VENTILATION MISTAKES AND CONSEQUENCES - REAL LIFE EXPERIENCES

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ABSTRACT

The uninterrupted operation of a ventilation system is critical to ensure the mine meets its scheduled production and, as important, is vital to the health and safety of all personnel working underground. Those operating the mine ventilation system must have fundamental engineering training in the art of fluid dynamics and have a good comprehension and control of the mine ventilation network. Ventilation management by untrained and inexperienced personnel may result in serious consequences when the system becomes ineffective. This paper shares observations and experiences pertinent to the occurrence of upset conditions as a result of the improper design and operation of mine ventilation systems. A series of real life case studies are presented to describe disruptions to mine ventilation systems and the gradual deterioration of system operational efficiencies leading to eventual failure. Special focus is given to mistakes made and on the resulting serious consequences. The case studies also demonstrate how each upset condition was resolved, permitting the mines to safely resume production activities.

KEYWORDS

Ventilation design, Ventilation management, Ventilation practice

INTRODUCTION

The ventilation of operating mines is a continuously changing and evolving system; upset conditions will occasionally occur but should be promptly resolved in order for the system to function properly, according to design and in compliance. Those designing, managing, or operating the mine ventilation system must have pertinent training and have a good understanding of fundamental ventilation concepts to be able to devise and implement engineering solutions to day-to-day challenges. Realistically, the operator must also have extensive practical experience and be able to effectively apply operating procedures, design criteria and ‘best practices’. They must be able to, on a daily basis, evaluate the mine ventilation system, determine and locate any problems, understand the causes of each problem, find a solution, and promptly and efficiently correct those problems.

Ten case studies are presented to demonstrate how fundamental design or operational mistakes can lead to adverse conditions or to catastrophic consequences, how detailed on-site engineering assessments can be employed, and how simple, low cost, engineering solutions can be implemented to successfully resolve the issues and return the ventilation system to compliance, permitting the mines to safely resume production activities.

CASE STUDY 1 - MAIN FAN ASSEMBLAGE DESIGN FLAW

A return air raise, serviced by two surface fans, was designed to exhaust 190 m^3/s. The 2.13 m diameter fans were installed in two parallel stacks and designed to operate at a flow of 95 m^3/s and 2.5 kPa total pressure. The fan assemblage design (Figure 1) called for the fans to be installed horizontally following a 90 degree elbow, 3 m × 2.5 m in section. The elbow was to be connected to the 2.13 m diameter fans via two converging transition sections with a wall angle of approximately 6 degrees. The design fan outlet cone was 3.17 m in diameter and 4.6 m in length.

During normal operation of the system, in several occasions, fan blade failures would unexpectedly occur. Vibrational energy (pinging sound noticed by operators) seemed to have initiated the mechanical failure of the fans, this being normally associated with the formation of a fan stall condition.

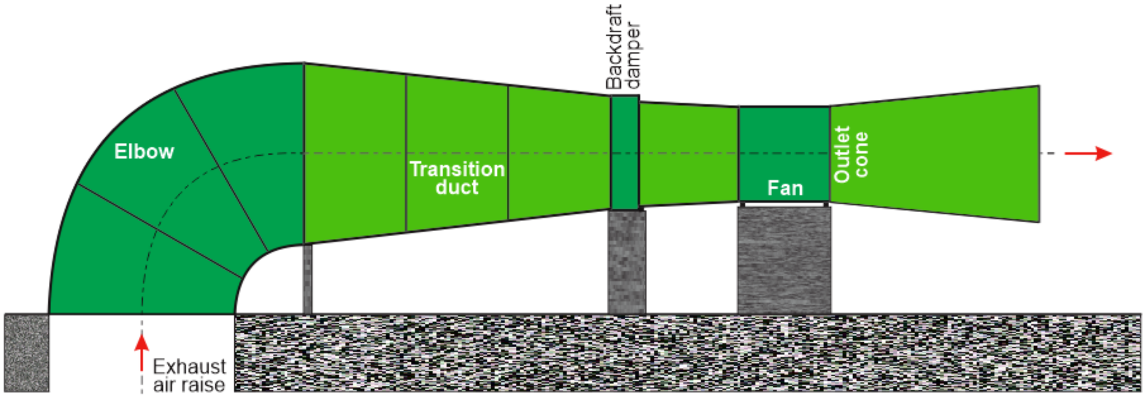

Figure 1. Case Study 1: Original fan assemblage design

A detailed inspection indicated that the manufacturer did not follow the original assemblage design. The fans were connected to the elbow via two 2.13 m diameter, 6 m long, straight ducts (Figure 2). The connection to the elbow formed sudden contractions to the two stacks instead of the original gradual contraction design. This increased the shock loss resistance pressure by 37%. In additional, a much smaller cone (2.35 m diameter, 1.5 m long) was installed, increasing the cone losses by 82%. The two installation 'short-cuts' resulted in a fan total pressure of 2.8 kPa instead for the designed 2.5 kPa. This increase in resistance pressure brought the fan operation outside its normal operating range, causing a stall condition to occur. Also, the fans were drawing high amperages, with an input power of 396 kW, much higher than the original motor design size of 336 kW. All the fan operating parameters described above were verified following detailed pressure surveys.

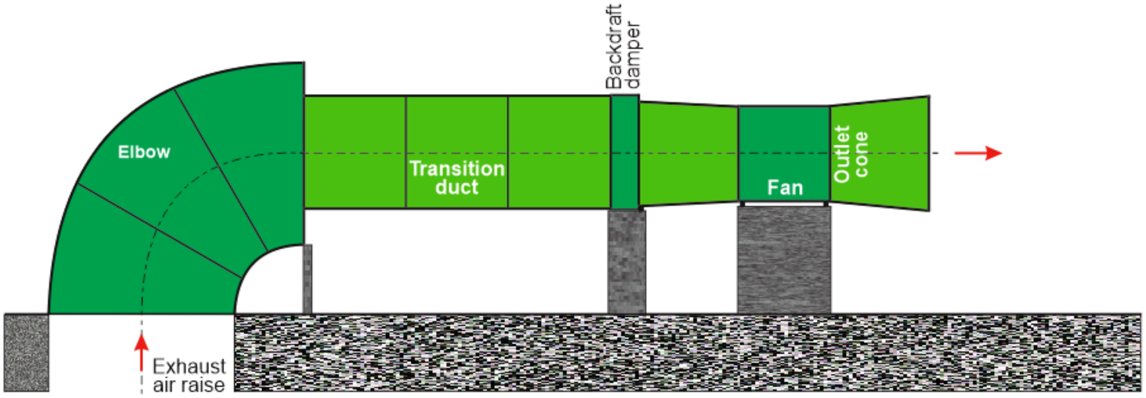

Figure 2. Case Study 1: As-built fan assemblage

Changes to the fan assemblage were proposed to conform to his original design. The fan cones were to be replaced by the larger designed cones and the straight ducts were to be replaced by originally designed converging transition sections. Following the changeover, the fans performed according to the original expectations, with no further operational issues.

CASE STUDY 2 - BOOSTER FAN INTAKE IMBALANCE

Unanticipated failure of a main booster fan resulted in the disruption of mining operations, affecting production targets and operating costs in a hard rock mine. An investigation of the booster fan failure was conducted to assess the causes in view of providing guidelines to the mine to prevent future failure occurrences. Two factors were found to contribute to the fan failure. The primary cause was associated with cyclical bending due to an imbalance in fan inlet flow. During the site inspection, it was observed that personnel had been storing surplus materials in close proximity to the fan inlet, creating an uneven flow distribution entering the fan inlet bell. Variations in air velocity across the fan inlet area led to a gradual fatigue failure of the fan blades due to cycles of stress loading and unloading of the blades. In addition, a severely reduced inlet area was noted due to build up of debris. This markedly increased the system resistance bringing the fan operating point to a higher pressure closer to stall.

Barriers were installed to prevent personnel from storing material in the fan drift and appropriate signage placed at the fan station. A fan monitoring program and inspection procedures were implemented to evaluate fan performance and to alert the onset of gradual failure.

CASE STUDY 3 - BOOSTER FAN OUTLET CONCERN

While conducting a ventilation energy audit for a hard rock mine, it was observed that an underground booster fan installed in a bulkhead, while operating adequately and supplying the required flow of 73 m^3/s, was drawing considerable amperage and consuming excess energy. The fan diameter was 1.68 m and the hub diameter was 0.66 m. The fan had a 112 kW motor running at 1,200 rpm. The assessment found that while the booster fan was properly fitted with an inlet bell and screen, it did not have an outlet cone installed in it.

It was proposed to install a 2.18 m outlet diameter, 3.34 m long cone in the fan to save on operating costs while maintaining the same flow. Pressure and flow surveys were conducted after the cone installation and change in blade setting. The fan velocity pressure, including loss, was reduced to 0.37 kPa from 0.93 kPa (no cone). The fan total pressure, including assemblage shock losses, was reduced to 0.52 kPa from 1.12 Pa and the brake power flow was reduced to 82 kW from 139 kW for the same supply flow.

The fan operating points before and after the cone installation are shown in Figure 3. Fan operating cost savings approximating 41% were incurred, and a payback period of 8 months was determined. Following the confirmed savings, cones were installed in all other booster fan installations in the mine. This case demonstrates how a simple corrective action of a common poor practice can reduce power consumption and lower operating costs.

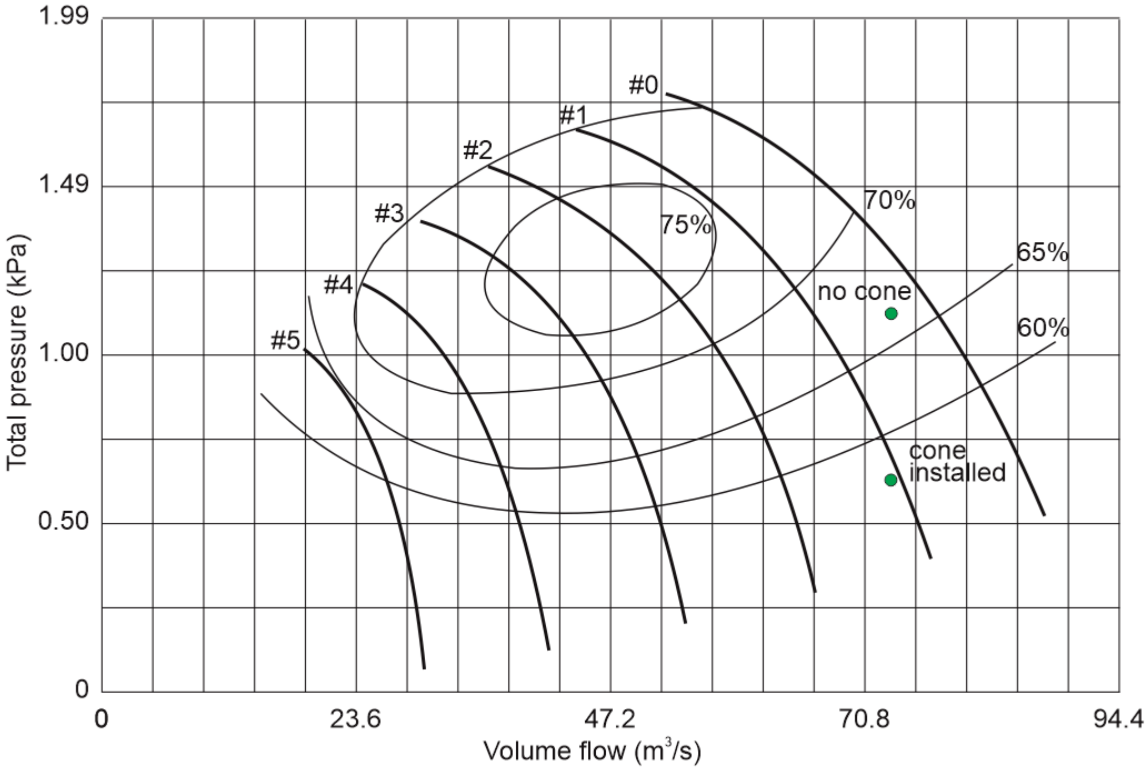

Figure 3. Case Study 3: Fan operating points

CASE STUDY 4 - BOOSTER FAN ADVERSE EFFECTS

An investigation was conducted in a hard rock mine due to an incident associated with worker exposure after level re-entry following a scheduled blast. The production level (1220 m level) was ventilated with 18.3 m^3/s and based on the available flow, a safe re-entry time of 30 minutes was being practiced by the mine. Upon entering the level via an access ramp, workers were exposed to toxic gases.

The investigation revealed that at the time of the blast, the level was being ventilated by only 5.1 m^3/s and not by the expected flow of 18.3 m^3/s, thus compromising ventilation quality and safety. A detailed assessment found that workers in a lower level (1270 m level) had changed the variable frequency drive (VFD) setting of a booster fan operating in that level. The fan had been installed to improve ventilation in the 1270 m level, which offered a higher resistance. Initially, the 1270 m level was being ventilated with 23.6 m^3/s with the booster fan set at a lower rpm (Figure 4a). The change to the booster fan VFD setting increased the airflow to 40 m^3/s (Figure 4b). The booster fan pressure increased from 0.13 kPa to 1.03 kPa. This resulted in a loss of pressure and reduction in airflow (to 5.1 m^3/s) in the 1220 m level.

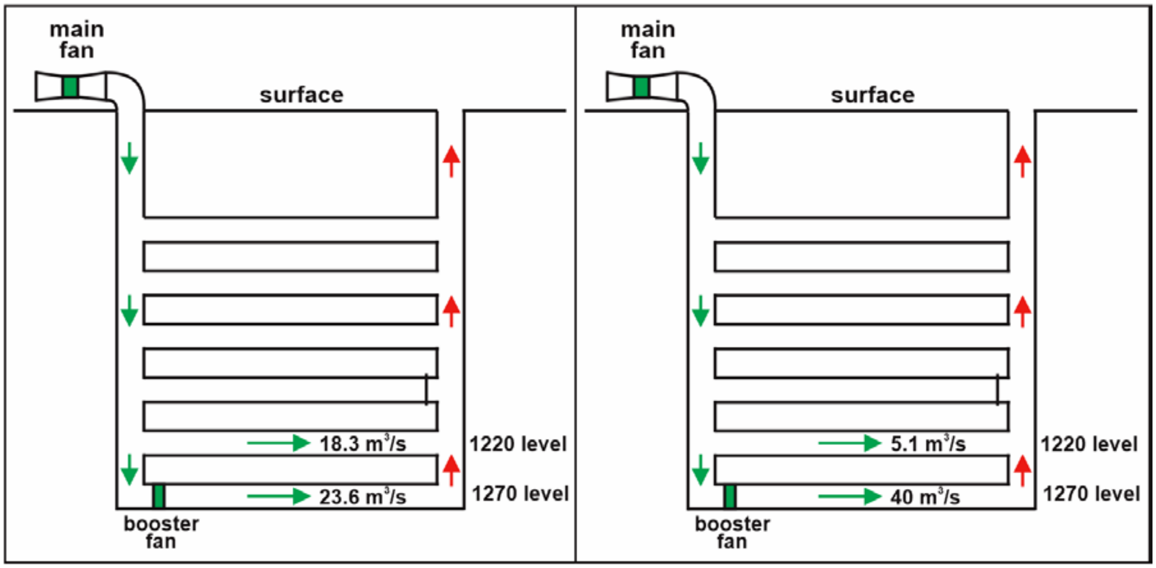

Figure 4. Case Study 4: Mine ventilation schematic showing a) design flow distribution and b) altered flow distribution

Had the workers increased the booster fan flow to 46 m^3/s, a full cessation of flow would have occurred in the 1220 m level, further compounding the issue. In this case, the booster fan would have been operating at the critical pressure (1.3 kPa), above which air recirculation between the two levels would have occurred.

The fan VFD was returned to its original setting, and the flows in the two levels were restored. The working crew received training and communication not to change the settings of any ventilation appliance, including doors, regulators, and fans installed in the mine.

CASE STUDY 5 - IMPROPER BOOSTER FAN SITING

A bulkheaded booster fan system consisting of two fans in parallel was designed to transfer air from a main airway to a production area via an access drift driven perpendicular to the main airway. The booster fan system was installed in very close proximity to the intersection between the drifts (Figure 5a). This created a ‘starving’ condition on the outer booster fan. The improper siting of the booster fans created a lower flow volume feed and an uneven airflow volume loading of the blades on the outer fan. This could have led to fatigue failure associated with stress loading and unloading cycles of the fan blades. To correct the situation, the booster fans were relocated farther down the drift where air streamlines formed a full flow condition across the airway section such that both fans were equally loaded (Figure 5b). The aerodynamic conditions at the inlet and outlet of the fans were now balanced, and all blades were evenly loaded across the fan inlet area.

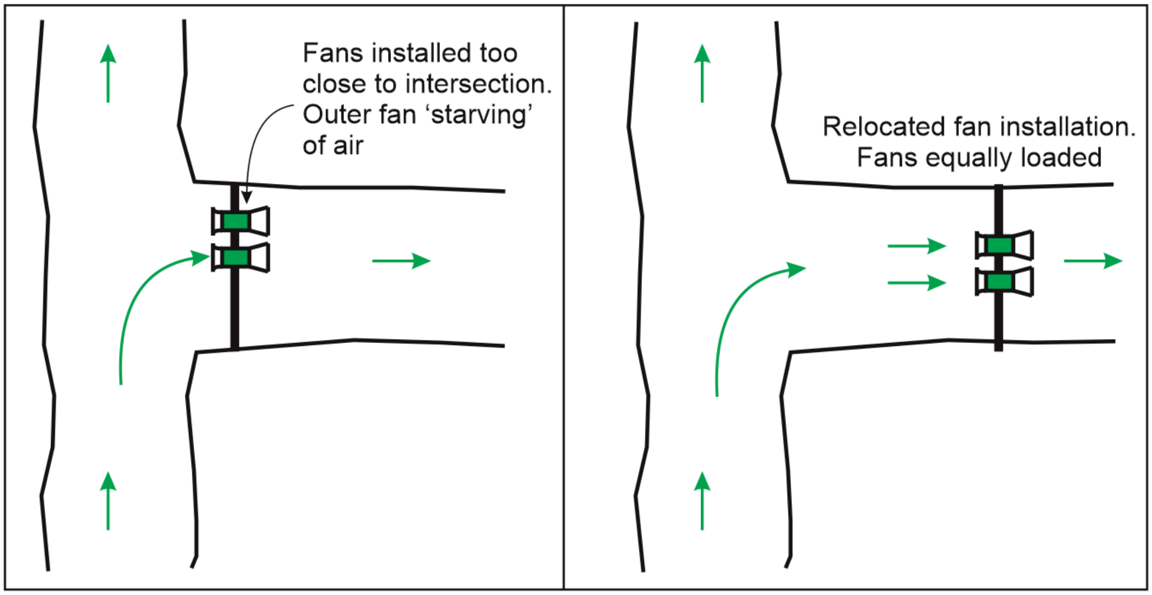

Figure 5. Case Study 5: a) Initial and b) relocated booster fan system siting

CASE STUDY 6 - SHOTCRETING PRACTICES

This case study describes an investigation of a booster fan failure occurrence during shotcreting of a new ventilation bulkhead installation. The booster fan located downstream from the bulkhead being built was drawing a large volume of air, passing through the bulkhead construction site, and delivering the air to a production area. Shotcrete spray overshooting carried by the high air velocity in the fan drift impacted the fan blades and created an imbalance on the fan resulting in an instantaneous catastrophic failure.

Two control factors were found critical to avoid fan failure occurrences during shotcreting: control at the source by using the correct application techniques and ventilation control by preventing rebound from becoming airborne. Reducing the rebound during the shotcrete spraying process represents a very complex challenge. Several factors influence the rebound quantity, including:

- Using the right spraying equipment
- Operator technical skill and experience
- Using the correct application technique including the spraying direction
- Shotcrete formulation
- Substrate condition

Use of advanced technology components of mechanized shotcrete equipment will ensure greater projection precision, therefore reducing the rebound rate.

The most important factor to avoid rebound will always be the operator because an incorrect application can cause greater loss of shotcrete material. Proper application techniques include:

- Correct distance between the nozzle and the surface
- Application angle in which the nozzle must be kept at a 90° angle to the surface
- Maintaining a homogeneous layer by applying the shotcrete in slow circular movements
- Controlling the speed of projection

The fan speed should have been reduced to prevent rebound from becoming airborne and from being carried towards fan. When shotcreting in proximity to underground fans, either the ventilation flow should be reduced or the fan protected (stopped, if possible) to prevent damage to the fan(s). In this particular case, a new fan had to be installed since the booster fan was damaged beyond repair.

CASE STUDY 7 - PRODUCTION LEVEL MATERIAL HANDLING

Ore handling in the main production levels of a hard rock mine was generating dust levels in excess of company guidelines. An inspection of the operation indicated that, although sufficient airflow was being provided for diluting and removing mineral dust from the level, a number of planning and operational inefficiencies amplified the generation and propagation of harmful mineral dust underground. Some effective dust suppression techniques were being employed underground, including the use of water trucks to suppress dust in the haulage drifts and water sprays for wetting down the blasted rock prior to mucking of material. Wetting down the area surrounding the blast before a blast, which further helps to prevent dust from previous operations from becoming airborne, was not practiced.

During stope development, blasted rock was being loaded into trucks on the level at the cross-cut. In-level truck loading and truck haulage was a major contributor to dust contamination. Loading trucks off the level in the access ramp was suggested to improve air quality in the level.

Dust control in the orepass was ineffective since its escape and dispersion during dumping was not being well managed. Confinement was not effective since the orepass doors were not airtight and spray bars were not being used at the dump entry. Adding water sprays at the tipping sites and providing exhaust ventilation within the orepass, such that the dump entry is maintained under suction ventilation, were recommended. In addition, the orepass was located upstream from the stopes; the airstream ventilating the stopes was being contaminated during ore dumping. Ideally, orepasses should be located downstream from the stopes such that contaminated air would be directed directly to exhaust raises. It was also recommended that, when appropriate, blasting off-shift should be practised to reduce dust exposure.

CASE STUDY 8 - INSUFFICIENT AIRFLOW CONDITIONS

A new fresh air raise 4.3 m in diameter and 900 m long was driven and 1.943 m diameter surface fans—installed in parallel configuration—were commissioned to supply a flow of 165 m^3/s underground. When the system was commissioned, the mine noted the flow supply underground was only 145 m^3/s, below the original required design flow of 165 m^3/s based on requirements for its diesel fleet (Figure 6a). This restricted the operation of production equipment underground and affected planned production targets. The mine suspected leakage issues but could not identify any sources.

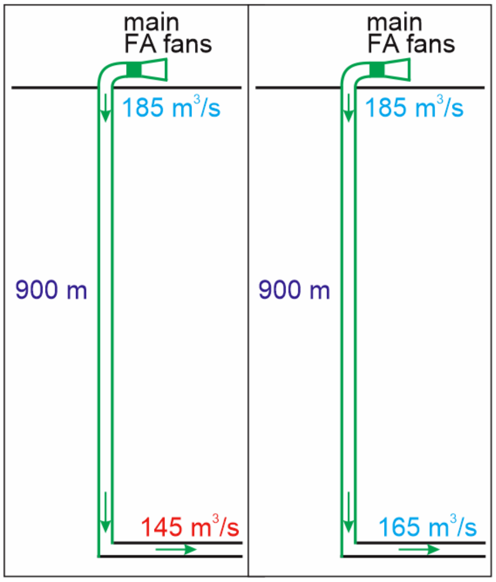

Figure 6. Case Study 8: The effect of autocompression on raise flow distribution in a) incorrect design and b) correct design

An inspection indicated that the designer made a fundamental error in design: they failed to incorporate the effect of autocompression when determining the fan flow. The surface fans were sized to supply a flow of 165 m^3/s when they should have been sized for a flow of 185 m^3/s (Figure 6b). The fan total pressure was incorrectly determined (2.5 kPa versus required 2.8 kPa) and the motors were undersized (260 kW versus required 335 kW). Unfortunately, the new fans did not have the capacity to supply the required flow of 185 m^3/s at a total pressure of 2.8 kPa. Also, the installed motors were hugely undersized by 75 kW each. In this case, a new source of fresh air had to be procured to make up the additional required flow of 20 m^3/s underground.

CASE STUDY 9 - RESISTANCE PRESSURE AND FAN STALL

An operating mine uses a push system with 2.13 m diameter primary surface fans operating in a parallel configuration installed on a dedicated fresh air raise. The fans had 186 kW motors. Based on the operating diesel fleet, overall underground flow requirements were estimated at 113 m^3/s.

The mine had four active levels and nine mined out levels. The surface fans were delivering 172 m^3/s and, with a leakage of 33% at raise connections to the 9 inactive levels, the flow reaching the active mining area was 115 m^3/s, slightly above the minimum flow requirements (Figure 7a). The fans were operating at a total pressure of 1.59 kPa, and the brake power was 152 kW (Figure 8, point A). The raise resistance pressure was 1.34 kPa.

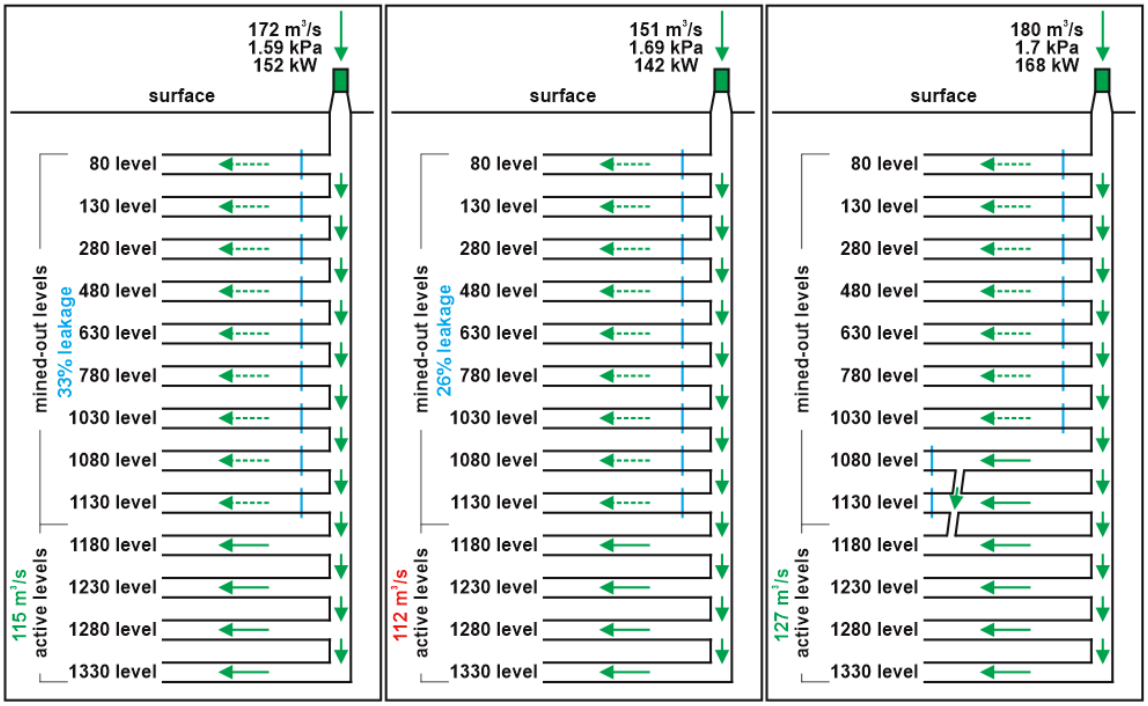

Figure 7. Case Study 9: Ventilation system schematic a) under original conditions, b) after leakage control and c) under final conditions

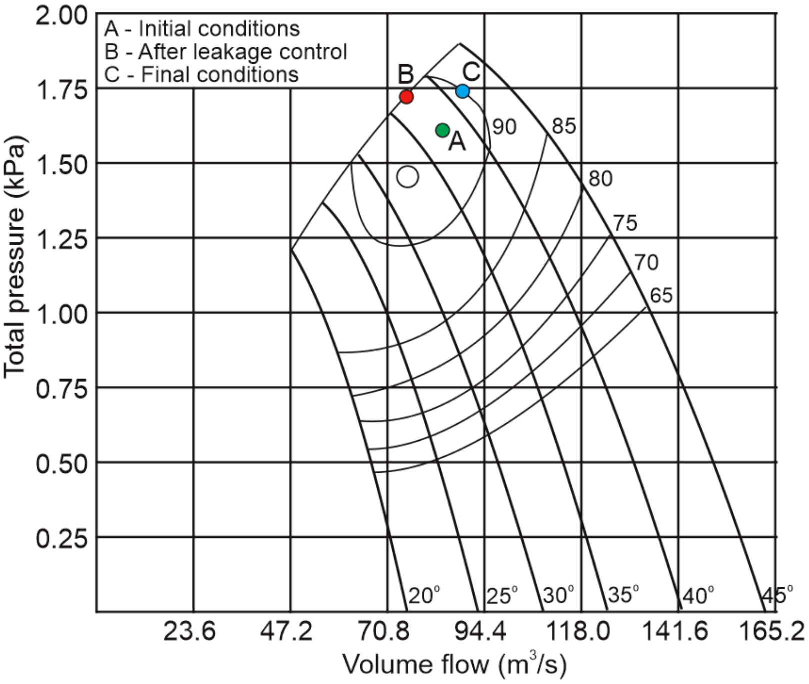

Figure 8. Case Study 9: Fan operating conditions

In order to increase the airflow volume in the active levels, the mine worked at reducing leakage by approximately 7% by sealing off and shotcreting all bulkheaded raise connections to the nine inactive levels. During completion of the remedial work, a survey conducted by the mine indicated that the flow in the active levels had actually reduced to 112 m^3/s, slightly below the minimum flow requirements (Figure 7b). Mine personnel were perplexed and could not understand the cause for the reduction in fan flow.

In an engineering assessment, it was noted that by sealing of the raise connections, the raise resistance pressure was increased to 1.44 kPa. In effect, the fan operating point was changed to 151 m^3/s at 1.69 kPa. The fan was operating very high on the curve at the outset of stall (Figure 8, point B). Sealing off the raise connection did not change the raise resistance but increased the resistance pressure, compromising the mine operation. The mine was advised that, prior to reducing leakage in airways or ventilation ducts, they must carefully investigate the effect of the associated increase in resistance pressure on the linked fans.

To correct the situation, two actions were taken. The raise resistance pressure was first decreased by transferring air to the active levels via mined out levels and old ore passes (Figure 7c). The fans blade setting were then changed—within the constraints of the motor size—and the flow reaching the lower active levels were increased to the point where normal mining activities could be resumed (Figure 8, point C).

CASE STUDY 10 - EXHAUST BOOSTER FAN CRITICAL AIR VELOCITY

A 610 m long Alimak ventilation raise served by a 1.37 m diameter underground booster fan installed in a bulkhead was commissioned for exhausting spent air directly to the surface. The axial flow fan has a 0.69 m hub diameter and is fitted with a 186 kW motor running at 1780 rpm. The blade setting is 17 degrees. The fan is fitted with and inlet bell and screen but with no outlet cone.

Repeated failure of the booster fan roughly every 6 months prompted an investigation of the conditions leading to fan stall since the frequent unavailability of the raise became unacceptable from an operational point of view, preventing the mine from meeting its production schedule. An assessment made by the mine indicated that when in normal operation, the fan did not show any signs of structural instability. Assessment of all fan components did not show any issues in terms of damage to flange, bell, casing, and hub; shaft misalignment; blade fatigue; blade pitting; individual fan blade setting; blade tip-to-casing clearance; motor condition; and power source stability. Inspection of the raise did not find any structural issues (sloughing, wall convergence, etc.) that would have increased the resistance of the raise.

A ventilation survey at the fan station indicated a stable fan operation, falling within its design operating point of 37.8 m^3/s at 2.1 kPa total pressure. The fan efficiency was 75%, and the brake power was 104 kW. Figure 9 point A shows the fan curve and initial operating point. However, the air velocity in the raise was estimated at 8.3 m/s, and it was thus contemplated that water blanketing could be affecting the fan performance since the air velocity for water blanketing to become critical is approximately 8 m/s.

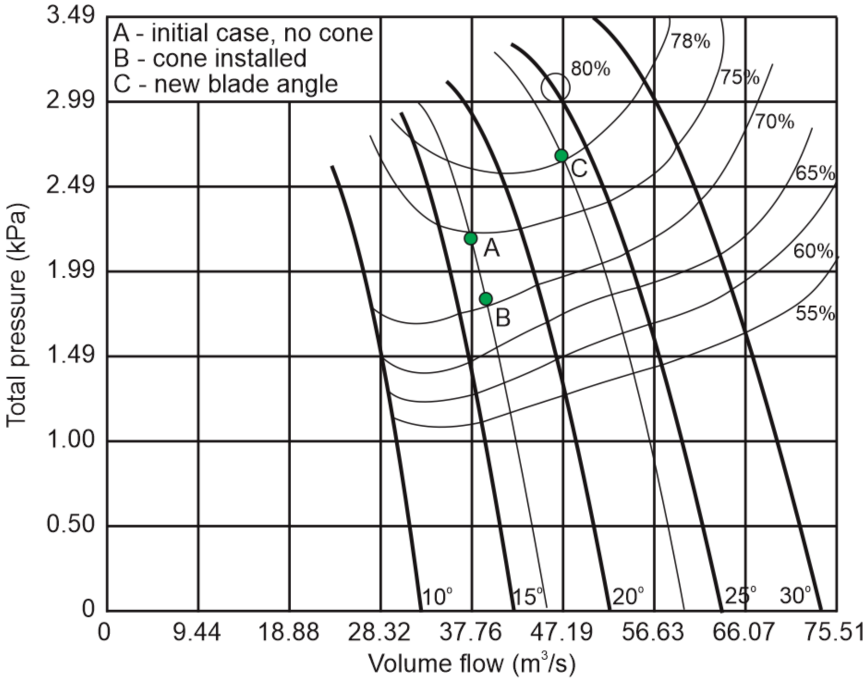

Figure 9. Case Study 10: Exhaust booster fan curve and operating points

Psychrometric surveys indicated the air entering the raise was under full saturation conditions. When the spent saturated air was transferred by the fan and rose in the raise, water was being condensed out of the air. The droplets formed stayed suspended in the air within the raise, gradually increasing the resistance pressure. It seems that it was taking approximately 6 months for the water blanketing associated resistance to increase to the point of fan stall.

A two-step control solution was proposed and implemented. The first step included a low-cost retrofit of simply installing an efficient, 1.24 m long cone with an 1.83 m outlet diameter. The fan flow increased to 39.2 m^3/s, and the fan total pressure dropped to 1.84 kPa. Even though the fan operating point was now much lower on the fan curve (Figure 9, point B), the air velocity within the raise (8.6 m/s) was still within the critical air velocity range.

In the second step, the fan blade angle was adjusted to 23 degrees and operate at a flow of 47 m^3/s (Figure 9, point C), bringing the raise air velocity to 10.4 m/s, outside the critical velocity range. The fan total pressure was now 2.68 kPa, the efficiency increased to 78%, and the brake power at 162 kW. With these simple, low-cost, procedural remedial actions the raise exhaust capacity was increased and the fan continued to operate without any further issues, thus permitting the mine to safely resume production activities.

CONCLUSIONS

Ten case studies demonstrate the consequences of fundamental mistakes in design or operation of mine ventilation systems. Through an iterative management program, consisting of an audit, a verification, and development of corrective action procedures, the author has efficiently and consistently corrected mine ventilation systems when upset conditions are reported. This paper also demonstrates how detailed on-site engineering assessments, supported by extensive scientific and technical experience and by the devised management program, were effectively used to successfully restore the mine ventilation operations to conformity.

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Paper reviewed and approved for publication by the Maintenance, Engineering and Reliability Society of CIM.

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