Exploring the effect of energy recovery potential on comminution efficiency

the Glencore Raglan Mine case

Peter Radziszewski\textsuperscript{1} and David Hewitt\textsuperscript{2}

\textsuperscript{1} Metso Minerals Canada
\textsuperscript{2} Glencore Raglan Mine
Metso mountain.

Metso is Finnish for grouse

What is the name of this mountain?

kaseybane.com
Exploring Energy Recovery Potential

Metso

A leading process performance provider, with customers in the mining, oil and gas, and aggregates industries, Metso has its corporate headquarters in Helsinki Finland, offices in 50 countries and manufacturing facilities on five continents. Metso’s services and solutions improve the availability and reliability in minerals processing and flow control, providing sustainable process improvements and profitability.
Exploring Energy Recovery Potential

Efficiency

- Ballantyne & Powell – Energy curve
- Nadolski, Klein – Benchmark Energy Factor
- McIvor – Bond Operating work index

Relative efficiency measures

b) HPGR ball mill circuit - 25% increase in efficiency over a SABC circuit (Wang et al. 2013)

d) VERTIMILL® - upto 50% increase in efficiency over ball mills for regrind applications (Merriam et al., 2015)

a) blast design - upto 15% increase in comminution efficiency (Hart et. al., 2006.)

c) HRC® - flanged design produces potential 15% increase in efficiency over non-flanged HPGR (Knorr et al., 2013)
Exploring Energy Recovery Potential

Efficiency

Energy efficiency is defined as a dimensionless ratio of the work produced over the work input or energy consumed in order to produce that work.

\[ \eta = \frac{W_{\text{produced}}}{W_{\text{input}}} \]

In comminution processes, the work produced can be described as the new surface energy produced in a given device.

- Lowrinson (1976) less than 1% efficiency
Exploring Energy Recovery Potential

Efficiency

So, what is happening with the remaining 99% the energy input?

Typically, we assume that this energy is lost as heat of some form or another and has little or no value.

However, what if this was no longer the case and evolving technologies have the potential to capture some portion of the heat that is currently lost?

\[ \eta = \frac{W_{\text{new\_surface\_energy}} + W_{\text{energy\_captured}}}{W_{\text{input}}} \]
Exploring Energy Recovery Potential

Objective

The focus of this paper is to:

- explore the other 99% of the energy input into a given mill
- and investigate the sources of energy loss and how they could be minimised
- as well as the potential and means for energy recovery

With support of circuit data from Glencore`s Raglan Mine.
Exploring Energy Recovery Potential

Glencore Raglan Mine

- Found along the 62nd parallel
- -10C annual average
- below -40C lows in winter
- -15C average ambient underground
- 4 operating UG Ni mines over 70km
- Not connected to grid
- Wind energy project led to exploring capturing the local wind potential
- Currently, 5% of total energy production is through wind

June 2015
- 6.76 GWh produced
- Displacing 1.7 million litre of diesel
- Reducing GHG emissions by 4838 Tonnes

www.kpmindustries.com
Exploring Energy Recovery Potential

David Hewitt
Exploring Energy Recovery Potential

Defining a Thermodynamic Model

\[ \dot{W}_{c.v.} - \dot{Q}_{\text{lost}} = \dot{m}_{sl} (h_2 - h_1) \]

@ constant pressure, for an incompressible fluid/solid

\[ \dot{W}_{c.v.} - \dot{Q}_{\text{lost}} = (\dot{m}_{\text{ore}} c_{\text{ore}} + \dot{m}_{\text{water}} c_{\text{water}})(T_2 - T_1) \]
Exploring Energy Recovery Potential
Defining a Thermodynamic Model (suite)

Solving for heat loss, allows one to explore the sources of heat loss:

\[ Q_{\text{lost}} = Q_{cc} + Q_{\text{rad}} + Q_{\text{evap}} \]

Furthermore, rearranging for discharge temperature, allows one to explore the effect of different measures on discharge temperature:

\[
T_2 = \frac{\dot{W}_{c.v.} - \left( Q_{cc} + Q_{\text{rad}} + Q_{\text{evap}} \right)}{\left( \dot{m}_{\text{ore}} c_{\text{ore}} + \dot{m}_{\text{water}} c_{\text{water}} \right)} + T_1
\]
Exploring Energy Recovery Potential
Defining a Thermodynamic Model (suite)

Ultimately this leads to estimating the energy recovery potential using Carnot:

$$\eta = \frac{T_H - T_C}{T_H}$$

30°C ΔT indicates about 10% energy recovery potential

Organic Rankine cycle turbines and Sterling engines have the potential to reach the Carnot efficiency limit. However, they require more infrastructure.

TEGs \(\rightarrow\) 1.2 kW/m²
Exploring Energy Recovery Potential

The Grinding Circuit
## Exploring Energy Recovery Potential

### Thermal Data Collection

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Ball mill [m]</th>
<th>SAG mill [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter</td>
<td>4.27</td>
<td>7.3</td>
</tr>
<tr>
<td>Belly length</td>
<td>6.4</td>
<td>3.2</td>
</tr>
<tr>
<td>Shell thickness</td>
<td>0.075</td>
<td>0.1</td>
</tr>
<tr>
<td>Liner (average) thickness</td>
<td>0.25</td>
<td>0.185</td>
</tr>
<tr>
<td>Liner material</td>
<td>rubber</td>
<td>steel</td>
</tr>
<tr>
<td>Thermal conductivity [W/m-K]</td>
<td>0.13</td>
<td>43</td>
</tr>
<tr>
<td>Estimated forced convection coef.</td>
<td>200</td>
<td></td>
</tr>
</tbody>
</table>

### Mineral Composition

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Composition [%]</th>
<th>Heat Capacity [kJ/kg-K]</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pentlandite</td>
<td>10</td>
<td>0.576</td>
<td>Infotherm (2015) : 0.445 kJ/mol-K x 0.77194 kg/mol</td>
</tr>
<tr>
<td>Chalcopyrite</td>
<td>5</td>
<td>0.534</td>
<td></td>
</tr>
<tr>
<td>Pyrrhotite</td>
<td>15</td>
<td>0.594</td>
<td></td>
</tr>
<tr>
<td>Gabbro</td>
<td>70</td>
<td>0.825</td>
<td>average of 0.65 and 1.0 kJ/kg-K</td>
</tr>
<tr>
<td><strong>average ore</strong></td>
<td></td>
<td><strong>0.7509</strong></td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td></td>
<td>4.183</td>
<td></td>
</tr>
<tr>
<td>Soda Ash</td>
<td></td>
<td>1.06</td>
<td></td>
</tr>
</tbody>
</table>
## Table 3 Ball Mill Thermal Quantities

<table>
<thead>
<tr>
<th></th>
<th>Mill Power</th>
<th>slurry flow rate</th>
<th>slurry density</th>
<th>ore density</th>
<th>point 1 temperature</th>
<th>point 2 temperature</th>
<th>Slurry Specific Heat</th>
<th>Heat Input ((\dot{W}_{cv}))</th>
<th>Shell Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[kW]</td>
<td>[m(^3)/hr]</td>
<td>[% solids]</td>
<td>[s.g]</td>
<td>[C]</td>
<td>[C]</td>
<td>[kJ/kg-K]</td>
<td>[kW]</td>
<td>[C]</td>
</tr>
<tr>
<td>initial data</td>
<td>2240</td>
<td>173</td>
<td>71</td>
<td>3</td>
<td>33.8</td>
<td>37.4</td>
<td>1.75</td>
<td>2218</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1746.9</td>
<td>250</td>
<td>71</td>
<td>3.35</td>
<td>28.8</td>
<td>33.8</td>
<td>1.75</td>
<td>1729</td>
<td>29</td>
</tr>
<tr>
<td>2</td>
<td>1730.5</td>
<td>208</td>
<td>71</td>
<td>3.26</td>
<td>28.1</td>
<td>32</td>
<td>1.75</td>
<td>1713</td>
<td>27</td>
</tr>
<tr>
<td>3</td>
<td>1755.3</td>
<td>166.4</td>
<td>71</td>
<td>3.3</td>
<td>25</td>
<td>31.9</td>
<td>1.75</td>
<td>1738</td>
<td>23</td>
</tr>
<tr>
<td>4</td>
<td>1794.5</td>
<td>77.1</td>
<td>71</td>
<td>3.19</td>
<td>31.5</td>
<td>39.4</td>
<td>1.75</td>
<td>1777</td>
<td>27</td>
</tr>
<tr>
<td>average</td>
<td>1853.44</td>
<td>174.98</td>
<td>71</td>
<td>3.2</td>
<td>29.4</td>
<td>34.9</td>
<td>1.75</td>
<td>1834.91</td>
<td>26.6</td>
</tr>
</tbody>
</table>
# Exploring Energy Recovery Potential

**Thermal Data Collection (suite)**

Table 4 SAG Mill Circuit Thermal Quantities

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2264.4</td>
<td>63.04</td>
<td>180</td>
<td>-14.5</td>
<td>39.14</td>
<td>17.28</td>
<td>16.6</td>
<td></td>
<td>28.77</td>
<td>18.9</td>
<td>28.4</td>
<td>28</td>
</tr>
<tr>
<td>2</td>
<td>2464.58</td>
<td>63.35</td>
<td>177</td>
<td>-20</td>
<td>32.28</td>
<td>22.5</td>
<td>16.2</td>
<td></td>
<td>59.03</td>
<td>16.5</td>
<td>28.4</td>
<td>30</td>
</tr>
<tr>
<td>3</td>
<td>1854</td>
<td>60</td>
<td>204</td>
<td>-1.2</td>
<td>40.6</td>
<td>23.2</td>
<td>12.6</td>
<td></td>
<td>30.1</td>
<td>12.6</td>
<td>21</td>
<td>21</td>
</tr>
<tr>
<td>4</td>
<td>2451</td>
<td>57.6</td>
<td>166</td>
<td>0</td>
<td>43.6</td>
<td>23.8</td>
<td>17.7</td>
<td></td>
<td>61.9</td>
<td>16.7</td>
<td>27</td>
<td>28</td>
</tr>
<tr>
<td>Average</td>
<td>2258.50</td>
<td>61.00</td>
<td>181.75</td>
<td>-8.93</td>
<td>38.91</td>
<td>21.70</td>
<td>15.78</td>
<td></td>
<td>44.95</td>
<td>16.15</td>
<td>26.2</td>
<td>26.88</td>
</tr>
</tbody>
</table>

\[ \dot{W}_{c.v.} = 0.993(\dot{W}_{SAG} + \dot{W}_{Crusher}) \]
Exploring Energy Recovery Potential

Sources of heat loss

Convection / Conduction

\[
\dot{Q}_{cc} = f \frac{T_1 - T_a}{\ln(r_2/r_1)} + \frac{T_3 - T_a}{\ln(r_3/r_2)} + \frac{1}{hA_{so}}
\]

Radiation

\[
\dot{Q}_{rad} = f\varepsilon\sigma \left(T_3^4 - T_a^4\right)A_{so}
\]
Exploring Energy Recovery Potential

Sources of heat loss

Evaporative

\[
\dot{Q}_{evap} = \dot{m}_{evap} h_{evap}
\]

\[
\dot{m}_{evap} = f_e \Theta A_{sl} (x_s - x)/3600
\]

Table 5 Estimated losses in Raglan Mine’s SAG and ball mills

<table>
<thead>
<tr>
<th>Mill</th>
<th>Mill Power</th>
<th>Conduction &amp; convection loss</th>
<th>Loss by radiation</th>
<th>Loss by evaporation</th>
<th>Other losses</th>
<th>Total lost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ball mill</td>
<td>1853.44</td>
<td>0.84</td>
<td>4.97</td>
<td>635.23</td>
<td>-</td>
<td>641.04</td>
</tr>
<tr>
<td>SAG mill circuit</td>
<td>2319</td>
<td>48.10</td>
<td>2.71</td>
<td>50.33</td>
<td>399.26</td>
<td>500.40</td>
</tr>
</tbody>
</table>
Exploring Energy Recovery Potential

Estimating energy recovery potential – Ball Mill

Heat Loss [%]

- Q_rad
- Q_cc
- Q_vap
- Q_lost

Baseline, reduced radiation, reduced air flow, increase water temp., decrease cold source, cumulative
Exploring Energy Recovery Potential

Estimating energy recovery potential – Ball Mill

Heat Loss [%]

<table>
<thead>
<tr>
<th>Category</th>
<th>Heat Loss [%]</th>
<th>N_carnot [%]</th>
<th>Value [k$/yr]</th>
</tr>
</thead>
<tbody>
<tr>
<td>baseline</td>
<td>100.00%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>reduced radiation</td>
<td>10.00%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>reduced air flow</td>
<td>1.00%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>increase water temp.</td>
<td>0.10%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>decrease cold source</td>
<td>0.01%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>cumulative</td>
<td>1.00%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Exploring Energy Recovery Potential

Estimating energy recovery potential – SAG circuit

![Heat Loss Chart](image)
Exploring Energy Recovery Potential

Estimating energy recovery potential – SAG circuit

Heat Loss [%]

Baseline
Reduced radiation
Reduced air flow
Reduced conduction
Increase water temp.
Decrease cold source
Cumulative
Plus reduced circuit evap.

N_carnot [%]
Value [k$/yr]
Exploring Energy Recovery Potential

Discussion – Assumptions and issues


<table>
<thead>
<tr>
<th>Impact of alternative means to increasing the energy recovery potential.</th>
<th>Slurry heat capture ratio (%)</th>
<th>( T_H ) (°C)</th>
<th>( T_C ) (°C)</th>
<th>Carnot efficiency (%)</th>
<th>Energy saving (97% availability) (GW h/y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Un-insulated/un-sealed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brunswick SAG mill</td>
<td>44.3</td>
<td>30.0</td>
<td>10.0</td>
<td>6.60</td>
<td>1.8</td>
</tr>
<tr>
<td>Cadia SAG mill</td>
<td>44.3</td>
<td>25.3</td>
<td>10.0</td>
<td>5.12</td>
<td>3.7</td>
</tr>
<tr>
<td>Insulated/sealed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brunswick SAG mill</td>
<td>99.0</td>
<td>42.4</td>
<td>10.0</td>
<td>7.09</td>
<td>4.4</td>
</tr>
<tr>
<td>Cadia SAG mill</td>
<td>99.0</td>
<td>31.7</td>
<td>10.0</td>
<td>7.14</td>
<td>11.4</td>
</tr>
<tr>
<td>Cadia SAG/Ball circuit</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Un-insulated</td>
<td>44.3</td>
<td>29.7</td>
<td>10.0</td>
<td>6.50</td>
<td>8.6</td>
</tr>
<tr>
<td>Insulated/sealed</td>
<td>99.0</td>
<td>41.6</td>
<td>10.0</td>
<td>10.06</td>
<td>29.6</td>
</tr>
</tbody>
</table>
Exploring Energy Recovery Potential

Discussion – Assumptions and issues

Assumptions addressed in this paper:

1. heat capacity: 1 kJ/kg-K vs 1.75 kJ/kg-K based on composition,
2. portion of energy captured: based on anecdotal information and literature vs industrial measured,
3. Implementation: adiabatic vs estimate of reality using heat transfer models,
4. Accounting for all input /outputs

Remaining Issues:

1. Validation of 99% at heat,
2. Effect of higher slurry temperatures on flotation
3. Effect of higher slurry temperatures on wear
4. Efficiency
Exploring Energy Recovery Potential

Discussion – Efficiency

\[ \eta = \frac{W_{\text{new\_surface\_energy}} + W_{\text{energy\_captured}}}{W_{\text{input}}} \]

\[ \eta_{\text{SAG}} = 17\% \]
\[ \eta_{\text{BM}} = 18\% \]

\[ \eta = \eta_{\text{nse}} + \eta_{\text{tech}} \eta_{\text{Carnot}} \]
Exploring Energy Recovery Potential

Discussion – Efficiency

\[ \eta = \eta_{nse} + \eta_{tech} \eta_{Carnot} \]

For Sterling engines and Organic Rankine cycles

\[ \eta_{tech} \rightarrow 1 \]

For TEGs

\[ \eta_{tech} \rightarrow ? \]

@ \Delta t = 30C \text{ TEGs} \rightarrow 1.2 \text{ kW/m}^2
Exploring Energy Recovery Potential

Next Steps

CMIC- Canmet Mines project

Validate the model with data from three Canadian mine sites

- Focus on 99% assumption
- Other losses – sound, vibrations, transmission,
- Provide an Excel based tool

Metso

Dry grinding application plus stirred milling application for IMPC2016
Exploring Energy Recovery Potential

Conclusions

• Average energy lost from the Glencore Raglan Mine ball mill is 34.6%
• Average energy lost from the Glencore Raglan Mine SAG mill circuit is 21.6%
• Conduction/convection represents a quite small amount of energy lost for the two cases examined.
• Conduction/convection losses can be reduced by the use of rubber. Although it was not estimated, one could expect similar reductions with polymetallic liners.
• Possible means to reduce radiation losses are related to mill paint can coatings.
• Mass transfer due to evaporation was found to be the major cause of heat loss to the environment.

It is possible to consider that energy is a potential second product of comminution
Exploring Energy Recovery Potential

Lord Kelvin

“If you can not measure it,
you can not improve it”

so measure it!
Exploring Energy Recovery Potential

Acknowledgements

The authors would like to thank Glencore’s Raglan Mine and Metso for granting permission to publish and present this work and associated data and results.

Thank you!