HYDRO POWER AND STOPE DRILLING SYSTEMS
- AN ENERGY-SAVING PERSPECTIVE -

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Synopsis

Electricity supply constraints in SA are increasingly challenging mines to operate more energy efficiently without reducing production output. Mining compressed air systems are well known to be operated inefficiently and are also a major power consumer.

Two available and proven technologies can be applied on new and existing mines to replace or optimise available compressed air facilities and achieve meaningful reductions in electrical power consumption;

- Hydro powered drilling and mining is significantly more energy efficient than compressed air and provides drilling rates that are twice as fast.
- Stope drilling systems using compressed-air or water drills allow further energy savings.

The technologies are discussed and a broad strategy to selectively apply these together is presented.

1. Electrical Power Constraints - a Further Challenge to Mining in SA.

The recent electrical power crisis has had a stark effect on power-hungry mining operations; showing that power constraints can severely hamper this primary industry. It is obviously also not a short-term problem. Mining uses approximately 15% (ref 1) of the power generated in SA and, as an industry, has been told to reduce consumption by 5 to 10% to avoid load-shedding. The Chamber of Mines estimates that a forced 10% reduction in power could cause a 20% drop in production on deep mines (ref 12) with a serious effect on jobs and profitability.

Despite the high energy usage of compressed air systems, their use has endured as it is a familiar technology throughout the industry, systems are forgiving and ‘low-tech’ at the operator interface; they were also the safe bet at the mine design level.

These high energy costs were accepted as a given until January 2008 when electric power was suddenly restricted and mining production levels were put under threat.

Although the crisis is being actioned through scheduled outages, probable rate hikes and other energy conserving measures, it is an unavoidable fact that the cost of power will increase and/or supplies will be interrupted. Power costs have been kept uneconomically low by Government and are set to increase sharply in the near future as the crisis is addressed. The cost of mining will rise for those mines that choose not to do things differently; either through higher power costs or as lost production. Both translate significantly to the bottom line.
The SA narrow vein mining industry is of worldwide importance. It also has some of the greatest challenges to meet to retain its dominance; the deepest and hottest mines, significant seismicity, challenges in respect of labour skills and HIV infections. This type of mining is historically very labour intensive and is not easily mechanised. The long-term solutions for energy-efficient operation should also address these factors.

Proven technologies to reduce power consumptions are available and will allow continued or increased production. The cost of implementation should be compared with opportunity cost of not reducing power usage.

All technological changes are by nature disruptive – they upset the status-quo and cause unease, partly why the technologies presented in this paper have historically not been more widely employed. The industry driving forces are now stronger and the threat to the industry is both immediate and serious.

2. **Hydropowered Mining Technology**

The technology was developed from the early 1980’s specifically for deep level gold mining by the Chamber of Mines and its collaborators. The elegance of the technology lies in employing the gravity head available in the vital cooling water to directly power mining machinery, involving minimal loss and providing a powerful energy source.

Water rockdrills and later a full range of equipment were developed by the industry and the technology has steadily proven to be an effective mining system. Rollout was somewhat constrained due to the slowdown in new deep shafts from the 1990’s and resistance to water use by platinum miners.

![Fig 1: Novatek Water Rockdrill in Operation at Tau Lekoa Gold Mine](image-url)
More recently, a wider range of mines have employed micro-hydropower as a technology in flat end development. The productivity advantages and costs have better suited these applications where localized pumps are used to supply the necessary high-pressure water.

The benefits of hydropower systems are chiefly that they are much more energy efficient than compressed air systems, drilling rates are much higher and productivity can be greatly improved – especially if water jet cleaning is used and human resources are managed to suit the technology. It also integrates with mine cooling and contrary to expectations, usually uses less cooling water than non-hydropowered mines consume.

Because high-pressure water leaks cannot be tolerated, the systems are better managed than compressed air systems.

3. Comparison of Hydropower Against Other Powering Systems

The powering systems available to miners include:

- Compressed air.
- Hydropower in gravity fed or pumped format.
- Electrical via utilities or self-generation.
- Oil hydraulic power, usually via diesel or internal combustion engines or plug-in electrical power when drilling.

Oil hydraulic systems generally apply to self-powered machines more suited to operating in relatively flat ore bodies with good access and where mobility justifies the high capital cost. These machines are often unsuited to steeper ore bodies with extensive support; they necessitate better ventilation and ore dilution is an additional consideration.

Self generation of electricity is generally also not a viable option; the installed cost of diesel generators is in the range of R 2000 to R 3000 per kW and operating cost is in the region of R 2.40 per kWh (compared to the current SA electrical power rate of approx R0.15 to R 0.55 per kWh (seasonal and peak dependent, ref 5)). The expense of self-generation may be justifiable in the short-term to maintain key operations; however, the cost of energy wastage is increased at least five-fold.

The remaining systems are further compared in respect of energy usage and actual performance, as follows.

3.1. Power to Mass Ratio

Electrical power is presently the most energy efficient form, widely used to power electrical motors for all applications. It is compelling, therefore, to consider its application to directly power portable mining tools; especially as a wide range of electrical industrial power tools are available. The power to mass ratio (or power ‘density’) is useful in comparing the technologies as it highlights the technical limitations. It is important in the mining context because drills and mining tools need to
be very powerful but also relatively light and compact in order to operate effectively in confined spaces.

Table 1 & figure 2 show that hydraulic and pneumatic machines have a considerably higher power/mass ratio than electric drills. The table also shows the performance loss as a consequence of operating pneumatic drill at sub-optimal pressures.

Table 1: Power to Mass Ratio of Various Rockdrills

<table>
<thead>
<tr>
<th></th>
<th>Pneumatic Drill (350 kPa) #</th>
<th>Pneumatic Drill (500 kPa) #</th>
<th>Water Drill *</th>
<th>Electric Drill #</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass kg (drill only)</td>
<td>21.25</td>
<td>21.25</td>
<td>20.6</td>
<td>23.9</td>
</tr>
<tr>
<td>Absorbed Power (kW)</td>
<td>2.43</td>
<td>4.2</td>
<td>12.8</td>
<td>1.65</td>
</tr>
<tr>
<td><strong>Power/Mass W/kg</strong></td>
<td><strong>114</strong></td>
<td><strong>198</strong></td>
<td><strong>623</strong></td>
<td><strong>81</strong></td>
</tr>
</tbody>
</table>

* Ref 6, * own data

Figure 2: Comparison of Power to Mass (Air Drills at 350 kPa)

Increasing the output power of electric drills will probably require a similar increase in mass and size – self-defeating for a constrained stoping environment. It is notable that
modern industry consistently uses hydraulics and pneumatics where power and compactness are required.

Current electric drill systems are efficient but are inherently lower in output; the drill is actually a packaged electric motor, compressor and expander in one unit. Physical and practical limits to motor power versus mass, speed, voltage and current dictate the overall size. Hence the poorest power to mass ratio of the three systems.

Hydraulic and pneumatic systems also generate fluid power using electrical motors, but the motors are located remotely in areas where large physical size and mass are tolerable. The energy-dense fluid can then be easily reticulated to compact powerful machines. In large mining and industrial systems, this power is often generated at centralised stations for efficiency reasons, to facilitate maintenance and cope with heat rejection. Localised heating and poor efficiency are reasons why small compressors are not commonly used underground.

Micro hydropower has the advantage that these systems are operated at optimum pressures, allowing the full advantage to be made of the high power/mass ratio of the water drills.

3.2. Energy Efficiency and Actual Drilling Performance

Table 2 shows a comparison between various drills in laboratory and field tests. Norite is used in laboratory tests due to its fairly consistent drilling properties and ready availability. Drilling results in quartz are usually slower due to higher hardness values. Results for UG2 reef are from field tests; platinum reefs are not as hard but are more resilient in respect of drilling behaviour.

The table 2 results show that the compressed air drills themselves are energy efficient (muffled drills are less efficient due to increased backpressure) and that electric drills have a similar value. This is not unexpected - electric drills are essentially a directly-powered pneumatic drill. Water drills actually consume the most power when tested in isolation.

However, these results do not fully represent the situation in actual practice.

Table 3 shows that in actual mining systems, the situation is very different. Electric drilling remains the most energy efficient, losing about 8% through transmission losses (Ref 11). Note that the consumption is possibly understated as power consumption and losses from ancillary equipment is not included.

Water drills in gravity-fed configuration are the next most efficient, followed by the pump powered option.

Pneumatic systems in existing mines are notoriously wasteful due to leaks and misuse; actual energy usage jumps to nearly 12 kWh/m in gold mines and 8 kWh/m in platinum mines (Refs in tables). Leak detection and sealing are major challenges in the extensive and ageing compressed air networks in most of our mines – leaks are not easy to see and
there is no real consequence to operators wasting this resource. It is generally accepted that compressors are kept operating wastefully during off-shifts just to keep the leaky systems at an acceptable pressure.

Table 2: **Rockdrill** Performance and Energy Usage per Metre Drilled

<table>
<thead>
<tr>
<th></th>
<th>Pneumatic Drill Standard (350 kPa) #</th>
<th>Pneumatic Drill Muffled (350 kPa) #</th>
<th>Water Drill *</th>
<th>Electric Drill #</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>OPERATION IN NORITE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Absorbed power (norite) kW</td>
<td>2.43</td>
<td>2.12</td>
<td>12.8</td>
<td>1.65</td>
</tr>
<tr>
<td>Penetration rate (norite) m/min</td>
<td>0.2</td>
<td>0.18</td>
<td>0.88</td>
<td>0.13</td>
</tr>
<tr>
<td>Energy usage (norite) kWh/m</td>
<td>0.21</td>
<td>0.205</td>
<td>0.243</td>
<td>0.219</td>
</tr>
<tr>
<td><strong>OPERATION IN UG2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Absorbed power (UG2) kW</td>
<td>2.43</td>
<td>2.12</td>
<td>12.8</td>
<td>1.93</td>
</tr>
<tr>
<td>Penetration rate (UG2) m/min</td>
<td>0.45</td>
<td>0.3</td>
<td>1.0</td>
<td>0.3</td>
</tr>
<tr>
<td>Energy usage (UG2) kWh/m</td>
<td>0.094</td>
<td>0.123</td>
<td>0.214</td>
<td>0.110</td>
</tr>
</tbody>
</table>

# Ref 6. * own data.  
Data adjusted to include energy of service water used for hole flushing.

Table 3: **System** Performance and Energy Usage

<table>
<thead>
<tr>
<th></th>
<th>Pneumatic Drill Standard</th>
<th>Water Drill – gravity hydropower</th>
<th>Water Drill – pumped hydropower</th>
<th>Electric Drill</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>OPERATION IN QUARTZ</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy usage (quartz) kWh/m</td>
<td>11.8 ^</td>
<td>0.613 ^</td>
<td>1.282 ^</td>
<td>0.238</td>
</tr>
<tr>
<td>Energy usage (quartz) kWh/T</td>
<td>15 *</td>
<td></td>
<td>1.5 *</td>
<td></td>
</tr>
<tr>
<td><strong>OPERATION IN UG2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy usage (UG2) kWh/m</td>
<td>8 #</td>
<td>0.54</td>
<td>1.128</td>
<td>0.12 #, &amp;</td>
</tr>
</tbody>
</table>

# Ref 7. * Ref 8  ^ Ref 9   & Ref 10  
Other data extrapolated for comparative purposes.
Calculations indicate that with 20% leakage, compressors can operate for an additional 130% of the required drilling time just to maintain acceptable pressures. Leaks are obviously continually present, hence the significant overall effect of apparently small leakage rates. Due to the volume of piping in these systems, they also have a large capacitance and can also take a long time to recharge.

With concerted management of reticulation systems, replacement of leaky pipes and valves, etc., this figure could be significantly reduced. An industrial norm is 10% air leakage up to 20% maximum, but it is unlikely that mining systems will reduce leakage to industrial levels, given the scattered and extensive nature of the systems, corrosion, inaccessibility and problems such as rock movement and damage.

As can be seen in the tables, although water drills are not quite as energy efficient as electrical drills, they nevertheless present a very significant power-saving opportunity and have a much higher drilling rate – essential in achieving productivity gains.

4. Stope Mechanisation Using Appropriate Technologies

The vast majority of drilling in the SA narrow reef mining industry is still done using hand held drills (jackdrills). A jackdrill in the hands of an experienced operator is an extremely effective and versatile tool, especially in the steeply dipping and narrow reef horizons where drilling is often in a maze of props. However, a growing reality is that drillers are a rapidly ageing workforce (estimated average age over 45 years) and younger workers do not want to do this demanding physical work.

Fig 3: Typical Pneumatic Jackdrilling in a Platinum Mine

Safety in the industry is also continually under the spotlight; rockfall and rockburst incidents accounted for 43% of fatalities and approx 26% of injuries in 2006 (ref 2). Drillers are the most exposed, working close to the rockface and also being subjected to noise, heat stress, airborne emissions and vibration.
Poor drilling skills and discipline often lead to inaccurate drilling which in turn results in poor advances, hanging wall damage, poor stope width control, concave face shapes, all of which greatly affect profits and are a waste of energy and resources. Ref 3 provides a statistical analysis of the problem.

Various methods and machines for stope mechanization have been developed and used in SA over many years with mixed success. Large-scale rollout has frequently been hampered by resistance based on fears of job losses by unionized staff, lack of management commitment or the technology being unsuitable for the particular mining situation (Ref 4). The threat of job losses is usually misplaced as other tasks become necessary to support the new systems and increased production.

Mechanisation using sophisticated self-powered machinery in steeply dipping rocky and narrow stopes is economically prohibitive as well as being incompatible with the labour skills and the mining environment. The “appropriate” form of mechanization in these situations is simple and robust equipment that reduces the hazard exposure of workers, reduces physical effort to an acceptable level and allows for improved productivity.

Mechanisation, by its nature, is usually more energy efficient, and this benefit should also be exploited in addressing energy usage. The greater efficiency of using a feed drill with in-line thrusting gives up to 50% better penetration rate compared to hand held drilling. In practice, 2 drills can do the work previously done by 3. Along with the energy saving, operator exposure to rockfalls is reduced by 50%. Consider that the operators are also located under support and away from the highest danger zone on the face – see fig 4. Although detailed statistics are not available, the author’s review of previously published figures suggests that the risk exposure of operators could be reduced by 75% as a result of being 2.5m back from the face. Experience of using the Novatek stope rig system over a number of years supports this assertion; despite various seismic events and rockfalls, there have been no injuries to operators.

Fig 4: Novatek Pneumatic Drilling System; Note Operator’s Position Relative to Support.
Numerous drill rig systems are available in the market, with sophistication and costs to suit the requirements of most mining methods, including hydropower. A Novatek water drilling system is shown operating in a narrow stope in fig 5.

Stope drilling systems deserve serious consideration from an energy-saving perspective; they now make even more economic sense and the health and safety benefits are undeniable.

Fig 5: Novatek Hydropowered Drilling System in a Narrow Reef

4.1. System Capital Costs

The capital and operating costs of applying hydropower are highly dependent on specific mine layout, conditions and management choices; however, broad figures are provided as a guide in tables 4 and 5.

Table 4: Capital Cost Estimates Relative to a Pneumatic System

<table>
<thead>
<tr>
<th></th>
<th>Pneumatic System</th>
<th>Water System – gravity hydropower</th>
<th>Water System – pumped hydropower</th>
<th>Electric Drilling System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital costs of complete system</td>
<td>100%</td>
<td>65 to 105%</td>
<td>Est 80 to 110%</td>
<td>Est up to 90% excluding drills (drills are leased), including ancillary equipment (typically hydropowered) #</td>
</tr>
</tbody>
</table>

# Ref 11 for source data. Ancillary equipment includes hydropower pumps, stoping tools other than drills.
Data based on author’s own analysis of specific scenarios.
Table 5: Estimated Operating Costs Relative to a Pneumatic System

<table>
<thead>
<tr>
<th></th>
<th>Pneumatic System</th>
<th>Water System – gravity hydropower</th>
<th>Water System – pumped hydropower</th>
<th>Electric Drilling System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating costs of</td>
<td>100%</td>
<td>70 - 80%</td>
<td>75 - 85%</td>
<td>108% including drill</td>
</tr>
<tr>
<td>complete system</td>
<td></td>
<td></td>
<td></td>
<td>lease costs &amp; cost of</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>operating ancillary</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>equipment. #</td>
</tr>
</tbody>
</table>

# Ref 10 for source data. Ancillary equipment includes hydropower pumps, stoping tools other than drills.
Data based on author’s own analysis of specific scenarios.

A review of the capital and operating costs shows that significant advantages may be gained by the use of hydropower. With power and labour costs set to rise and drillers becoming a scarcer resource, replacement technologies must also offer greater productivity potential.

The savings due to better yields, width control and efficiency of stope drilling systems alone can result in payback periods of less than 1 month.

5. Application Strategy for Hydropower and Stope Mechanisation

Hydropower in gravity fed or pumped form is a proven stable technology in use at Northam Platinum, Tau Lekoa, Kloof, Beatrix gold mines, numerous Anglo Platinum mines and on various other mines. Potential problems with water use in thixotropic ores and gold loss are addressable through correct mine design and waste water control.

The following strategies seek to provide a broad basis for applying these technologies in practice.

5.1. New Mining Operations

The powering system should be capable of meeting production targets within energy supply constraints. Additionally, it should provide a platform for productivity and efficiency improvement for the life of the mine.

Gravity fed hydropower is the most efficient hydro system. For operations less than 1500 m deep, pressure boosting may be required. Numerous feasibility studies have shown that these installations are generally cheaper than pneumatic systems.

Hydropowered systems tend to have slightly lower operating costs than pneumatic systems; the large reduction in labour and power costs being somewhat offset by higher maintenance costs. Considering that electricity costs are set to increase significantly and
that labour costs are outpacing productivity gains, the longer-term outlook indicates that the hydropower is an attractive choice.

Mechanisation, appropriate to the mining environment and skills, may also be used to boost the effectiveness of the system. Stope mechanized systems, flat and inclined development systems are all available and proven.

Mine layout and planning should also utilise the advantages of these systems to permit faster development, faster stope advance rates, water management and integrated cooling.

Labour and resistance to change issues are easier to manage on new operations, but training of management and production staff is an essential part of the technology management process and needs to be done effectively to ensure success.

### 5.2. Existing Mining Operations Using Compressed Air

The inefficiency of compressed air systems primarily lies in the system management and control of leaks, losses and misuse, not in the drills and other tools themselves. The difficulty lies in maintaining extensive compressed air piping systems, often old and leaky through corrosion and also in controlling misuse of compressed air for local ventilation, etc.

#### 5.2.1. Consolidate Compressed Air Usage to Maximise Efficiency

Where possible, the reticulation system should be consolidated to serve a reduced area where it can be better managed and maintained. Limiting the working areas served will also result in increased air pressures which in turn will permit drills to be operated at higher pressures and at faster drilling rates.

Productivity can be further enhanced and energy consumption reduced in these areas by using appropriate mechanization.

#### 5.2.2. Convert Selected Working Areas to Hydropower

Pumped hydropower is most effectively used to serve working areas that are more remote, scattered or where compressed air infrastructure is poor. Development of new areas using hydropower precludes the installation of compressed air services.

Mechanisation can also be used as appropriate.

Training of production personnel and engagement with unions is critical in achieving a successful transition without resistance. In particular, job security and improved worker health and safety issues need to be clarified.
6. Conclusions

Hydropowered mining technology and “appropriate” mechanization are both proven technologies that offer significant opportunities to reduce energy consumption in mining. Further to addressing the immediate need to reduce mine electrical power consumptions by 10%, these technologies offer productivity gains that will further benefit the mining industry.

Health and safety advantages such as lower risk exposure and noise exposure are also important in protecting operators.

Hydropowered mining and “appropriate” mechanisation are set to become far more widespread in the SA mining industry. They are practical and proven technologies that will meet the immediate and future challenges.

References

12. Many more than 6900 jobs, editorial, Mail & Guardian Feb 29 to 6 Mar 2008