CONVERSION OF A BACKFILL RAISE TO A VENTILATION EXHAUST RAISE, A SUCCESS STORY

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ABSTRACT

The Golden Giant Mine ventilation system has recently undergone major upgrading as part of its energy management strategy. One of the primary components of the upgrade design consisted of the conversion of a raise use for backfilling into a ventilation exhaust raise. A surface fan infrastructure, consisting of two 2.13 m (84") axial vane fans operating in parallel, was sized and designed to maximize raise exhaust airflow volume economically. This paper describes the exhaust raise design considerations, including system resistance calculations, and the design, sizing and construction of the surface fan infrastructure, including elbows, reducers and cones. A comparison between design and measured operating conditions is also provided. The new exhaust system not only met the anticipated operating conditions but also helped achieve the required expansion in overall mine exhaust capacity.

1. INTRODUCTION

Production requirements at the Golden Giant Mine demanded that the primary exhaust ventilation system be maximized. A series of system modifications were conducted over a number of years in an attempt to maximize exhaust flow and optimize system performance while minimizing operating costs. One of the major components of the system upgrade consisted of the conversion of a raise use for backfilling into a dedicated ventilation exhaust raise. The process of dumping some 8 million tonnes of broken rock to produce backfill underground had changed the Alimak driven raise characteristics - making it larger in size and producing smoother walls - thus making it ideal for conversion to a ventilation raise.

A surface fan infrastructure consisting of two 2.13 m (84") axial vane fans operating in parallel stacks, and fitted with 261 kW (350 HP) variable frequency motors each, was meticulously designed to exhaust between 179 m^3/s (380,000 cfm) and 198 m^3/s (420,000 cfm) at pressures ranging between 740 Pa (2.97" w.g.) and 1877 Pa (7.55" w.g.).

This paper describes the philosophy behind the successful expansion of the mine primary exhaust system and shows how the detailed surface fan selection study and infrastructure design was successful in meeting all anticipated operating conditions.

2. THE MINE MAIN VENTILATION SYSTEM

The primary ventilation system is a complex network of raises capable of handling 481 m^3/s (1,020,000 cfm), schematized in Figure 1. Each component of the mine ventilation system is briefly described below (Krog, 2000).

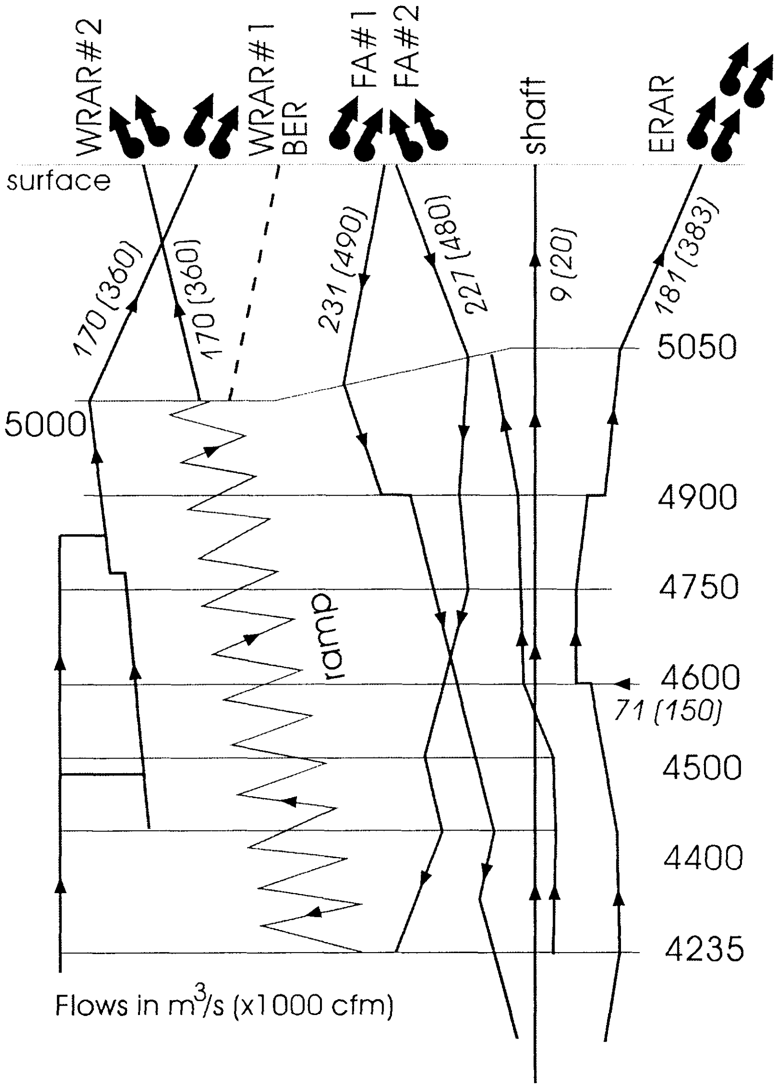


Figure 1. The mine main ventilation system

2.1 The Fresh Air System

The fresh air system, located on the eastern side of the mine and near the production shaft, comprises two raises, the Fresh Air Raise #1 (FA#1) and the Fresh Air Raise #2 (FA#2), which supply approximately 458 m^3/s (970,000 cfm) of fresh air to the production areas. A main ramp is used to distribute the fresh air to required mining blocks of the mine. In general, fresh air is added to the ramp on primary levels and exhausted on sublevels. FA#1 primarily supplies air to the upper sections of the mine and FA#2 supplies fresh air to the lower production sections of the mine. The fresh air system only uses surface fans; such fans being capable of supplying all the pressure required to transport the fresh air through the raises to the bottom of the mine. FA#1 uses two centrifugal fans operating in parallel to supply 231 m^3/s (490,000 cfm) underground. The fans are belt driven by four 186 kW (250 HP) motors. Each fan operates at a break power of 268.5 kW (360 HP), 1.71 kPa (7" w.g.) static pressure and 74% efficiency. FA#2 uses two centrifugal fans operating in parallel to supply 227 m^3/s (480,000 cfm) underground. The fans are direct driven by two 522 kW (700 HP) variable frequency motors. Each fan operates at a break power of 309.5 kW (415 HP), 2.19 kPa (9" w.g.) static pressure and 80% efficiency.

2.2 The Exhaust System

The exhaust air system consists of raises located at both extremities of the ore body. The western and the eastern exhaust systems handle approximately 60% and 35% of the total exhaust air volume, respectively. The reminder of the exhaust air volume is expended via the production shaft.

2.2.1 *The East Return Air Raise System*

The East Return Air Raise System (ERAR) system uses surface fans to generate all the pressure required to exhaust the air volume from the bottom of the mine. Regulators are used to control individual level exhaust flows. ERAR uses four 1.98 m (78") diameter axial flow fans operating in series-parallel, in two stacks, to exhaust 181 m^3/s (383,000 cfm). The fans are driven by four 186 kW (250 HP) motors. Each stack operates at a break power of 257.5 kW (345 HP), 2 kPa (8.2" w.g.) total pressure and 75% total efficiency.

2.2.2 *The West Return Air Raise System*

The West Return Air Raise System (WRAR), the primary topic of this paper, was upgraded to exhaust an additional 57 m^3/s (120,000 cfm) by the conversion of a backfill raise to a ventilation raise. The WRAR uses surface fans and underground booster fans, installed on each level connected to the exhaust system, to exhaust the airflow from the mine. Three surface raises were originally used to exhaust mine air via the WRAR; these have been reduced to two exhaust raises after the upgrade. Before introducing the WRAR new surface infrastructure, a description of the system layout, before and after the upgrade, is presented.

2.2.2.1 *The Original West Return Air Raise System*

The original WRAR consisted of two parallel primary underground ventilation raises which, with the assistance of booster fans, supplied exhaust air to the 5000 level. From the 5000 level, air was exhausted to surface via three raises, WRAR#1, the Backfill Exhaust Raise (BER), and the original backfill raise (BR).

The primary exhaust raise, WRAR#1 uses two 1.98 m (78") diameter axial flow fans operating in parallel, in two stacks, to exhaust 170 m^3/s (360,000 cfm). The fans are driven by two 186 kW (250 HP) motors. The fans operate at a break power of 298 kW (400 HP), 1.39 kPa (5.7" w.g.) total pressure and 78% total efficiency.

The mine backfill raise system consisted of two raises extending from the surface to the 5035 level: the original backfill raise (BR) and the backup raise (backfill exhaust raise, BER). BER used two 1.37 m (54") diameter axial flow fans operating in parallel, in two stacks, to exhaust 99 m^3/s (210,000 cfm). The fans were driven by two 149 kW (200 HP) motors. The fans operated at a break power of 186 kW (250 HP), 1.07 kPa (4.4" w.g.) total pressure and 57% total efficiency. The BER was converted to a dedicated backfill raise during the upgrade of the WRAR system.

BR used a single 1.37 m (54") diameter axial flow fan underground, installed on the 5035 level, to exhaust 38 m^3/s (80,000 cfm), when the raise was not being used for backfilling.. The fan was driven by a 149 kW (200 HP) motor. The fan operated at a break power of 52 kW (70 HP), 0.76 kPa (3.1" w.g.) total pressure and 56% total efficiency. During the upgrade program, this raise was converted to a dedicated ventilation exhaust raise, designated as WRAR#2, to exhaust 170 m^3/s (360,000 cfm).

2.2.2.2 *The West Return Air Raise System Upgrade*

The upgrade design of the West Return Air Raise System evaluated the performance of the three original raises, WRAR#1, BER, and BR.

The primary exhaust raise, WRAR#1, surface fan infrastructure was upgraded by the addition of smooth reducers, which permitted an increase in exhaust air flow from 99 to 170 m^3/s (210,000 to 360,000 cfm), while maintaining the same operating costs (De Souza 1997, Gotz & De Souza 1999).

The Backfill Exhaust Raise, BER was originally used exclusively to exhaust 99 m^3/s (210,000 cfm) but during the upgrade was converted to a dedicated backfill raise. The BER surface fan infrastructure was very inefficient. The BER surface fans were high-pressure fans, but because the raise had very low resistance, the fans operated at a very low efficiency of 57%. Also, an economic evaluation of alternatives revealed that replacement of this surface fan assemblage with high flow fans would not economically achieve the required increase in exhaust flow volume. This raise was therefore a primary candidate for conversion to a dedicated backfill pass.

The original Backfill Raise, BR, used to exhaust 38 m^3/s (80,000 cfm) when not being used for backfilling. The 1.37 m (54") diameter underground booster fan installation was very inefficient. The fan was mounted to a bulkhead with a small inlet bell but did not have an exhaust cone connected to it. Most of the fan pressure was being consumed by entrance and exit losses. During the upgrade, the underground booster fan assemblage was removed and the raise was converted to a dedicated ventilation exhaust raise, designated as WRAR#2, to exhaust 170 m^3/s (360,000 cfm). A new surface fan infrastructure was designed and installed, as described in the following section.

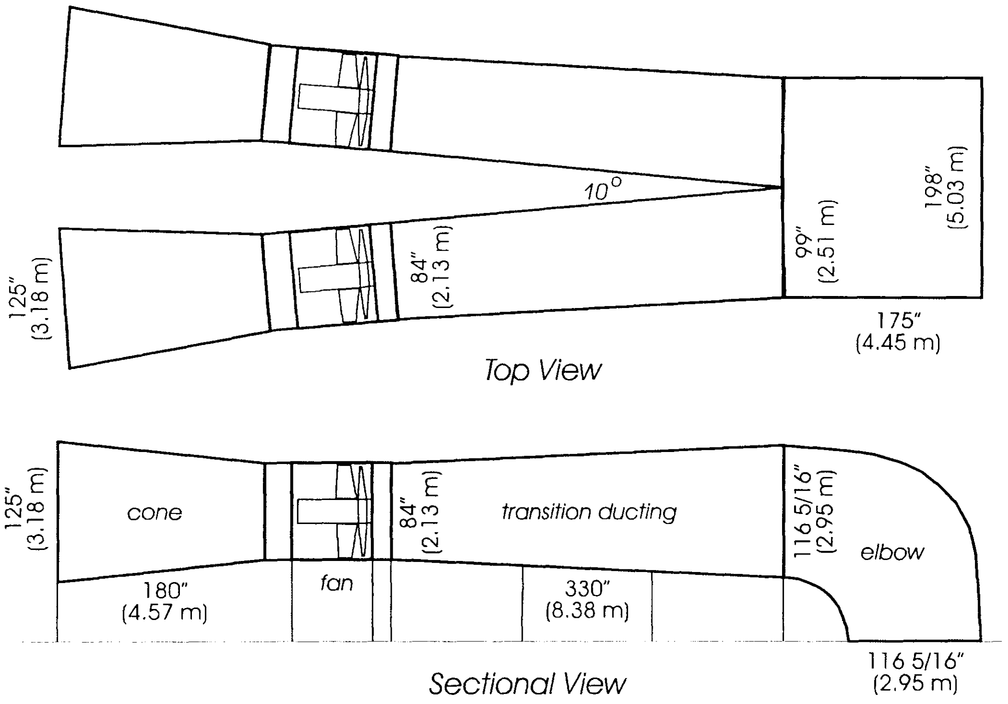
The primary motivation for switching roles for the two raises was that the BR had been used to dump approximately 8 million tonnes of broken rock for use as backfill underground. For this reason it was known that the BR had a much larger size than its original dimensions and much smoother walls. The BR was believed to be larger than the BER, therefore switching the backfill raises would allow more air to be exhausted economically.

3. WRAR#2 FAN INFRASTRUCTURE DESIGN

The WRAR#2 exhaust system was designed to maximize the exhaust airflow as much as possible in order to reduce demand on the rest of the mine exhaust system, primarily on the ERAR system. It was designed for air flow rates ranging between 179 m^3/s (380,000 cfm) and 198 m^3/s (420,000 cfm).

The primary obstacle to appropriately sizing the fans was the determination of the raise resistance. Because the actual dimensions and roughness of the WRAR#2 raise were not accurately known, resistance calculations were based on best and worst case scenarios. The system resistance was initially estimated to range between 0.019 and 0.059 $N.s^2/m^8$ (0.168 and 0.523 x 10^{-10} $lb.min^2/ft^8$). This corresponded to a system resistance pressure ranging between 740 Pa (2.97" w.g.) and 1877 Pa (7.55" w.g.) at the design flow ranges. Because of the uncertainty of the raise resistance, the design was based on a resistance of 0.034 $N.s^2/m^8$ (0.309 x 10^{-10} $lb.min^2/ft^8$), estimated based on a survey performed on one section of the raise. The corresponding system resistance pressure was 1231 Pa (4.94" w.g.) at 189 m^3/s (400,000 cfm). Because of the uncertainty in system resistance, care was taken to appropriately perform fan selection. The selected fan had to have excess pressure capacity to ensure that it could exhaust the minimum required air flow if the raise resistance was higher than estimated. At the same time selection considered the fact that unduly oversizing the fan would increase capital expenditure as well operating costs due to lower fan efficiencies.

The assessment of surface fan requirements for the WRAR#2 is presented in this section (De Souza 1999a). The proposed fan infrastructure is shown in Figure 2. The assessment takes into account the contribution of each component comprising the design: bend, split, transition ducting, diffuser and accessories to system resistance.



Top View

Sectional View

Figure 2. WRAR#2 surface fan infrastructure design

3.1 Bend

The 90 degree bend, Figure 2, is a rectangular bend of 502.92 cm x 295.434 cm (198" x 116 5/16") section. The bend radius, taken at mid-distance, is 295.434 cm (116 5/16").

The air velocity at the bend is 12.72 m/s (2,501.1 ft/min) and the air velocity head is 97.19 Pa (0.39" w.g.). Because of the large size of the bend and relatively small air velocities, splitter vanes were not used. In order to estimate shock losses at the bend, the following bend parameters are defined. The bend radius ratio, r, defined as the ratio between the bend radius, taken at mid-distance, R, and the bend height, A, is 1. The bend aspect ratio, a, defined as the ratio between the bend width, B, and the bend height, A, is 1.7. The shock factor for the bend, given as a loss in per cent of velocity pressure, is a function of the radius and aspect ratio. It is estimated from tables (De Souza, 1999b) as 0.21.Thus, the expected bend losses are, 20.41 Pa (0.0819" w.g.). Such relatively small value of bend loss indicates the appropriateness of the bend design.

3.2. Split

The ducting branching had a split angle of 10 degrees. The air velocity into and out of the split is 12.72 m/s (2501.1 ft/min) and the air velocity head is 97.19 Pa (0.39" w.g.). For low split angles, the shock factor is 0.05 (De Souza, 1999b) and the split losses are thus estimated as 4.86 Pa (0.02" w.g.).

3.3 Transition Ducting

The transition ducting (tapered duct) from the split to the fan has a rectangular intake, 251.46 cm by 295.434 cm (99" x 116 5/16") in size, and a circular outlet, 213.36 cm (84") in diameter. The length of the transition ducting is 8.382 m (330") and the taper angle is 2.8 degrees. The air velocity at the inlet is 12.72 m/s (2,501.1 ft/min) and the air velocity head is 97.19 Pa (0.39" w.g.). At the outlet, the air velocity is 25.44 m/s (5,196.9 ft/min) and the air velocity head is 418.46 Pa (1.68" w.g.). The shock loss factor due to gradual contraction is a function of the taper angle, and is estimated from tables (De Souza, 1999b) as 0.05. The pressure loss is due to gradual contraction is thus estimated as 337.38 Pa (1.355" w.g.). The friction head loss is estimated as 12.45 Pa (0.05" w.g.), based on an friction factor of 2.783 x 10^{-3} N.s^2/m^4(15 x 10^{-10} lb.min^2/ft^4). Thus, the transition ducting losses are estimated as 349.83 Pa (1.4" w.g.).

3.4 Diffuser

The diffuser has an intake diameter of 213.36 cm (84"), an outlet diameter of 317.5 cm (125") and is 4.572 m (180") long. The cone angle of divergence is 6.5 degrees. The air velocity at the cone inlet is 25.44 m/s (5,196.9 ft/min) and the air velocity head is 418.46 Pa (1.68" w.g.). At the cone outlet, the air velocity is 11.94 m/s (2,346.84 ft/min) and the air velocity head is 85.58 Pa (0.343" w.g.). The cone effectiveness value, η, is estimated from empirical diffuser curves (Jorgensen 1983) as 0.64. The cone regain is thus 213.21 Pa (0.856" w.g.), and the overall pressure loss in the diffuser is 205.24 Pa (0.824" w.g.).

3.5 Accessories

A pressure loss of 124.54 Pa (0.5" w.g.) associated with all accessories (dampers, joints, screens, etc.) was considered.

3.6 Overall System Losses and Fan Sizing

From the above calculations, the overall losses, which gives an indication of fan total pressure requirements, are estimated as 1935.88 Pa (7.8" w.g.). Based on system calculations, for a design flow of 94.5 m^3/s (200,000 cfm), 2.13 m (84") diameter axial flow fans were selected. Also, based on estimated power requirements of 244 kW (328 HP), 261 kW (350 HP) variable frequency motors were selected.

The fan curves, at a blade setting of 15 degrees, for different motor frequencies, are shown in Figure 3. The fans have a maximum exhaust capacity, at a motor frequency of 60 Hz, of 198 m^3/s (420,000 cfm) at a total pressure of 1.66 kPa (6.8" w.g.). The corresponding break power is 418 kW (560 HP), and the total efficiency is 78%.

4. DESIGN VERIFICATION

Figure 4 shows the WRAR#2 surface fans. When installed, the fans were running at 52 Hz. The corresponding operating point was 170 m^3/s (360,000 cfm) at a total pressure of 1.24 kPa (5.1" w.g.). The corresponding break power was 269 kW (360 HP), and the total efficiency is 78%. This matched exactly with the fan curve (Figure 3) and with the design calculations. The fans were operating at high efficiencies and cost analysis has indicated that the fans were near optimum operating levels.

The WRAR#2 upgrade increased the flow rate of the original backfill raises by 24%, from 137 m^3/s (290,000 cfm) to170 m^3/s (360,000 cfm), while only increasing the operating costs by 9%. The expected increase in operating cost, for a 24% increase in flow rate, would be 91%.

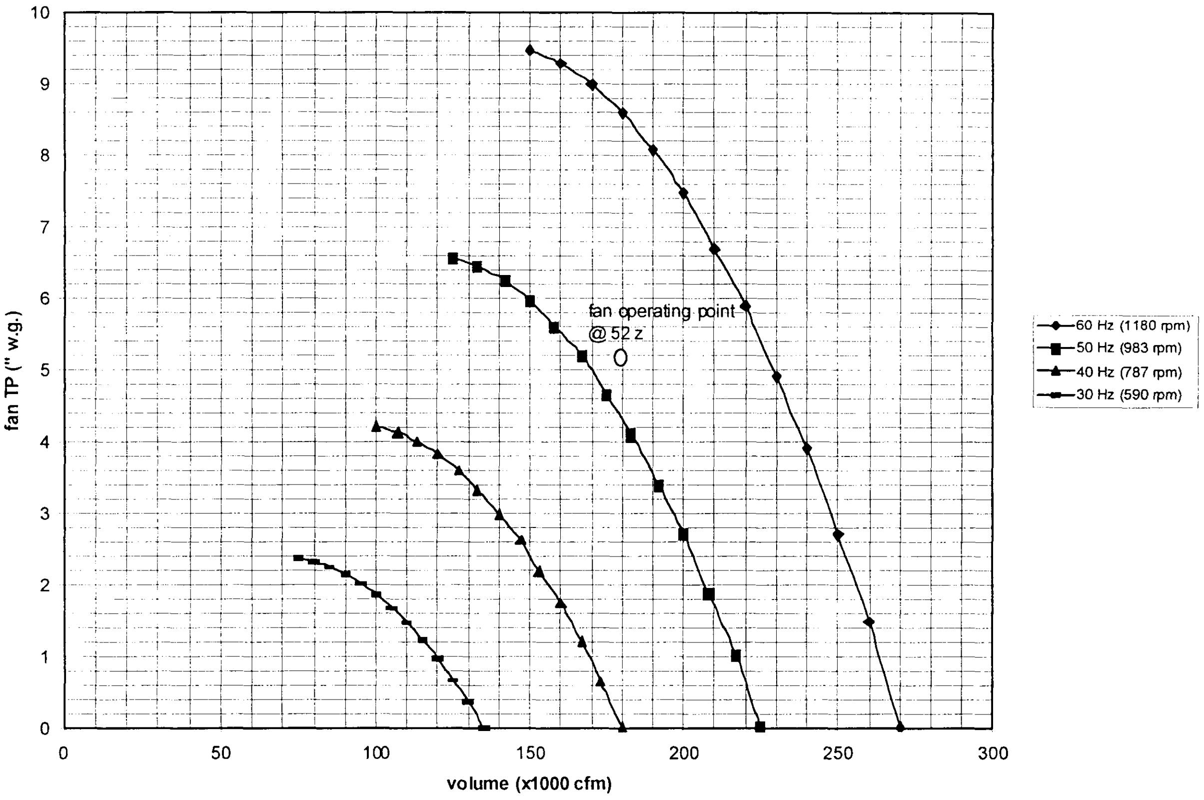


Figure 3. WRAR#2 fan curves at different frequencies (15 degrees blade setting)

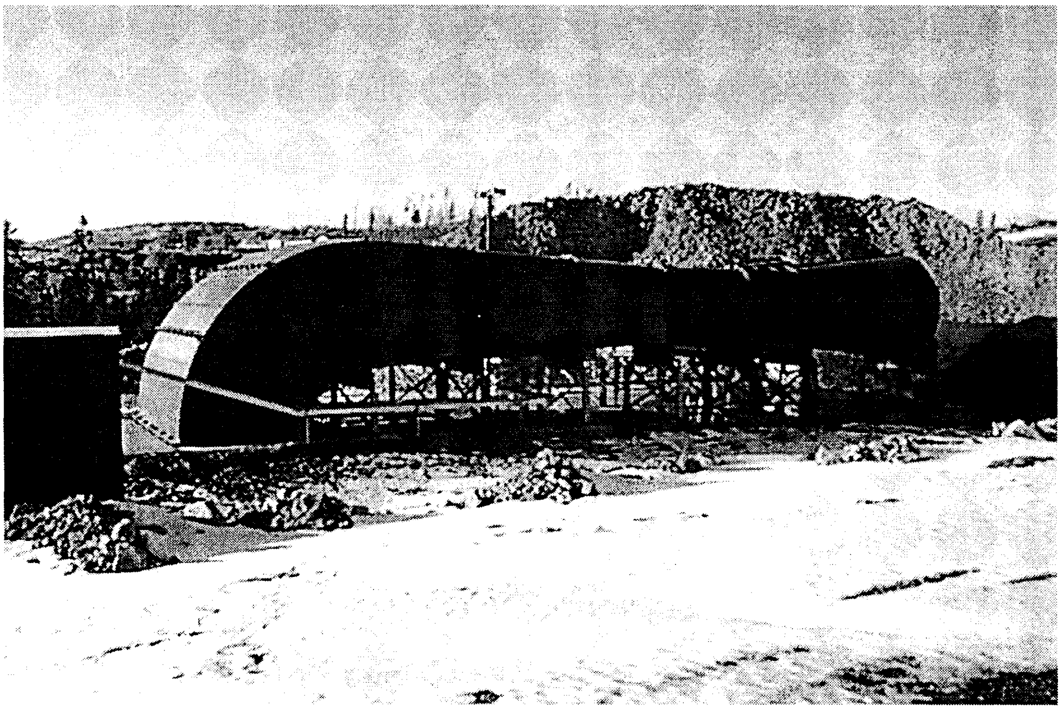


Figure 4. WRAR#2 surface fans

5. CONCLUSIONS

A comprehensive optimization program of the Golden Giant Mine ventilation system has been undertaken as part of the company's planned energy management scheme. A number of surface and underground installations comprising the mine's complex exhaust system have been upgraded over a phased study in order to increase its exhaust capacity, necessary to match the total intake mine flow rate. This planned study established a balanced mine ventilation system, optimized its performance and minimized its operating costs.

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