and the largest interval tested. The initial rate of breakage (primarily impact) is higher for the larger coal particles. Larger particles are more likely to contain larger cracks and thus are more susceptible to breakage on impact. It could also be due to the fact that the larger particles need less energy than smaller particles to degrade in size.

Effect of weathering on breakage

In using the one-size-fraction to isolate the breakage out the top size, coal samples from the size interval -53 mm + 37.5 mm, were wet sieved and left in an oxidative environment for different lengths of time. The mass percentage in each size interval wasere computed for each time length and plotted on a graph (Figure 7).

As can be seen from Figure 7 there is no significant difference between the samples that were left in an oxidative environment and the sample that did not undergo any weathering. The sample that was not exposed to air prior to the experiment produced 3.8% fines (<6.7 mm) with 77.5% recovered to the original size. The sample that was left in an oxidative environment for 1 month generated 5.8% fines and 73.3 % of the sample was recovered to the original size after the 20 minute experiment. In addition to these results, no significant structure deterioration was noticed. This is a very different result from that found by Wiese and Louw (2007)

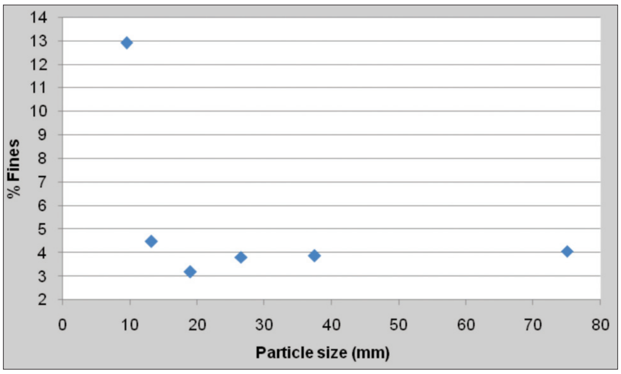

Figure 5—Percentage fines produced for different size intervals

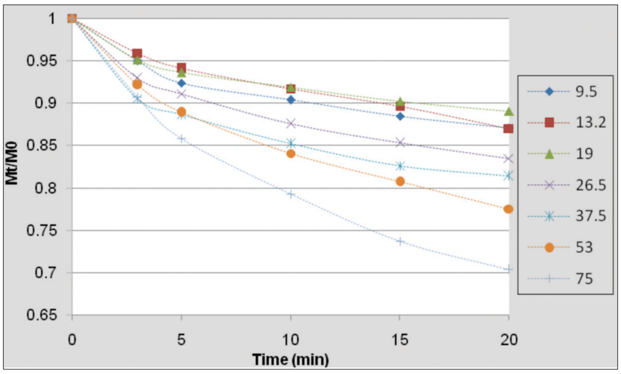

Figure 6—Effect of initial particle size on breakage

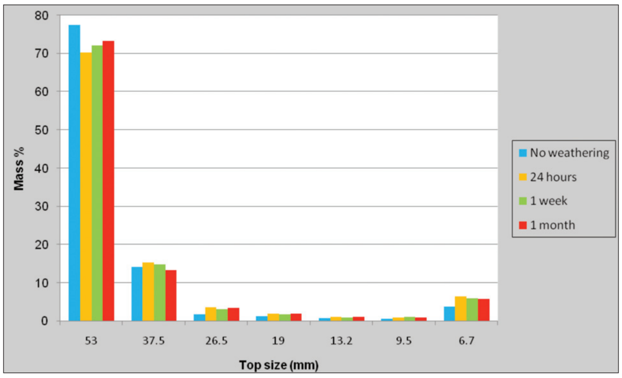

Figure 7—Particle size distribution for weathering samples

on a different coal. Wiese and Louw found that when coal from mine A is wet sieved and exposed to air for a time period, less than 50% is recovered to the original size. Results from the attrition tests carried out on the weathered samples in this investigation demonstrate that the strong structure of the type B coals was preserved.

Development of the breakage model

Since first order breakage has a breakage rate constant (s), double action breakage needs a breakage rate constant for both impact and attrition breakage.

Breakage via impact

The rate at which mass is lost from a single size fraction undergoing breakage can be expressed by the following equation:

$$\frac{dM}{dt} = -s_1 M \qquad [1]$$

where M is the mass of the coal sample remaining in the given size fraction after breakage; s_1 the impact breakage rate constant (min^{-1})for the given size fraction, and t the time succeeded in the breakage process. The initial assumption is made that the breakage is of first order with only impact causing size reduction.

Equation [1] is integrated with M_0 the initial mass of the coal sample and Equation [2] shows the formula obtained:

$$\ln\left(\frac{M}{M_0}\right) = -s_1 t \qquad [2]$$

Further simplification of Equation [2] yields:

$$\frac{M}{M_0} = e^{-s_1 t} \qquad [3]$$

Equation [3] defines the mass fraction that is left in the top size of the original feed after size degradation by means of impact.

Breakage via attrition

A similar approach as in the previous section for the mass loss rate of a particle undergoing attrition can be derived. The final mass fraction in the top size after time t is given by:

$$\frac{M}{M_0} = e^{-s_2 t} \qquad [4]$$

where s_2 is the attrition breakage rate constant (min^{-1})for the given size fraction.

Simultaneous attritions and impact breakage

During the handling process, both impact and attrition will contribute to size reduction. Parameter A is introduced and Equation [3] and Equation [4] are combined to form Equation [5].

$$\frac{M}{M_0} = Ae^{-s_2 t} + (1 - A)e^{-s_1 t} \qquad [5]$$

The fraction contributed by attrition breakage for the mass loss rate is denoted by A, and thus (1-A) is the fraction contributed by impact.

This equation fits all data obtained and the parameters obtained are listed in the Table II.

The high values of A are indicative of the high contribution of attrition to breakage.

Raw data from the interval -37.5 mm +26.5 mm, together with the model are plotted in Figure 8.

It can be seen that the model is a near perfect fit for the experimental data obtained.

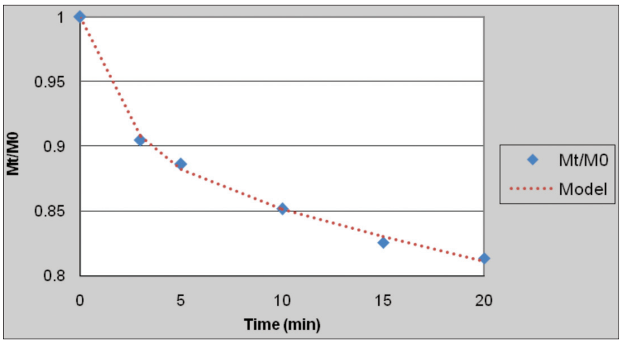

Figure 8—Comparison between model and experimental data

Table II

Breakage parameters for different size intervals

Top size (mm)	9.5	13.2	19	26.5	37.5	53	75
A	0.92550	0.96406	0.94450	0.91592	0.89132	0.90156	0.84663
s_1 (min^{-1})	0.30590	0.49869	0.44896	0.36786	0.44230	0.30607	0.20785
s_2 (min^{-1})	0.00303	0.00505	0.00297	0.00469	0.00473	0.00754	0.00952

Effect of initial particle size on the breakage model parameters

The effect of initial particle size on breakage has been discussed earlier. In this section it is aimed to provide a quantitative comparison.

Parameter A

The attrition contribution parameter A is plotted as a function of particle size in Figure 9. A negative linear relationship is displayed. It shows that with increasing initial particle size, attrition plays a smaller role. This confirms the previous discussion, concluding that larger particles are more likely to contain larger cracks and thus are more susceptible to breakage on impact.

Impact breakage rate constant: s_1

Figure 10 show a weak negative linear relationship between the impact breakage constant and particle size. The rate of breakage due to impact appears to decline with increasing particle size. This can be attributed to the mechanical strength of the type B coal. Larger lumps of coal need more energy to break into smaller pieces and therefore the rate at which impact breakage takes place decreases with increasing particle size.

Attrition breakage rate constant: s_2

Figure 11 displays the rate of breakage by attrition as a function of particle size. It shows a positive linear relationship where the rate of attrition increases with increasing particle size. This is in contrast with the experimental results obtained, which show that larger particles produce fewer fines.

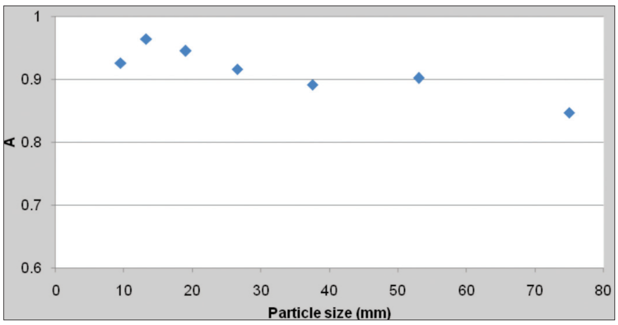

Figure 9—Effect of initial particle size on parameter A

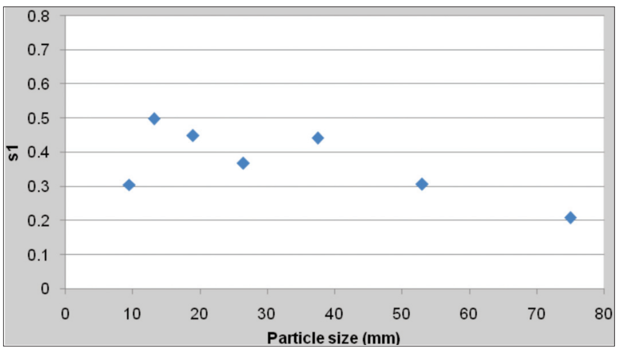

Figure 10—Effect of initial particle size on impact breakage constant s_1

Error margins and sensitivity analysis

Due to the fact that questionable results were obtained for the model parameter, s_2, a sensitivity analysis was completed to test the accuracy of the model.

Three test runs were completed for each size interval and the average values obtained were used to determine the parameter values. To determine the error margin on each parameter, the model were fitted for each individual test and compared to the average parameter value. The error margins on parameter A range between 0% and ±5%, between 0% and ±45% for parameter s_1 and for parameter s_2 it ranges between 0% and ±80%.

There are several reasons for this margin of error including human errors during hand sieving. There could be measuring errors on the laboratory scale. Even with the best of care being taken, some particles can be lost during handling between sieves and shaking drum.

Figure 12 shows the sensitivity of each parameter on the model for the size interval -37.5 mm + 26.5 mm. It can be seen that parameter A is the most sensitive to error. Parameter s_1 is not sensitive to error and parameter s_2 is only sensitive when the margin of error is very big.

The sensitivity analysis proves that the model used to fit the data, is not sensitive to error. This means that the model is underdefined; almost any value can be chosen for the parameters and the model will still show a near perfect fit for the data. This could explain why the experimental results show a decrease in fines production for an increasing particle size, while the attrition rate constant (s_2) shows an increase in fines production with increasing particle size.

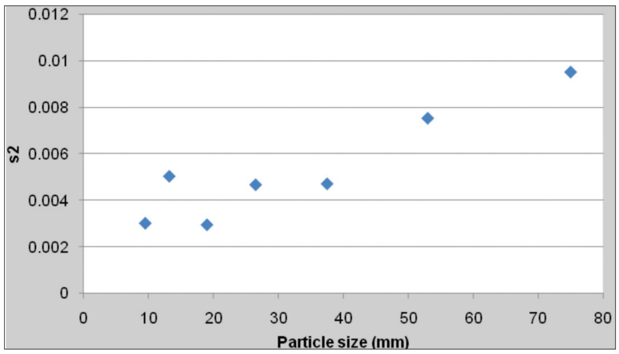

Figure 11—Effect of initial particle size on attrition breakage constant s_2

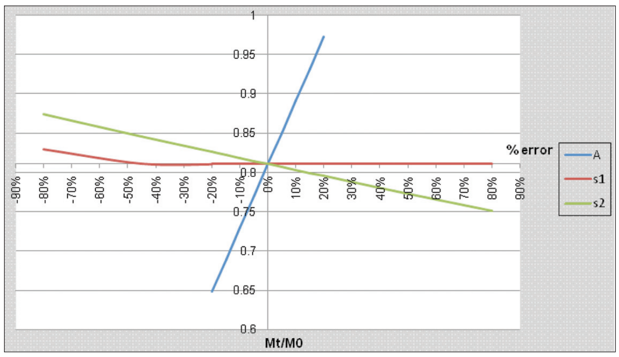

Figure 12—Sensitivity analysis on model parameters

Conclusions

Several factors were investigated, which can possibly influence the attrition breakage of coal. These factors, which include initial particle size and weathering, influenced breakage as follows:

- ➤ Increasing particle size showed a decrease in the generation of fines
- ➤ Weathering tests conducted, showed that it had no significant effect on the breakage of type B coal.

The double breakage model was used and parameters determined. The breakage parameters are influenced as summarized:

- ➤ Parameter A (attrition contribution) decreases with increasing initial particle size
- ➤ The impact breakage rate constant (s_1) decreases with increasing initial particle size
- ➤ Parameter s_2, which is the attrition breakage rate constant, increases with increasing initial particle size which is in contrast with experimental results.

The sensitivity analysis showed that the model is not sensitive to errors, which could explain the difference in experimental results and the model fitted to the data.

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