VENTILATION SYSTEM DESIGN FOR THE WASSA UNDERGROUND MINE

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ABSTRACT

This paper describes a ventilation project at the Wassa gold mine in Ghana. Golden Star (Wassa) (GSWL), a subsidiary of Golden Star Resources, owns and operates the mine. Golden Star holds a 90% interest in GSWL, while the Ghanaian Government holds the remaining 10% ownership, earning a 5% royalty on the gross revenue of GSWL's gold production. Construction of the underground mine began in mid-2015 and pre-commercial production started in June 2016. Commercial production from the underground mine was achieved in January 2017. This paper describes the ventilation studies performed to support the initial development and production at the mine. The initial ventilation design included four, parallel surface exhaust fans. Future designs will include booster fans, new primary fans, and additional connections to surface. The paper describes the long-term ventilation planning goals and expectations as the mine achieves a production of 4,000 tpd with truck haulage to surface.

KEYWORDS

Case Studies, Ventilation Design

INTRODUCTION

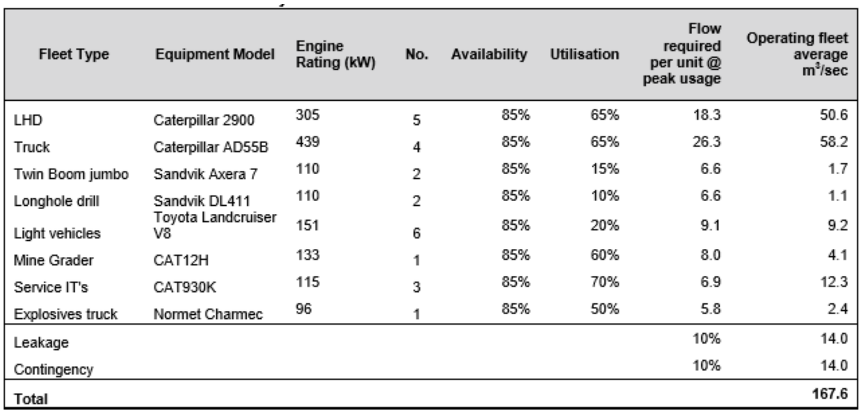
The Wassa Gold Mine is located in the southern portion of the Ashanti Greenstone Gold Belt in Ghana, northwest of Tarkwa as shown in Figure 1. The mine has been in production as an open pit since 1998, with some minor disruptions, but the surface minable reserves have become exhausted and the mine started a transition to an underground operation in 2015. The underground mine was initially developed with twin decline accesses extending from the base of the open pit to the mining areas. The mining method selected was sub-level open stoping with cemented rock backfill. The original production level for the mine was 2,500 tpd with ore and waste transported by trucks hauling in the ramps to surface. In 2017 the production goal was set to increase to approximately 4,000 tpd. This resulted in an increase in the truck haulage fleet in addition to a significant increase in ventilation requirements. This paper describes the ventilation upgrades at the mine as it transitioned from a surface to an underground operation and the adjustments the ventilation system needed to make in order to accommodate a significant increase in production.

Figure 1. Location of the mine

Airflow Requirements and Changes Over Time

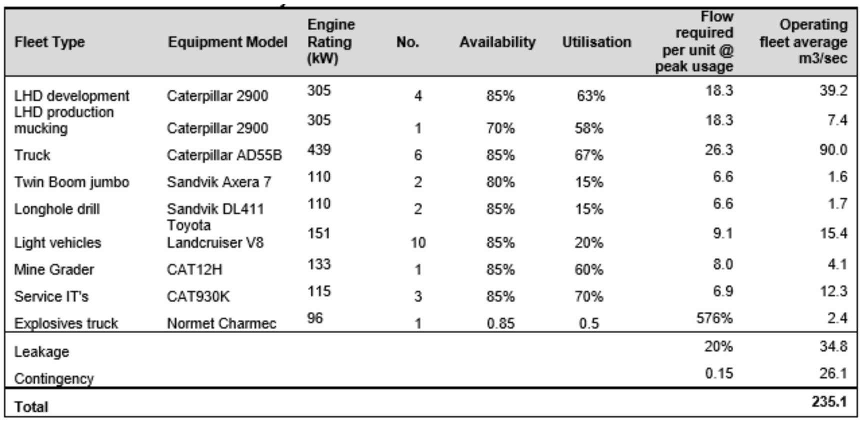
The initial airflow estimate for the mine was based on a projected equipment fleet accounting for availability and utilization percentages. The total airflow was calculated using a dilution factor of 0.06 m^3/s per kW. During the ramp up phase, called Phase 1, an airflow of 167.6 m^3/s was calculated as shown in Table 1. Post ramp-up, termed Phase 2 represented a steady state condition with a computed airflow of 235.1 m^3/s as shown in Table 2. The ventilation system was modeled so that leakages through any closed level regulators (given a resistance of 250 Ns^2/m^8) would be included in the airflow calculation. Another criteria was maintaining the ramp air velocity below 6 m/s.

Table 1. Phase 1 overall airflow determination



Fleet Type	Equipment Model	Engine Rating (kW)	No.	Availability	Utilisation	Flow required per unit @ peak usage	Operating fleet average m^3/sec
LHD	Caterpillar 2900	305	5	85%	65%	18.3	50.6
Truck	Caterpillar AD55B	439	4	85%	65%	26.3	58.2
Twin Boom jumbo	Sandvik Axera 7	110	2	85%	15%	6.6	1.7
Longhole drill	Sandvik DL411	110	2	85%	10%	6.6	1.1
Light vehicles	Toyota Landcruiser V8	151	6	85%	20%	9.1	9.2
Mine Grader	CAT12H	133	1	85%	60%	8.0	4.1
Service IT's	CAT930K	115	3	85%	70%	6.9	12.3
Explosives truck	Normet Charmec	96	1	85%	50%	5.8	2.4
Leakage						10%	14.0
Contingency						10%	14.0
Total							**167.6**

Table 2. Phase 2 overall airflow determination



Fleet Type	Equipment Model	Engine Rating (kW)	No.	Availability	Utilisation	Flow required per unit @ peak usage	Operating fleet average m3/sec
LHD development	Caterpillar 2900	305	4	85%	63%	18.3	39.2
LHD production mucking	Caterpillar 2900	305	1	70%	58%	18.3	7.4
Truck	Caterpillar AD55B	439	6	85%	67%	26.3	90.0
Twin Boom jumbo	Sandvik Axera 7	110	2	80%	15%	6.6	1.6
Longhole drill	Sandvik DL411	110	2	85%	15%	6.6	1.7
Light vehicles	Toyota Landcruiser V8	151	10	85%	20%	9.1	15.4
Mine Grader	CAT12H	133	1	85%	60%	8.0	4.1
Service IT's	CAT930K	115	3	85%	70%	6.9	12.3
Explosives truck	Normet Charmec	96	1	0.85	0.5	576%	2.4
Leakage						20%	34.8
Contingency						0.15	26.1
Total							**235.1**

The production rate was increased to approximately 4,000 tpd which resulted in an expansion to equipment fleet incorporating three additional trucks, one additional LHD, and several additional pieces of support equipment. One major increase was the replacement of the proposed AD55 haul trucks at 439 kW with AD60 haul trucks at 567 kW. The airflow requirement was recalculated to incorporate both the higher equipment numbers and elevated power requirements. The equipment was evaluated such that if the equipment was operating in the mine it would require 100% of the dilution ventilation as shown in Table 3. Several additional assumptions were made in this calculation. First it was assumed that one truck would be on surface, hauling to the ore or waste stockpiles. Second it was assumed that one of the six LHDs would be under maintenance. Furthermore, all equipment operated primarily by electricity was excluded from the calculation.

Table 3. Re-evaluated airflow requirement for 4,000 tpd

Equipment	Type	engine size (kW)	Total Fleet	Fleet in Mine Operating	Utilisation (%)	Airflow per Unit (m^3/s)	Operating fleet (m^3/sec)
LHD development	Caterpillar 2900	305	2	2	100%	18.3	36.6
LHD production mucking		305	4	3	100%	18.3	54.9
LHD production backfill		305	0	0	100%	18.3	0.0
Truck	Caterpillar AD60	567	9	8	100%	34.0	272.2
Twin Boom jumbo	Sandvik Axera 7	110	2	2	0%	6.6	0.0
Longhole drill	Sandvik DL411	110	3	3	0%	6.6	0.0
Light vehicles	Toyota Landcruiser	151	12	6	50%	9.1	27.2
Mine Grader	CAT12H	133	1	1	0%	8.0	0.0
Service IT's	CAT930K	115	3	2	100%	6.9	13.8
Charge-up machine	Normet Charmec	96	2	2	100%	5.8	11.5
Leakage						15%	62.4
Contingency						15%	62.4
Total							541.0

The airflow required per production level is based on the operation of a single LHD and a single truck which requires approximately 50 m^3/s. The airflow per development heading is based on the operation of a single LHD requiring approximately 20 m^3/s. The development at the base of the ramp (ramp extension) has the same airflow requirement as a production level, that is a single LHD and a single truck for a flow of 50 m^3/s. However, based on the use of a full utilization value for the airflow calculation the "contingency" value can be minimized which results in decreasing the airflow requirement to approximately 480 m^3/s. The leakage value is assumed at 15%, however, through the development of the ventilation models this can be more closely determined based on the types of ventilation controls constructed in the mine.

BASIC MINE VENTILATION SYSTEM DESIGN

For the 2,500 tpd rate, the design of the ventilation system was divided into two phases; Phase 1 (shown in Figure 2) and Phase 2 (shown in Figure 3). The Phase 1 ventilation system is designed for initial development and limited production. The Phase 2 ventilation system is designed to support the life of the mine. Based on the initial development of the mine and the continued evolution of the mine plan, the Phase 2 ventilation system has evolved since the initial feasibility studies. The Phase 1 ventilation system incorporates two parallel declines that access the initial mining areas. Haulage and primary access will be through the fresh air decline which connects to the mining area access ramps. Exhaust air from the stopes is through raises that connect to an exhaust decline. In order to provide ventilation quickly the exhaust fan system installed at the portal of the exhaust decline is made up of four fans mounted in a concrete bulkhead operating in parallel. A bank of four small fans mounted in a portal bulkhead could be procured and installed faster than a single large fan and at a lower cost.

The Phase 2, LOM ventilation system places both declines on intake with an exhaust raise developed to surface developed at the edge of the mining area. An exhaust fan would be mounted on surface of the raise.

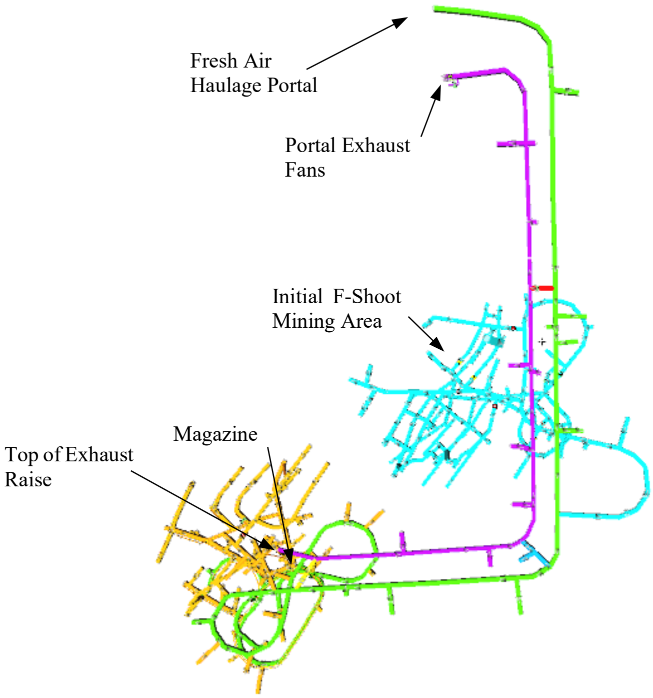


Figure 2. Phase 1 basic layout

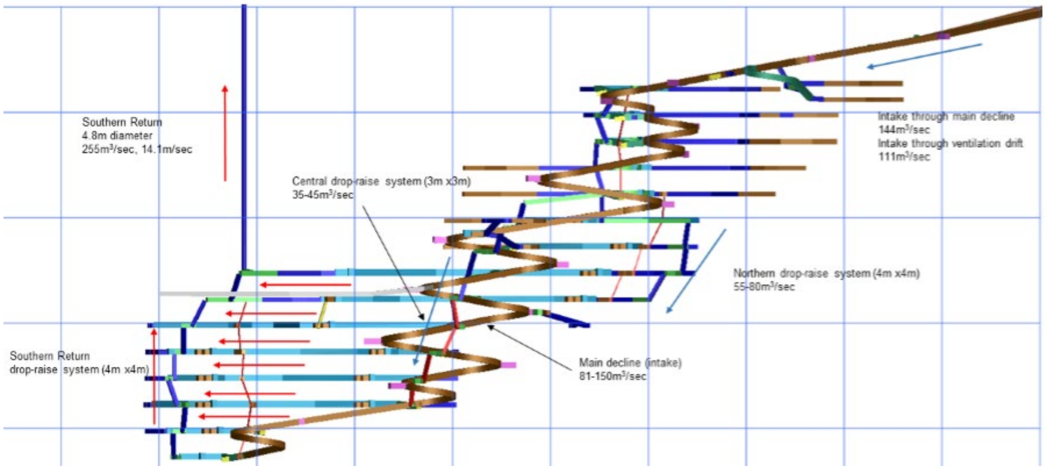


Figure 3. Phase 2 LOM basic layout

OBSERVATIONS MADE DURING A SITE VISIT

After the Phase 1 ventilation system was installed, a partial survey was performed to determine the resistances of ventilation controls in use in the mine and how the ventilation system was actually being developed. A diagram of the system is shown in Figure 4. This was an important step so that the ventilation models could be calibrated to more closely reflect the conditions that would be expected to occur in the mine in the future.

The ventilation survey identified airflows in key locations, leakages, and actual fan operating pressures. Several observations were made during the site visit;

- The average fan system efficiency measured for the temporary Phase 1 exhaust system was measured at 62%. The entry and exit losses associated with the four parallel fans are significant. The fan orientation is shown in Figure 5

- Until the new exhaust ventilation raise is in, the mine will have no more than 170 m^3/s at a delivered pressure of under 250 Pa (at roughly the 795 Level)
- There is significant leakage in the Link 3 access door (non-airlocked). A picture of this door is shown in Figure 7.
- The future mine plans need to include the drive to the new raise location
- The mining time and new fan commissioning needs to be evaluated
- The new ventilation system will need an exhaust fan to pull more air than the current 190 m^3/s (roughly 350 m^3/s)
- The fan needs to be sized based on long range ventilation needs
- A ventilation plan is needed on how to convert the existing system to the new system – this includes how to intake the current exhaust system and how to connect to the new exhaust raise.
- Leakage resistances and fan pressures were modified in the ventilation model to achieve a correlation error of less than 10%.
- The F-Shoot mining area was completed, but the ventilation system was still open which significantly decreased the airflow to the development and lower mining areas.

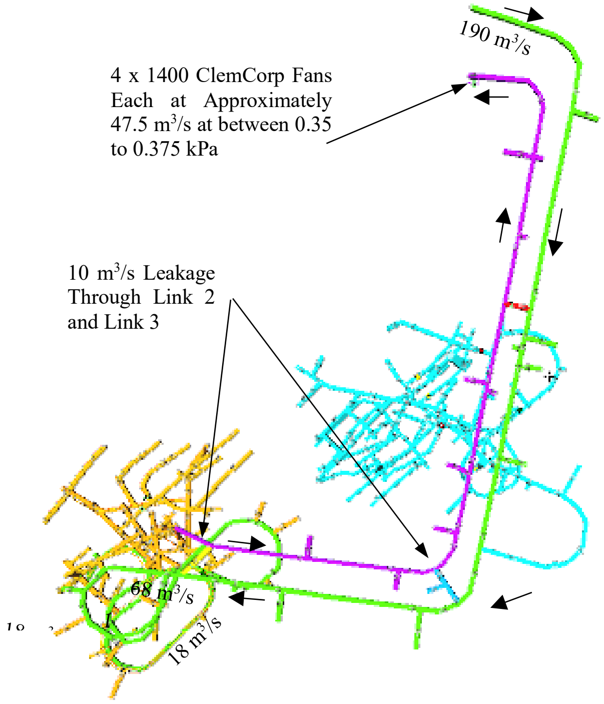
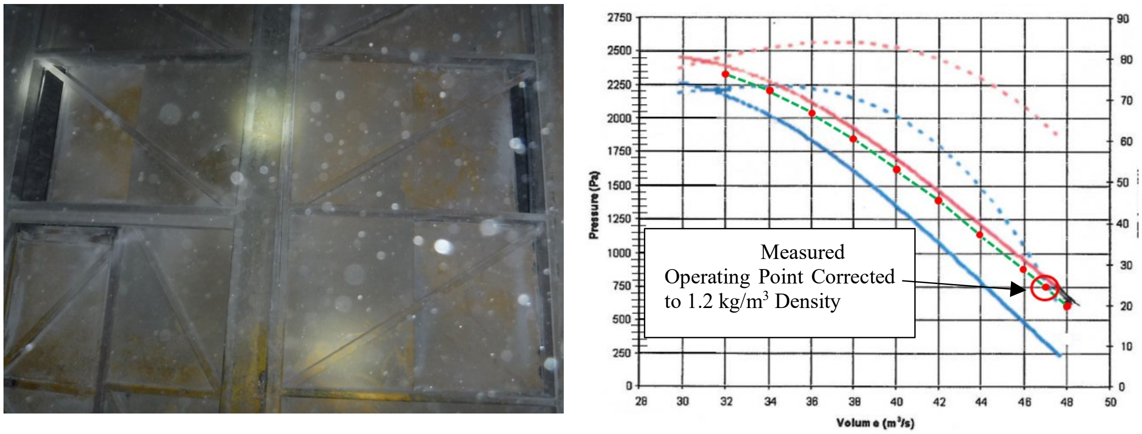


Figure 4. Ventilation system at initial site visit

Phase 1 fan installation 4 x CC1400 fans

Closed regulators requiring sealing

Figure 5. Phase 1 fan installation and leaky regulators



Measured Operating Point Corrected to 1.2 kg/m³ Density

Link 3 leakage

Measured fan performance for Single CC1400

Figure 6. Link 3 leakage and fan performance measurement

Initial Optimizations (Airflow Increases)

The Phase 2 ventilation system represents a step change in the overall airflow quantity. With the maximum airflow quantity in the ramp system limited to approximately 165 m^3/s (air velocity limitation) a ventilation raise will be required. The original Phase 2 airflow quantity was estimated at approximately 235.1 m^3/s, however, with an increase in the equipment load and production rate the revised airflow quantity reaches approximately 480 m^3/s. This identifies the need for additional intake and exhaust connections to surface.

Operating the Phase 1 Portal Fans at Higher Pressure

As an interim step in increasing the airflow through the ventilation system and maximizing the airflow to the lower areas of the mine, the existing exhausting four parallel fan installation was examined to re-pitching of the fan blades. To accommodate this setting, the fan motors were upgraded from 90 kW to 132 kW. Using the fan manufacturers curve, the operating point was plotted. The red vertical arrow is the fan airflow (190 m^3/s or 47.5 m^3/s per fan) and the blue horizontal line is the fan total pressure (2.07 kPa adjusted to standard density of 1.2 kg/m^3 to give 2.2 kPa) for the scenario of 4 fans operating in parallel with 132 kW motors. The shaft power calculates at about 143 kW (shown by the two blue arrows from the operating point). Adjusting this for density (1.14/1.20) gives a shaft power of 135 kW. This relates to a fan efficiency of 73%. These operating points are identified on Figure 7.

However, there may be a potential problem with starting four fans in parallel at a higher pressure operating point. As fans in parallel start in sequence, the second fan needs to develop sufficient pressure to overcome the operating point of the first fan, then the third fan needs to develop sufficient pressure to overcome the first two fans, etc. It is often the third or fourth fan that cannot develop this pressure on startup and will stay in a stall condition (the pressure line plotted is called the Hagen line). This condition is particularly noticed when there is a high mine resistance (fans operated at higher pressure). As a mine develops and the required operating point moves up the fan curve, the more difficult it will be to start the fans.

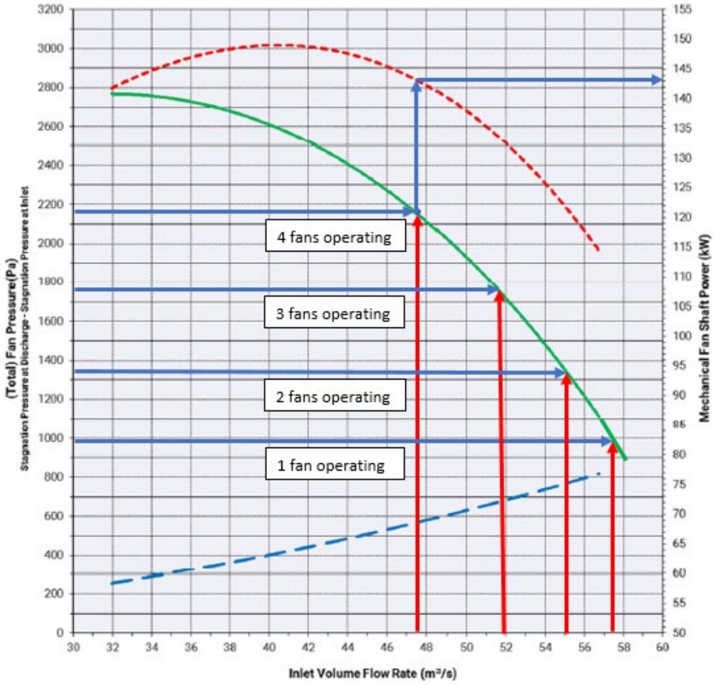


Figure 7. Staged fan curve for up to four fans operating

The key risk of stall during multiple fan start-up is the system resistance. If it is too-high then it may not be possible to start all four fans without one or more going into stall. However, in looking at the curve, it does appear that operating a single fan does start low on the resistance curve. This bodes well for the option of getting most of the fans operating successfully. The challenge may be in getting the fourth fan started, since at this time the other three fans are riding higher on their respective curves. In order to successfully start all four fans a procedure was developed where a by-pass would be developed by opening the door in Link 3 which would decrease the fan system operating pressure. The door would then be slowly closed to prevent shocking the fans when the short circuit is closed. The fan manufacturer, ClemCorp, confirmed the applicability of the startup procedure.

The proposed system should provide nearly 190 m^3/s at the portal and nearly 70 m^3/s to the ventilation raise at the ramp bottom.

New Exhaust Raise and Fresh air Ramp

In order to provide a step change increase in the ventilation system additional fresh air and exhaust raises were considered in addition to a third portal developed into the exhausted pit as shown in Figure 8. The resulting airflow criteria for each time phase is shown in Table 4 and Table 5.

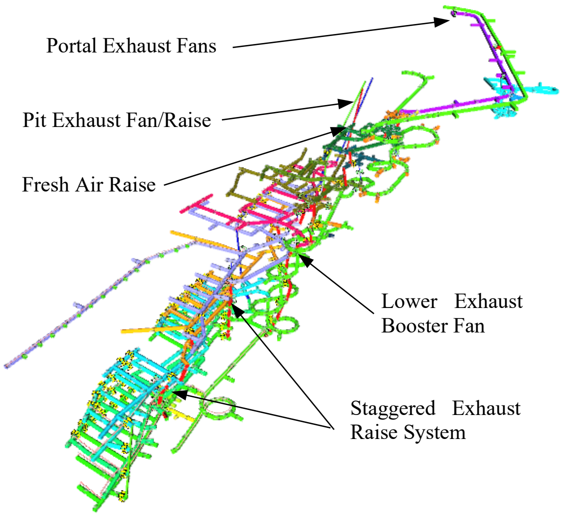
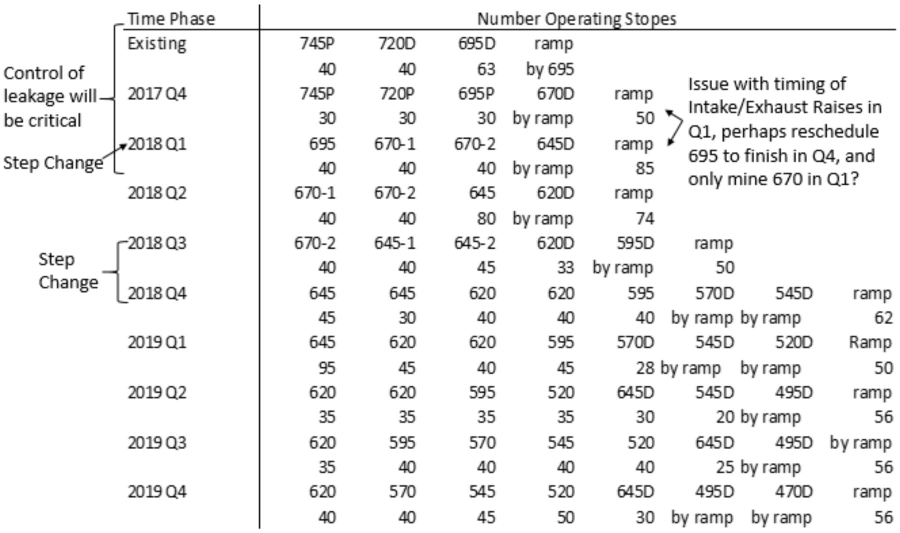


Figure 8. Intermediate life of mine analysis

The ventilation system was examined on a quarterly basis with the following assumptions;

- Surface losses are an estimate based on 8m of 1.7m duct. They should not be used but should be estimated for the actual installation.
- Surface raises are 4.1m diameter (k-0.005 kg/m^3)
- Internal raises are 4m x 4m blasted (k-0.015 kg/m^3)
- Ramp 5.5m x 5.8m (k-0.012 to 0.015 kg/m^3)
- Level/Stope access 5m x 5m (k-0.012 kg/m^3)
- Bulkhead resistance set at 50 Ns^2m^8 (provides a more realistic long-term leakage)

Table 4. Airflow requirements for time phases



Time Phase	Number Operating Stopes							
Existing	745P	720D	695D	ramp				
	40	40	63	by 695				
2017 Q4	745P	720P	695P	670D	ramp			
	30	30	30	by ramp	50			
2018 Q1	695	670-1	670-2	645D	ramp			
	40	40	40	by ramp	85			
2018 Q2	670-1	670-2	645	620D	ramp			
	40	40	80	by ramp	74			
2018 Q3	670-2	645-1	645-2	620D	595D	ramp		
	40	40	45	33	by ramp	50		
2018 Q4	645	645	620	620	595	570D	545D	ramp
	45	30	40	40	40	by ramp	by ramp	62
2019 Q1	645	620	620	595	570D	545D	520D	Ramp
	95	45	40	45	28	by ramp	by ramp	50
2019 Q2	620	620	595	520	645D	545D	495D	ramp
	35	35	35	35	30	20	by ramp	56
2019 Q3	620	595	570	545	520	645D	495D	by ramp
	35	40	40	40	40	25	by ramp	56
2019 Q4	620	570	545	520	645D	495D	470D	ramp
	40	40	45	50	30	by ramp	by ramp	56

Control of leakage will be critical

Step Change

Step Change

Issue with timing of Intake/Exhaust Raises in Q1, perhaps reschedule 695 to finish in Q4, and only mine 670 in Q1?

Table 5. Fan summary for interim ventilation layout

	Portal Fans		Pit Fans		Lower Fans	
Time Phase	(m^3/s)	(kPa)	(m^3/s)	(kPa)	(m^3/s)	(kPa)
Existing	174.4	1.185				
2017 Q4	174.0	1.198				
2018 Q1	168.0	1.386	80.0	1.753		
			surface loss	0.257		
2018 Q2	167.0	1.390	80.0	1.753	regulated intake	
			surface loss	0.257		
2018 Q3	175.8	1.144	80.0	1.413	regulated intake	
			surface loss	0.257		
2018 Q4	161.0	1.567	80.0	1.985	114.0	3.241
			surface loss	0.257	surface loss	0.522
2019 Q1	156.6	1.690	80.0	2.162	150.0	5.101
			surface loss	0.257	surface loss	0.896
2019 Q2	158.4	1.638	80.0	2.118	150.0	4.991
			surface loss	0.257	surface loss	0.896
2019 Q3	157.3	1.669	80.0	2.165	150.0	5.043
			surface loss	0.257	surface loss	0.896
2019 Q4	155.1	1.730	80.0	2.247	150.0	5.096
			surface loss	0.257	surface loss	0.896

Expansion to 4,000 tpd Modeling

The increase in the production rate combined with the development of the deeper reserves requires a further step change in the ventilation system. The requirement for 480 m^3/s through the system to ventilate the equipment load leads to the requirement of a new exhaust raise as shown in Figure 9. The ventilation system was further enhanced by the addition of a new fresh air raise. Because of the new raises and surface exhaust fan the proposed lower booster fan would not be required.

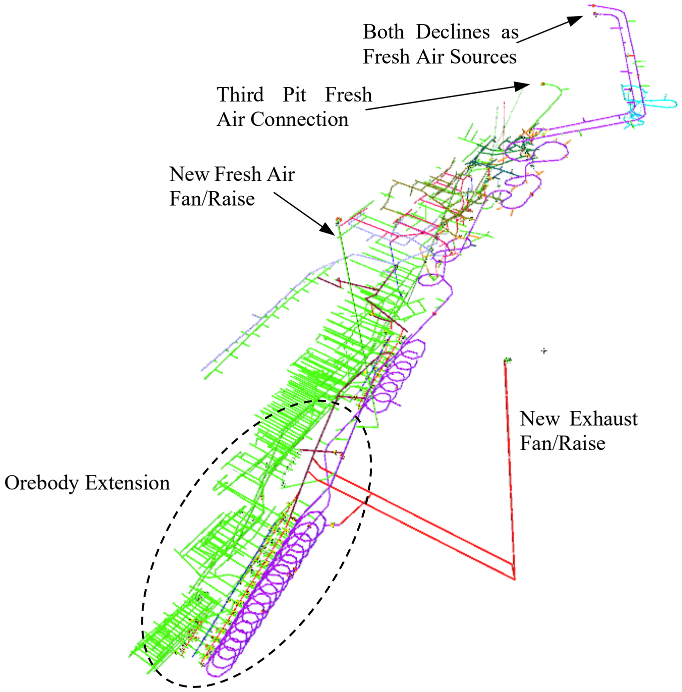


Figure 9. Expanded mine for 4,000 tpd

Refrigeration Issues

Because of the increased production at the lower levels of the mine in combination with the higher equipment load the temperatures are projected to be fairly elevated. Based on the deeper mining area the heat load associated with auto-compression was calculated at approximately 1.9 MW. The heat load associated with the operating mobile equipment was estimated at approximately 8.5 MW. With the natural cooling provided by the ventilation airflow at 7.8 MW the need for refrigeration is indicated. The ventilation model was modified for the thermal attributes of the equipment load, rock mass, climatic conditions, and auxiliary ventilation systems to simulate the positional effects of the equipment load. This reflected the requirement for a bulk air cooler on the top of the fresh air raise in the order of 6.5 MW. This refrigeration requirement is higher than the requirement determined by the cursory thermal balance because it reflects the positional effects of the mobile equipment operating in areas of lower airflow, and auxiliary ventilation systems.

CONCLUSIONS

The development and planning of a ventilation system is an iterative process. As the mine plan, equipment load, and production rate changes the design of the ventilation system needs to be able to be revised. This is where flexibility becomes important. Designing the ventilation system based on a simplistic equipment list with utilization factors provides for a reasonable first step for project evaluation, however, when the ventilation system is being designed, the actual equipment load in operation should be used as the basis of design. Once the mine enters the production phase or at least during the late stages of development the ventilation system needs to be evaluated to ensure that the design assumptions are correct (friction factors and leakage resistances) and that the system is operating close to how it was designed to ensure that the fan selection is correct.

A mine plan evolves with an increased knowledge base for the gained through the development process the ventilation system is likely to be modified because of tweaks to the mine plan. A certain amount of those tweaks can be overcome by designing flexibility into the ventilation system from inception, but some changes will require the redevelopment or expansion of the ventilation system.

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