AGNEW GOLD MINE EXPANSION MINE VENTILATION EVALUATION USING VENTSIM

E. Widzyk-Capehart
Curtin University of Technology
Western Australian School of Mines
Mining Engineering Program
Kalgoorlie, Australia

B. Watson
Curtin University of Technology
Western Australian School of Mines
Mining Engineering Program
Kalgoorlie, Australia

ABSTRACT

The Redeemer Gold Mine is a sub-level caving gold operation located in Western Australia. The underground mining commenced in 1989 and followed a slightly subvertical ore body to the depth of approximately 600-m below surface (9810 level). Underground diamond drilling identified a range of satellite ore bodies of which the Redeemer Deeps located due north from the main ore body extends from the 9860 level to at least 9500 level. The Redeemer Deeps ore body is, at present, an indicated resource located approximately 150 m laterally from the existing workings.

This paper reviews the existing ventilation conditions at Redeemer Mine and investigates the requirements for an economically viable primary ventilation system for the planned Redeemer Deeps workings. Computer simulations using VentSim were performed to determine the optimum ventilation network that would best service the Redeemer Deeps mining area with regards to its compatibility with existing ventilation infrastructure, system and fan performance, ease of installation, power distribution, future extension/production upgrades and capital and operating expenditures.

KEYWORDS

Mining, ventilation, simulation, VentSim, sub-level caving, fans, capital and operating costs, mining law

INTRODUCTION

The dynamics of a ventilation system are matched by the dynamics of mine development. Periodically, it becomes necessary to upgrade the existing mine ventilation system as mine development progresses.

Western Mining Corporation (WMC) Agnew Gold Operation operates two underground gold mines: Crusader and Redeemer. The Redeemer Underground Gold Mine is located 25 km from the town of Leinster, Western Australia. The Redeemer originated from the bottom of the Redeemer Open Pit operation in 1989. Currently, mining activities are approaching the lowest levels of the main ore body. Further mineralisation has been identified at depth and named the Redeemer Deeps. Were the Redeemer Deeps resources exploited in the future, the current ventilation system would not have been sufficient to maintain the required air quality and quantity. Therefore, to ensure the ventilation system compatibility and flexibility with the future mine extension, several mine ventilation scenarios were investigated using VentSim simulation package.

MINING STATUS

The Redeemer Underground Mine access commences from a portal near the base of the depleted Redeemer Pit at 10,365 m RL (the surface is at approximately 10,475 m RL). The decline is located on the western side of the orebody, with cross cuts extending eastwards at 25-m vertical intervals. The mining method has been sub-level caving (SLC) with longitudinal extraction carried out from below the base of the open pit to the 10,085 m RL level. Below this level to 9,985 m RL, transverse SLC has been used. Below the 9,985 m RL level, the main lode narrows significantly and a reversion to longitudinal SLC stope development has commenced on the 9,960 m RL and lower levels.

Stope production is currently focussed on the 9,960 m RL and 9,935 m RL levels, with ore development proceeding on the 9,935 m RL and 9,910 m RL levels. Additional production was also extended into "satellite" zones on the 9,985 m RL, 9,960 m RL and 9,935 m RL levels. The decline face is currently between the 9,910 m RL and 9,885 m RL levels.

GEOLOGY

The Agnew area (Figure 1) is located in the northern section of the Norseman - Wiluna greenstone belt with distinct eastern and western domains. The eastern domain comprises a structurally complex, elongated, north-northwest trending sequence of mafic, ultramafic and felsic volcanic and sedimentary rocks. The western domain comprises the tightly folded mafic and ultramafic rocks of the Lawlers Anticline and Mt. White Syncline, which are overlain by the Scotty Creek formation sediments.

The Redeemer Mine is located within the Scotty Creek formation, the basal units of which are a mafic conglomerate hosting the orebody. In the upper part of the mine, the sandstone is in the footwall but due to flexure of the orebody below 10,085 m RL this unit becomes the hangingwall.

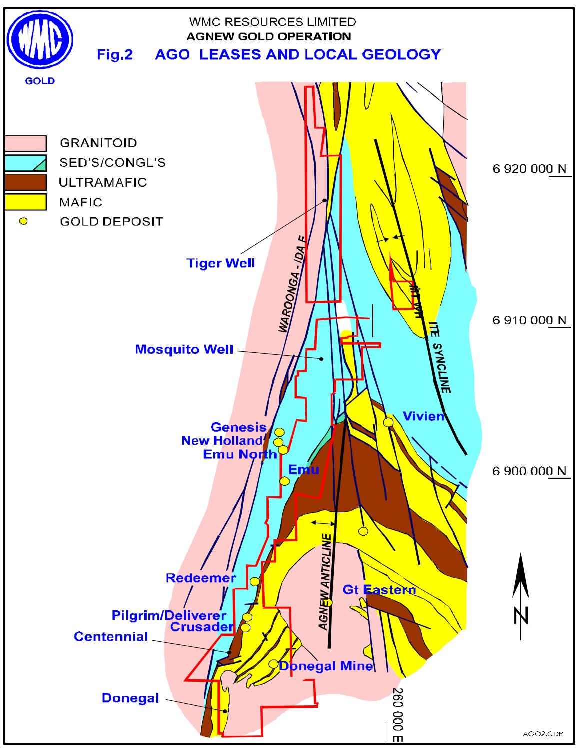

Figure 1. Agnew Gold Mine geology

VENTILATION SYSTEM

Current Redeemer Ventilation System

The current Redeemer ventilation system is an example of a parallel exhaust network (Figure 2) since air may enter the return airway at a number of different levels as required. Redeemer uses a primary exhausting ascensional ventilation system with negative pressure created by the action of two centrifugal exhaust fans operating from the surface. The primary ventilation circuit consists of the decline, escape way and return airway rises. The current primary fans are Richardson 1780CY (535 RPM) fan and Howden HS 288 330 (315 RPM) fan.

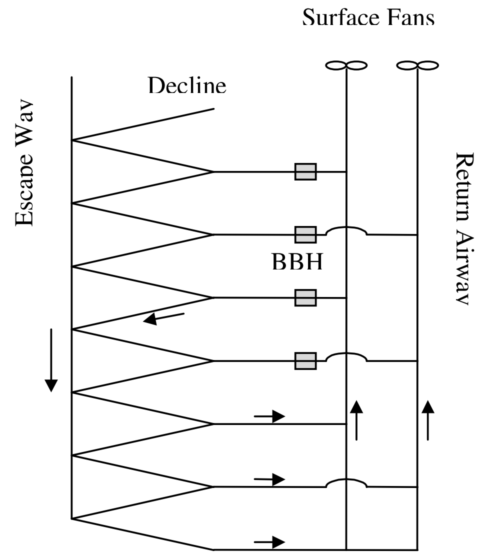

Figure 2. Parallel ventilation system (After Teasdale, 2000)

The secondary ventilation system comprises of secondary fans and flexible ventilation ducts, which achieve ventilation of active headings. In addition, rises within stoping areas are used to assist in secondary ventilation since the Redeemer main ore body has a shallower plunge at depth and the stoping levels have a greater horizontal component. These rises run parallel to the main intake airway and the decline and create parallel ventilation. The rises are situated adjacent to the main stoping block.

Quality and Quantity Requirements

The determination of the required quality and quantity of air to be delivered to the mine workings in Western Australia (WA) is enshrined in the WA Mines Safety and Inspection Regulations 1995.

Regulations: The main consideration in assigning air quantities at the Redeemer Mine is the maximum number of diesel unit operating in each individual stope or development heading. The Regulations stipulate that the volume flow supplied must be not less than the sum of the volume requirement for the individual diesel units with the exception of light four wheel drive vehicles, drill jumbos and other diesel units of small engine capacity, operated intermittently.

The WA Mines Safety and Inspection Regulations 1995 state that the airflow in any workplace in which a diesel unit is operated must be not less than 2.5 m^3/s. In addition, the required ventilation volume flow rate is specified with regard to the amount of exhaust gas emission in terms of the maximum rated engine output power.

The equipment used for calculating current ventilation requirements at Redeemer is listed in Table 1.

Table 1. Ventilation requirements for current Redeemer equipment.

Equipment	Power [kW]	No.	Quantity [m^3/s]
73B Dump Truck	485	4	96.0
Elphinstone R2900	268	2	26.8
980C Charge-Up	200	1	10.0
UC500 Charge-Up	96	1	Disregard
Cat 12H Grader	104	1	Disregard
Cat IT28B Tool Carrier	93	1	Disregard
Total			**135**

VENTILATION PLANNING

At the time of simulation, it was understood that in order to reduce high stress fields expected as mining progresses with depth, the gradient and dimensions of the Deeps access decline will have to differ from the dimensions of the existing decline. The grade of the decline will be altered from 1:10 to 1:7 while the new decline dimension will be 5 m by 5 m as compared to 6 m by 6 m for existing decline. These changes reduce tonnage and the length of the decline access development, which is predicted to offset the expected increase in ground support costs. The changes in decline dimensions influence also the selection of mining equipment. The results of the equipment selection studies conducted by the Agnew Mine Planning Department were used in ventilation simulation completed by the WA School of Mines using VentSim.

VENTILATION MODELLING

VentSim Program

The simulation of the Redeemer Deeps ventilation network was performed using the computer software VentSim 3.2. The evaluation of airflow in VentSim is based on the Hardy Cross method, an iteration estimation method used to adjust the airflow until the estimation errors lie within acceptable limits.

VentSim Capabilities

VentSim, used as a tool, provides the user with the capabilities to:

1. Simulate and provide a record of flows in an existing mine
2. Perform 'what if' simulations for planned new development
3. Help in Short and Long Term planning of ventilation requirements
4. Assist in selection of types of circuit fans for mine ventilation, development fans and ventilation bags
5. Assist in financial analysis of ventilation options
6. Simulate paths and concentrations of smoke, dust or gas for planning or emergency situations.

VentSim Modelling Procedure

VentSim model is created based on the data acquired during ventilation surveys, airway coordinates and ventilation devices' specifications. The user follows the following modelling procedure:

1. Enter or import the airways' specifications and their dimensions into VentSim.
2. Prepare the network for simulation, that is, ensure all airflow is in the correct dimension, ensure all surface entries and exits are operative and shock losses are included in the airway characteristics.
3. Use the FIX function in airway attributes, fix the intake quantity at the value observed from the ventilation surveys.
4. Alter the resistances in all airways until airflow matches the airflows observed in quantity surveys.
5. UNFIX the intake airway and position the primary fans in their correct positions.
6. Check simulated operating points with actual data to ensure that the VentSim fan curve approximates actual fan performance.

VentSim Model

The VentSim representation of the current Redeemer ventilation network was constructed by importing centreline strings from Surpac. However, this network had a degree of complexity that was not necessary for computer simulation, as the current Redeemer system essentially became a static conduit for the Redeemer Deeps section. Therefore, the current ventilation Redeemer system was simplified by four vertical airways traversing the distance between the 10,380 m and the 9,860 m RL levels, surface and the limit of current development, respectively. The loss of airway length due to the absence of the horizontal component of the decline was modelled as shock loss in terms of equivalent length. The conceptual model of the Redeemer Deeps airways was connected with the simplified Redeemer system, constituting the model used in the simulations (Figure 3).

Airway Characteristics in VentSim Model

Three main airways were used in VentSim modelling; declines, escape ways and return airway rises. The current (future) declines have the following characteristics:

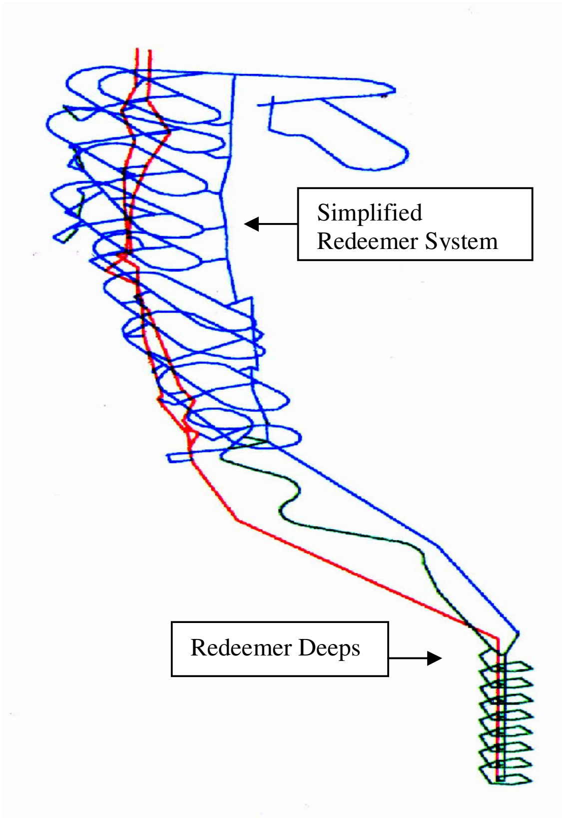

Figure 3. Redeemer Deeps simulation model

- Dimensions: 6 m ×6 m (5 x 5 for Deeps Section)
- Average blasted friction factor of 0.01 Ns^2/m^8
- BBH used to seal break throughs into the RAW's Leaks through bulkheads are simulated using brick bulk heads with doors at between 1 - 0.5 m^3/s.
- 25 m equivalent length shock loss used per 180° bend.

The escape ways possess the following characteristics:

- Dimensions:
  2.4 m ∅ for 10,010 m up; 1.8 m ∅ from 9,910 m to 10,010 m; and 1.5 m ∅ for 9,885 m down.
- 20 m equivalent length shock loss per section
- Fixed volumetric flow at 10 m^3/s
- Raise-bored airway friction factor 0.004 Ns^2/m^8
- BBH with doors used to seal break throughs into the decline, the leaks through these bulkheads were simulated at between 0 - 0.5 m^3/s.

The return airways rises are characterised as follows:

- Dimensions:
  2.4 m ∅ from surface to 10,210 m; 3.1 m ∅ from 10,210 to 9,860 m; 3.6 m ∅ from 9,860 to 9,610 m
- Raise-bored airway friction factor of 0.004 Ns^2/m^8
- 50 m equivalent length shock per 25 m sections

- Howden HS 288 330 (315 RPM) surface fan on one rise and Richardson 1780CY (535 RPM) surface fan on the other rise.

By having the escape way rise and the return airway rise adjacent to each other the development process can be minimised and both airways can be developed using the same raise boring equipment.

The optimal ventilation system for Redeemer Deeps in terms of the quantity and quality of air delivered to the active workings was considered with respect to:

- Haulage scenarios
- Deeps ventilation options – fan requirements
- Secondary egress alternatives
- Fan selection vs haulage scenarios
- Capital and operating costs.

<u>Haulage Scenarios</u>

The changes in dimensions of the access decline to the

Deeps must allow for a 0.9 m of lateral clearance on either side of underground diesel equipment, according to the Mine Safety and Inspection Regulations 1995. Therefore, the current transport equipment, Cat 73D trucks, will not be able to enter the Redeemer Deeps decline. Consequently, three haulage scenarios were identified to adhere to new mining conditions:

- Rehandle Ore - Self Loading
- Rehandle Ore – Ore Pass
- No Rehandling – Only 69D Trucks.

<u>Rehandle ore – self loading:</u> The rehandle ore – self loading scenario requires that a rehandling point is designated above the change of the decline dimensions and that an Elphinstone R2900 underground loader is stationed at the rehandling point. The scenario requires the 73D operators "self loading" using the loader. The ventilation requirements for this option are summarised in Table 2.

<u>Rehandle ore – ore pass scenario:</u> The rehandle ore – ore pass scenario requires the installation of an ore pass, grizzly and automatic loading facility. The 69D units would dump material into the ore pass on level x while the 73D units loading from the pass at level x-1 would accomplish material transfer. The ventilation requirements for this scenario are shown in Table 3.

<u>No rehandling - only 69D trucks scenario:</u> The no rehandling - only 69D trucks scenario focuses on utilising only the Cat 69D trucks for material transport from the Deeps area. This method is the simplest in operation and the least expensive in capital and operating costs based on preliminary study. The ventilation requirements for the trucks only system are summarised in Table 4.

In all scenarios, the UC500 Charge-up, the Cat 12H Grader and the Cat IT28B Tool Carrier were disregarded in calculating the quantity requirements.

Table 2. Self loading ventilation requirements

Equipment	Power [kW]	No.	Quantity [m^3/s]
69D Dump Truck	380	2	36.0
73B Dump Truck	485	2	48.0
Elphinstone R2900	268	1	13.4
Elphinstone R1700	231	1	11.6
980C Charge - Up	200	1	10.0
Total			**120**

Table 3. Ore pass ventilation requirements.

Equipment	Power (kW)	No.	Quantity (m^3/s)
69D Dump Truck	380	2	36.0
73B Dump Truck	485	2	48.0
Elphinstone R1700	231	1	11.6
980C Charge – Up	200	1	10.0
Total			**106**

Table 4. 69D trucks only ventilation requirements.

Equipment	Power (kW)	No.	Quantity (m^3/s)
69D Dump Truck	380	4	72.0
Elphinstone R1700	231	1	11.6
980C Charge – Up	200	1	10.0
Total			**94**

<ins>Deeps Ventilation Options – Fan Requirements</ins>

Three ventilation options were simulated to determine the fan pressure necessary to deliver the required volumetric flow to the Redeemer Deeps, namely:

1. Alter or replace the low pressure Howden fan operating from surface.
2. Use a booster fan in close proximity to the Deeps.
3. Utilise a booster fan in series with, and to exclusively aid, the Howden surface fan.

<ins>Surface fan alteration or replacement:</ins> Varying airway resistance at different mine levels and varying operating characteristics of the Richardson surface fan associated with mine development alter the air pressure and quantity required to be delivered to the Deeps. This also affects the operating conditions of the Howden fan as the required mine characteristics do not intercept the fan characteristics (Figure 4). It is evident that the Howden impeller is not suited to provide the required high pressure for low quantity of the optimum operating points. Therefore, either the Howden fan impeller speed would have to be altered or a new fan needs to be chosen to replace the Howden fan.

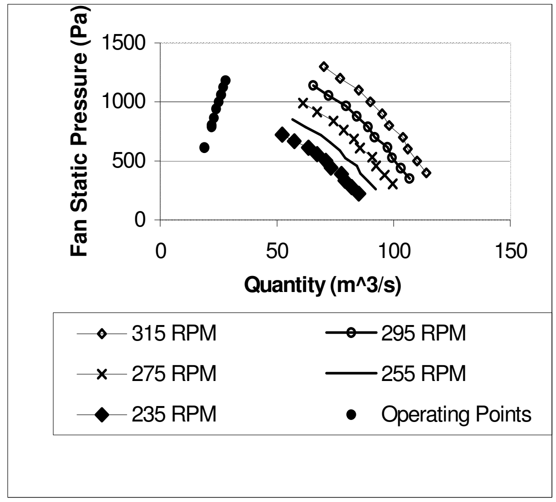

Figure 4. Howden impeller speed variations relative to optimum operating points for 69D trucks

The axial AL1200 fan is suitable for the future mine characteristics (Figure 5). The fan curve of this axial fan can be eralted to provide maximum efficiency for the majority of mine operating points due to the variability of the AL1200 blade pitches.

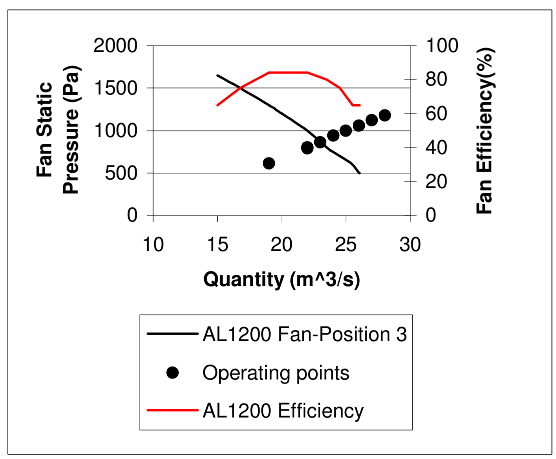

Figure 5. AL1200 fan with blades at position 3 relative to the optimum operating points for 69D trucks

<ins>Booster fan in close proximity to the Deeps:</ins> The location of the booster fan in close proximity to the Redeemer Deeps results in its series connection with two primary fans. The haulage options do not govern the performance of the booster fan; however, the booster fan must operate at a point, which ensures that the Howden primary fan operates outside the stall

region. The booster fan must handle a large quantity of air at high pressure as it is in series with both primary fans. Both the booster fan and the Howden must also operate at a high power level; however; this will restrict the Richardson fan from achieving its maximum efficiency. The booster fan arrangement requires high capital investment and is technically deficient. However, its installation could be justified by short mine life and comparatively lower capital cost than that of main replacement fan.

<u>Booster fan in series with Howden primary fan:</u> The booster fan in this option was placed in series with the Howden primary fan only with the Howden fan controlling the output of the booster fan. Consequently, the high capacity booster fan compensated for the Howden fan impeller low-pressure characteristic. However, the booster fan's location limits its utilisation and thus it was disregarded from further analysis.

<u>Secondary Egress Alternatives</u>

Currently, the escape way is located entirely in fresh air. Brick bulkheads fitted with doors seal the break-throughs into the decline. In an emergency situation, personnel may enter the breakthrough development, termed "fresh air bases", and seek refuge. For future development, the secondary egress will be a raise bored 1.5 m diameter airway adjacent to the return airway drives. Three alternatives were considered in terms of mine ventilation and development:

1. Secondary egress in return air and refuge chamber
2. Steel ducting, and
3. Current escape way development.

<u>Secondary egress in return air and refuge chamber:</u> Due to large amount of development needed for fresh air escape way, it has been proposed to have an escape way operating in exhaust air. The escape way rise and the return airway rise will break into the same drive, which would then conduct escapees past the return airway rises and into the existing fresh air escape way. Refuge chambers would be in place in case of an emergency being caused by the creation of a gassy environment. Refuge chambers are used on site at Crusader Underground Mine in the same fashion. This alternative adds a degree of complexity to emergency and escape training.

<u>Steel ducting:</u> The steel ducting alternative allows for the return airway and the escape way rise to be developed into the same drive and a steel duct to be used to provide escapees with safe passage along the drive to the existing return airway. Thus, fresh air bases could be maintained to the bottom level of the mine.

<u>Current escape way development:</u> The current escape way can be extended via additional development to conduct fresh air to the lowest level of mining activities. This alternative was considered to be the best outcome in terms of safety and practicality.

<u>Fan Selection vs Haulage Scenarios</u>

The determination of the range of fan performances required is achieved in VentSim in four stages:

1. Create a number of different models corresponding to various systems to be considered.
2. If the existing fans do not operate at the required outputs, FIX the target airflow in the fan airway:
   a) If the simulation is to determine the required booster fan, FIX the pressure in the booster fan airway, query the airway and determine the required fan performance.
   b) If the simulation is for a surface fan, remove the fan from the airway and FIX the required quantity. Build the system resistance curve.
3. Repeat the process for all levels of the conceptual workings for various scenarios.
4. Tabulate the ranges of operating conditions and select the optimal fan.
5. Create a system resistance curve and assess its interaction with the fans.

<u>Fan selection vs rehandle ore – self loading scenario:</u> In order to ensure that the position of the optimum operating points of the fan are contained within the fans high efficiency regions with respect to the mine system curve, the axial flow fan AL1700 was selected (Figure 6) for the rehandle ore – self loading haulage scenario.

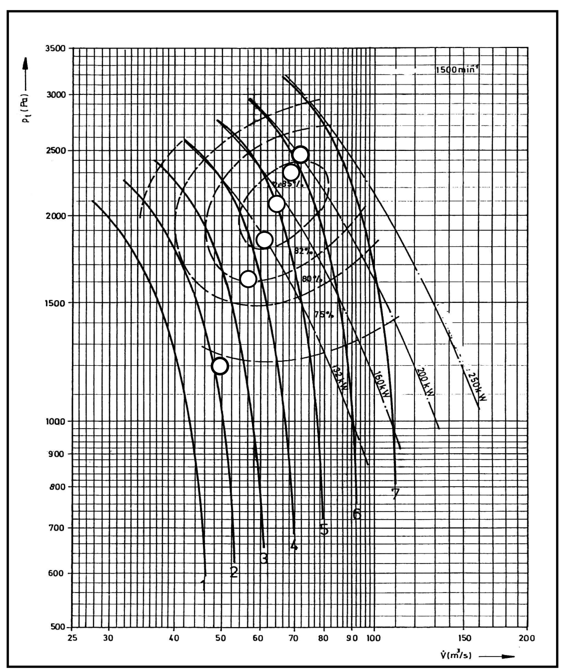

Figure 6. Korfmann AL 1700 axial flow fan (SDS Ausminco, 1998)

(○ = represents optimum operating points)

The AL1700 was simulated in VentSim to determine its interaction with other main fans and the network. Two blade pitch positions were simulated and the air quantity achieved at each level was recorded. Figure 7 shows the operating ranges of two blade pitch settings. The Position Hurdle curves show the air quantity the fan must provide at each level in order for the quantity of the existing surface fans to reach the required value. It is evident that a 160 kW motor will be required and the operating static pressure of 2,300 Pa should not be exceeded with this motor size. The static pressure restriction will not affect the currently identified Deeps levels, though, it will be of importance if further mine development is undertaken. In addition, the blade pitch change from 4 to 5 should be made before the 9,710 level is developed.

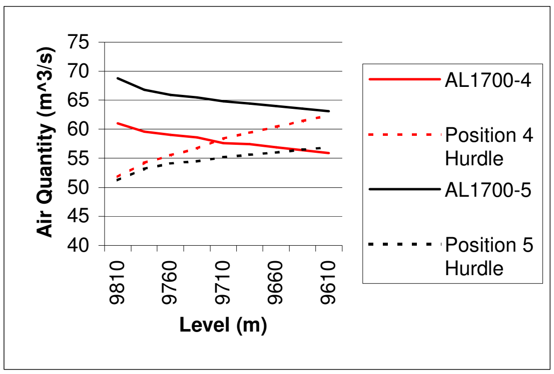

Figure 7. Axial flow fan AL1700 simulation in Redeemer network

Fan selection vs rehandle ore – ore pass scenario: Similar procedure to that outlined in the fan selection for self loading scenario was followed in the fan selection for the ore pass scenario. The results of the simulation indicated that the blade pitch change from 3 to 4 should be made before the 9710 level is developed. Furthermore, a 90 kW motor would be required and an operating static pressure of 2,250 Pa should not be exceeded with blade pitch position 4 to avoid entering the fans stall region.

Fan selection vs no rehandling - only 69D trucks scenario: The axial flow fan AL1200 was chosen for the 69D trucks scenario. During simulation with VentSim it was shown that the fan blade pitch change from 3 to 4 must be made before the 9,710 level is developed and a second blade pitch change should be made from 4 to 5 before the 9,660 level is developed. The fan curve indicated that a 45 kW motor would be required and an operating static pressure of 1,500 Pa should not be exceeded with a blade pitch position of 5 for this motor.

Capital and Operating Costs

The size of the return airways to be developed in the Deeps workings will have a considerable baring on the mine resistance, the pressure to be supplied and the development costs. The return airways in the primary circuit have all been raise bored in the past due to a number of favourable conditions: lower friction factor than blasted, no blast damage, easier to develop over longer lengths. Therefore, circular return airways were considered for future developments. The most economical airway (the optimum airway) results when the total ventilation cost (operating and capital costs) is minimised. The total cost of the airway can be found as:

$$TC = C_C + \frac{P_A \times T \times C_{rate} \times t}{12} \quad (1)$$

where: TC = total cost [\$]; C_C = capital cost (development cost) [\$]; P_A = air power [Pa]; T = operation hours per year; C_{rate} = unit power cost [\$/kWhr]; and t = project duration in months.

The total cost was calculated for the airways of diameter 2.4 m, 3.1 m and 3.6 metres. Since the estimated project duration for Redeemer Deeps is 24 months, the 3.6 m diameter return airway was found to be the most suitable airway for Redeemer Deeps system.

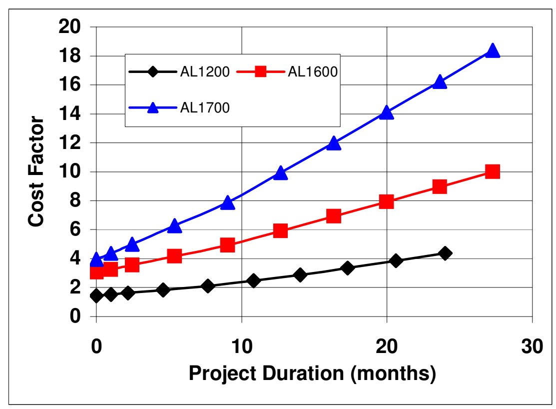

Figure 8. Capital and operating cost factors of fan option[1]

In addition, when determining the operating costs of each fan option, the working time on each haulage level should be calculated as the various pressure/quantity operating points that dictate the power requirements are governed by the mine resistance or by the extent of development being ventilated. In addition, higher ventilation costs are incurred for longer periods of time as a result of longer haulage routes. Figure 8 shows the cumulative capital and operating cost of each fan for the required project duration taking into account the impeller blade pitch changes. The greater the quantity required the greater the capital and the operating costs of fans, as governed by the haulage option.

[1] Costing is expressed relative to the lowest annual power cost of running the axial flow fan AL1200 with the 9810 level developed.

Table 5. Effects of future development on proposed systems.

Fan Type	Mine Quantity [m^3/s]	Stall Region Motor Status	Courses of Action	Disadvantages
AL1700-5	101	10% of pressure range from stall region. Motor limit passed.	Change blade position to 6 (110 m^3/s). Upgrade motor to 200 kW. Diesel restrictions.	Cost of new motor. Production
AL1600-4	93	20% of pressure range from stall region. Within motor limits	For flow increase upgrade to 132 kW motor and move to blade position 6 (105 m^3/s). Diesel restrictions.	Cost of new motor. Production
AL1200-5	86	20% of pressure range from stall region. Motor limit passed.	Change blade position to 6 (90 m^3/s). Upgrade motor to 55 kW. Diesel restrictions.	Diesel restrictions. Cost of new motor. Production

FUTURE DEVELOPMENT

Three possible scenarios for future development need to be considered, namely:

1. Lateral development from any part of the mine.
2. Vertical development from any part of Redeemer, excluding the Deeps workings.
3. Vertical development from the last level of the Redeemer Deeps.

Any of the three fan selections discussed previously will provide sufficient quantity and quality of air for the first two scenarios. However, the ventilation for the vertical development from the Redeemer Deeps last level has to be evaluated, as the currently proposed changes to the ventilation system will not be sufficient. Future conditions were simulated in VentSim whereas eight levels or 200 m of vertical developments were added to the Deeps workings. The results are summarised in Table 5.

CONCLUSIONS

Provided the Redeemer Deeps is exploited, the primary ventilation system requires the following:

- Utilisation of both exhaust rises
- Replacement of the Howden HS 288 330 (315) surface centrifugal fan
- Development of a 3.6 m diameter return air rises between levels in the Deeps workings
- Development of a 1.5 m diameter escape way parallel to the return air rises.

In order to complete the design of the primary ventilation network, the main block stoping arrangements and the haulage scenario need to be finalise.

ACKNOWLEDGEMENT AND DISCLAIMER

The authors would like to thank the Management of Agnew Gold Mine for the permission to publish the paper and the Agnew Gold Mine personnel for their assistance in data collection and the construction of the ventilation network.

The authors would also like to acknowledge that the Agnew Gold Mine is conducting a comprehensive ventilation network analysis independent of the evaluation presented in this paper.

REFERENCES

Bandopadhyay S., 1992, "Computer Applications in Mine Ventilation and the Environment," SME Mining Engineering Handbook, Hartman, ed., SME, Littleton, CO, p.1139-1150

CMS Software, 2000, VentSim User Manual 3.2

Hall, G.C., Clarke, B.N., 1988, "Ventilation Design and Practice at the Olympic Dam Mine, South Australia," Proceedings, 4th Intern. Mine Vent. Congress, A.D.S. Gillies, ed., AusIMM, Melbourne, pp. 575-583

Hartman, H. L., Mutmansky, J.M., Y.J. Wang, 1982, Mine Ventilation and Air Conditioning. John Wiley & Sons, New York.

SDS Ausminco, 1998, Primary and Secondary Ventilation Fans. Product Catalogue, Australia

Teasdale P., 2000, Ventilation Design Guidelines and Operating Practices, WMC Internal Document, Australia

WA Mines Safety and Inspection Regulations 1995, Government Gazette, No. 169, Australia