11th MILL OPERATORS CONFERENCE
HOBART 2012

AUTOGENOUS/SEMI-AUTOGENOUS SAG MILL
SPECIFIC ENERGY CALCULATIONS

BY
DON BURGESS FAusIMM
DB CONSULTING (DBC)
THIS PRESENTATION IS ABOUT:

A METHOD OF CALCULATING AG/SAG MILL SPECIFIC ENERGIES USING ONLY A COMBINATION OF BOND WORK INDICES AND JK PARAMETERS THEN APPLYING EFFICIENCY FACTORS
I HAVE BEEN DEVELOPING THIS METHOD FOR A NUMBER OF YEARS

I STARTED IN THE 80’S STUDYING ART MACPHERSON’S TEST RESULTS AND MODIFIED MY APPROACH WHEN THE HELLYER MINE WAS BUILT IN TASMANIA IN 1987

THIS MINE HAD A 22FTDIA X 8FT LG FLAT ENDED SAG MILL WITH 1800KW DRIVE

I WORKED ON EFFICIENCY FACTORS FOR CLOSED AND OPEN CIRCUIT MODES OF OPERATION FOR THIS MILL DURING THE FIRST FEW YEARS OF THE HELLYER MINE LIFE AND THEN RECENTLY WHEN THIS MILL WAS RECOMMISSIONED TO PROCESS THE FOSSEY DEPOSIT.
OTHER AG/SAG MILLS I HAVE STUDIED REGARDING EFFICIENCY FACTORS ARE SHOWN HERE WITH COMMISSIONING DATES:

<table>
<thead>
<tr>
<th>Location</th>
<th>Size and Description</th>
<th>Commissioned</th>
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<tbody>
<tr>
<td>MT ISA QLD</td>
<td>Two 32ft High Aspect SAG Mills</td>
<td>1990</td>
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<tr>
<td>Burdekin NSW</td>
<td>16ft Low Aspect SAG Mill</td>
<td>1994</td>
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<tr>
<td>MIRAH Indonesia</td>
<td>15.5ft Low Aspect SAG Mill</td>
<td>1995</td>
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<td>Olympic Dam SA</td>
<td>38ft High Aspect AG Mill</td>
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<td>Cannington QLD</td>
<td>28ft High Aspect AG</td>
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<td>CADIA NSW</td>
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<td>FOSTERVILLE NSW</td>
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<td>ALBA BAHRAIN</td>
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<td>CHELOPECH BULGARIA</td>
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Mt Isa - two 32ft SAG MILLS 6400kW
ALBA BAHRAIN - 16FT HIGH ASPECT DRY AG MILL
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HOBART 2012

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<thead>
<tr>
<th>NOW TO BEGIN WITH THE BACKGROUND FIRST THEN THE METHOD</th>
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<tr>
<td>ROTARY MILLS ARE INEFFICIENT WHEN PROCESSING LARGE HARD MATERIAL INCLUDING:</td>
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<tr>
<td>SINGLE STAGE BALL MILLS</td>
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<td>ROD MILLS</td>
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<td>AG/SAG MILLS</td>
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• SINGLE STAGE BALL MILLS TREATING HARD ORE ARE INEFFICIENT

• FOR EXAMPLE THE 22FT DIA X 40.5 FT LG XSTRATA ZINC MILL AT MT ISA

• THE BOND LABORATORY RMWI AND BMWI VALUES ARE RECORDED AT 16kWh/t

• THE OPERATING WORK INDEX IS CURRENTLY IN THE REGION OF 21kWh/t TO 25kWh/t

• IN OTHER WORDS

• OVER 30% HIGHER THAN THE BOND WORK INDICES DUE TO LARGE HARD FEED MATERIAL.
ANOTHER EXAMPLE ARE THE ORIGINAL NINE 18FT DIA X 21.5FT LG BALL MILLS INSTALLED IN BOUGAINVILLE PNG IN 1968.

THESE MILLS WERE FOUND TO BE OPERATING INEFFICIENTLY IN THE 18% TO 25% RANGE DUE TO THE HARD FEED MATERIAL

THIS INEFFICIENCY WAS OVER AND ABOVE THE APPLIED EF4 OVERSIZE FEED FACTOR
DB CONSULTING RECOMMENDS THAT WHEN CALCULATING POWER FOR SINGLE STAGE BALL MILLS USE THE RMWI FOR THE TOTAL EF4 CALCULATION IF THE RMWI IS HIGHER THAN THE BALL MILL BMWI HOWEVER LIMIT THE INCREASE IN POWER OVER THE ROWLAND METHOD TO 10%
THE FOLLOWING ROD MILL AND BALL MILL EFFICIENCIES HAVE BEEN VERIFIED DURING THE AUTHOR’S WORK ON

• THE WORSLEY LINE NO1 14FT ROD MILL AND 14 FT BALL MILL CIRCUIT

AND

• THE MT ISA 12.5FT ROD MILL AND 16.5FT BALL MILL CIRCUITS
IF THE P80 PRODUCT PARTICLE SIZE ANALYSES PLOTTED ON LOG-LOG GRAPH PAPER ARE USED TO CALCULATE ROD AND BALL MILL EFFICIENCIES THEN THE ROD MILL WILL HAVE AN INEFFICIENCY FACTOR IN THE REGION OF 1.27 AND THE BALL MILL WILL HAVE AN EFFICIENCY FACTOR IN THE REGION OF 0.67 ADDING THE TWO TOGETHER RESULTS IN A CIRCUIT THAT IS NEAR 100% EFFICIENT
ONE MOST IMPORTANT FACT IS:

ROD MILLS DESIGNED TO PRODUCE A CERTAIN PRODUCT SIZE P80 BY THE BOND METHOD WILL NOT ACHIEVE THIS REQUIRED P80 AS PLOTTED ON LOG-LOG GRAPH PAPER

UNLESS A FACTOR IS ADDED

THE SAME APPLIES TO AG/SAG MILLS
BECAUSE OF THE EXTRA FINES IN THE ROD MILL PRODUCT

THE CORRECTED P80 VALUE IS SMALLER BY A FACTOR OF 1.7 THAN THE ACTUAL ROD MILL PRODUCT SIZE P80 VALUE PLOTTED ON LOG-LOG GRAPH PAPER

THIS MAKES THE ROD MILL MORE EFFICIENT AND THE BALL MILL LESS EFFICIENT

HOWEVER THE EFFICIENCY OF THE CIRCUIT IS STILL NEAR 100%
IN SUMMARY

SO EVEN THOUGH THE DESIGNED ROD MILL P80 SIZE IS NOT ACHIEVED BASED ON THE BOND SE CALCULATION WITHOUT A ROD MILL FACTOR

OR EVEN THOUGH THE DESIGNED AG/SAG P80 SIZE IS NOT ACHIEVED WITHOUT THE DBC FACTOR

THE FINE MATERIAL IN THE ROD AND AG/SAG PRODUCTS CAUSES THE FOLLOWING BALL MILL TO BE QUITE EFFICIENT

SO MAKING UP FOR THE APPARENT UNDER ACHIEVEMENT OF THE ROD OR AG/SAG MILL.
SO IN THE CASE OF A ROD MILL OR A AG/SAG MILL WORKING ALONE A FACTOR MUST BE ADDED FOR THESE MILLS TO ACHIEVE THE DESIGNED T80 PRODUCT SIZE AS PLOTTED ON LOG - LOG GRAPH PAPER.
WORSLEY ALUMINA TEST LINE NO1 14 X 20 ROD MILL AND 14 X 23 BALL MILL CIRCUIT 30 AUG 04

LOG-LOG GRAPH PAPER

PARTICLE SIZE ANALYSES

CIRCUIT BALL MILL PRODUCT 250 MICRONS

BALL MILL DISCHARGE

ROD MILL DISCHARGE

CORRECTED ROD MILL P80 1700 MICRONS

ACTUAL ROD MILL P80 2800 MICRONS

ROD MILL CIRCUIT FEED F80

Cum % Passing
ROD MILLS AND AG/SAG MILLS HAVE SIMILAR PRODUCT PARTICLE SIZE DISTRIBUTION SLOPES NORMALLY LESS THAN 0.5 AS PLOTTED ON LOG-LOG GRAPH PAPER
COMPARISON OF ROD MILL AND AG/SAG MILL DISCHARGE GRADATIONS

TYPICAL FINE AG/SAG MILL DISCHARGE GRADATION

ENVELOPE OF AG/SAG & ROD MILL PRODUCT SIZES

TYPICAL COARSE AG/SAG DISCHARGE GRADATION

TYPICAL FINE ROD MILL DISCHARGE GRADATION

TYPICAL COARSE ROD MILL DISCHARGE GRADATIONS

PARTICLE SIZE ANALYSES

LOG-LOG GRAPH PAPER

Cum % Passing

Microns

1 10 100 1000 10000 100000

1 10 100 1000 10000 100000
THE DBC METHOD INPUTS THE FOLLOWING LABORATORY GENERATED PARAMETERS INTO THE BOND FORMULA

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<tr>
<td>BOND CRWI</td>
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<tr>
<td>JK Ab AND ta VALUES</td>
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<tr>
<td>BOND RMWI</td>
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<td>BOND BMWI</td>
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The Bond Third Theory states that:

\[
SE = \frac{WI \times 10}{\sqrt[3]{P80}} - \frac{WI \times 10}{\sqrt[3]{F80}}
\]

Specific energy for the stage =

The energy in the product from that stage minus

The energy in the feed to that stage
THE NEXT GRAPH SHOWS TYPICAL PARTICLE SIZE GRADATIONS FOR EACH MODE OF COMMINUTION.
THE STAGES ARE:

1. **DROP WEIGHT TESTER P80** – 25000UM TO 3000UM
2. **ROD MILL P80** – 1000UM
3. **BALL MILL CYCLONE OVERFLOW** – 200UM AND LESS
PRODUCTS FOR DWT, ROD MILL AND BALL MILL

- **BALL MILL**
- **CYCLONE**
- **OVERFLOW**

**MICRONS**

**DWT PRODUCTS**

**PRODUCT SIZES ANALYSES**

**LOG-LOG GRAPH PAPER**

**Cum % Passing**

**Cum % Passing**

**MICRONS**

Log-log graph paper for product sizes analyses.
IT IS MY VIEW THAT YOU CANNOT USE THE Ab VALUE FROM 25000UM DOWN TO T80’S LESS THAN 3000UM.

IT FOLLOWS THAT THE WORK INDICES FOR T80’S FINER THAN 3000UM MUST BE USED TO ACHIEVE ACCURATE RESULTS.
THE DBC METHOD BEGINS BY CALCULATING THE BOND SPECIFIC ENERGIES THROUGH THE FOLLOWING COMMINUTION STAGES:

1. **THE BOND PRIMARY CRUSHER WI** FROM PRIMARY CRUSHER PRODUCT TO 25000UM

2. **THE Ab PARAMETER CONVERTED TO AN APPARENT RMWI** FROM 25000UM TO 3000UM

3. **THE BOND RMWI** FROM 3000UM TO 1000UM

4. **THE BOND BMWI** FROM 1000UM TO THE AG/SAG T80 SIZE

5. **THE ta PARAMETER VALUE CONVERTED TO AN APPARENT BMWI** IS USED AS A GUIDE
IN ORDER TO BE ABLE TO INPUT THE Ab AND ta PARAMETERS INTO THE DBC CALCULATION THESE PARAMETERS MUST BE CONVERTED TO:

AN APPARENT RMWI VALUE DERIVED FROM THE Ab PARAMETER AND
AN APPARENT BMWI VALUE DERIVED FROM THE ta PARAMETER

THIS IS DONE BY EMPLOYING THE FOLLOWING GRAPHS
Ab CONVERSION GRAPH TO AN APPARENT RMWI

JK Ab VALUES TO BMWI & JK Ab VALUES TO DBC RMWI VALUES

ORIGINAL JKMRC GRAPH 1999

DBC GRAPH POST 1999
THE DBC AG/SAG EFFICIENCY FACTOR GRAPH HAS BEEN DEVELOPED OVER MANY YEARS. IT WAS THOUGHT IN THE EARLY YEARS THE FACTORS VARIED FROM:

1.13 TO 1.25 FOR FINE T80’S TO 1.8 TO 2.5 FOR COARSER T80’S
IT TRANSPRIED THAT FACTORS TO BE APPLIED TO BOND SPECIFIC ENERGY VALUES FOLLOW A POWER LAW DESCRIBED BY A REGRESSION FORMULA. THESE FACTORS, CALCULATED FROM THIS FORMULA, WHEN APPLIED TO THE BOND SPECIFIC ENERGY VALUES, WILL RESULT IN THE AG/SAG SPECIFIC ENERGY TO ACHIEVE THE REQUIRED AG/SAG T80 VALUE. (THIS DOES NOT INCLUDE PEBBLE CRUSHING POWER)

CORRECTIONS FOR S.G. AND A\text{b} VARIATIONS ARE REQUIRED

ALSO A LOW ASPECT MILL SELECTION NEEDS AN ADDITIONAL POWER CORRECTION
DBC HAS FOUND THAT THE AG/SAG SPECIFIC ENERGY FACTOR VARIES ACCORDING TO THE POLYNOMIAL REGRESSION FORMULA:

THIS FORMULA IS DEPICTED IN THE FOLLOWING GRAPH
THE DBC AG/SAG EFFICIENCY FACTOR GRAPH

DBC FACTOR vs T80um
THE DBC METHOD IS BASED ON:
Ab = 40 t/kWh

SPECIFIC GRAVITY = 2.78 t/m³

THE AG/SAG SE MUST BE CORRECTED BY ADDING OR SUBTRACTING THE S.G. FACTOR IF THE S.G IS GREATER OR SMALLER THAN 2.78.

THIS CORRECTION IS CALCULATED FROM THE AG/SAG SE RESULTING FROM THE AG/SAG MILL FEED F80 TO A T80 OF 750UM

THE CALCULATION IS AS FOLLOWS:
S.G FACTOR = AG/SAG SE(at 750um)X (2.78/S.G.) - AG/SAG SE(at 750UM)

0.23
CHANGES TO AG/SAG SE DUE TO S.G. VARIATION
IF THE Ab IS GREATER OR LESS THAN 40
A CORRECTION IS APPLIED TO THE AG/SAG SE IF THE
T80 IS LESS THAN 150UM

THIS CORRECTION IS CALCULATED BY THE FORMULA

\[
\frac{40}{Ab} \quad \text{FOR LOWER Ab’S}
\]
\[
\frac{Ab}{40} \quad \text{FOR HIGHER Ab’S}
\]
CHANGES TO AG/SAG SPECIFIC ENERGY DUE TO AN Ab VARIATION FOR T80’S LESS THAN 150UM
AN ADJUSTMENT IS NEEDED TO AG/SAG SPECIFIC ENERGY IF A LOW ASPECT MILL IS SELECTED
HIGH ASPECT AG/SAG MILL
PLUS NIL TO SE

L/D 0.3-0.6

LOW ASPECT AG/SA MILL
PLUS 5% TO SE

L/D 0.7-0.9

LA AG/SAG MILL
PLUS 7.5% TO SE

L/D >0.9
THE FOLLOWING GRAPHS SHOW THE BOND SPECIFIC ENERGY AND THE AG/SAG SPECIFIC ENERGY REQUIRED TO SATISFY THE PARAMETERS SHOWN ON THE GRAPHS BASED ON 150MM F80 FEED SIZE:

• GRAPH 1-FOR T80’S FROM 750UM TO 2500UM AND
• GRAPH 2-FOR T80’S FROM 75UM TO 750UM AND
• GRAPH 3-IS GRAPH 2 SHOWING A COMPARISON WITH THE SMC METHOD THROUGH THE SAME T80 RANGE
GRAPH 3

- S.G 2.78
- CR-14.69
- Ab -45
- RMWI-18.36
- BMWI-18.36
- Ta -0.4

Graph 3 shows the relationship between T80 um and SE kWh/t. The graph includes data for DBC SE, SMC SE, and BOND SE.
AN EXAMPLE OF THE DBC METHOD vs THE SMC METHOD IS AS FOLLOWS:

Find the AG/SAG mill SE grinding from a F80 of 150mm to a product size T80 of 80% passing 107um

The input criteria:

CRWI -13.54kWh/t
Ab - 50 = RMWI EQUIVALENT =16.93
BOND RMWI -16.93kWh/t
BOND BMWI -14.85kWh/t
ta - 0.53 = BMWI equivalent =14.85
S.G. 2.78
The Bond SE is 14.44 X DBC factor of 1.2 for a T80=107um

Then AG/SAG SE = 17.32 kWh/t

S.G. correction N/A as S.G. 2.78

Ab - 50 correction factor is less 1.68% (Refer diagram)

SE FOR THE OPERATION = 17.32/1.0168 = 17.034 kWh/t.
THE SMC METHOD

For a S.G. of 2.78 and Ab of 50 the DWi = 5.56kWh/m³

Coarse stage Sag mill WI - Mia = 16.49kWh/t
SE from 150mm to 750um = 8.98kWh/t

Fine stage Sag mill WI - Mib = 18.71kWh/t
(Calculated from a Lab BMWI of 14.85kWh/t)
SE from 750um to 107um = 8.28kWh/t

TOTAL SE=8.98kWh/t + 8.28kWh/t
SMC SE FOR THE OPERATION = 17.26kWh/t.

COMPAARED TO
DBC’S SE OF 17.034 kWh/t
DBC found that differences occur between the DBC and the SMC AG/SAG specific energies if the laboratory bond RMWI is higher than the apparent RMWI. Then the DBC specific energy will be higher than the SMC specific energy and visa versa if the laboratory bond RMWI is lower.
THE NEXT GRAPH SHOWS AN AVERAGE CORRELATION BETWEEN DWi AND Ab VALUES.

MAKE SURE IN EACH CASE THE SG IS STATED TO OBTAIN AN ACCURATE CORRELATION

WITHOUT THE S.G. THE VALUES CAN ONLY BE USED AS A GUIDE
DWi vs Ab VALUES

PINK SQUARES ARE DWi PLOTS

S.G. = ?
NOT STATED

S.G. = 3.5

S.G. = 2.1
THE NEXT GRAPH SHOWS A TYPICAL CORRELATION BETWEEN Ab AND AG/SAG SE VALUES.

MAKE SURE IN EACH CASE THE F80, T80 AND THE S.G. ARE STATED

WITHOUT THESE VALUES THE GRAPH CAN ONLY BE USED AS GUIDE.
SPECIFIC SAG POWER vs Ab VALUES

BLUE DIAMONDS ARE Ab PLOTS

F80=175MM, P80=1000UM  S.G.=2.78
SE=6.74kWh/t

F80=150MM, P80=2500UM
S.G. =2.78, SE=4.96kWh/t

F80= ?um
T80= ?um
S.G. = ?
NOT STATED
• THE DBC METHOD CALCULATES AG/SAG SE’S
• THE METHOD CAN BE USED IF ONLY THE BOND RM & BM WORK INDICES ARE AVAILABLE
• THE DBC METHOD CORRELATES WITH THE SMC METHOD
• HOWEVER IF THE Ab VALUE CONVERTED TO AN APPARENT RMWI IS DIFFERENT FROM THE BOND RMWI THEN DIFFERENCES IN THE SE VALUES WILL OCCUR
• THIS METHOD CORRECTS FOR S.G. AND Ab VARIATIONS AND THE MILL ASPECT RATIO
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THIS METHOD IS OPEN FOR ANYONE TO USE
WITHOUT RESTRICTIONS
WITH NO PROPRIETORY PARAMETERS INCLUDED
THE AUTHOR HOPES THE DBC METHOD WILL AID PROCESS PRACTITIONERS IN THE FUTURE WITH THIS QUICKER AND CHEAPER SOLUTION TO AG/SAG SPECIFIC ENERGY EVALUATIONS
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THAT COMPLETES MY PRESENTATION

AUTOGENOUS/SEMI-AUTOGENOUS SAG MILL

SPECIFIC ENERGY CALCULATIONS

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