A Method of Calculating Autogenous/ 
Semi-Autogenous Grinding Mill 
Specific Energies Using a Combination 
of Bond Work Indices and Julius 
Kruttschnitt Parameters, then Applying 
Efficiency Factors

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ABSTRACT
Since the days of mandatory high cost pilot plant testing in 6 ft × 2 ft SAG mills autogenous 
grinding/semi-autogenous grinding (AG/SAG), mill specific energy is now calculated by various 
empirical formulae and pilot testing carried out in small laboratory mills. Barratt (1989) described 
a method using Bond Indices than adding a single factor of 1.25 to arrive at the AG/SAG specific 
energy. In 1991 the Canadians developed the SAGPower Index (SPI), test using 2 kg of material 
in a 300 mm diameter mill. This test has been further developed by Starkey, Hindstrom and Orser 
(2006). This test now includes a Bond Ball mill work index test.

The Macpherson test is still being offered by some testing facilities. This dry test requires at least 
180 kg of material.

Morrell (2004) formulated an AG/SAG specific energy generator based on a drop weight index 
Value (DWi). This DWi value is related to the Ab parameter and the material specific gravity. 
Morrell reconfigured the Bond’s Third Theory formula to cause extra power requirements to be 
inputed. This technique incorporates the material specific gravity (SG). The AG/SAG specific 
energy values produced using this method are susceptible to higher values of crushing and rod 
mill work indices.

This paper offers describes a more simple method to generate AG/SAG specific energies. 
This programme incorporates Bond work indices, the JKMRC parameter Ab measuring impact 
breakage and the parameter ta measuring the abrasion rate, then employs a series of efficiency 
values nominated for each transition size (AG/SAG T80). These efficiency values have been 
compiled over the years from actual operating plants and documented reports.

INTRODUCTION
Rotary mills have been found to be inefficient when grinding 
large hard material. Single stage balls mills, when processing 
hard to grind, large sized material incur an oversize inefficiency 
problem over and above the Bond oversize feed factor (EF4). 
Rod mills suffer from this inefficiency phenomenon and AG/ 
SAG mills mimic the same shortcoming.

It follows that in order to obtain the specific energy (SE) to 
achieve a certain transfer size, based on the 80 per cent passing 
value, an inefficiency factor must be applied to the SE of single 
stage ball mills, rod mills or AG/SAG mills when calculating 
power according to the Bond Third Theory method.

Rod mill and AG/SAG mill products are similar and tend to 
be not as steep as a 0.5 slope when plotted on log-log paper. 
This is because the particle size distribution (PSD), these mills 
produce have a coarse fraction but also a fine fraction which is 
not credited for in an 80 per cent passing assessment. A slope 
less than 0.5 depicts finer material and a slope greater than 0.5 
depicts coarser material where a slope of 0.5 equals a rise of 
one on the ‘y’ scale and two on the ‘x’ scale.

If the AG/SAG product size is assessed at the 80 per cent 
passing point as plotted on a log-log graph, then AG/SAG 
mills require more energy compared to the SE calculated 
using Bond rod mill work index (RMWI), and Bond ball mill 
work index (BMWI). However, the author has developed a 
relationship between the Bond third theory SE values and the 
AG/SAG SE values to enable the additional power required 
for AG/SAG milling to be determined.

AG/SAG inefficiency varies according to the transfer size 
(T80), whereby the finer sizes have less inefficiency than the 
coarser sizes. This means a closed circuit single stage AG/ 
SAG mill can operate at a reasonable efficiency if the final 
product is in the 75 μm range. Burgess (1991) stated that the 
AG/SAG inefficiency factors to be applied to Macpherson test 
results were 1.10/1.25 for closed circuit grinding and 1.40 for
an open circuit operation. This paper suggests the factors vary from 1.17 to over 2.5, depending on the transfer size.

Morrison et al (2011) stated that the Ab value generated from the drop weight tester (DWT) is equal to only 40 percent of the energy required by a SAG mill. Put another way, the SAG mill energy required according to this statement, is 2.5 times more than the Ab value to produce the same degree of particle breakage.

There is a specific gravity factor that affects AG/SAG power draw. The lighter material, in the 2.5 specific gravity (SG) range, will require more energy to grind to the same transfer size than an ore with a 3.5 SG. This fact is not evident in the JKSimMet Simulation software where only the Ab and ta parameters are inputted for the specific power calculation. The SG value is included, but only used for charge weight and volumetric flow calculations.

Morrell (2004), SE calculation is sensitive to SG values. One single Ab value can equal many different drop weight index (DWi) values depending on the SG of the ore.

In regard to the author’s method the ranges of T80 sizes are discussed relating to the various modes of comminution. This range covers crushing, DWi, Ab, rod milling and ball milling where different work index values are applied to each range to arrive at the Bond SE value. After applying the AG/SAG factor to the Bond SE value corrections are made for the SG, Ab values and low aspect (LA) mill configuration if applicable.

The final DB Consulting (DBC) AG/SAG SE calculation is based on an AG/SAG circuit without a pebble crusher.

Comparisons are made between the SMC and the author’s method of AG/SAG SE evaluations using examples. Two published graphs, relating to Ab and DWi values, are discussed highlighting the nature of their contents.

**ROD MILLS**

Rod mills are limited in size to 2000 kW because the longest commercial grinding rod available is 6 m long. For this reason rod mills are rarely selected in the present day environment of large AG/SAG mills and large ball mills. However, it is necessary to discuss their operation because a Rod mill product has a similar slope to AG/SAG mills. This product slope averages less than 0.5 when plotted on log/log paper and therefore contains an extra amount of fine material compared to a PSD, having a 0.5 slope. This fine material, when received by the following ball mill, gives a credit to the ball mill SE. When assessing the operating work indices using the plotted 80 per cent passing values the rod mill averages an inefficiency value in the region of 1.25 because the design 80 per cent passing value is not achieved. The ball mill usually assesses at an efficiency of 0.85 or better because the cyclone oversize P80 is achieved seemingly from an over coarse rod mill product. This then makes the efficiency of the total circuit close to or better than 100 per cent efficient.

An unpublished survey by Rowland (1976) regarding the Mt Isa No 4 concentrator in 1976 showed the 12.5 ft rod mills were operating at an average inefficiency of 1.25 and the 16.5 ft ball mills with an efficiency of 0.88.

A study carried out by the author in 2004 on the Worsley Alumina Rod/Ball Circuit Line No 1, showed efficiencies of 1.27 for the rod mill and 0.67 for the ball mill. The particle size distributions reported are shown in Figure 1. It follows that the No 1 rod mill/ball mill circuit was operating very efficiently when comparing the combined operating work indices for both mills with the rod mill and ball mill laboratory work indices.

Note, in Figure 1, that the rod mill product slope is less than 0.5 due to an extra amount of fines present being finer than 650 μm. These fines proceed to the ball mill improving the ball mill efficiency.

Also, the plotted rod mill P80 value, as shown in Figure 1, is 2900 μm. If the rod mill fines are taken into account the rod mill product can be theoretically corrected to show a P80 of 1700 μm, the plotted 80 per cent passing size divided by 1.7.

It should be remembered, Rowland and Kjos (1978), stated that if a rod mill is operating alone, an inefficiency factor of 1.2 should be added provided the mill feed is screen undersize. If the rod mill feed is produced from an open circuit crusher the factor to be applied increases to 1.4.

**SINGLE STAGE BALL MILLS**

Single stage balls add to the argument that rotary mills are not efficient when processing large hard material. If a single stage ball receives material of 80 per cent passing 6 mm and larger, then the Bond oversize inefficiency factor EF4, will apply even if the material has rod and ball mill laboratory work indices as low as 10 kWh/t and a reduction ratio as high as 30.

Actual cases are, the initial nine 18 ft ID × 21 ft EGL overflow ball mills installed at Bougainville in 1969. An unpublished survey by Rowland (1975) and inefficiency values calculated by Steane and Hinkfuss (1978), both calculated inefficiency values of 1.18 to 1.25. Rowland (1975), theorised the problem was low retention time averaging 0.85 minutes and Steane and Hinkfuss (1978), claimed the 18 ft diameter mill size was less efficient than smaller mills. However, the author argues the hard coarse ore was the culprit. It was surprising that the ball mill work index was averaging only 11.6 kWh/t, which is not hard. A rod mill work index figure was not found but was thought to be in the 16 kWh/t to 18 kWh/t range.

The Xstrata Zinc 22 ft ID × 40 ft EGL overflow ball mill was installed at Mt Isa in 2009. This mill was put into single stage service due to the installation of the original circuit, including a 32 ft SAG mill, being put on hold. This mill has been operating inefficiently due to the hard coarse feed. The rod mill work index has not been defined as yet. The ball mill work index is confirmed at 16 kWh/t. The operating work index, though, is in the range of 21 kWh/t to 25 kWh/t showing high inefficiency.

This raises the point that, in some cases, the Bond EF4 oversize factor calculation is not sufficient to compensate for the milling inefficiencies that arise. This can result in the mill being undersized. To counter this problem it is recommended that the rod mill work index is used for the bond Fo, the optimum feed size calculation, and the highest
Some Australian companies use such methods. It is thought OMC, Lycopodium, Fluor, and Ausenco are helpful if available. The accuracy of this result will not be as reliable as having the full range of parameters available to be inputted into the calculation.

Several practitioners use empirical methods to calculate AG/SAG mill SE. OMC, Lycopodium, Fluor, and Ausenco are some Australian companies using such methods. It is thought that none of these companies have published facts and figures relating to their various energy programs, although OMC does compare the AG/SAG SE results with a $F_{sag}$ factor. The $F_{sag}$ factor is the difference between the SE for a conventional crushing, rod/ball circuit compared with the SE for a AG/SAG circuit. Julius Kruttschnitt Mineral Research Centre (JKMRC), JKSimMet simulation software does not explain how the Ab and ta parameters are transformed into AG/SAG SEs.

Morrell (2004), published the only program to date, that can be used to calculate AG/SAG specific power from laboratory parameters.

Barrett (1989) described a method that can be used as a guide to calculate AG/SAG SEs but only one inefficiency factor is used. This paper details a mathematical relationship between the Bond third theory SE and the AG/SAG SE values.

The DBC method is based on the AG/SAG mill transfer size (T80), being the actual 80 per cent passing size as plotted on a log-log graph and not the corrected 80 per cent passing, when taking into account the fines in the T80 PSD as depicted in Figure 1.

This method can also be used even if an Ab or a DWi value is not readily available by employing just the RMWI and the BMWI. The crushing work index (CRWI), value is always helpful if available. The accuracy of this result will not be as reliable as having the full range of parameters available to be inputted into the calculation.

Sherman (2011) described an interesting relationship between rod mill and AG/SAG mill breakage rates. This theory was closely linked to the current author’s method, whereby the RMWI is a key parameter.

The DBC method of generating AG/SAG SEs is by calculating the SE according to Bond’s Third Theory equation (Bond, 1961), then adding a factor to increase the power to equal high aspect (H/A) AG/SAG mill energy requirements. This calculation is based on a SG of 2.78 t/m³ and an Ab value of 40.

In order to calculate a SE value by the DBC method, the Bond calculation is divided up into comminution ranges. These consist of crushing to 25 mm, the Ab drop weight value converted to a RMWI to 3 mm, rod milling from 3 mm to 1 mm then ball milling the remainder to the T80 value where 75μm is considered to be the finest. Assessment is made of the ta value, if available, which is taken as an extension of the ball milling area.

Depending on the transfer size, the resulting Bond SE in kWh/t at the pinion is multiplied by the appropriate AG/SAG factor (refer to Figure 2). The resulting power is adjusted depending on the SG and Ab values of the material being assessed.

A conversion of Ab and ta values to Rod mill and Ball mill work indices are achieved by using the formulae suggested by Julius Kruttschnitt Mineral Research Centre (JKMRC) in the publication Mineral Comminution Circuits: their Operation and Optimisation (Napier-Munn, 1999). However, the author has modified the Ab calculation to better reflect the relationship between the Ab and the RMWI range of comminution. This is because the Ab parameter is more related to rod mill grindability as the JK drop weight index (DWi), P80s range from approximately 15000 μm down to 3000 μm. The Ab parameter therefore, does not directly relate to BMWIs as the P80 range for ball milling is much less.

It follows that, to comply with the DBC method, the Ab value must be converted to a RMWI value (refer to Figure 3).

Similarly, the ta value must be converted to a BMWI value (refer to Figure 4).

**FIG 2 - Autogenous/semi-autogenous DBC Consulting factors for material with a specific gravity of 2.78 and an Ab of 40.**

**FIG 3 - Conversion of JK Ab to Bond ball mill work index values and JK Ab to DB Consulting Bond rod mill work index values.**

**VARYING LABORATORY PARAMETERS**

Problems evaluating AG/SAG mill SEs occur when the converted Ab values are not close to the laboratory RMWI values. These cases arise when the Ab converted value is low and the RMWI value is high causing a higher AG/SAG SE
than when using only the converted Ab value. The opposite is true when the Ab converted value is higher than the RMWI value.

In these cases the Process Practitioner must make a judgement as to the best approach to achieve a reliable AG/SAG mill SE value.

Figure 2 shows the factors required to convert Bond SE to AG/SAG SE depending on the T80 value required. The factors are based on a SG of 2.78 and an Ab of 40.

Figure 3 shows a graph for converting Ab values to RMWI values. The JK graph has been modified by the author to better reflect a more realistic RMWI value.

Figure 4 shows the relationship for converting ta values to BMWI values.

Figure 5 depicts the Bond SE values plotted from 750 μm to 2500 μm T80 values calculated from the parameters shown on the graph. The efficiency factors from Figure 2 have been applied according to the DBC method to generate the AG/SAG SE values. Note how the two curves have similar slopes.

An example is shown in Figure 6 where AG/SAG SEs are calculated for T80s of 750 μm to 75 μm based on the input parameters shown on the graph. Note how the two curves become near parallel when the T80 is equal to and greater than 250 μm.

Figure 7 shows Figure 6 with the addition of a graph calculated by the SMC method using the same parameters. In this case the DBC and SMC curves are almost identical.

VARIATIONS IN SPECIFIC ENERGIES DUE TO DIFFERENCES IN SPECIFIC GRAVITIES

Another problem arises with a variation in the SG of the material to be assessed.

The DBC method is based on a nominal SG of 2.78 t/m³ with a bulk density of 1.67 t/m³. If the material being assessed has a different SG value then a correction factor must be applied. The Bond SE power is calculated from the F80 down to a P80 of 750 mm and the factor taken from Figure 2 applied.

The correction formula is:

\[
\text{SG factor} = \text{AG/SAG SE (at 750 mm)} \times (2.78/\text{SG})^{0.23} - \text{AG/SAG SE (at 750 mm)}
\]

The reduction or addition of SE is then added to, or subtracted from, the final AG/SAG SE power. The increase or decrease can be as much as 7.8 per cent for SGs varying from 2.0 to 3.85.

Figure 8 shows the difference in specific energy varying from a SG of 2.78 to a SG of 2.0 and from a SG of 2.78 to a SG of 3.85. The higher the specific gravity the lower the specific energy required and vice versa.
A METHOD OF CALCULATING AUTOGENOUS/SEMI-AUTOGENOUS GRINDING MILL SPECIFIC ENERGIES

COMMMENTS ON HOW EXISTING TEST METHODS ADJUST FOR VARIATIONS IN SPECIFIC GRAVITY

SMC method

The SMC method converts Ab values by dividing the SG by the Ab value then multiplying by 100. The SMC AG/SAG mill operating work index (SAGOWi), value is then selected based on the DWi value which has the units kWh/m³. This is converted to kWh/t by dividing the SAGOWi by the SG of the material to achieve the Mia value which is the SMC AG/SAG work index which has the units kWh/t. This process causes the Mia value to vary with the SG to the point where a low SG results in a higher Mia value and a higher SG results in a lower Mia value.

JKSimMet specific gravity adjustment

As far as the author is aware, the Ab value used in a JKSimMet simulation is not corrected for the SG effect to fine tune the AG/SAG specific energy. JKSimMet does calculate the charge mass and mill power with varying densities but does not show an increase or decrease in SE for variations in SGs. This is because the Ab is calculated in t/kWh and not in kWh/m³ as per the DWi method.

Starkey method

Starkey, Hindstrom and Orser (2006) state that less SE is required as the SG increases to achieve the same amount of comminution and more energy is required if the SG reduces. In other words the target P80 of 1700 μm takes less energy, as the SG increases in value and more energy is required if the SG reduces.

Pilot testing method

Pilot mill testing corrects for the SG as the mill charge is sensitive to weight difference, which reflects in a mill power draw increase or decrease.

Macpherson test method

The Macpherson test (Macpherson, 1989), corrects for the SG as the mill charge is sensitive to weight difference, which reflects in a mill power draw increase or decrease.

ADJUSTMENT REQUIRED DUE TO AB VARIATION

The DBC method is based on an Ab of 40. Should the ore being assessed be harder or softer than Ab of 40 then an adjustment is made according to Figure 9 for T80s less than 150 μm.

COMPARISONS OF SPECIFIC ENERGIES BETWEEN THE DBC AND THE SMC METHODS

Example 1 – soft ore

The input criteria:
- AG/SAG mill SE grinding from a F80 of 150 000 μm to product size T80 of 80 per cent passing 75 μm
- CRWI - 7 kWh/t
- Ab = 70 RMWI equivalent = 13.08 kWh/t (refer to Figure 3)
- RMWI - 13.0 kWh/t
- BMWI - 13.0 kWh/t
- ta = 0.63 (used only as a guide in the calculation)
- BMWI equivalent = 13.0 kWh/t (refer to Figure 4)
- SG - 2.5

DBC method

- Bond SE 14.62 × factor of 1.18 (from Figure 2) = 17.25 kWh/t
- DBC SE = 17.25 kWh/t AG/SAG mill SE at the pinion at 2.78 @ SG
- Corrections for SG - SE to 750 μm = (6.92 × (2.78/2.50) 0.23) - 6.92 = +0.171 kWh/t
- AG/SAG S.E = 17.25 + 0.171 = 17.42 kWh/t
- Ab correct for T80 below 150 μm is (70/40) 2.3 = 3.62 per cent less power (refer to Figure 9)
- SE for the operation = 17.42/1.0362 = 16.81 kWh/t.
**SMC method**
- DWi = 3.571 kWh/m³
- Mia = 13.02 kWh/t
- SE at 750 μm = 7.09 kWh/t
- Mib = 17.56 kWh/t (Mib is the AG/SAG fine material work index derived from a BMWI of 13.0 kWh/t)
- SE at 750 μm to 75 μm = 9.73 kWh/t
- SE for the operation = 16.82 kWh/t.

**Comment**
Both the results are similar. As the converted Ab value of 70 equals 13.08 kWh/t it is very close to the RMWI and the BMWI values of 13.0 kWh/t. This means the converted Ab value is taken through the comminution range from 150 000 μm to 75 μm in both cases.

**Example 2 – medium-hard ore**
The input criteria:
- AG/SAG mill SE grinding from a F80 of 150 000 μm to product size T80 of 80 per cent passing 107 μm
- CRWI - 13.54 kWh/t
- Ab - 50 = RMWI EQUIVALENT = 16.93 (refer to Figure 3)
- RMWI - 16.93 kWh/t
- BMWI - 14.85 kWh/t
- Ta - 0.53 (used only as a guide in the calculation)
- BMWI equivalent = 14.85 kWh/t (refer to Figure 4)
- SG - 2.78.

**DBC method**
- Bond SE 14.44 × factor of 1.2 (refer to Figure 2) = 17.32 kWh/t
- SG correction N/A
- Ab - 50 correction factor is minus 1.68 per cent (refer to Figure 9)
- SE for the operation = 17.32/1.0168 = 17.034 kWh/t.

**SMC method**
- DWi = 5.56 kWh/m³
- Mia = 16.49 kWh/t
- SE to 750 μm = 8.98 kWh/t
- Mib = 18.5 kWh/t (derived from a BMWI of 14.8 kWh/t)
- SE at 750 μm to 75 μm = 8.19 kWh/t
- SE for the operation = 17.16 kWh/t.

**Comment**
The results are very close. The converted Ab value of 50 equals 16.93 kWh/t. This value is the same as the RMWI value. However, the BMWI value is less at 14.8 kWh/t. The DBC calculation takes the Ab value through the comminution range from 25 000 μm to the rod mill F80 value of 3000 μm. The remaining calculation is ball milling from a F80 of 1000 μm at 14.8 kWh/t to a P80 of 107 μm. The two results are similar because the only difference is that the SMC calculation took the coarse range Mia, to a T80 of 750 μm whereas the DBC method reverts to the BMWI at a F80 of 1000 μm.

**Example 3 – hard ore**
The input criteria:
- AG/SAG mill SE grinding from a F80 of 150 000 μm to product size T80 of 80 per cent passing 750 μm
- CRWI - 17.80 kWh/t
- Ab - 35 = RMWI equivalent = 22.26 (refer to Figure 3)
- RMWI - 18 kWh/t
- BMWI - 16 kWh/t
- ta - 0.48 (used as a guide only in the calculation)
- BMWI equivalent = 16 kWh/t (refer to Figure 4)
- SG - 3.5.

**DBC method**
- Bond SE 6.51 × factor of 1.6 (from Figure 2) = 10.42 kWh/t
- DBC SE = 10.42 kWh/t AG/SAG mill energy at SG of 3.5
- Correction for SG SE to 750 μm = (10.42 × (2.78/3.5) o.23) - 10.42 = -0.537 kWh/t
- SE for the operation = 10.42 - 0.537 = 9.88 kWh/t
- Ab factor is plus is 1.36 per cent (refer to Figure 8)
- SE for the operation is 9.88 × 1.0136 = 10.01 kWh/t.

**SMC method**
- DWi = 10.00 kWh/m³
- Mia = 20.62 kWh/t
- SE to 750 μm = 11.23 kWh/t.

**Comment**
The SMC AG/SAG SE is 12 per cent higher than the DBC AG/SAG SE. The CRWI at 17.8 kWh/t accounts for more than two per cent of this difference compared to using a CRWI of 22.26 kWh/t. The Ab converted equivalent RMWI is 22.26 kWh/t, whereas the RMWI is stated at 18 kWh/t. The BMWI is lower again at 16 kWh/t. The SMC method takes the Mia of 20.62 kWh/t down to a T80 of 750 μm, whereas the DBC method uses the Ab converted value to a P80 of 3000 μm. Then the DBC calculation used the RMWI of 18 kWh/t to a P80 of 1000 μm before employing the BMWI of 16 kWh/t to finish at a T80 of 750 μm. This is a good example of SE differences in the SMC and DBC values due to the equivalent Ab RMWI value differing from the RMWI and BMWI.

As the RMWI and the BMWI values are lower than the Ab equivalent kWh/t value the lower AG/SAG SE value of 10.01 kWh/t pinion shaft power is more accurate.

The difference with the SMC approach compared with the DBC method is that the SMC specific energy calculation only varies with the Ab and the SG for the coarse section of the calculation down to a T80 of 750 mm, whereas with the author’s approach the SE can vary according to the values of the CRWI, the converted Ab, and RMWI.

**COMMENTS REGARDING CURRENT LABORATORY TESTING METHODS**

**Drop weight test product sizes**
Kojovik and Shi (2011), states the rotary JK drop weight test (JKDWT), crushes material in the size range of 50 to 16 mm. The resulting PSD for the percent passing one tenth of the original size (T10), are in a range of 20 per cent to 50 per cent and the 80 per cent passing values are in a range of 3 mm to 15 mm (refer to Figure 10).

In other words this test does not investigate the energy required to reduce material below the 3 mm product range. It would appear that this could be the reason the SMC method reverts to using BMWIs when calculating transfer sizes smaller than 750 μm. Also, the JKDWT does not cover the energy required to reduce the coarse range from an average primary crusher product of 80 per cent passing 150 mm down to 63/13.2 mm, the JKDWT feed sizes.

To develop an energy register for finer sized products a drop weight tester is required with the ability to crush small pieces in the 5 mm to 3 mm range.
Starkey SAGPower test
The Starkey SAGPower procedure found that to cover the energy required for grind sizes less than a P80 of 1700 μm, some of the test mill product must be used to generate a BMWI value. This BMWI is then employed to calculate the SE required for the fine section of the grind. This SE is added to the SAGPower SE obtained from the SagPower test to arrive at the total power required. The Starkey SAGPower test does not calculate the energy required to reduce the coarse section from an average primary crusher product of 80 per cent passing 19 mm, the phantom cyclone approach. Although this method goes on to describe this phenomenon. However, it is far safer to leave the Ball mill operating work index to an efficiency factor to obtain the crushing power to equal the operating work index to an efficiency factor to obtain the crushing power to equal the timer required. This SEMC is then multiplied by the T80 size involved in this statement is in the range of 3 mm to 15 mm. Details of a method to convert Ab values into AG/SAG specific energy values are few. Morrison et al. (2011) states that AG/SAG mills need about 2.5 times as much energy compared to a DWI value to generate a similar PSD. In other words, an AG/SAG mill is only 40 per cent efficient compared to a DWI. The author assumes that the T80 size involved in this statement is in the range of 3 mm to 15 mm. Details of a method to convert Ab values into AG/SAG specific energy values are few. Morrison et al. (2011) states that AG/SAG mills need about 2.5 times as much energy compared to a DWI value to generate a similar PSD. In other words, an AG/SAG mill is only 40 per cent efficient compared to a DWI. The author assumes that the T80 size involved in this statement is in the range of 3 mm to 15 mm.

Working from the ball mill power back to the autogenous/semi-autogenous specific energies
The PSD from an AG/SAG mill does not follow a 0.5 slope. The average slope is less steep. This means more energy has been inputted into this material, making it easier to grind to a required finer product size when assessing the actual 80 per cent passing value against the corrected value. A ball mill that follows an AG/SAG mill can be reduced in size to allow for this phenomenon. However, it is far safer to leave the Ball mill at the original size calculated, using the uncorrected T80. McKen, Raabe and Mosher (2001) suggested a method to compensate for the shallower slope of the PSD by correcting the AG/SAG T80 value. McKen, Raabe and Mosher (2001) also suggested that the average real T80 is 2.5 times smaller than the measured T80. Also, this method goes on to describe the phantom cyclone approach. Although this method compensates for the reduction of tonnes per hour to the ball mill by increasing the F80 of the scalped material, it does not suggest a method of increasing the material grindability value. This increase in hardness occurs due to the fact that the larger material has survived the AG/SAG process and, therefore, must be harder to grind than the original feed material.

One way to find the true AG/SAG T80 is to set the ball mill operating work index to an efficiency of 100 per cent. Knowing the ball mill circuit F80, the ball mill SE kWh/t value and the BMWI value, the ball mill F80 can be back calculated. This, then, is the corrected transfer size from the AG/SAG mill. The AG/SAG mill T80 should aim at this value times 1.70. This coarser transfer size will then produce the correct F80 to be fed to the ball mill.

FINE SEMI-AUTOGENOUS MILL FEED SIZES
When proposed SAG mill feed sizes are reduced as fine as 30 mm to 25 mm the AG/SAG mill mode of grinding changes from SAG mill to a single stage grate discharge ball mill operation. This has been observed especially with LA SAG mills where the mill feed is so fine there is no large rock present to act as media. Mill operators then load up the mill with balls to make tonnage and grind converting the SAG mill to a grate discharge ball mill.

It is suggested that if contemplating using SAG mill process power calculations when confronted with fine feeds, consider using ball mill SE and ball mill power calculations to size the mill if the feed size is 30 mm or less.

COMMENTS ON PUBLISHED DROP WEIGHT INDEX VERSUS AB CURVES
Figure 11 shows SMC DWi values plotted against JK Ab values. This graph is a guide only and relates in general to the relationship between DWi and Ab values. As stated in this paper the DWi varies with the SG value for the same Ab value. Therefore, when comparing an Ab value with a DWi value the SG value must be known. In other words there are separate DWi/Ab curves for different SG values.
than the converted Ab parameter, the resulting SE will be transpired that if the laboratory RMWI has a higher value a close correlation between the two methods. However, it shows that the method are described in the paper. These comparisons show a close correlation between the two methods. However, it transpired that if the laboratory RMWI has a higher value than the converted Ab parameter, the resulting SE will be higher. Conversely, if the laboratory RMWI is lower, the AG/SAG mill SE will be lower.

It was found that the AG/SAG SE calculation is sensitive to variations in SG and the Ab values. The DBC method requires corrections to be made to the AG/SAG SE if the one S,G varies from 2.78 t/m³ and the Ab value of 40. A third correction is required if a low aspect mill is being considered. Although the author has developed this method over a number of years, further refinement of the method will continue.

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CONCLUSIONS

It has been stated on several occasions that scaling up from Bond third theory SEs to AG/SAG SEs was not possible. This paper describes a mathematical relationship that the author has found to exist between the Bond third theory SE calculation and AG/SAG mill SE requirement.

The method describes a quicker, cheaper, way to evaluate AG/SAG SE values compared to other methods such as the SMC method, where the parameter Mia is proprietary and is only available through SMC sources. The DBC method described in this paper has resulted in a robust set of calculations, without restrictions, that can be used by Process Practitioners with confidence, when assessing AG/SAG mill SE requirements.

The DBC method expands the current available methods of calculation using solely the DWi, Ab and ta parameters by providing a more comprehensive assessment of the power required by incorporating CRWI, RMWI and BMWI parameters.

This manuscript has explained how AG/SAG mill SEs can be obtained from laboratory work indices using the DBC method. Even if an Ab or a DWi parameter is not available, an AG/SAG mill SE can still be developed using only the RMWI and BMWI values and then applying a correction factor according to Figure 2.

As the Ab value only covers the coarse range of comminution, it follows that because AG/SAG products finer than 3000 μm are usually required, then the AG/SAG mill SE should be calculated incorporating the actual RMWI and BMWI values generated from the material to be assessed as well as the Ab or DWi parameters.

In order for an AG/SAG SE calculation to be made Ab and ta parameters must be converted to RMWI and BMWIs. A graph describing conversion of the Ab parameter to an apparent RMWI value is shown in Figure 3. A graph describing the conversion of a ta parameter to an apparent BMWI is shown in Figure 4.

Comparisons between the SMC method and the DBC method are described in the paper. These comparisons show a close correlation between the two methods. However, it transpired that if the laboratory RMWI has a higher value than the converted Ab parameter, the resulting SE will be higher. Conversely, if the laboratory RMWI is lower, the AG/SAG mill SE will be lower.

It was found that the AG/SAG SE calculation is sensitive to variations in SG and the Ab values. The DBC method requires corrections to be made to the AG/SAG SE if the one S,G varies from 2.78 t/m³ and the Ab value of 40.

A third correction is required if a low aspect mill is being considered. Although the author has developed this method over a number of years, further refinement of the method will continue.

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