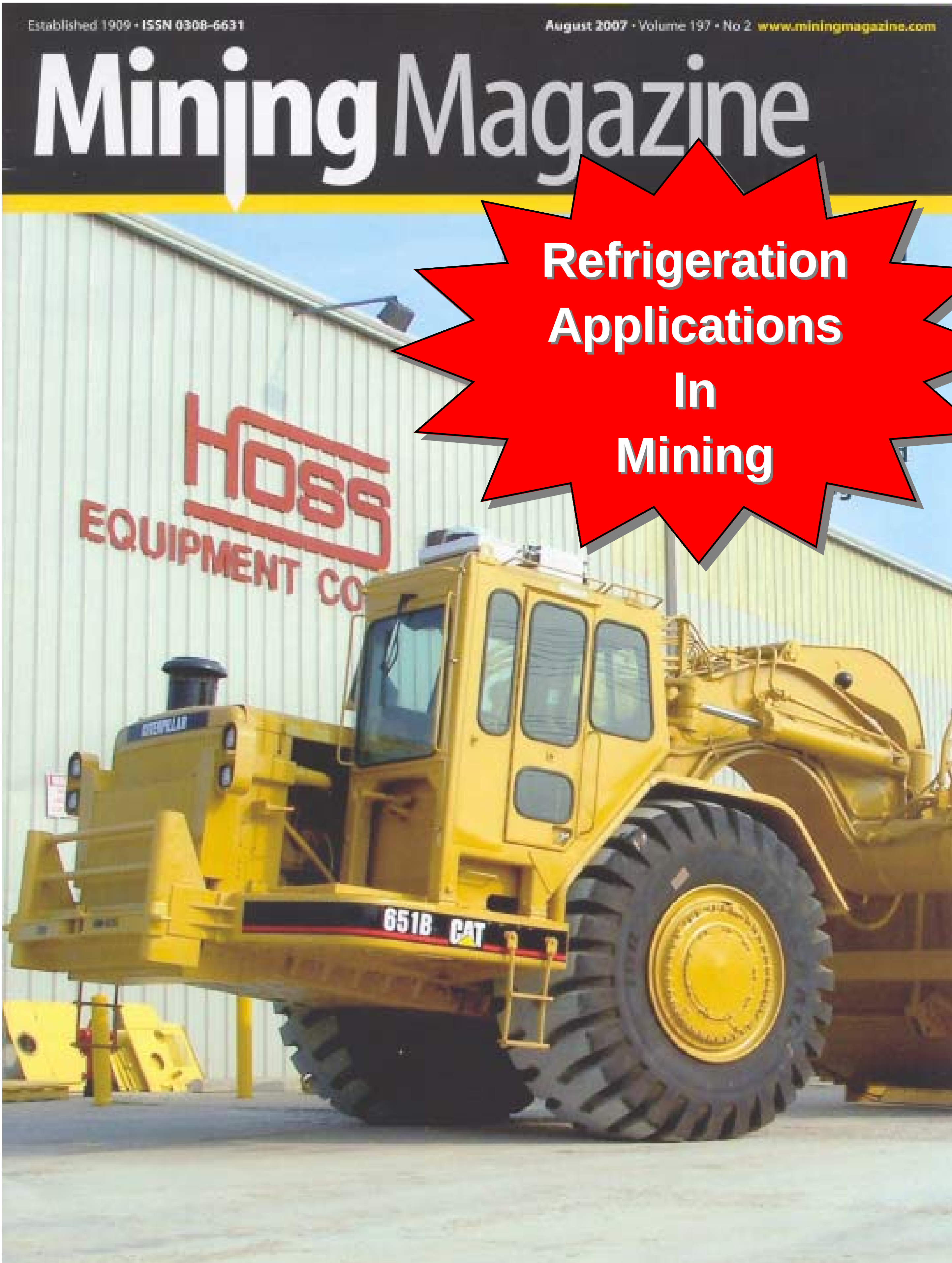
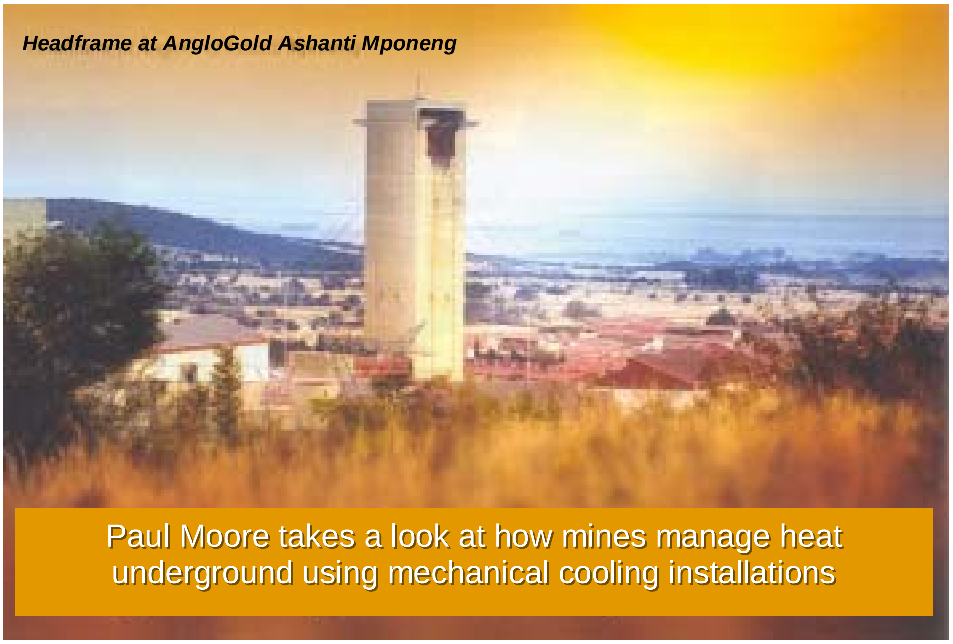


Refrigeration Applications In Mining

Standing the Heat



Headframe at AngloGold Ashanti Mponeng

Paul Moore takes a look at how mines manage heat underground using mechanical cooling installations

FREEZING ground to allow mine development and operations where there is water saturation is common in large, underground projects. However, the same type of equipment is also used in chilling systems to cool ventilation air in mines. The basic components of the refrigeration system are the same for either; it is the operating conditions that will differ.

A lower suction temperature in ground freezing will require more brake horsepower-per-tonne of refrigeration (BHP/TR) of cooling. The style of evaporator may change, depending on whether cooling is derived from water or from air for cooling shafts. Typically, ground freezing is done using a shell-and-tube or plate-and-frame heat exchanger. The refrigerant (ammonia) chills a fluid (usually salt based, such as calcium chloride) that is pumped into the ground through a network of pipes.

Mine cooling mainly addresses working conditions. John Buis, managing director of AustCold Refrigeration, one of the leading refrigeration engineering companies told *Mining Magazine:* "The problem arises when mines get deeper - in Australia, this is generally when the mine reaches a depth of 1km. The heat from the ground, combined with the high humidity caused by natural water seepage, makes it impossible for miners to continue unrestricted working. Rather than reduce the working time available, mines generally opt for some type of cooling."

Mr. Buis said that this is typically done using one, or a combination of, the following methods: increasing the main ventilation airflow; surface refrigeration of total mine airflow; or underground refrigeration of air to a development head.

AustCold manufactures both surface and underground mine air-cooling equipment, and provides operational support for these installations. The company has provided various services to mines and consultants, from just manufacturing the refrigeration skid through to complete installation for a mine, including the design, manufacture, installation and maintenance of the equipment.

Usually, the placement of the equipment and calculation of the required refrigeration capacity of the plant is done in conjunction with a ventilation engineer - either one employed by the mine or a consultant that the mine uses. Mr. Buis commented, "Ventilation engineering of mines is an art in its own right and these engineers are in high demand in Australia, particularly given the minerals boom we are going through."

The main areas where there are deep mines requiring air cooling are in Australia, South Africa, Europe, the US and Canada. In each of these countries there are companies that manufacture air-cooling equipment - some of these compete globally, such as South Africa's Bluhm Burton Engineering (BBE), AustCold in Australia and CIMCO Refrigeration in Canada.

Recent BBE installations include: AngloGold Ashanti Mponeng (Ice Thermal Storage System 800 t ice mass - and modifications to the existing refrigeration plant); Barrick South Deep (94 level Phase 1, three 8.5 MW underground plant (R134a) and bulk air-coolers); and Impala Platinum (large R134a surface-refrigeration plants and bulk air-coolers at the No 20 and No 16 shaft).

continued >

AustCold cooling plant at Newcrest Telfer

AustCold cooling projects have included BHP Billiton Olympic Dam, Newcrest Telfer, Barminco Eloise and Xstrata Copper's Kidd and Mount Isa. ***Some of the work done by CIMCO is outlined in the box below.*** Key component firms include: US-based Howden Buffalo and Frick; Mycom (Mayekawa Manufacturing) and Kobelco in Japan, and Aerzener in Germany, which all produce screw compressors. Evapco, Alfa Laval and Ivensys APV are leading suppliers of condensers and plate evaporators.

REFRIGERATION EQUIPMENT

There are four components to any refrigeration system: the compressor; condenser; flow control device and evaporator.

David Sinclair, district sales manager at CIMCO Refrigeration, commented: "You cannot produce 'cold'; you can only remove heat. The compressor is used to raise the pressure - and therefore the condensing temperature - of the refrigerant gas, and it provides the energy that 'pumps' the gas through the entire refrigeration system". The high-pressure gas travels first from the compressor to the condenser. Using either air forced out through fans or water, or both, heat is removed from the gas travelling through the condenser and released to the environment. Once the heat is removed from the gas, it condenses into a high pressure liquid. This high-pressure liquid is pumped through a flow-control device that converts the liquid from high to low pressure. The low-pressure liquid is pumped to the evaporator.


AustCold cooling plant at Xstrata Mount Isa

In the evaporator, heat is absorbed into the refrigerant (ammonia) from the secondary coolant (water, brine or glycol). The low-pressure liquid refrigerant, which is at a lower temperature than the secondary coolant, absorbs heat and boils or is evaporated into a gas. In giving up its heat, the secondary coolant can then be circulated to remove heat from the ground, which now becomes cold. The refrigerant gas is sent back to the compressor to be re-pressurized and the cycle repeats.

The gas needs to become hot so that, when it reaches the condenser, it is warmer than the ambient air. As heat flows from warm to cold, the heat that is dumped outdoors is ultimately the heat that was picked up from the evaporator.

According to Mr. Sinclair, the preferred refrigerant compound combination is the use of ammonia as the primary refrigerant and calcium chloride brine as the secondary refrigerant. Ammonia has these advantages: it is extremely efficient (carries more BTUs/lb of refrigerant); requires lower HP systems; uses smaller heat exchangers and smaller-diameter pipe; is environmentally-friendly (zero ozone depleting potential ODP and global-warming potential GWP); is economical to purchase; can tolerate a large volume of water without any adverse affects to the thermodynamic properties of the refrigerant; and it is self-alarming (pungent odour). Calcium chloride has excellent thermodynamic properties, is cheap to purchase and is relatively environmentally-friendly.

CIMCO REFRIGERATION

Mining Magazine spoke to CIMCO Refrigeration in Canada, which has been involved in deep-mining projects for over 50 years. The majority of this work has been in ground freezing for both uranium and potash mines, but, more recently, this has included chilling systems for cooling ventilation air to minimize the number of rest periods required during summer operations.

Two key cooling projects include:

- ### Agnico-Eagle Mines - LaRonde

  In 2003, CIMCO Montreal designed and installed a 1750 HP ammonia-based air-cooling system for the LaRonde mine. The system incorporated an M&M/Howden screw compressor with a CIMCO-fabricated exchanger skid, which included an APV plate-and-frame condenser and evaporator. Chilled water is circulated from the refrigeration plant to a bulk air chiller in the supply air shaft to the mine.

  CIMCO also converted, from R-22 to ammonia, three existing 600 HP water-chilling packaged units (supplied by AustCold) each with a screw compressor and plate-and-frame heat exchangers. These four water-chilling units, with a total refrigeration capacity of 3,348 TR, are cooling 225 l/s (3,982 usgpm) of water from 14.7°C (water entering the chiller) to 2°C at the outlet.

  According to Agnico-Eagle engineer Christian Quirion, the cooling system used at Agnico-Eagle is located on the surface and operated from April through to October. The installation cools the mine below the 1,700 level, cooling the air at the surface and distributing it underground using a main axial fan. Mr. Quirion said that, as LaRonde is expanded through the LaRonde II project, the company will more than double its cooling capacity by adding 4,000 t of refrigeration equipment underground.

- ### Falconbridge - Kidd Mine D

  ClMCO provides the technical and mechanical support for a 1,800 HP ammonia screw compressor, Bulk Air Cooler (BAC) System, which provides chilled air for ventilation. The firm has been involved in diagnosing and troubleshooting the Australian-manufactured equipment, and it helped to get the plant registered under Canadian boiler and pressure-vessel regulations. ClMCO's central operator's group has provided around-the-clock operating and maintenance support for the past two operating seasons.

How Kidd keeps its cool


Cold stope drawpoint access

Kingsley Hortin, senior ventilation engineer at Xstrata Copper's Kidd mine in Timmins, Ontario, outlines in detail how heat is managed at the operation.

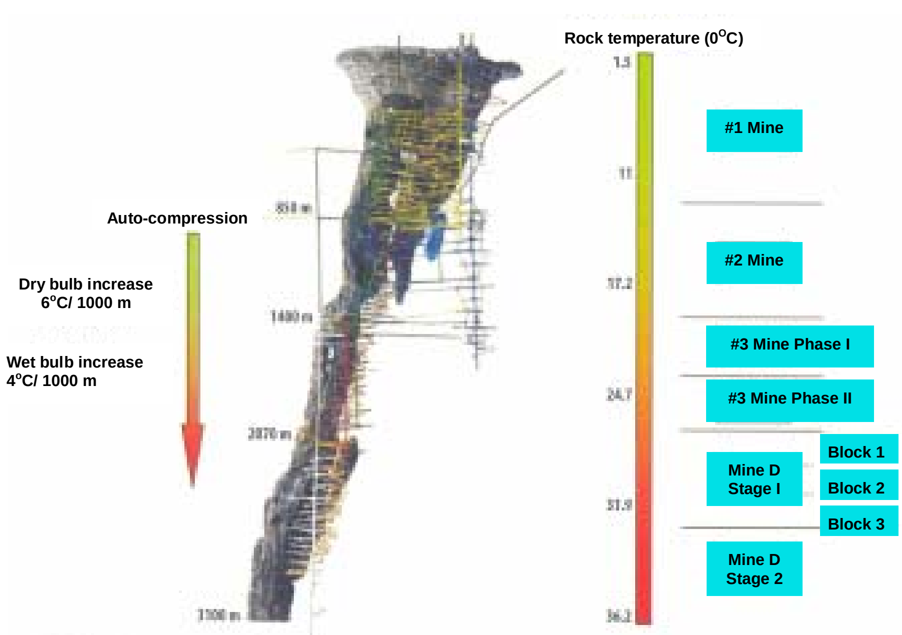
DIESEL equipment, electrical equipment, broken rock movement and, to a lesser extent, the paste-filling process and sulphide rock oxidation all contribute some heat load at the Kidd mine. However, the predominant heat load is due to the effects of auto-compression.

This is a process by which the potential energy of a column of air at the surface converts out as enthalpy as it descends into the mine. This results in an increase in pressure and the internal energy of the air, and it therefore follows that temperature increases as well.

The larger the difference between the surface and the bottom of that column of air (i.e. the deeper it is in the mine) the higher the potential energy, and therefore the greater the increases in temperature. At Kidd, auto-compression accounts for an increase of about 6°C (dry bulb - Tdb) for every 1,000 m of depth and approximately 4°C (wet bulb - Twb) for every 1,000 m. As a result, the temperature at which air enters the mine at the surface has a big influence on underground air temperatures.

Rock temperature also affects air temperature underground. In many operations around the world, heat transfer from the surrounding rock is a significant heat load. Kidd, however, enjoys a much more favourable situation. A very cool surface rock temperature, coupled with a shallow geothermal gradient, means that, for much of Kidd Mine, the rock acts as a heat-sink rather than a heat load.

The geothermal gradient - the rate at which the temperature of the rock increases with depth averages 11.2°C for every 1,000 m. With a surface rock temperature of l.5°C, the temperature of the in-situ rock (virgin rock temperature) is still only 24.7°C at the 68 level. which is the top of the Mine D ore zone; increasing to 31.9°C at the bottom of the Mine D Stage 1 ore zone on level 90.



Kidd mine long-section, indicating the different mining areas and primary heat sources

IMPACT ON AIR TEMPERATURE

The impact of heat transfer from the surrounding rock on mine air temperature is also dependent on the relationship between the thermal properties of the exposed rock and the properties of the ventilating air going past that rock. This includes the length of time since the opening was originally mined, the wetness of the exposed rock, and the ventilating air's temperature and velocity.

As mentioned, the surface climatic conditions have a significant impact on underground air temperatures and are therefore significant in determining the heat transfer and depth at which the rock transcends from a heat sink to a heat load. This varies by season. That said, while this depth is variable, the rock only acts as a heat source in Stage 2 of Mine D.

A study undertaken in 2000 by Dr. M.J. Howes of RHP Consulting in Cornwall, UK, as part of the Mine D feasibility established that the heat load for Phase II of #3 Mine is 4.7 MW; 8.4 MW for stage 1 of Mine D and 11 MW for Stage 2 of Mine D. Of this, auto-compression accounts for 75-100% of the total heat load. In Mine D Stage 2, the heat load from the rock is only 8% of the total load.

Surface ventilation infrastructure at Kidd

NATURAL CHILLING - 3 MINE

Kidd uses two methods of chilling mine air: a mechanical refrigeration system and a natural refrigeration system. Both systems are used to cool certain portions of the fresh-air intake and therefore service two different areas of the mine. The natural refrigeration system or 'cold stope' was set up in the early 1990s and is mainly used to cool #3 Mine, particularly Phase I fresh-air supply.

Following the completion of the Kidd open-pit and migration to underground long-hole open-stoping, some of the early stopes broke through to the bottom of the pit and were then backfilled with rubble. This allows a conduit, albeit through broken rock, from the surface to the underground workings.

During the winter, cold air from the surface is drawn through the bottom of the pit into these rubble-filled stopes and out on to a series of level drawpoints 350-425 m below surface. The average surface Tdb temperature in each month from November to March is below 0°C, with the average minimum temperature in January being -25.7°C (the lowest recorded was -45.6°C on February 1, 1962).

With consistently cold temperatures, the process of drawing chilled air through the cold stope during the colder months creates a great deal of ice in the draw points, draw-point accesses and gaps around the rubble. It was estimated by Dr. Howes that about 120,000 t of ice is created during a typical year by this process. This act of cold air passing through the cold stope also helps cool the rubble within the stope.

During the more temperate months, the warmer surface air is drawn through the same cold stope. The melting of this large amount of ice, and the contact of the warmer air with the previously-cooled rubble, cools the air being delivered to the underground workings. Airflow through the cold stope is collected in a raise and delivered to the 2,800 level, where the flow is controlled through two 54 in 250 HP axial fans. These fans, in turn, deliver the cooled air to the top of #3 Shaft (internal hoisting shaft) on the 4,700 level for distribution in #3 Mine and, in particular, Phase I.

Tdb temperatures measured at the 2,800 level vary from 2-12°C, while the Twb varies from -0.5-8.5°C with the total airflow through the original cold stope remaining relatively constant at 150 m^3/s.

The cold stope has subsequently been expanded to cool a further 90 m^3/s air, although this expanded cold stope has its air delivered into #1 Shaft to complement its mechanically-refrigerated airflow. The total cooling provided by the original cold stope, plus the expanded cold stope, is 8.5 MWR (megawatts refrigeration) and makes up 25% of Kidd's total air intake.

MECHANICAL REFRIGERATION - MINE D

Stage 1 of the Kidd Mine D expansion project is now complete and production has commenced from all blocks in Mine D. As part of the expansion project, it was decided that a mechanical-refrigeration system was required to address the heat loads at depth. As such, a single-compressor set was ordered in January 2004, and installed and commissioned for use in July of that year. This refrigeration system provides cooling for Stage 1 of Mine D and a portion of #3 Mine Phase II.

The Kidd mechanical-refrigeration system delivers 7.5 MWR of cooling, and was designed and engineered by Dr. Howes and South Africa's Bluhm Burton Engineering, with construction managed through MacIntosh Engineering. As Ontario law requires a stationary engineer to be present at all times during the operation of the plant, CIMCO has been contracted to provide this engineering and maintenance service.

The entire refrigeration plant and Bulk Air Cooler (BAC) are located on the surface of the mine. The refrigeration plant was supplied by Australia's AustCold. The compressor set for the plant is a 1750 HP Howden screw compressor with matching plate-and-frame heat-exchangers for the condenser and evaporator. The plant uses ammonia as the refrigerant.

The plant chills the water to be delivered to the BAC. In turn, the returning water from the BAC is circulated back to the plant to, once again, be chilled. This effectively forms a closed-loop system, although some make-up water is required from time to time to replenish that which is lost to evaporation. The water is circulated between the plant and BAC through twin 400 mm HDPE pipes of 38 mm.

The BAC was supplied by Baltimore Aircoil Co. and is located in the disused crane bay of #1 Shaft. This shaft is a decommissioned, hoisting shaft with the conveyances removed and is solely used for ventilation. Approximately 35% of the total mine air intake is through the collar of #1 Shaft. Then, through a series of drifts and raises, the #1 Shaft chilled air is delivered to #4 Shaft (internal hoisting shaft), which supplies the majority of fresh air for Mine D.

The BAC is a two-stage cross-flow. Chilled water (at around 6^{o}C) is delivered to the top of the first bank of fill and flows down the outside of the fins of the fill. The water is collected in a basin at the bottom of the bank before being pumped to the top of the second fill bank, located directly in front of the first. Again the water passes over the fins of this second bank.

At the same time, ambient surface air is drawn across both banks and is cooled by the air-water interface before travelling down #1 Shaft. The temperature of the water leaving the second bank and being pumped back to the refrigeration plant is around 13.4^{o}C, while the temperature of the outside air is chilled to an average 10.1^{o}C Tdb and 9.3^{o}C Twb.

SEASONAL EFFECTS

As mentioned, the surface air temperature in the winter is consistently below freezing. As such, the plant cannot be operated before April 1 and after October 31 due to the potential for water freezing.

Over this period of time, the surface temperatures are lower than what the refrigeration plant delivers during its summer operation. As such, the air is allowed to enter #1 Shaft directly. Again, as the air temperature entering the mine is now much cooler, the temperatures in the mine are also cooler even at depth with the influence of auto-compression.

As a result of the below-freezing surface-air temperatures in the cooler months, the plant is 'winterized' as part of the shutdown at the end of the operating season. This entails the complete drainage of all water from the BAC, pipes, condenser towers and other exposed infrastructure.

The plant building is also heated during the cooler months to around 10^{o}C to ensure key equipment is not damaged by exposure to cold temperatures. Additionally, water

Refrigeration plant showing the twin HDPE water pipes and cross-flow condenser cooling towers

trenches in the plant are filled, so any accidental and significant leak of liquid ammonia is collected in the water before being released as a gas in a controlled manner.

After the winter period, a trigger-point needed to be established to determine when to restart the plant. This point was given by Dr. Howes to be when the surface Twb is greater than 7.5^{o}C for more than four consecutive hours. It is at this point that preparations are made to ready the plant f or start-up, usually in the middle of May. Similarly, Dr. Howes established the trigger-point for plant shutdown to be at the end of the operating season. It is determined To be when the Twb is less than -5^{o}C for more than four consecutive hours, usually around mid-October.

FUTURE PLANS

The refrigeration plant was designed so that a second compressor set could be installed within the existing building in preparation for any refrigeration expansion plans. At present, approval is being sought to continue mining below Stage 1 of Mine D and into Stage 2. As part of this, the need for expansion of the mechanical refrigeration plant is being examined.

Further expansion of the cold stope is also being examined. It is cheaper to run a cold stope system than a mechanical one, and any gains that are made are likely to be implemented, regardless of any further extension to the mine. While #3 Shaft is cooled through this natural refrigeration process, #2 shaft air is not refrigerated at all; primarily because it supplies fresh air to the upper parts of the mine, which do not require the air to be chilled.