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Design and construction of a surface air cooling and refrigeration installation at a South African mine

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ABSTRACT: Impala Platinum's No.16 Shaft mine is currently under construction and is expected to reach full production of 256 500 tons per month by 2014. Mining will start at 1 260 m below surface with a maximum mining depth of 1 535 m where virgin rock temperatures of 56.6°C will be experienced. As a result of depth, high virgin rock temperature and narrow reef mining, an expected total of 31.5 MW[R] of air cooling capacity will be required to achieve acceptable underground conditions. This will be achieved by cooling mine intake air in a single dedicated air cooling installation located on surface. The compact installation includes air cooling spray chamber, refrigeration machines, condenser cooling towers, evaporator and condenser water reticulation as well as all electrical and control systems. Construction and commissioning of the first phase of this air cooling installation has recently been completed on a turn-key contract basis.

1 Introduction

In general, the most appropriate strategy for cooling hot underground mines is to first introduce air cooling and refrigeration on surface (Bluhm *et al*, 2003). As a result, the first experience mines have with air cooling and refrigeration is often with surface installations. This can be an advantage because the installation, operation and maintenance of surface installations are considerably easier and often cheaper than comparable underground installations (Wilson *et al*, 2003).

The introduction of air cooling and refrigeration on surface can allow hot underground mines to exploit deeper reserves, extend the maximum limits of mining and increase production where underground air temperatures are the limiting factor.

In this paper, the design and construction of a surface air cooling installation at the Impala No.16 Shaft mine is described.

The objective is to provide readers with an introduction to both the scale and typical design issues encountered during the designing and construction of a surface air cooling and refrigeration installation. It is recognized that there are significant differences between mines and the installation described in this paper may not be appropriate for all deep hot underground mines.

1.1 Background to Impala No.16 Shaft

Located in South Africa, near Rustenburg in the bushveld igneous complex, Impala Platinum's No.16 Shaft mine is currently under construction and is expected to reach full production of 256 500 reef tons per month by 2014. Mining will start at a depth of 1 260 m below surface and will extend to a maximum depth of 1 535 m where virgin rock temperatures of 57°C will be experienced (Tassell, 2007).

As a result of depth, high virgin rock temperature and narrow reef mining, a total of 31.5 MW[R] of intake ventilation air cooling will ultimately be required to achieve acceptable underground conditions. Intake ventilation air will be cooled on surface, in an air cooler and refrigeration installation, serving the main intake shaft.

1.2 Refrigeration System Phase-In

Mining is a continuously evolving and dynamic process and an essential feature of any good mine ventilation, cooling and refrigeration system is that it must be sufficiently flexible to adapt to change. The modular approach used for the No.16 Shaft system provides both the required flexibility and allows for equipment to be phased-in as required by the mine heat load.

Numerical modeling of the underground environment indicated that the maximum air cooling requirement would be 31.5 MW[R]. Implementation of the air cooling and refrigeration system will unfold over an extended period in a number of phases. The first phase will provide a nominal 14.5 MW[R] of air cooling capacity. Air cooling capacity will be increased to 25 MW[R] for the second phase and then further increased to 31.5 MW[R]. Provision has been made to allow the system to be expanded to an ultimate air cooling capacity of 40 MW[R] but this will only be required if there are significant changes in the mining method or total production.

Construction of the first phase started in November 2006 and commissioning is due to be completed by March 2008. The first phase includes a horizontal air cooling spray chamber, axial flow fans, refrigeration machines, condenser cooling towers, evaporator and condenser water reticulation systems, all electrical and control systems as well as all civil, building and structural steel works.

Provision has been made in the plant room and spray chamber for expansion to the ultimate system. The only additional construction required would be construction of additional cooling towers as more refrigeration machines and ultimately an ice thermal storage system are installed.

2 Construction Management

With any construction project an important decision is the selection of the most appropriate management approach and this is worth a note here. Of the available approaches, the EPCM and turn-key approaches were considered.

With the EPCM approach, a company is contracted to provide Engineering, Procurement, and Construction Management services. This company is responsible for all engineering and will assist in placing contracts for all equipment and construction services necessary. The EPCM Company will manage all other contractors on behalf of the mine.

The EPCM Company is mandated to work within a prescribed (and calculated) this budget and schedule. Project risks associated with budget and schedule are carried by the mining company.

With the turn-key approach, the mine places a single contract, for a fixed lump sum, with a single company to design, build and commission the installation. Historically, South African mining companies have followed the EPCM approach but, since 2003, there has been a significant movement towards the turn-key approach. The reasons for this are varied, but the primary driving force is the trend towards outsourcing and the desire to minimize exposure to risk. From the mine's perspective, turn-key contracts are far simpler with the full responsibility resting with a single contractor. This must be compared to the EPCM approach which would require contracts with about 60 individual companies, with a high level of design and management input from mine personnel. With the turn-key approach the project risk is transferred to the turn-key contractor and significant provision for contingencies does not have to be made by the mine.

Impala Platinum favored the turn-key approach over the EPCM approach and the first phase of the refrigeration installation at Impala No.16 Shaft has been completed by BBE as a turn-key contract.

3 System Description

3.1 General Process Description

A system process description for the first phase is given below with reference to the simplified schematic diagram shown in Figure 1, the photograph of construction of the first phase shown in Figure 2 and the site layout shown in Figure 3. Nominal process conditions for the first phase are shown in Table 1.

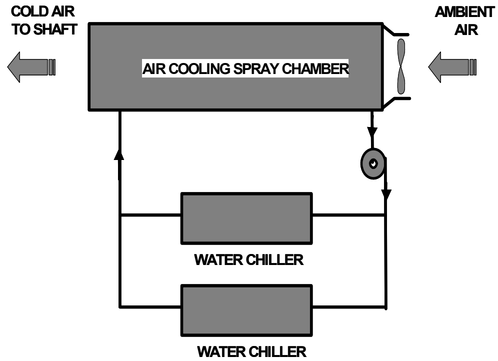

Figure 1. Schematic diagram.

Table 1. Nominal process conditions [mid day]

Description	First Phase
Air cooling duty	14.5 MW[R]
Air flow	670 kg/s
Ambient air [wet-bulb]	20°C
Cooled air [wet-bulb]	13.1°C
Water chilling duty	15.6 MW[R]

The air cooler is a horizontal spray chamber which is essentially a direct contact cross flow heat exchanger. Water is re-sprayed in a second stage to provide a high thermal efficiency that is higher than what can be achieved in a conventional packed tower (Bluhm *et al*, 2001).

Figure 2. Construction of first phase

Warm return water from the air cooler is cooled by two water chilling refrigeration machines. Condenser water cooling is provided by mechanical draft, packed, counter-flow type cooling towers.

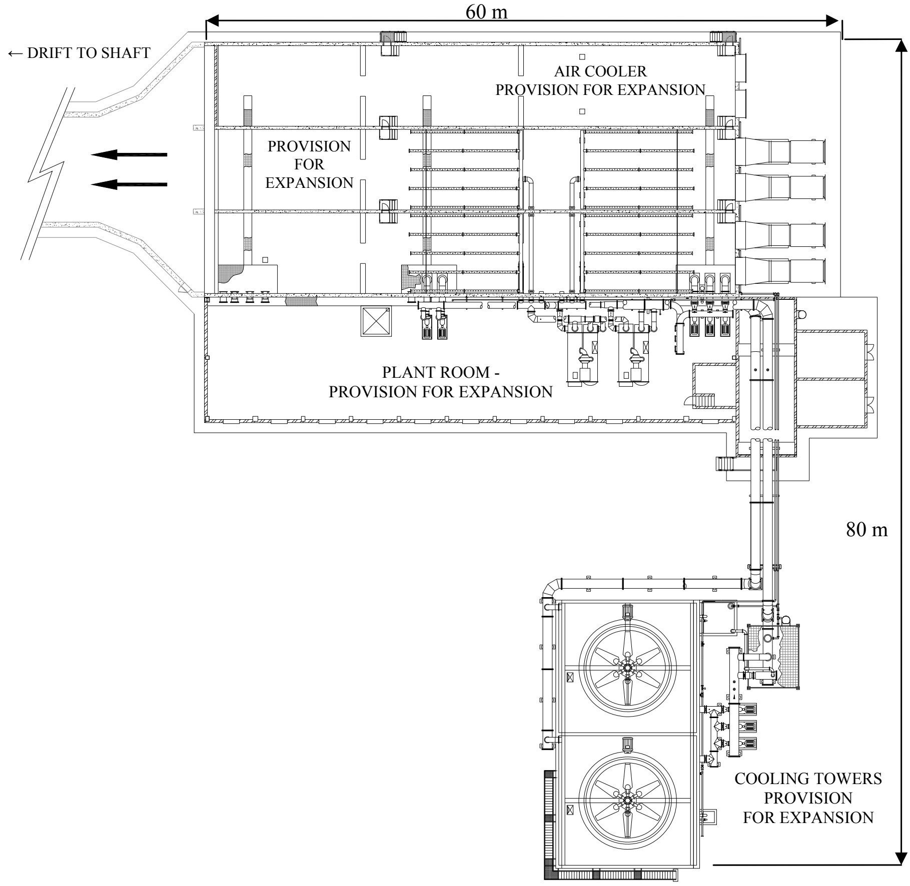

Figure 3. Site layout for first phase

Significant features of the air cooling system include:

- Compact design
- 20 year design life
- Energy efficient design
- Phased construction, expandable to ultimate duty of 40 MW[R]
- Standard modular equipment.

The compact arrangement is clearly visible from the photograph and site layout. Extensive provision for future expansion is also clear.

3.2 Air cooling spray chamber and fans

The two stage horizontal spray chamber was used for the air cooler in preference to vertical packed towers or closed circuit cooling coils. For this type of application horizontal spray chambers are preferred because of superior thermal performance, flexibility, aerodynamic considerations, capital and running costs (Bluhm *et al*, 2001).

The inside of a spray chamber is shown in Figure 4 and the simplicity and absolute minimum of internal equipment subject to fouling and maintenance should be noted.

In the first phase, two stages of sprays were installed with provision in the civil construction for a third stage to be included at a possible later phase. Mist eliminators were installed at the outlet to the spray chamber to ensure that no water is carried out.

The spray chamber was constructed from reinforced concrete and the roof assembled from pre-cast concrete slabs [see Figure 5]. Concrete construction method was selected to provide the required 20 year design life with the minimum of maintenance. The water level inside the spray chamber is such that a person can walk through the chamber in water-proof boots.

Figure 4. Internals of typical spray chamber (Wilson, 2003)

Figure 5. Pre-cast roof slabs of air cooler.

Figure 6. Air cooler fans of typical spray chamber.

Fans force ambient air thought the air cooler and drift to the shaft sub-bank area. Axial flow fans are better suited to the low pressure and high flow duty than centrifugal fans and were selected for this reason. Inlet silencers were installed to reduce noise levels to acceptable limits. A photograph of typical air cooler fans is shown in Figure 6.

3.3 Refrigeration

An important decision to be made when considering refrigeration is the choice of refrigerant. Of the available refrigerants, environmental, financial and safety issues typically limit the choice to R134a or ammonia for large industrial applications.

The most significant difference between these refrigerants is that in the event of a leak, R134a is non-toxic while ammonia is a toxic gas. Safety concerns dictate that an ammonia installation cannot be installed closer than 200 m from a mine shaft and that a number of stringent safety systems must be installed. This automatically precludes the use of ammonia in compact installations where refrigeration equipment is located near to the mine air-intake shaft. Safety concerns associated with R134a are less restrictive.

In terms of the Kyoto Protocol, R134a is defined as a "controlled" substance meaning that its usage must be properly managed and measures must be taken to prevent accidental discharge. The current debate around the use of R134a concerns its use in applications where losses are high, such as in automotive air–conditioners. There are no plans to limit or phase-out R134a for large industrial type applications.

Environmentally unacceptable refrigerants such as the CFCs [R11, R12] or the HCFCs [R22, R123] are either banned by the Montréal protocol or have defined phase-out dates and should be avoided for practical as well as environmental reasons.

Standard industrial type refrigeration machines [from York] using refrigerant R134a were used. The machines are factory assembled units with single-stage centrifugal compressors and shell-and-tube evaporators and condensers. These machines were selected because of low capital cost, high efficiency and proven design. A minimum of on site assembly was required. Similar refrigeration machines can be sourced from a number of manufactures. Refrigeration machines and inside of the plant room are shown in Figure 7.

Figure 7. Plant room

3.4 Plant Room and Piping

Apart from refrigeration machines, equipment installed in the plant room includes: overhead crane, evaporator water piping, strainers and valves, condenser water piping and valves, evaporator pumps, spray pumps and water treatment equipment.

The compact layout evident in Figure 7 was achieved while providing for maintenance requirements and allowing for future expansion. The plant room shares a common wall with the air cooler. This compact arrangement minimizes the length of chilled water piping and improves energy efficiency by reducing thermal and pumping system losses. To minimize the length of electrical cable all electrical and control equipment is installed in a brick building that shares a common wall with the plant room.

Conventional galvanized piping with standard industrial specification valves was used. Pumps were standard end-suction unit with cast-iron impellers.

It is important to note that the system was deliberately separated from the mine water system. This significantly reduced the corrosion risk to piping, valves and heat exchangers. Systems exposed to mine water generally experience higher corrosion which may require the use of titanium heat exchangers and stainless steel piping at a significantly higher cost.

3.5 Condenser Cooling Towers

Condenser cooling towers used were mechanical draft, packed counter-flow type towers constructed from reinforced concrete. Multiple prefabricated modular units could have been used but concrete was favored because of the required 20 year design life and lower maintenance of single concrete units as opposed to multiple prefabricated steel and fiberglass units.

Figure 8. Civil construction inside cooling tower

The internal concrete structure of the condenser cooling towers is shown in Figure 8. Note that the photograph was taken before installation of the mechanical components.

4 Summary and Conclusion

This paper has presented a brief description of the air cooling and refrigeration installation under construction at Impala No.16 Shaft. Construction of the first phase started in November 2006 and commissioning is due to be completed by March 2008. Commissioning will be completed on schedule and within budget.

According to current mine planning and numerical modeling of the underground environment, air cooling requirements will increase with production build-up to approximately 25 MW[R] by 2012 and the additional cooling will be provided by the second phase of the project. The third phase will increase air cooling capacity to 31.5 MW[R] and will be required by nominally 2015. The first phase has been designed and constructed to allow for seamless installation of the future phases with minimum disruption. Significant features of the design include:

- Compact and energy efficient layout
- Use of standard modular equipment
- Phase construction approach

The air cooling and refrigeration installation at No.16 Shaft will not be unique and five similar installations have recently been designed, installed and commissioned by BBE in both South Africa and Ghana on a turnkey contracting basis.

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