Case study

Hard ice technology delivers cost savings

Howden installed a 30 kg/sec 10 MW(R) hard ice plant, using plate ice makers and ammonia refrigeration screw compressor sets, at Mponeng. The use of hard ice technology instead of vacuum ice or conventional water chillers brought significantly reduced rates of water flow, and considerable savings in the return water pumping power consumption and costs for this deep level mine.

Howden Projects was invited to investigate and design an energy efficient cooling system that reduced the return water pumping costs by using hard ice cooling technology.

The cost of electrical energy to industrial users such as the mining industry has risen steadily over recent years. It has now reached a point where the cost of cooling deep mines now threatens their economic viability. As mine workings reach ever-greater depths, the rock temperature increases and working conditions become less sustainable, new, innovative cooling technologies are now required.

The challenge

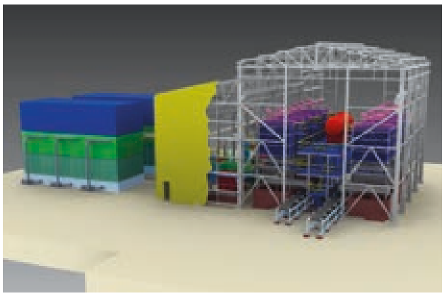
Mponeng is one of South Africa's deepest mines, with virgin rock temperatures reaching up to 54.5˚C at 3.5 km below surface. For miners to be able to work at acceptable temperatures, the ambient air has to be cooled down to 28˚C Wetbulb temperature.

Until now cooled air and/or water has been used, but Mponeng Mine has now reached the point where ice is a serious option for their deep mining operation. There are powerful reasons for using ice cooling systems, one of several techniques available for cooling deep mines, because of the savings on pumping energy, but up till now it has not been financially justifiable.

However, once a mine is 1500m to 2000m deep, the balance tips in favour of using ice, as the capacity to install more heat rejection machinery underground becomes limited and pumping costs become very high. Ice-cooling is more energy-efficient than water-based systems, with every 1 kg/s of ice providing equivalent cooling to 5 l/s of chilled water, bringing savings of approximately 75%-80% on pumping costs.

AngloGold Ashanti planned to deepen its Mponeng Mine to maintain production levels and extend the life of the mine as output at present depths begins to decline. The mine currently has an installed refrigeration capacity of more than 100 MW(R). The deepening project required an increase of 40 MW(R) in refrigeration capacity. With conventional water chillers and vacuum ice plants, this would incur huge pumping costs for the return water.

Phase 1 of the deepening project, to a depth of 3.8 km, began in 2009. Howden Projects were invited to investigate and design an energy efficient cooling system that reduced the return water pumping costs by using hard ice cooling technology. Howden subsequently received an order to supply a nominal 10 MW(R) ice plant for Phase 1, based on the ultimate requirement of a nominal 40 MW(R) cooling capacity. In accordance with AngloGold Ashanti's technical specification we were able to include design, supply, erection and commissioning as part of a turnkey hard ice plant project.



The solution

After a full investigation, Howden established that using hard ice technology will bring huge power and cost savings on the return water pumping.

Hard ice advantages and energy efficiency

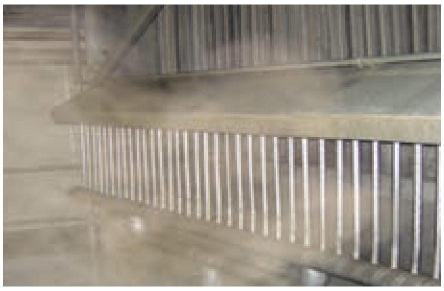
Making ice on the surface in ice-making machines, sending it down the mine into a dam, then circulating the cold melt water through air coolers is more energy efficient than a conventional chilled water refrigeration system, because the latent heat capacity of a kilogram of ice means it can take up far more heat than a kilogram of cold water. This accounts for significant savings in operational costs. Once the ice melts, the water still has to be pumped back up to the surface, but the quantities are much smaller and pumping costs are reduced to less than a quarter of the costs of a chilled water refrigeration system. In general, the ratio of mass flow rate for hard ice compared to water would be 1:5.

The proportion of water turned to ice is also important. Vacuum ice only achieves ice mass fractions of 60%, while hard ice is in the range 93% to 98% depending on the water quality. A lower ice mass fraction means more ice needs to be sent underground to achieve the same cooling duty, thus increasing the quantity and pumping costs of the return water. In general, the ratio of mass flow rate for hard ice compared to vacuum ice would be 1:1.35.

Although ice plants are slightly more expensive in capital outlay than conventional refrigeration plants, the initial investment is offset by lower operating costs, in particular the reduced pumping costs of smaller volumes of water and the more effective low temperature underground cooling.

C.O.P. (Coefficient of Performance)

When evaluating a cooling system, the C.O.P. of the complete cooling loop must be considered. For example, when a vacuum ice plant is compared with a hard ice plant in terms of ice production only, the C.O.P. of the vacuum ice plant is higher than that of the hard ice plant. However, the vacuum ice has an ice mass fraction (I.M.F.) of 60% compared with hard ice at 93% to 98%. This means that extra water from the vacuum ice must be pumped back to surface, and for depths greater than 1000m to 1500m this tilts the C.O.P. comparison back in favour of hard ice. The Joule-Thompson (Auto-Compression) effect of energy loss at 9.79 kJ/kg for every 1000m should also be taken into consideration when assessing the overall C.O.P. of cooling capacity at the ice melting dam.



Technical data: Hard ice plant duties

The cooling energy of hard ice involves three distinct phases.

Phase 1

Solid Phase Specific Heat, as solid ice passes from -2.0˚C to 0˚C. This value is usually neglected.

Phase 2

Latent Heat of Fusion (as the solid ice melts).

Phase 3

Liquid Phase Specific Heat, as the liquid changes from 0˚C to 25˚C.

The ice mass flow rate is calculated using the following formula:

$$M_{ICE} = \frac{Q_{ICE}}{IMF \times h_i + C_p \times \Delta T}$$

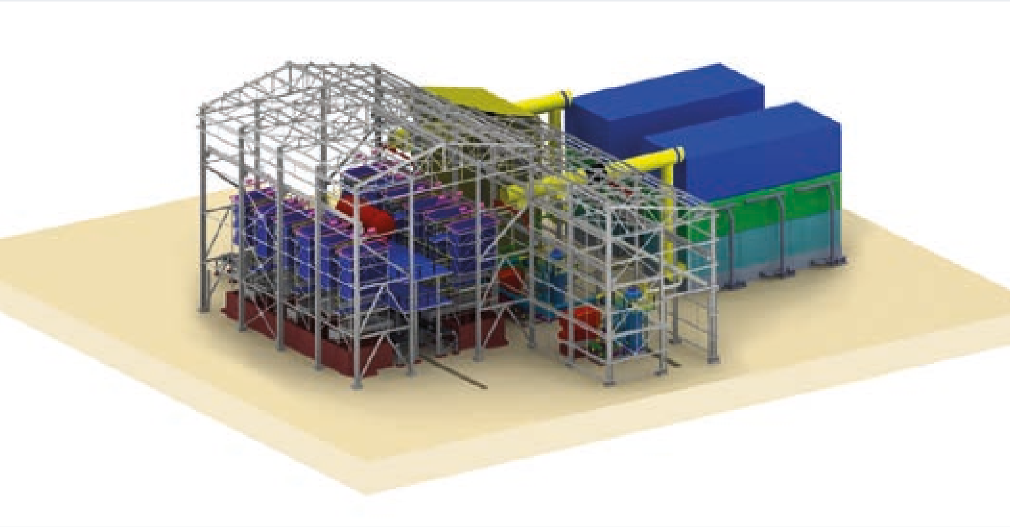
(Rewritten from: $Q_{ICE} = M_{ICE} \times IMF \times h_i + M_{ICE} \times C_p \times \Delta T$)

Q_{ICE}	Cooling Ice Duty (12525 kWR at point of delivery above shaft surface, as specified by the mine)
IMF	Ice Mass Fraction (93%)
h_i	Latent Heat of Melting Solid Ice (334 kJ/kg)
C_p	Specific Heat Capacity of Water (4.187 kJ/kg˚C)
ΔT	Temperature Differential - Return Water Temperature (25 – 0˚C)

$$M_{ICE} = \frac{12525}{0.93 \times 334 + 4.187 \times (25-0)}$$ = 30.16 kg/sec **Hard Ice (Ratio 1:1)**

$$M_{ICE} = \frac{12525}{0.60 \times 334 + 4.187 \times (25-0)}$$ = 41.06 kg/sec **Vacuum Ice (Ratio 1:1.36)**

$$M_{WATER} = \frac{12525}{0 \times 334 + 4.187 \times (25-6)}$$ = 157.44 kg/sec **Chilled Water (Ratio 1:5.22)**



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The benefits

Operating Return Water Pumping Cost Comparison: Hard ice vs vacuum ice vs chilled water. In the case study for the Mponeng cooling systems, the following values are used:

Mponeng ave mining depth	4000 m (future)
Return water temperature	25˚C
Auto-compression coefficient	9.79 kJ/kg per 1000m
Surface cooling duty required	12525 kWR
Typical pump efficiency	75%
Average power cost	0.075 USD / kWhr (or 657 USD / kW per year)

Energy balance		Hard ice	Vacuum ice	Water
Chilled water supply temperature	˚C	-	-	6
Ice mass fraction	%	0.93	0.60	-
Fluid mass flow (ice mass flow or chilled water)	Kg/s	30.16	41.06	157.44
Calculated auto-compression losses	kW	1181	1608	6165
Calculated cooling duty u/g	kW	11344	10917	6360
Return water pump power requirements				
Total pumping absorbed power requirements	kWE	1608	2190	8397
Cost comparisons				
Return water pump operating cost per year	USD/yr	$1 056 781	$1 438 584	$5 516 775

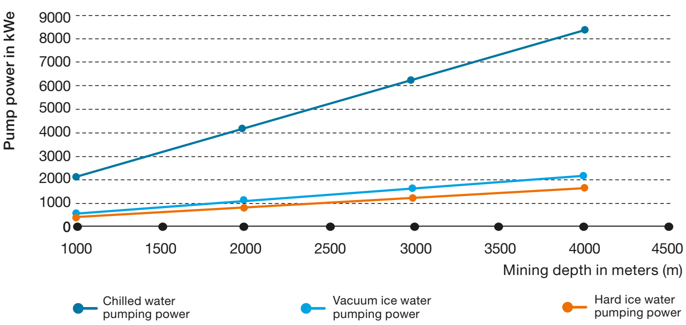
The benefits: Hard ice compared with chilled water

Hard ice systems compared to conventional water chiller plant brings savings of 6788 kWE (or US$ 4.46 Million) per year in pumping power consumption. The percentage cooling loss due to auto-compression effects is orders of magnitude higher in water systems than in hard ice systems (50% of cooling load at 4000m). This clearly demonstrates that, if available cooling at shaft bottom is used as the criterion, ice systems are economically attractive for shallow hot mines as well as deep mines.

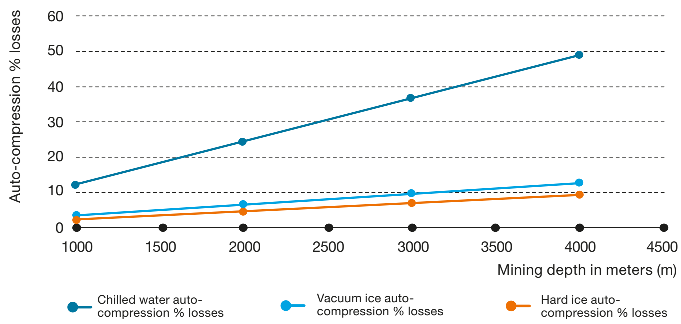
The benefits: Hard ice compared with vacuum ice

Hard ice systems compared to vacuum ice plant bring savings of 581 kW (or US$ 0.38 Million) per year in pumping power consumption. This is a total saving, over 20 years, of US$ 7.6 Million). The percentage cooling loss due to auto-compression effects is 13% for vacuum ice compared to 9% for hard ice.

Return water pumping power



Auto-compression % losses



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