Destruction of underground methane at Beatrix Gold Mine

by J.J.L. du Plessis* and D.C. van Greuning†

Synopsis

Beatrix Gold Mine, a deep-level gold mine in the Free State province of South Africa, has the highest methane emission rate of any gold mine in the country. Methane is emitted from underground sources intersected during mining operations and is liberated into the general mine atmosphere. The total methane emission rate for the mine is of the order of 1 600 l/s and the South section of the mine emits approximately 1 000 l/s of methane gas. The mine has a history of gas accumulations which have led to a number of underground explosions. Following the last explosion in 2001 and the subsequent investigation, a number of recommendations were made. Two of these were to consider extracting the underground mine methane to render the mine atmosphere safe, and to declare hazardous locations that require special operating procedures. A number of such workplaces have now been declared at the South section of the mine.

Methane gas is a potent, explosive greenhouse gas whose contribution to global warming and climate change is 21 times higher than that of carbon dioxide. To reduce its inherent danger and to mitigate its global warming impact, a carbon credit project under the Clean Development Mechanism (CDM) of the Kyoto Protocol has been developed and implemented, the aim being to capture and destroy the methane at Beatrix mine.

The mine has constructed an extraction system to capture and extract 400 ℓ/s of the methane. Percentage methane (per volume) of the gas intersected at source is 85%, with negligible concentrations of other hydrocarbons and water associated. The mine contracted the services of Group Five to design and construct the flare and ancillary equipment on surface, and Promethium Carbon was contracted to assist with the carbon-related aspects, approval framework, and administration of the project.

A number of design and construction challenges had to be faced to extract and transport the gas effectively to the surface of the mine as the emitters are approximately 3 600 m away from the mine shaft at a depth of 860 m. Further considerations were the requirements for the type of column to be used to transport the methane gas, the pressure loss over the system, the safety systems needed to address the risk factors involved in the transport of the methane gas, and a suitable pumping system to extract the gas to the surface. The system operates under negative pressure provided by two blowers on surface delivering the emissions to a flare capable of burning off 450 ℓ/s of methane gas.

In this paper a number of benefits for the mine are discussed. These include, but are not limited to, the removal of approximately 55% of the total volume of methane gas from the general body of the air in the geographical areas of the mine where the methane gas is emitted into the atmosphere, and reducing the risk of methane-related incidents. A further benefit of this project is the mitigation of the global warming impact of the methane gas and the reduction of the mine's carbon footprint by approximately 25%. This project could also assist in alleviating the energy shortage being experienced in South Africa by means of the planned generation of 4 MW of electrical power, utilizing the methane gas, as a second phase of the project.

Keywords
methane, extraction, flare, power generation, gold mine, safety, carbon credits

Introduction

Beatrix Gold Mine is situated in a methane-rich area in the Free State province of South Africa, and is fully owned by Gold Fields. Highly explosive methane gas is unlocked into the mine atmosphere in the course of normal mining operations, during which it is diluted with the ventilation air to below its explosion limits and then released into the atmosphere through the mine's ventilation shafts. Not only is methane a potent greenhouse gas, but it is also a major underground safety hazard.

In 2006 the mine entered into an agreement with Promethium Carbon to assist in the development and registration of a Clean Development Mechanism (CDM) project on its behalf to mitigate the global warming effects of the methane gas released by the mine. The Project Design Document (PDD), a requirement for project registration, was approved by the United Nations Framework Convention on Climate Change (UNFCCC) in October 2008. This project was registered under the Clean Development Mechanism of the Kyoto Protocol in April 2011[1].

In the PDD both the fugitive emissions from methane from surface boreholes and the capture of the methane released by the mine's South section, which is the area with the most active underground methane sources, were described. The challenge is to capture approximately 50% of the gas released in this area and to transport it over a distance of 3 600 m underground, at a depth of 866 m, then up a vertical shaft to a selected site where the methane gas will initially be flared subsequently, and be then used to generate electricity.

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The method used to transport the methane gas, the pressure loss over the system, the safety systems to address the risk factors involved in the transport of the gas, as well as a pumping system to extract the gas to the surface, are addressed in the paper. Also described is the gas-monitoring system installed at strategic positions along the methane gas-extraction column, whose principle of operation is to monitor the flow rate and quality of the methane gas being extracted. All information from this monitoring system is transmitted to the mine's central control room. The extraction system can also be shut down at various underground locations in the event of a system failure or when technical problems are experienced.

Description of Beatrix Gold Mine

Beatrix Gold Mine is situated in the Free State province of South Africa near the town of Theunissen and 40 km south of the city of Welkom. It is 280 km south of Johannesburg. The mine consists of three mining sections, namely the North, South, and West sections.

The North and South sections operate from the main complex of the mine and are served by three operating shafts which supply the downcast ventilation air. The No. 2B ventilation shaft is situated to the west of number 2 shaft, its primary purpose being to supply ventilation to the South section. Two upcast shafts, one of which is a brattice shaft, remove air from the mine.

The West section, which is 17 km north of the main complex of the mine, operates from the number 4 shaft system, which has two downcast shafts from surface to 5 level and a single subvertical shaft from 5 level to shaft bottom. The upcast facility consists of a subvertical upcast shaft from 21 level to 5 level, and from 5 level the No. 1B ventilation shaft which extends to surface.

The mean rockbreaking depth of Nos 1 and 2 shafts is 866.6 m, that of No. 3 shaft is 1 091 m, and that of No. 4 shaft is 2 036 m. The virgin rock temperature varies from 33.4 °C at Nos 1 and 2 shafts to 49.6 °C at No. 4 shaft. Production from stoping and development amounts to approximately 225 000 t/month for the three sections of the mine. The total airflow quantity circulating through the mine is 1 826 kg/s, and 60 MW of refrigeration is utilized to maintain acceptable environmental conditions at the West and North sections to counter the effects of the high rock temperatures encountered as a result of the depth at which mining operations take place.

The geographic locality of the mine is shown Figure 1.

Methane history

The gold mining area in the Free State is rich in methane, and Beatrix Gold Mine has the highest methane emission rate. The methane, which emits from deep-seated sources within geological features such as faults, fissures, and dykes, is

Figure 1–Geographic locality of Beatrix Gold Mine

unlocked during normal mining operations and released into the atmosphere where it acts as a potent greenhouse gas[2]. The gas is a major safety hazard underground and despite continuous efforts to keep methane levels under control, methane explosions have occurred in numerous mines in the region, including Beatrix.

The underground methane emission rate at the mine is 1 600 ℓ/s, of which approximately 1 000 ℓ/s is emitted at the South section, 100 ℓ/s at the North section and 500 ℓ/s at the West section. The concentration of the methane being emitted varies from 82% to as high as 90%. The concentrations of other hydrocarbons emitted are negligible, to the extent that they are not even considered.

The mine has a well-executed methane management system to control this risk and to protect its employees against the inherent dangers of methane.

Registration of the project at the United Nations Framework Convention on Climate Change

To mitigate the environmental impact of methane emissions associated with mining at Beatrix Gold mine, the mine entered into an agreement with a carbon project development firm, Promethium Carbon, to assist in the design and development of a project that aims to mitigate the global warming effects of the methane released by the mine.

As already mentioned, a PDD was submitted to the CDM Executive Board and approved in October 2008 by the United Nations Framework Convention on Climate Change. The PDD includes the destruction of methane from the underground sources as well as methane emitting from certain old geological boreholes.

The methane gas extraction and destruction project has two phases. The first phase is the destruction of methane emitting from the old geological boreholes and the capturing and piping of this methane to surface, where it is flared. The second phase will be the installation and operation of an electrical power generation plant, with any excess methane being flared.

Execution of the underground project

Underground gas reticulation system

Due to the layout of the mining operations and the associated methane intersections, it is not possible to capture all the methane gas. It was therefore decided to target specific working areas where high methane emission rates are being experienced.

The current target area for the capture of methane is situated towards the western boundary of the South section, where the highest rate of methane emission takes place. During the planning and construction of the methane reticulation system, various issues had to be considered. The final project design and blueprint include the aspects detailed below.

Reticulation route

The depth at which the methane gas is captured varies between 830 and 866 m below surface. During the initial planning of the methane gas reticulation route, various options were considered in terms of routing the extraction system to the proposed flaring and power generation site, which is situated in close proximity to the Eskom electrical substation. The power generated will be fed into the national electricity grid supplied to the mine, offsetting its dependency on Eskom.

It was finally decided to carry the underground extraction column along the 16 level haulage road to the No. 1 shaft and to install it in the shaft, from where the column would have to be constructed across a relatively short distance to the site selected for flaring and power generation.

The main underground infrastructure intersecting this depth is the 16 level main haulage road and other tunnels. The design of the reticulation pipe column was based on the calculated methane emission rates from the individual sources. The main column is carried on 16 level, which is the lowest level of the South section at 866 m below surface. A diagrammatic layout of the underground methane gas reticulation system is depicted in Figure 2.

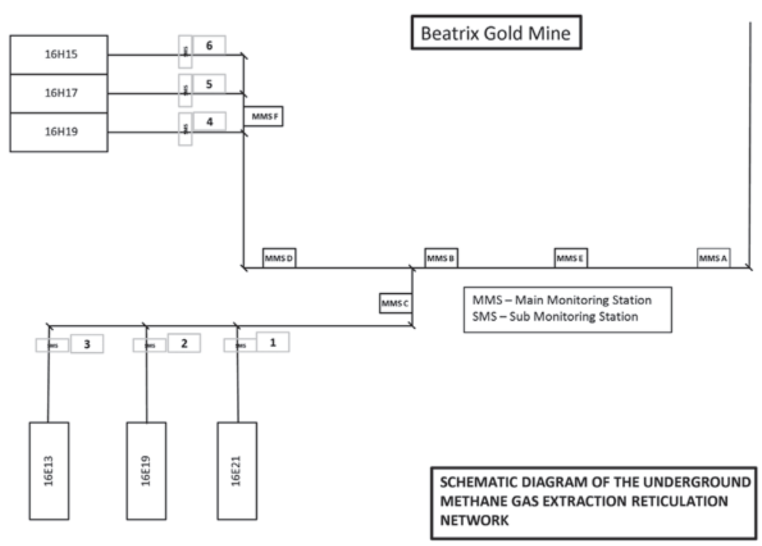

Figure 2—Schematic diagram of the underground methane gasreticulation network

Pipe selection

Underground

The methane gas is captured at various localities and fed into the main reticulation column. An ideal gas transport velocity of 11 m/s was used when calculations were performed to determine the pipe sizes required for the reticulation system[3].

The reticulation system has various branches feeding into the main column, consisting of pipe sizes ranging from 110 mm diameter up to the final column size of 250 mm diameter. The final pressure loss calculated across the reticulation system is 25 kPa.

The initial pipe selection for the methane drainage column was galvanized pipes with standard flanges. It was realized, however, that selection of the wrong type of gasket could result in numerous leakages. Further investigation into a suitable type of pipe was done, and finally titanium-reinforced PVC (T-PVC) pipes were selected for the underground piping. (Group 5, 2010) These antistatic pipes are joined by making use of sleeved couplings with splines to secure them in position. The pipes are also impact-resistant and fire-resistant and are capable of handling both high positive and high negative pressures, making them the most suitable choice for this type of application. Figure 3 shows a typical T-PVC pipe coupling system.

Shaft column

It was decided to install a 450 mm diameter galvanized iron pipe column in the shaft and overland on surface, as such pipes were available for use at one of the sister mines in the Gold Fields Group. The pipeline is located in a separate compartment in the shaft, away from the rest of the installed pipe ranges. The 6-m pipes are individually anchored against the sidewall in the shaft and are connected using 'Klamflex' coupling sleeves. Protection skirts are located at each of the pipe joints to prevent damage to and build-up of dirt and grit in the couplings. This method of connecting the pipes allows for the safe replacement of a coupling or a pipe should it be required in future. Details of the coupling assembly of the pipe column in the shaft are shown in Figure 4.

Safety considerations

The safety of mine employees is of the utmost importance. All identified risks were considered and care was taken to ensure the safe operation of the methane extraction system at all times. The whole underground system will operate under negative pressure, and the methane gas concentration in the column will not be allowed to drop to below 40%. The system will also trigger an alarm when the oxygen level reaches 4% and will shut down at 8% as per the design guidelines[5]. The planned average gas concentration to be maintained in the system is between 70% and 80%.

The system is equipped with flashback arrestors which isolate the surface main flare installation and the underground system from the main shaft column. Self-closing devices (slam-shut valves) are installed at all monitoring positions and will shut down whenever any of the system operating conditions is breached. The status of the extraction system's operating conditions are monitored on a continuous basis. This is done through the gas-monitoring stations installed at strategic positions along the length of the methane gas extraction column.

Peer review

A peer review was conducted on the design and installation of the underground methane gas extraction system as a due diligence and safety issues exercise[6]. It was facilitated by a professional engineering company with a proven record of expertise in this field of work. A number of recommendations were made, which the mine acted upon before the underground extraction and flaring project was commissioned. The recommendations made by the peer review group included the following:

➤ Perform a hazardous area classification of the underground extraction system

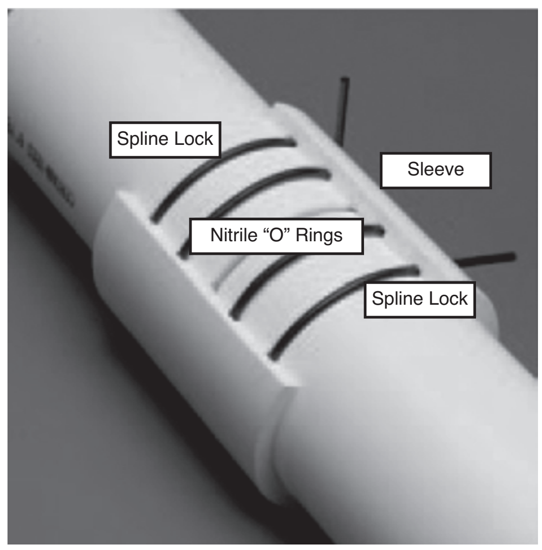

Figure 3-Details of a T-PVC pipe coupling system

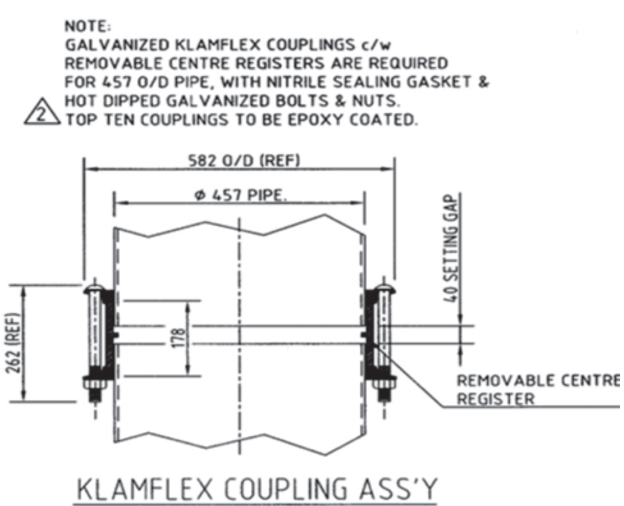

Figure 4—Shaft pipe coupling arrangement

- ➤ Perform a physical audit of all ignition sources along the route
- ➤ Carry out a flexibility analysis on the piping design to address pipeline issues such as expansion, support systems, connection, and stiffness
- ➤ Implement an earthing plan to prevent the build-up of static electricity
- ➤ Carry out leak detection after installation and any modification to the piping.

Flexibility analysis of the underground piping

A flexibility analysis was carried out on the underground pipe column to determine whether there is any danger of pipe movement during start up and normal operation that could potentially compromise the integrity of the pipe column and pipe joints, resulting in pipe failure and/or methane leakage. Calculations indicated potential expansion or contraction of up to 200mm for each 358m of installed pipe length[7]. Expansion joints, as well as pipe anchors were designed, manufactured, and installed in accordance with the recommendations made in the report. This work was done to ensure the integrity of the extraction pipeline under all thermal operating conditions and to limit any potential resonance during operation. Figure 5 shows a typical expansion joint installation, which allows for 200 mm movement.

Capturing the methane gas

The incidence of methane gas intersections varies from drill holes in the rock face to methane seeping through cracks and, in some instances, geological features and anomalies. The high emission rates, particularly in the South section, led to problems in that elevated methane concentrations of up to 1% in the general atmosphere were recorded even after the gas had been diluted by the through-ventilation flow. One way to overcome this problem was to drill holes into the methane fissures and inject compressed air through them into the rock strata.

Two methods of capturing the methane are being utilized, namely methane capture at source and methane capturing through the construction of methane chambers that encapsulate worked-out areas by means of explosion-resistant seals.

Methane is captured at source, in areas where holes were drilled into the methane fissures as part of prospect and cover drilling processes, by connecting the sources directly to the methane extraction column. No special holes have been drilled in an attempt to locate methane sources for capturing, as there is an abundance of methane sources present that were intersected during the course of normal mining operations.

Three worked-out mining areas with numerous methane sources, collectively emitting approximately 400 ℓ/s of methane gas into the mine atmosphere, were identified to be sealed off by means of explosion-resistant seals to create methane chambers. These chambers are treated as three individual methane gas sources and are connected as such to the methane gas extraction system. Figure 6 shows the location of the areas from where the methane gas is being captured.

A total of 25 methane-containment seals were constructed to create four main methane chambers from where methane gas is extracted. The seals are able to withstand a blast pressure of 140 kPa and were constructed in accordance with a civil engineering design. Each seal consists of two steel-reinforced walls 2 m apart, with a void fill in between. A section view of the seal layout is shown in Figure 7.

Table I summarizes the stopes that were sealed off to create the chambers from which the methane gas is extracted.

The monitoring system

Six main monitoring stations and six submonitoring systems were installed along the extraction system. The system, which is supplied by Trolex, monitors both the quality and quantity of the methane being extracted and all information is relayed to a control room at the flaring site, as well as to the mine's main control room.

Figure 5—Expansion joint installation

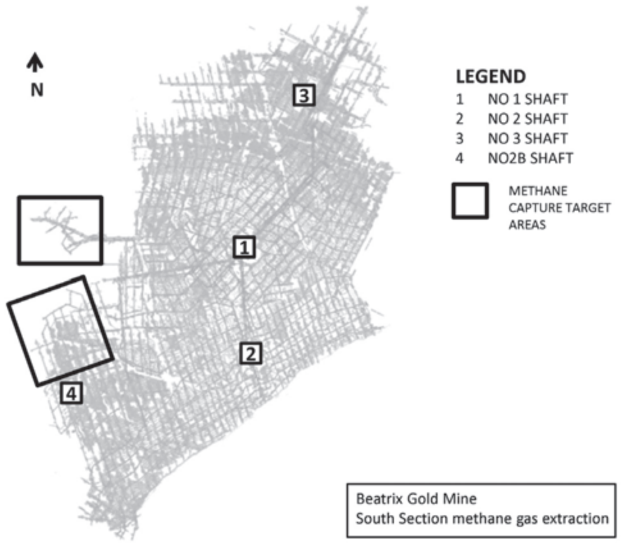

Figure 6—Plan view showing the geographical areas from where the methane gas is captured

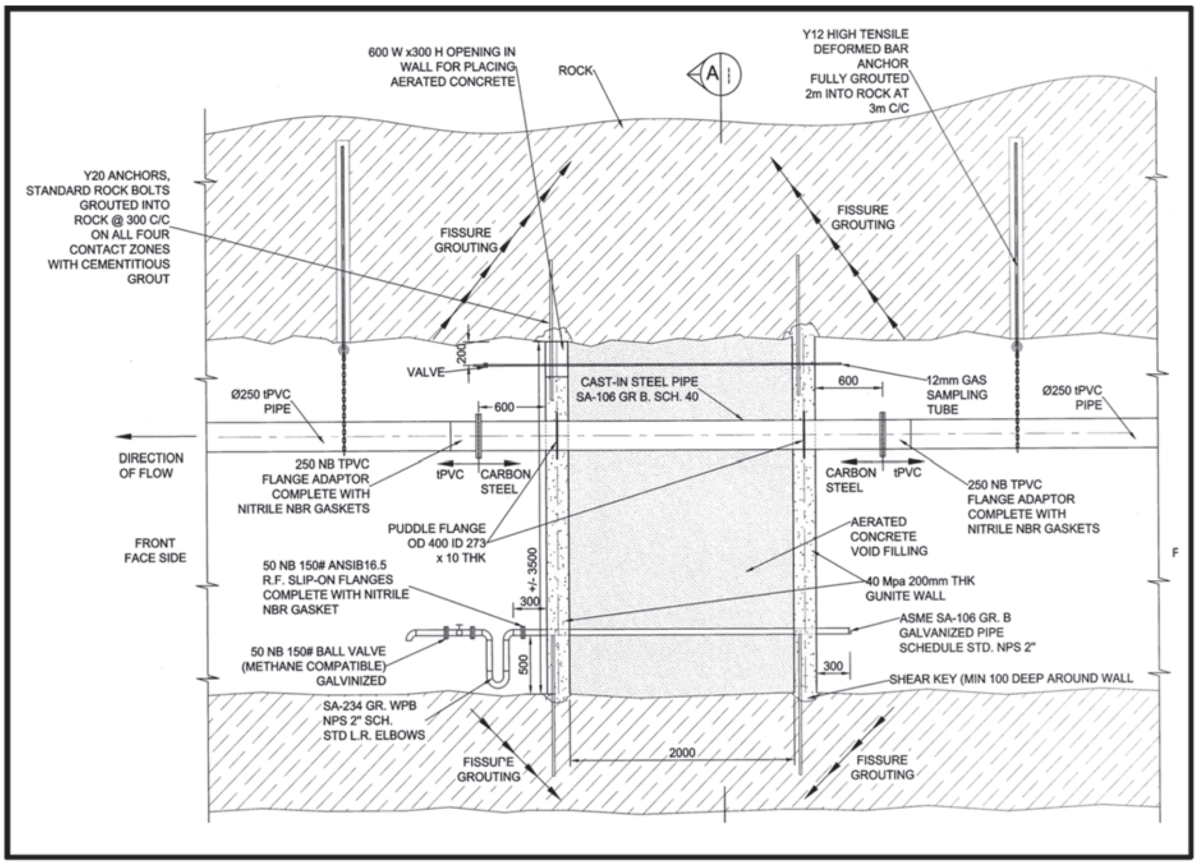

Figure 7—Sectional view of a methane-containment seal

Table I

Underground methane chambers

Location	Estimated volume (m^3)	Number of seals	Methane emission rate
16G19, 16H19 stope	59 480	6	79 l/s
16G17, 16H17 and 16I17 stope	122 423	11	148 l/s
16G15, 16H15 and 16I15 stope	77 798	7	186 l/s
16E19 cross-cut	700	1	20 l/s

The methane gas being transported in the column is sampled using infrared and chemical gas-sensing equipment. After the methane has passed through a drying process to remove moisture, its purity is calculated using mathematical algorithms. Pressure- and flow-regulating equipment is used in conjunction with a sampling pump to ensure that a constant sample is supplied to the sensors.

The methane gas-monitoring system includes the following features and instruments:

- Continuous accurate methane monitoring based on mathematical determination of the gas ratio
- Detection of component gases such as carbon dioxide and oxygen, and precise calculation of the methane content
- Gas velocity measurement using mass flow conversion algorithms
- Process pressure monitoring
- 'No methane' hydrocarbon error correction
- Full system data display with periodic data-logging
- SCADA (supervisory control and data acquisition) package and communication interfacing to central monitoring stations.

Preset alarm levels will activate strategically placed shut-off valves in the event of an emergency situation.

Surface installation

The surface pipe installation

The surface pipe is approximately 300 m in length and is a continuation of the 450 mm diameter steel pipe column installed in the shaft. It has two condensate drainage points along its length so as to minimize the condensate passing through the blower station.

Blower station

To be able to overcome the calculated pressure loss of 25 kPa over the methane extraction system and to supply a flow rate of 400 ℓ/s of methane gas to the flare, two blowers, each capable of handling 225 ℓ/s, are installed in close proximity to the flare (Figures 7 and 8). The main operating specifications of the blowers are as follows:

Nominal gas flow rate:	Maximum:	1 600 Nm^3/s
	Minimum:	200 Nm^3/s
Suction pressure at the entry to the blower station:	Maximum:	-250 mbar
Utilization pressure:	Maximum:	180 mbar
Gas temperature at the entry to the blower station:		20–30°C
Gas temperature at the outlet of the blower station:		104–140°C

Main flare

The main flare was manufactured and supplied by Hofstetter in Switzerland in accordance with the requirements of this project. Both the flare and the blowers are operated from a purpose-built control room at the flaring site and automatically start up after the required start pressure is reached. The flare is activated by an automatic ignition device and its burner control unit controls the ignition process and monitors the flame. The combustion within the flare is automatically regulated by the air supply in relation to the optimum combustion temperature.

The main flare is equipped with all the necessary safety features to ensure the safe handling and combustion of the methane gas. These include electric slam-shut valves, flame arrestors, IP 55 system protection against dust and water, continuous monitoring of the combustion temperature, safety turn-off in case of overheating of the burner, and automatic ignition and flame monitoring.

The technical specifications of the main flare are as follows:

Height		8.05 m
Diameter		2.02 m
Number of burners		23
Methane gas flow rate	Maximum	1 450 Nm^3/h
	Minimum	30 Nm^3/h
Inlet gas temperature	Maximum	60°C
Combustion temperature		1 000–1 200°C

The flaring system is equipped with a gas chiller between the discharge of the pumps and the inlet to the flare to cool the methane gas to below 60°C before it enters the flare. Figures 8 and 9 shows the section and plan views of the main flare and blower station.

Commissioning of the methane gas extraction system

Prior to the commissioning of the methane extraction system, the mine ensured that all the requirements of the peer review had been met and that all the relevant documents were in place[7]. (Axis Development Report, 2011) A commissioning procedure was written with the main aim of ensuring the safety and health of the mine's employees during the start-up of the system. This procedure took cognisance of the following:

- Cleaning and leak-tight testing of the underground gas reticulation pipeline
- Purging of the gas line before startup, including guidelines for the safe handling of nitrogen
- Opening-up sequence for the various isolation valves underground
- Starting up of the blowers and flare.

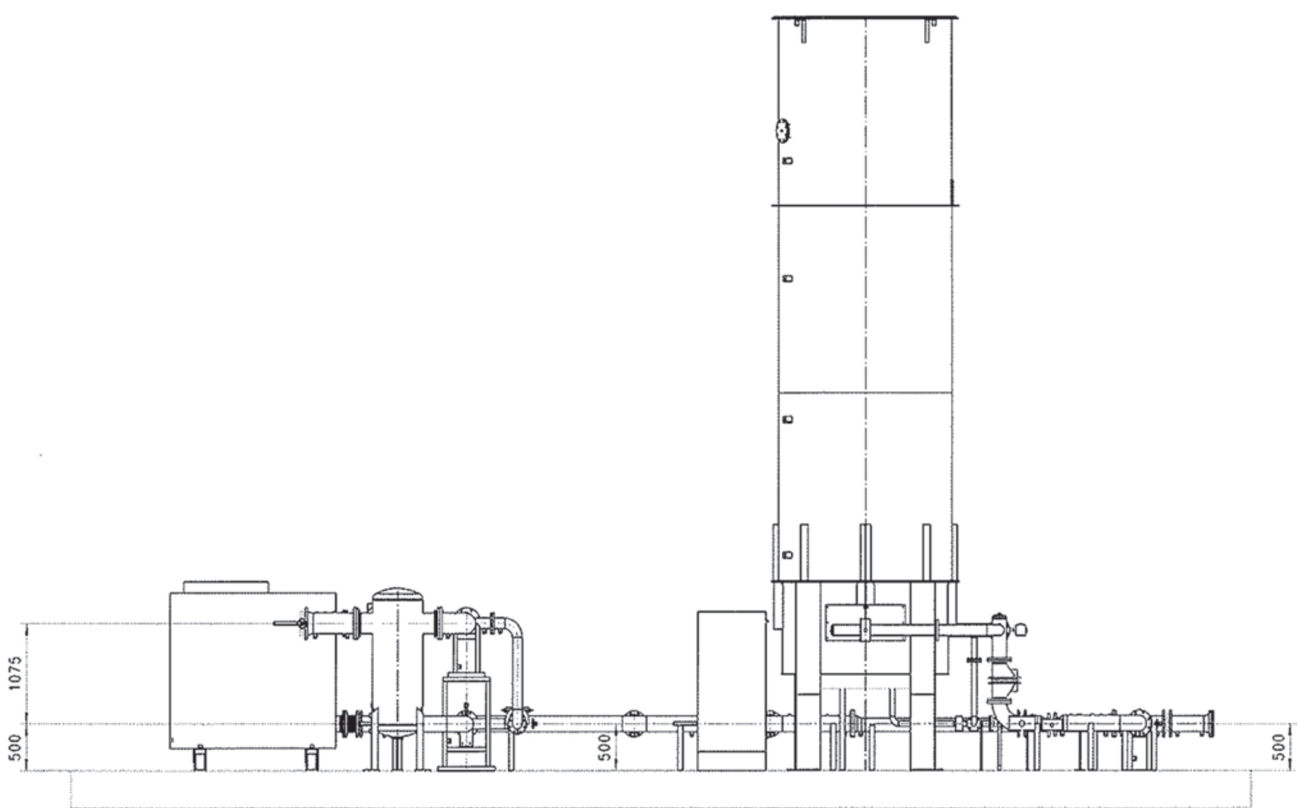

Figure 8—Section view of the flare and blower station

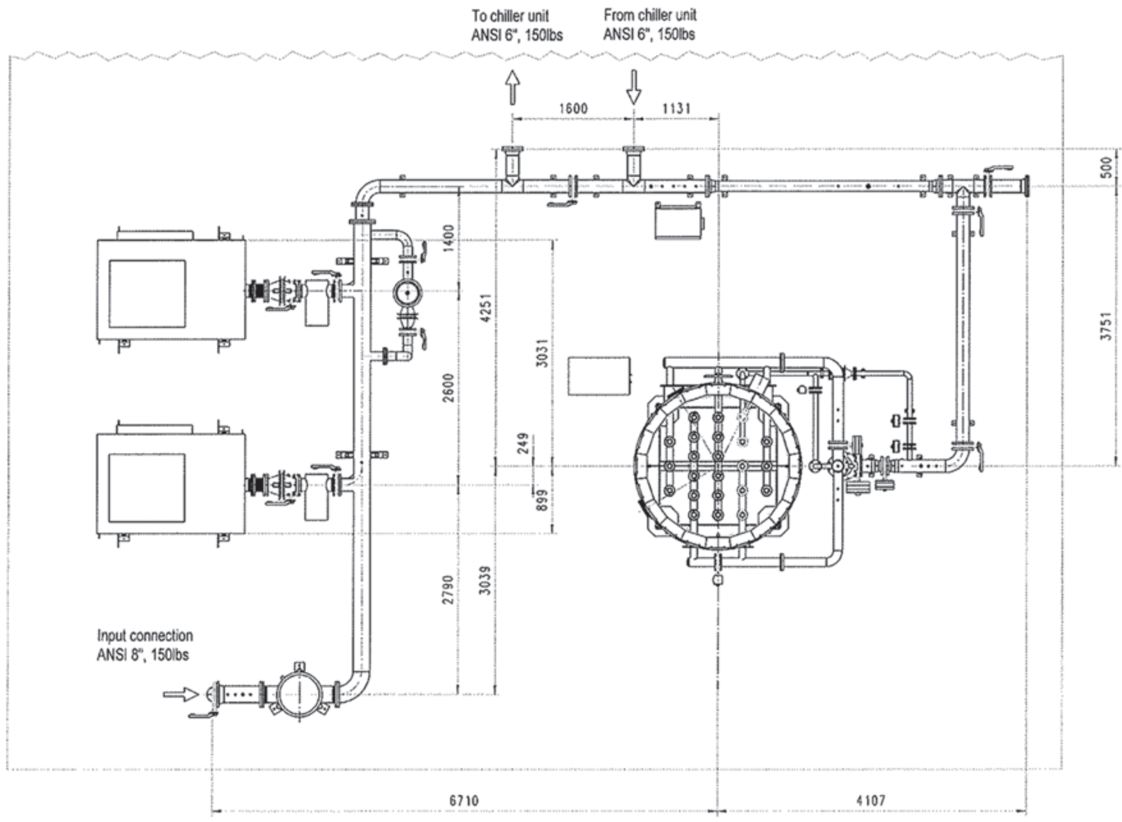

Figure 9—Plan view of the flare and blower station

Commissioning of one leg of the underground extraction system took place safely on 21 May 2011 and the complete system was commissioned on 9 June 2011. The design and capital approvals for the power generation phase will be concluded during the latter part of 2011.

Conclusion

The project idea was initiated towards the end of 2006, but a number of hurdles had to be overcome, mainly as a result of all the regulatory approval processes, the UNFCCC approval process, project planning, and financing of the project.

This project has major benefits in terms of reducing carbon emissions resulting from the release of methane gas into the atmosphere. It will reduce the mine's carbon footprint by approximately 28%, which is important in terms of the mine's contribution towards reducing global carbon emissions. This could also potentially result in a major Carbon Tax offset as described in the Carbon Tax Policy White Paper of 2011.

The project will furthermore contribute towards reducing the release of methane into the underground atmosphere at the Beatrix Gold Mine South section by 40%. This is a significant contribution towards maintaining conditions conducive to the safety of the employees at the mine.

Acknowledgement

We wish to extend our sincere appreciation to the management of Gold Fields for their support.

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