Energy efficient fans in underground auxiliary ventilation systems

by C D Pitts, Femco Mining Motors, and A Livingstone, Anglo Gold

Auxiliary ventilation is vital in the mining industry, removal of dust, gases and heat being the main reasons. Poor air control creates an unhealthy and unsafe environment on the one hand whilst increasing ventilation is expensive in terms of increased fan power on the other. With mining operations progressing to ultra deep levels efficiency becomes critical.

Millions of rand are spent annually on investments, maintenance, repair and electricity costs for underground auxiliary ventilation.

The method for optimization proposed in this paper can be further developed to assess ventilation energy efficiency at ultra deep levels, improving company corporate energy policy.

The axial fans used in mine auxiliary ventilation have some basic components (electric motors with rated power under 100 kW, impellers and guide vanes, housings and sound attenuators), all influencing the product efficiency and price.

This paper analyzes 45 kW type “F” axial fans running 8760 hours annually.

Initial investment versus energy running cost

Let’s consider two “F” fans driven by two different 45 kW, 525 V, 2 pole PAD electric motors.

Absorbed electric apparent power, \( S [kVA] = \frac{P}{\eta \times \cos \phi} \)

where \( P [kW] \) is shaft power (motor rated power).

A standard performance electric motor fitted to a 45 kW fan generates additional annual losses of R 10 000 to the electricity bill.

For a 24 hour process, energy efficient motors pay for themselves in a very short time, after which they will save many times their difference in the purchase cost.

Electric motors in deep level conditions

Courtesy of certain Gold mines and fan manufacturers, tests have been conducted on site.

According to test certificates average standard performances @ 1.2 kg/m\(^3\) air density for 45 kW “F” type fans have been found as: \( Q = 12.02 \text{ m}^3/\text{s} \) volume air flow @ 2000 Pa with an absorbed motor power of 48.4 kW, i.e. shaft power of 45.01 kW

On deep level conditions @ 1.4 kg/m\(^3\) air density, with the same impeller used for 1.2 kg/m\(^3\) air density, the performance is \( Q = 12 \text{ m}^3/\text{s} \) volume airflow @ 2333 Pa; motor shaft power becomes 52.52 kW.

High power impellers or not?

From Table 2 it can be seen that a type “F” fan with a standard motor and “1,2 Impeller” will burn out if used at an air density of 1.4 kg/m\(^3\) [1]. Shaft power under these conditions would be 52.52 kW. As reference, “F” fan performances @ 1.4 kg/m\(^3\) air density are specified [1]. Under these conditions the fan will be moving 12 m/s of air. This raises the question of de-rating the impellers. Typical fan design problems are schematically presented in Fig. 1.

The impeller design has to fulfill the following conditions:
- High air power output
- High efficiency
- Low noises level

As an interim solution to prevent motors burning out at ultra deep levels where air density is 1.4 kg/m\(^3\) or more, a de-rated impeller has been designed and manufactured. The so-called

<table>
<thead>
<tr>
<th>Motor type</th>
<th>Efficiency ( \eta ) [%]</th>
<th>Power factor ( \cos \phi )</th>
<th>Absorbed electric apparent power [S] @ 45 kW output</th>
<th>Electricity bill for year 2003 @ R0,14/kVAhr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard motor</td>
<td>0.93</td>
<td>0.84</td>
<td>57.60 kVA</td>
<td>R 70 640</td>
</tr>
<tr>
<td>Energy efficient motor</td>
<td>0.97</td>
<td>0.94</td>
<td>49.35 kVA</td>
<td>R 60 523</td>
</tr>
</tbody>
</table>

Table 1: Comparison of electricity bill paid during 2003 per “F” fan (45 kW motor)

<table>
<thead>
<tr>
<th>Parameters @ 45,01 kW shaft power @ 1.2 kg/m(^3)</th>
<th>Standard motor</th>
<th>Energy efficient motor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature rise [°C]</td>
<td>105°C (F class ins.)</td>
<td>72°C</td>
</tr>
<tr>
<td>Absorbed current [A] @ 525 V</td>
<td>63.5</td>
<td>55.0</td>
</tr>
<tr>
<td>Speed [rpm]</td>
<td>2960</td>
<td>2970</td>
</tr>
<tr>
<td>Efficiency</td>
<td>0.93</td>
<td>0.97</td>
</tr>
<tr>
<td>Power factor</td>
<td>0.84</td>
<td>0.943</td>
</tr>
<tr>
<td>Absorbed apparent power [kVA]</td>
<td>57.6</td>
<td>49.35</td>
</tr>
</tbody>
</table>

Table 2 – Motor performances comparison at different air densities (deep levels)

A standard motor driving high power “1,2 Impeller” cannot perform at ultra deep levels!
"1,4 impeller" delivers only 10 m³/s air flow @ 2000 Pa. This loads standard motors to rated shaft power, (corresponding to 1.2 kg/m³ air density) and prevents motor temperature rise above insulation class levels.

Note: In order to maintain the same ventilation conditions [2] by using a "1,4 impeller," an increase of least 20% in the number of fans is required. This results in additional investment, maintenance, logistic and electricity costs.

However, if air density increases beyond the value of 1.4 kg/m³, the "1,4 impeller" will be in the same situation as the normal "1,2 impeller" for 1.4 kg/m³ air density! A new de-rated "1,5 impeller" should be required, and so on.

Should a high power "1,2 impeller" be used for ultra deep levels keeping the fans as per standard? Such an impeller would need to be driven by electric motors having the following salient features:

- Rated power in a range of 55 to 65 kW (in order to provide the higher power needed)
- Same frame as original 45 kW (in order to keep same size of the fan casing and impeller)
- Improved class of insulation (H class, able to withstand to 125°C temperature rise conditions)
- Improved performances (energy efficient in a range of 75% to 125% of the load)

Energy costs of ventilated air

Using absorbed apparent power [kVA] data from Table 2, the annual energy cost @ 1.4 kg/m³ air density is:

- For a standard motor = R 89 904
- For a energy efficient motor = R 70 775

FEEI = \( \frac{S \times C}{Q \times \rho \times 3.6} \) [R/ton of ventilated air]

where

- \( S \) = apparent power [kVA]
- \( C \) = electricity price [R/kVAh]
- \( Q \) = volume airflow on site [m³/s]
- \( \rho \) = air density on site [kg/m³]

Conclusions

- When energy efficient electric motors with high power impellers are used, the FEEI is cheapest, and approximately constant, regardless the environmental working conditions. Before replacing existing fans (standard motors with de-rated impellers) with high efficiency fans (high power impellers and energy efficient motors), an interim solution can be adopted in order to save the old investment.

- The interim solution using de-rated "1,4 impellers" driven by standard motors results in an increase of 20% on FEEI if the same number of fans are used. Taking into account the fact that 20% more fans are required to move the required amount of air, FEEI will increase by 44.4%.

- Validation: measurements on "F" type fans in an ultra deep level shaft have been done. Average air density = 1.40 kg/m³

### Table 3: Air quantity annually delivered by one "F" type fan for different assumptions

<table>
<thead>
<tr>
<th>Assumption</th>
<th>Description</th>
<th>Tons of ventilated air annually delivered per &quot;F&quot; fan</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&quot;1,2 impeller&quot; @ 1.2 kg/m³ air density</td>
<td>454 118</td>
</tr>
<tr>
<td>2</td>
<td>&quot;1,2 impeller&quot; @ 1.4 kg/m³ air density</td>
<td>529 805</td>
</tr>
<tr>
<td>3</td>
<td>&quot;1,4 de-rated impeller&quot; @ 1.4 kg/m³ air density</td>
<td>441 504</td>
</tr>
</tbody>
</table>

### Table 4: Estimations of FEEI (specific electric energy costs) in auxiliary ventilation "F" fans

<table>
<thead>
<tr>
<th>Scenario</th>
<th>&quot;F&quot; fan description</th>
<th>FEEI in [Rand/ton of air]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&quot;1,2 impeller&quot; @ 1.2 kg/m3 air density driven by a standard motor</td>
<td>0.1555</td>
</tr>
<tr>
<td>2</td>
<td>&quot;1,2 impeller&quot; @ 1.2 kg/m3 air density driven by energy efficient motor</td>
<td>0.1333</td>
</tr>
<tr>
<td>3</td>
<td>&quot;1,2 impeller&quot; @ 1.4 kg/m3 air density driven by a standard motor</td>
<td>Burned out</td>
</tr>
<tr>
<td>4</td>
<td>&quot;1,2 impeller&quot; @ 1.4 kg/m3 air density driven by energy efficient motor</td>
<td>0.1335</td>
</tr>
<tr>
<td>5</td>
<td>&quot;1,4 de-rated impeller&quot; @ 1.4 kg/m3 air density driven by standard motor</td>
<td>0.1877</td>
</tr>
<tr>
<td>6</td>
<td>Same as scenario no. 5 but taking into consideration the 20% additional fans required. (See the NOTE above)</td>
<td>0.2253</td>
</tr>
</tbody>
</table>
Comments:

- The standard motor modified for high energy efficiency gives very good technical and economical fan performance. Premium efficiency electric motors will be able to cover ultra deep level conditions where air density can reach values of 1.4 to 1.6 kg/m$^3$.

- In spite of good energy cost/ton of air (R0.14/ton), the fan is under-performing technically (because of impeller design), the real FEEI being at least R0.157/ton of air, and the risk of the motor being burned out.

- The fan with de-rated “1.4 impeller” is an expensive solution (54.54% more expensive energy costs). FEEI estimations have been confirmed by direct measurements.

A three cent increase in the FEEI gives a R15 000 change in annual costs per “F” fan. There are at least ten 45 kW “F” type fans per shaft. Therefore the estimated annual savings per shaft range between R10 000 and R150 000. Regardless the depth, high performance fans (impellers and motors) pay for themselves in a very short time (pay-back period for energy efficient motor is 1.2 to 1.5 years) after which they will continue to earn savings worth many times their purchase price as long as they remain in service.

References


Contact Dan Pitis, Femco Mining Motors, Tel (011) 250-2101, danpitis@femco.co.za

<table>
<thead>
<tr>
<th>Number</th>
<th>Fan type</th>
<th>Impeller type</th>
<th>Motor type</th>
<th>Apparent absorbed power S [kVA]</th>
<th>Air volume flow [m$^3$/sec]</th>
<th>FEEI [R/ton of air]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>FDL 165, 45 kW</td>
<td>“1.2 impeller”</td>
<td>Modified</td>
<td>57.42</td>
<td>14.50</td>
<td>0.11</td>
</tr>
<tr>
<td>2</td>
<td>FDL 082, 45 kW</td>
<td>“1.2 impeller”</td>
<td>Standard</td>
<td>53.79</td>
<td>10.64</td>
<td>0.14</td>
</tr>
<tr>
<td>3</td>
<td>FDL 149, 45 kW</td>
<td>“1.4 impeller”</td>
<td>Standard</td>
<td>59.85</td>
<td>9.78</td>
<td>0.17</td>
</tr>
</tbody>
</table>

Table 5 – FEEI values (specific energy costs per ton of air) measured in an ultra deep level Gold mine