This article investigates ways to reduce the volume of chilled water required on a mine by improving the efficiency of cooling units and by re-using the outlet water of these units.

Reducing chilled water requirements on an underground bulk air cooler

South African mines, with their extreme depths, create a real challenge to ventilation engineers. The virgin rock temperature rises with depth below surface, as does the air temperature, due to auto-compression. This places a significant load on the mine ventilation system [1]. Air which is cooled on-surface may be too warm by the time it reaches the work place.

Bulk air coolers (BACs) are used widely to overcome this problem. This system is disadvantaged by the cost involved in pumping water to the surface. While recovery turbines and three-chamber pumping systems reduce the pumping bill, the cost of pumping remains high, even in mines where these techniques are used [2]. The cooling duty of these units reduces over time when their efficiency degrades due to fouling, resulting in increased air temperatures.

At the same time, the lower outlet water temperature of the water, which is too low, indicates that the water is not utilised fully before it is pumped back to the surface.

The cost of chilled water

The main contributors to the cost of chilled water are the fridge plant to cool the water and the pumps to return the water to the surface. A simple mine water reticulation system is shown in Fig. 1.

This system can be much more complex, with additional components to reduce the overall cost of the operation of the system.

The energy required for the system shown in Fig. 1 can be calculated by relating the water flowing down the mine (m^3) over a period of time to the overall energy required by the fridge plant and pumps (kWh). To simplify, the unit it may be expressed as kW/ℓ/s. In an ideal scenario, this should scale with the depth of the mine.

A number of South African gold mines with similar depths were evaluated and the power required for their water reticulation system was determined (see Table 1).

<table>
<thead>
<tr>
<th>Mine</th>
<th>Pump energy (kW / ℓ/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>45</td>
</tr>
<tr>
<td>B</td>
<td>67</td>
</tr>
<tr>
<td>C</td>
<td>60</td>
</tr>
</tbody>
</table>

Table 1: Energy required for chilled water.
Mine A has a three-chamber pumping system to reduce pumping power, which explains why its energy requirement is lower. It does, however, also have pumps on other levels and its pumping power requirement is therefore still significant.

Table 1 shows that a deep level mine without any form of energy recovery system consumes approximately 60 – 67 kW for every ℓ/s of water used. This is significant when considering that a gold mine can use between 7 and 35 ℓ/s of water per day. The power required can therefore be up to 20 MW.

The actual cost of this energy further depends on the pump and fridge plant scheduling during the day to optimise the use of the chilled water dams and so limit the time the equipment must run during Eskom’s peak tariff periods [3]. Although scheduling operating times saves money, it does not save any energy and is energy neutral. This study shows that large energy savings are possible by making minor changes to the system.

**Air cooling units**

Direct contact and indirect contact coolers are the two main types of cooler used in mines. As their names suggest, their main difference is that, in the former, the two fluids are in direct contact with each other while they are separated by metal tubes in indirect coolers.

The number of air coolers may vary between mines but, in some cases, the flow to these cooling units can be up to 35% of the total flow supplied to the underground workings. This represents a significant portion of the overall energy used by the mine.

Fig. 2 shows an indirect cooler. Although there are differences in the operation and performance of the two types of cooler, they will be considered similar for the purpose of this study.

The temperature variations of the two fluids flowing through a cooler in counter flow configuration are shown in Fig. 3. In its simplest form, the efficiency of the cooler can be expressed as:

\[ \eta = \frac{T_{\text{water, out}} - T_{\text{water, in}}}{T_{\text{air, in}} - T_{\text{air, out}}} \]  

The efficiency in fact depends on the flow rates of the two fluids as well as on the cooler design. It is best to contact the supplier to establish what the expected efficiency should be for the specific site conditions.

Important to note is that the efficiency gives a direct indication of how much of the potential cooling duty of the water is used. In the case of indirect cooling units such as cooling coils, fouling of the surfaces limits the contact between the two fluids and, therefore, heat transfer. Temperature increase in the water is reduced and the potential cooling duty is lost. In the extreme, the water at the exit would be at the same temperature as at the inlet.

Also at play is the effect of changing the water flow rate through the unit while all the other variables are kept constant. This is shown in Fig. 4 for a typical cooling coil unit used in mines. It can be seen that efficiency decreases with increasing water flow rate.

The effect on the cooling duty is also shown in Fig. 4. As expected, greater water flow through the unit increases the cooling duty but reduces efficiency. It is clear that the cooling duty does not increase linearly with the water flow rate and that, for very high flow rates, a point will be reached where the cooling duty will no longer increase.

The energy cost of chilled water therefore has a direct impact on the life cycle cost of the unit. The annual energy cost will exceed the purchase price of the equipment in most cases and it is therefore important to ensure that equipment is sized correctly and used efficiently.

The following scenarios may ultimately reduce the cooling duty of the air cooling unit:

- Bypass of the air stream due to leaks in ducting or structure.
- Fouling of coils causing reduced heat transfer and higher pressure drop over the coil. This, in turn, increases the possibility of air bypass.
- Wrong fan selection which result in low air flow.

**Investigation**

The air coolers used in mines were therefore highlighted in this study as part of the overall energy efficiency projects at the mines. These units are usually installed in remote areas and the flow is normally adjusted once-off.

The investigated mine uses cooling cars in areas in need of spot cooling, as well as a single underground BAC. The water supply to the BAC accounts for some 15% of the cost of chilled water supplied to the mine.

The performance of the BAC was established through on-site measurements and compared to the supplier's original design values. Important to note is that the humidity of the air in the mines may be very high and that any performance comparison should take this into account as the effect of condensation in the cooler may change the results significantly. The comparison should also be done at the same fluid inlet temperatures and flow rates.

A comparison of the measured
and design efficiencies is shown in Table 2. The measured efficiency and design values differ significantly. On closer inspection, it was found that significant fouling exists on the air side and that some of the coils are blocked almost completely. This results in air bypassing most of the coils and more load on some of the coils.

As required by law, the mine's ventilation team performs regular measurements to ensure that the working conditions are lawful. The condition of the cooling equipment is only investigated once these conditions are met, which means that the equipment may not be serviced and cleaned regularly. Ensuring that the equipment is operated efficiently creates an opportunity to reduce the mine's energy bill.

The outlet temperature of the water shown in Table 2 also warrants inspection. The supply temperature in this case is approximately 10,5°C, and the outlet temperature for both the design and measured conditions is still acceptable to use for other applications such as drilling. The pressure of the water supplied to the workings from the cooler outlet will be lower than the normal supply pressure. This can be rectified by using small booster pumps.

Even if the pressure is increased from atmospheric pressure to 1300 kPa, the energy required would be some 1,8 kW/L/s water pumped. This still remains a fraction of the 45 – 67 kW/L/s savings incurred by re-using the water.

For the specific case investigated, the water saving will be between 30 and 40 ℓ/s, which amounts to between 1,3 and 1,8 MW savings, 24 hours a day. The payback period is less than a month needed in the case under study but the pay-back time is still under a year.

Optimisation of existing units

One of the simplest and most cost effective solutions here is to clean and maintain the units on a regular basis. Standard cooling coils tend to collect dust and surfaces remain wet because of condensate removed in the cooling process. In the case of the studied BAC, the same cooling duty can be achieved again with a ~30 ℓ/s reduction in water needed due to the non-linearity of the cooling duty and efficiency which varies with varying water flow rates. This results in ~1,35 MW savings in energy use.

Conclusion

The investigation into the use of chilled water and the condition of cooling units showed that huge energy savings opportunities exist within the gold mines. For the investigated mine, the savings may vary between R4-million and R10-million per annum.

Acknowledgement

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References


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Fig. 5: BAC outlet water re-use.

<table>
<thead>
<tr>
<th>Value</th>
<th>Efficiency (n)</th>
<th>Outlet Water Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design</td>
<td>0,61</td>
<td>15,7</td>
</tr>
<tr>
<td>Measured</td>
<td>0,38</td>
<td>13,6</td>
</tr>
</tbody>
</table>

Table 2: Design efficiency and outlet temperature compared to measured values.

**Interventions**

The following opportunities were identified and are in the process of being implemented:

Re-use of cooler outlet water

The outlet temperature of the water determines whether the water can be re-used. Water can only be re-used for drilling and cleaning of the work areas (see Fig. 5). The outlet temperature may be too high to be used in other coolers and the modifications should therefore be considered carefully.

The layout of the mine determines whether this water can be used elsewhere. In the cooler under investigation, the water can be re-used with minor modifications to the piping.

The pressure of the water supplied to the workings from the cooler outlet will be lower than the normal supply pressure. This can be rectified by using small booster pumps.

Even if the pressure is increased from atmospheric pressure to 1300 kPa, the energy required would be some 1,8 kW/L/s water pumped. This still remains a fraction of the 45 – 67 kW/L/s savings incurred by re-using the water.

For the specific case investigated, the water saving will be between 30 and 40 ℓ/s, which amounts to between 1,3 and 1,8 MW savings, 24 hours a day. The payback period is less than a month due to the simplicity of the modifications.

Re-using existing equipment

It was found that an older cooler still existed at the mine which could be used to improve the overall efficiency of the cooling system. The layout of the ventilation network makes it possible to use this unit as a pre-cooler to the main BAC (see Fig. 6). By using the BAC outlet water as the inlet to the old cooler, the two units were arranged as a two-stage cooling system in counter flow arrangement, thereby increasing the overall efficiency.

The mine is satisfied with the working conditions and this improved efficiency will therefore result in water savings. It is predicted that the intervention will result in a 15 – 20 ℓ/s reduction in water supply to the combined cooling unit. This amounts to a approximately 0,67 – 0,9 MW saving. Some changes to the existing systems were needed in the case under study but the pay-back time is still under a year.

Optimisation of existing units

One of the simplest and most cost effective solutions here is to clean and maintain the units on a regular basis. Standard cooling coils tend to collect dust and surfaces remain wet because of condensate removed in the cooling process. In the case of the studied BAC, the same cooling duty can be achieved again with a ~30 ℓ/s reduction in water needed due to the non-linearity of the cooling duty and efficiency which varies with varying water flow rates. This results in ~1,35 MW savings in energy use.