Ventilation System and Groundwater Control in Underground Mining, An Overview

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Abstract

This paper explores underground mining. It delves into its ventilation system, and underground water control. By providing a comprehensive overview of their involvement. It aims to highlight the airflow system in underground mining, ground water and control by shedding light on the multifaceted responsibilities of geologist/miners in the extractive mineral industry underground mining. It also aims to underscore their indispensable role in ensuring the responsible and sustainable utilization of valuable mineral resources. The paper recognizes the ongoing importance of geologist in shaping the future of mineral extraction practices, enhancement, installation of devices / equipment and its usage in improving and maintaining the health of miners thereby reducing their health risk.

Keywords: *Excavation, Ore, Extraction, Airflow, Grouting, Tunneling, Airflow, Dewatering, Fans.*

1.0 INTRODUCTION

Mining is the extraction of valuable geological materials and minerals from the earth (Okeke, 2017).

Mining is required to obtain most materials that cannot be grown through agricultural processes, or feasibly created artificially in a laboratory or factory. Ores recovered by mining include metals, coal, oil-shale, gemstones, limestone; gravel etc. mining in a wider sense includes extraction of any non-renewable resources such as petroleum, natural gas or even water. Mining has been an integral part of human history since ancient times when people first began exploring below ground level looking at what they could find down there. cave ins, explosions, and extreme temperatures are some of the most perilous hazards observed in underground in underground mining .groundwater contamination due to mining is also a serious issue as mining operations intersect the water table of the mined area.

Renowned as one of the most dangerous jobs in the world - and for good reason. Cave-ins, explosions, toxic air, and extreme temperatures are some of the most perilous hazards observed to take place in underground mining.

Valuable minerals are found all over the world. And most often the only way to get to them is by mining into the earth's ground. Not an easy or riskless feat to achieve even in the simplest of locations.

Underground mining ventilation and water control, however are the most critical safety aspect in the operation of an underground mine.

2.0 VENTILATION SYSTEM IN UNDERGROUND MINING

2.1 Definition and Importance of Mine Ventilation

Underground mining is used to extract ore from below the surface of the earth safely, economically and with as little waste as possible. The entry from the surface to an underground mine may be through a horizontal or vertical tunnel, known as an adit, shaft or decline. It involves opening one or more portals or shafts into the earth that follow or intercept coal seams that are too deep for surface mining methods. Two main methods of underground mining are practiced in Pennsylvania: Room-and-Pillar: Generally used for seams that are relatively flat or gently dipping.

Mine ventilation is the process of supplying sufficient fresh air to the underground mining ventilation system and working to achieve the purpose of ensuring proper distribution, use and controlling of the air that returns to the surface as contaminated air.

Ventilation is an important consideration in underground mining. In addition to the obvious requirement of providing fresh air for those working underground, there are other demands. For example, diesel-powered equipment is important in many mining systems, and fresh air is required both for combustion and to dilute exhaust contaminants. In addition, when explosives are used to break hard rock, ventilation air carries away and dilutes the gases produced.

Special fans, controls, and openings are used to direct fresh air to the working places and spent or contaminated air out of the mine. In very cold climates incoming ventilation air must first be warmed by gas- or oil-fired heaters. On the other hand, in very deep mines, because of high rock temperatures, the air must be cooled by elaborate refrigeration systems. This makes the energy costs associated with ventilation systems very high, which in turn has created a trend toward sealing unused sections of the mine and changing from diesel to electric machines. (*Hustrulid et al., 2024).*

Underground mine ventilation provides a flow of air to the underground workers of a mine with sufficient volume to dilute and remove dust and noxious gases (typically NOx, SO2, methane, CO2 and CO) and to regulate temperature. The source of these gases are equipment that runs on diesel engines, blasting with explosives, and the ore-body itself.

The largest component of the operating cost for mine ventilation is electricity to power the ventilation fans, which may account for one third of a typical underground mine's entire electrical power cost.

2.2 Types of Mine Ventilation

There are two types of mine ventilation namely

i. Natural ventilation

Underground mine ventilation design plays a critical role in the types of mine ventilation. Natural mine ventilation is the process of supplying fresh air without using any mechanical systems. The external air moves into an enclose space because of pressure differences arising from natural forces. Natural mine ventilation distributes oxygen from fresh air which enhances pulmonary and heart function.

ii. Mechanical ventilation

Mechanical ventilation is used to supply air in areas where the miner operates, and this air is used to remove dust particles, noxious gases and regulation of temperature. Pressure difference is created by operating one or more mine ventilation fans in an airway. Each mine ventilation fan creates a certain amount of pressure, and that pressure is gradually lost as the air passes through the airway against its resistance. There are two main types of exhaust fans used in underground mine ventilation. These are the axial fan and the centrifugal fan. The axial fan looks like a propeller, and it draws air straight through the fan. The centrifugal fans look more like squirrel cages and draw air into the center of the fan and exhaust air at a perpendicular angle. Sufficient volume of air is required for proper ventilation which takes electric power to drive the fan.

2.2.1 Classification of Mechanical Ventilation

All powered machinery used to generate air flow through mine entrances or ducts are considered mechanical ventilation devices. Fans are the most important and most common of these but compressors and injectors also have application to ventilation.

Fig. 1: Classification of mechanical ventilation (Sandeep et al 2021)

1. **Centrifugal pump**

A centrifugal pump is a mechanical device designed to move a fluid by means of the transfer of rotational energy from one or more driven rotors, called impellers. Fluid enters the rapidly rotating impeller along its axis and is cast out by centrifugal force along its circumference through the impeller's vane tips. The action of the impeller increases the fluid's velocity and pressure and also directs it towards the pump outlet. The pump casing is specially designed to constrict the fluid from the pump inlet, direct it into the impeller and then slow and control the fluid before discharge.

A centrifugal pump operates through the transfer of rotational energy from one or more driven rotors, called impellers. The action of the impeller increases the fluid's velocity and pressure and directs it towards the pump outlet. With its simple design, the centrifugal pump is well understood and easy to operate and maintain. Centrifugal pump designs offer simple and low cost solutions to most low pressure, high capacity pumping applications involving low viscosity fluids such as water, solvents, chemicals and light oils. Typical applications involve water supply and circulation, irrigation, and the transfer of chemicals in petrochemical plants. Positive displacement pumps are preferred for applications involving highly viscous fluids such as thick oils and slurries, especially at high pressures, for complex feeds such as emulsions, foodstuffs or biological fluids, and when accurate dosing is required.

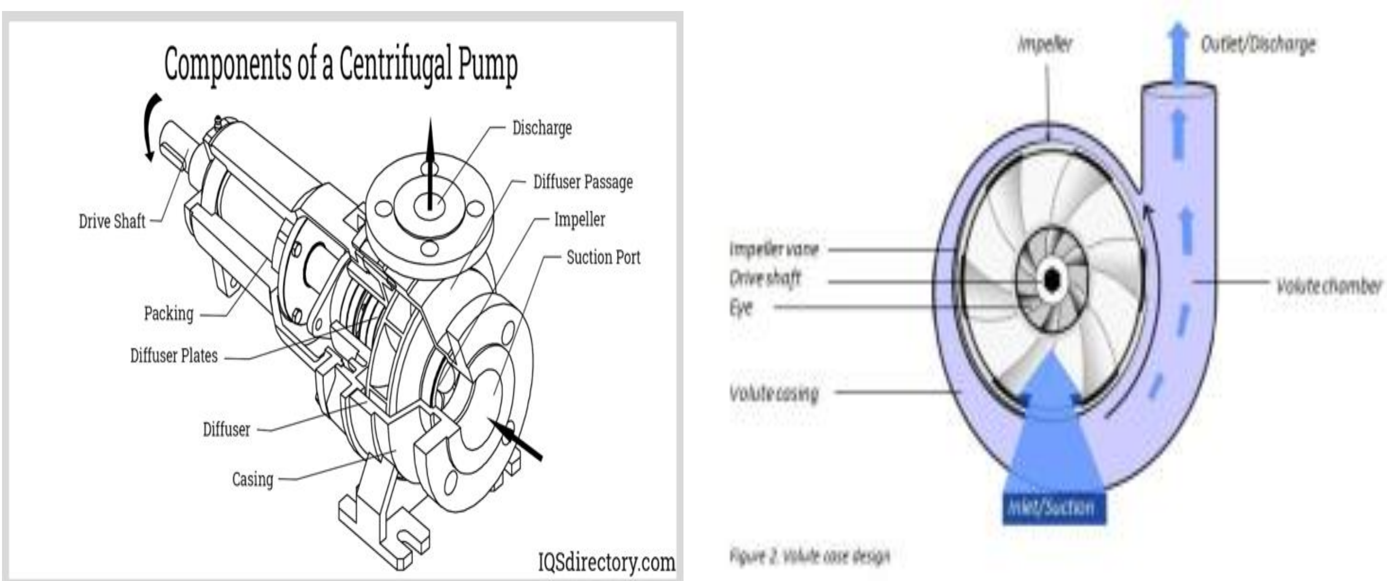

Fig. 2: centrifugal pump (https://www.michael-smith-engineers.co.uk/resources/useful.)

2. **Fans**

A fan is an air pump, a mechanism that generates air flow by creating a pressure differential in a duct or airway. The air pump or pressure source collects air at a certain input pressure and releases it at a higher pressure in a constant flow operation. The fan is an energy converter (from mechanical to fluid).

Centrifugal Fans

Air is sucked into a revolving impeller and released radially into an expanding scroll casing in centrifugal fans. It's further broken down into:

1) A plate of steel

2) There are many blades

Fig. 3: An industrial centrifugal fan (https://blaubergventilatoren.de/en/product/s-vent)

Axial air flow fan

Axial Air Flow Fans are divided into two kinds, both of which employ an impeller in a cylindrical housing with a mounting disc or air foil shaped blades to provide axial air flow. Axial flow mining fans with a diameter of 209 inches and a power rating of 5000 horsepower are used.

Fig. 4: An axial air flow fan (Sandeep et al 2021)

The mixed flow type

The mixed flow type resembles a cross between centrifugal and axial flow types, with an axial flow fan flaring in the direction of air flow and blades on the impeller that resemble a cross between centrifugal and axial flow types. This kind is rarely used.

3. **Compressors**

Because they also function as air pumps in the ventilation system, compressors for ventilation can be thought of as high-pressure fans.

Centrifugal and Axial Flow Compressors:

Centrifugal and axial flow compressors look similar to fans of the same type. They operate at considerably greater pressures than fans and handle lesser quantities of air.

Positive Blowers:

Positive blowers feature two spinning impeller that mesh in such a way that a virtually constant amount of air is displaced (in all other mechanical ventilation devices, the volume of air discharge varies with the pressure).

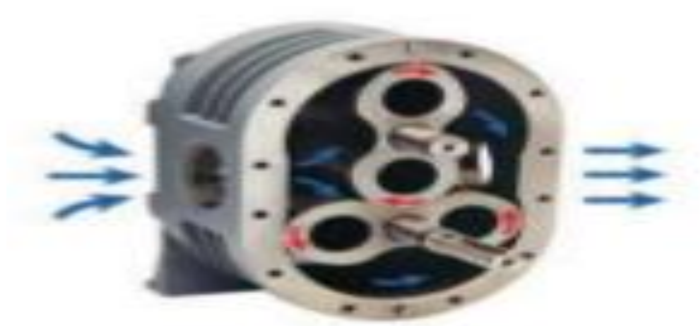

Fig. 5: Positive blowers (Sandeep et al 2021)

4. **Injectors**

Injectors use compressed air's kinetic energy to en-train ambient air, giving mostly kinetic energy to it. Injectors force a jet of compressed air into the open end of a short pipe segment or ventilation duct, en training the ambient air and establishing a flow. The injector's characteristics are determined by the geometry of the pipe or duct input.

2.3 Ventilation System in Mines

Ventilation systems in mines can be classified as boundary or unidirectional, central or bi directional, combined, depending on the relative position of intake and return airways.

1. Boundary ventilation system

The boundary ventilation system, in which air flows unidirectional from the intake to the return via the working, is by far the most efficient, requiring the least amount of ventilation control devices and resulting in high volumetric ventilation efficiency (70-80 percent). In its most basic form, it is used in metal mines that work steep lodes, with the intake and return shafts positioned at the mine's strike limits. Lateral extent, a central input shaft with two return shafts or winzes at either end is desirable. Two exhaust fans are installed in the property.

On the top of the intake shaft, a single forcing fan is sometimes utilized. However, this needs an air lock on the hoisting shaft, which is not ideal. When the mine is large enough on the strike, it can be split into multiple lateral parts, each with its own fan. Separate exhaust fans are usually installed on each parallel lodes in mines with several parallel lodes, but there may be a shared intake. A single forced fan is a less attractive option.

Advantages

1. The usage of ventilation control devices is limited by the boundary ventilation system.
2. This lowers leakage and results in a high volumetric efficiency.
3. In addition to conserving the capital spent in them as well as the cost of operation and maintenance.
4. Separate fans can be used to air two distinct areas of the mine. As a result, the overall flow handled by a single fan is reduced, lowering the fan's head demand.
5. Leakage is reduced to a lower head. The flow can be handled by narrower cross-sectioned airways.
6. Each portion's ventilation may be regulated individually, and a section can be separated quickly in an emergency.
7. Because there are more exits to the surface, there is more safety.
8. The mine characteristic remains almost constant throughout the mine's life, resulting in the fan's operation being consistently efficient.
9. The mine resistance, on the other hand, is constantly changing as the workings proceed.
10. The property line in the central ventilation system, where the fan must navigate a larger range of mine characteristics.

Disadvantages

i. The reversal of air flow is more difficult.
ii. The cost of operation, management, and maintenance of separate fan systems rises.

2. Central or bi-directional

Ventilation system that is either central or bidirectional is used. In-the-seam coal mines, where both the intake and return shafts are close by at the property's centre, the system is commonly used. In any district, intake and return air travels in opposite directions through parallel roadways, which are usually separated by stopping erected in the cross section between them. In order to join the main return, return air from a district must also pass the intake. Obviously, the central ventilation system permits a significant amount of leakage due to the number of stopping and air crossing points employed, resulting in a volumetric efficiency of just 4050 percent.

Advantages

After a brief development period, the deposit may be exploited, allowing for a speedier start to production. Because long development headings aren't required, there's no need to worry about ventilation. Mineral loss in shaft pillars is reduced in central pits. The expense of digging deep pits nearer is reduced since some common amenities may be shared by the pits. On the other hand, boundary pits that are located far away from the sinking site need the construction of a road, the expansion of power lines, and other costs. Although both central shafts can be used for hoisting, boundary shafts are rarely employed since this would need the extension of surface transport to these pits. If they're on the rising side, they can also be used as stowing pits (with hydraulic stowing pipes attached).

Disadvantages

i. The central mine ventilation method slows substantial leakage due to stopping and air crossing.

ii. With this system the loss of volumetric efficiency is 40% to 50%

i) Ascensional Ventilation

In this ventilation system fresh air is taken down to the bottom faces of a working district and is allowed to reach up the dip along the faces collecting heat from the freshly exposed rock at the face, this can lead to the development NVP that aids the fan pressure.

(ii) Descensional Ventilation

It implicit, taking the air to bottom faces from the rise side of a district to the bottom levels along with the working places and return are at the lower end of the working place. It has been asserted to reduce the quality of heat added to the air in workings, apart from making the workings less dusty.

(iii) Antitropal Ventilation

When air and mineral flow in different directions then the ventilation is known as antitropal ventilation.

(iv) Homotropal Ventilation

When the direction of air and mineral flow is same then it is known as homotropal ventilation

2.3 Ventilation Control Devices

There are several ways to get a mines air supply to the operating area. Signs indicate the location of air in a mine. To control the ventilation, devices can be used in the underground mine Ventilation. Some among the control devices are the following ones

1) **Stoppings**

To halt the airflow between intake and return when they are no longer needed for a ventilation. This will prevent the airflow from being short-circuited. These may be made from brick, stone, or concrete. Concrete blocks, or fireproofed timber blocks, can be used to build a structure. They should be securely anchored in the roof, floor and wall. Especially if the strata are weak or unstable. Inflammability of coal mining.

Fig.6: Ventilation stopping (Sandeep et al 2021)

2) **Air crossings**

Air crossings must be used where intake and return airways must cross over each other in order to prevent leakage between them. Air crossing erected upon the site of an existing crossing, has a decent level of rock-free terrain movement.

Fig. 7: Air crossing (https://www.slideshare.net/slideshow/distribution-and-control-of-mine-air)

3) **Regulators**

This is a device that creates a shock loss to limit airflow via a respiratory tract. Stoppings. The air amount may be changed by adjusting the pressure differential. The aperture's size can be altered. There are a number of regulators in the return airway to minimize the traffic interference. Locating the source of the problem at the intersection with other splits of a road. Leakage of air will be kept to a minimum.

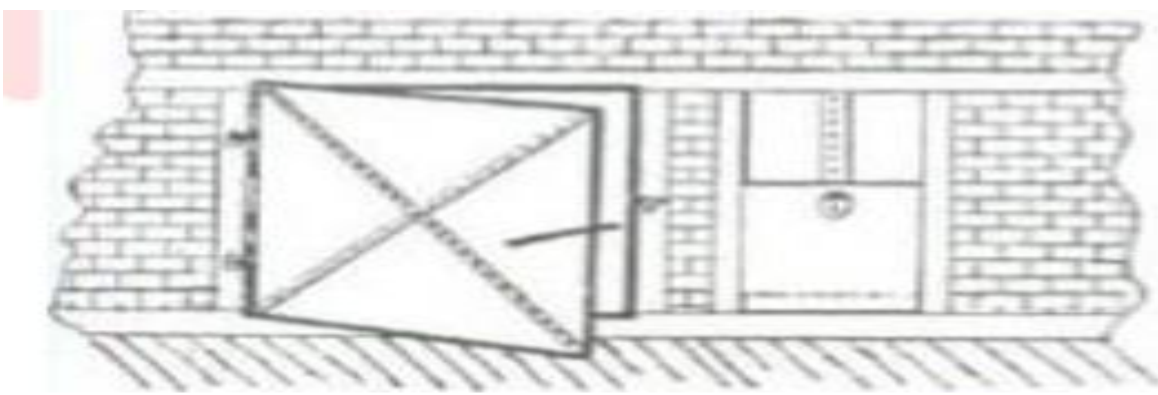

Fig. 8: regulator (Sandeep et al 2021)

Brattice cloth

It consists of a canvas sheet or sheets of canvas hanging on a strut to separate the aperture into intake and return airways. To prevent a short circuit of air from occurring, props and boards were used. Ventilation air is forced to return to the intake

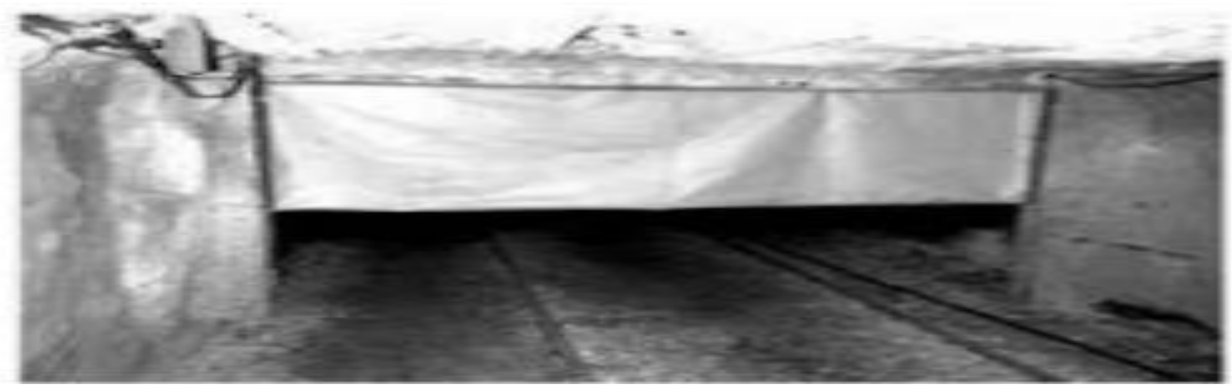

Fig. 9: Brattice cloth (Sandeep et al 2021)

2.3.1 Instruments

The instruments that were used in the underground mining to know the parameters are,

Barometer

A barometer is a device that is used to detect atmospheric pressure. The use of a barometer is beneficial in the operation of a mine because it displays changes in air pressure as they occur. A detailed examination of these pressure variations in relation to the gaseous state of the mine workings allows for more intelligent ventilation design and management, and may frequently predict a dangerous gaseous condition in the mine due to a fast drop in the barometer. Regular barometer readings are important in mining operations because they indicate the expansive effect caused by a sudden drop in barometer or decrease in atmospheric pressure. As a result, air and gases confined in a large abandoned area are forced out into the live workings, significantly increasing the explosive condition of the mine air.

Mine water gauge

A water gauge is a partly filled glass U-tube that is open at both ends and graded in inches. In Mine Ventilation, a water gauge is used to calculate the amount of power in the air. As a result, it should be mounted on the fan drift to account for the full resistance of the shaft and mine, which the ventilation fan must overcome. When the water gauge is in this position, the reading reflects the pressure created by the fan, which is either above or below atmospheric pressure, depending on whether the fan is blowing air into or expelling air from the mine. The change in the level of the water column of one inch is 5.2 lbs. per square foot.

Thermometer

A device for measuring temperature that is used to assess the relative humidity of mine air and to measure temperatures in sealed areas. Regular temperature readings within and outside the mine are critical for determining if the air has a higher or lesser capability for transporting moisture or absorbing moisture from the mine. In a dry and dusty mine, hygrometer readings are most useful.

Anemometer

Anemometers are commonly used in coal mining and consist of a metal ring with a revolving propeller of blades. The air stream striking the inclined blade rotates the bane, with a series of gears recording the number of rotations on the dial's face. The device is used to calculate the air current velocity in mine airways, which is given in feet. When taking a reading, choose a spot where the air is travelling straight and won't be diverted unequally to either side, then measure the area of the airway. Hold the anemometer at arm's length so that the blades move in a plane perpendicular to the air current, then use the anemometer's reset lever to reset all dial hands to zero, then release the brake lever near the handle. The anemometer is exposed to the air current for one minute, moving about to acquire an average reading for the airways enter sectional area, following which the anemometer is removed. Brake lever is released and the anemometer is exposed to the air current the amount of air moving in cubic feet per minute is calculated by multiplying the anemometer measurement by the square footage of the airway.

3.0 GROUNDWATER CONTROL

Numerous underground mines, have been developed in the last 10 years, or are planned to be developed in the near future in the United States. Most of these mines concentrate on recovery of gold, zinc, and copper. Although many of these mines are located in the arid or semiarid areas of the western United States, water related problems are of great concern at all of the mines. The presence of ground water in a mine has adverse impacts on mine production, ground control, and safety. Strict environmental regulations for the mining industry are being implemented by state and federal regulatory agencies, and the protection of surface and ground water resources is one of the main objectives of the mining regulations. The recent decline in the price of mineral commodities, and strict environmental regulations are leading to the implementation of more sophisticated water control methods during mining operations. The water control methods are aimed at the improvement of mining efficiency and safety, reduction of costs of mining and mine reclamation, and at the limitation of the probable hydrologic consequences of the mining activities. A well designed and implemented water management control system for an underground mine should consider the climatic, hydrologic and hydro-geologic characteristics of the mine area, the mining methods and the depth of the mine, and the potential environmental impacts of the mining operation during and after the completion of the production.

Groundwater Control Methods

The main objective in the control of water in underground mines is to develop efficient and safe working conditions and to limit the environmental impacts on surface and ground water resources. Ground water control methods can consist of prevention, (the limitation of water inflow into the mines and/or pumping of water prior to entering a mine) or, pumping from the mine. Our experience from many mining projects indicates that well-designed and executed mine water control programs can substantially improve mining conditions by increasing the efficiency of rubber-tired vehicles, creating a safer environment by working in dry, instead wet conditions, and, therefore, decrease the cost of operations. Considerable cost savings can be realized in a mine with an adequate water control system. Examples of cost savings include the use of dry hole blasting agents, increased efficiency of mining, and decreasing costs of pumping and water treatment.

There are many potential mine water control methods, however, only a few of them are practically and economically applicable for underground mines. The following are the most applicable methods used for water control in underground mines:

1) Impermeabilization at ground surface;
2) Ground freezing;
3) Grouting, and;
4) Mine drainage.

Table 1: summary of water control methods for underground mine (Straskraba, and Effner 1998.)

Selection of Water Control Methods

WATER CONTROL METHODS FOR UNDERGROUND MINES

WATER CONTROL METHOD	ADVANTAGES	DISADVANTAGES	EXAMPLES OF PRACTICAL APPLICATION
Surface Streams Sealing and Relocation	– Prevents inflow into mine – Limits impacts on surface streams – Good for limited areas and smaller streams	– Can be costly for major streams – Cost of maintenance after spring run-off	– Neves - Corvo, Portugal – Konkola, Zambia
Ground Freezing	– Highly efficient in aquifers with primary permeability – Most applications in shaft sinking	– Not practical in fractured rock – Most applications temporary only	– Many coal and potash mines in Europe and Canada
Grouting	– Highly effective to reduce flows and improve ground stability – Highly effective for smaller areas (faults) – Can be used in materials with both primary and secondary permeability (granular materials and fractures) – Variety of types of grouts (cement, bentonite, microfine and chemical grouts) unables grouting of materials with wide range of permeability – Used for shafts sinking and underground mines	– Can be costly if large areas are to be grouted – Grouting boreholes must be typically spaced at 1.5 to 10 meters. – Grouting of low permeable materials with microfine or chemical grouts is expensive – Potential impacts on water quality – Difficult in high pressure, high permeability conditions	– Many shaft sinking projects in a form of pre-grouting or cover grouting – Grout cover during drift mining in water bearing strata – Used as major water control method at many mines: Quirke 11 mine Canada, Deep Creek Mine, Canada, Southeast Missouri Lead district, Konkola Mine, Zambia, Lamefoot Mine, Washington
Wells from Ground Surface	– Dewatering accomplished before mining – Pumped water not impacted by mining activities – Large volumes of water from wells up to 1,000 meters deep – Efficient in certain hydrogeologic conditions for shaft sinking – No interference with the mining operation	– High cost of drilling deep wells – Not efficient in areas with many low permeable faults – High cost of pumping large volumes of water – Maintenance and power cost – Not efficient in low permeable strata and in rock with vertical fractures	– Several new gold mines in Nevada, USA (Meikle Mine, Turquoise Ridge Mine, West Leeville Mine). – Homer Wauseca Mines, Michigan
In-mine Drainage Boreholes	– Low cost if combined with definition drilling – Gravity flow, no pumps, and power necessary – Can be oriented to intersect major fractured systems – Boreholes can be used for drainage or grouting – Size of boreholes can be adapted for range of discharge	– Drainage possible only at later stage of mining – Plugging of boreholes in weathered of highly fractured ground – Discharge from typical size of boreholes is limited	– Exclusively used for mine drainage in many mines: Konkola, Mulfira, Nkana Nchanga, Chambishi in Zambia; Kipushi, Kambove, Kamoto, in Rep of Congo; Lamefoot, and K-2 in Washington; Deep Star, Rosebud in Nevada; Kensington in Alaska; Henderson in Colorado; Hamilton in Australia

Selection of the most appropriate method of water control for a particular mine should be based on a comprehensive study of local climatic, hydrologic, hydro-geologic characteristics of the mine area, and should consider the mining methods, and depth of the mine. The environmental considerations should include not only the potential impacts on surface and ground water resources during mining, but also the long-term impacts on water quality after the completion of mining. Cost considerations should be a part of any design of mine drainage. The cost study should consider not only the expenses related to drainage, sealing, or grouting, but also the potential expenses for water treatment and discharge, and other environmental consequences.

A study of the best method for mine water control should be based on an analysis of local climatic conditions and the development of a water balance for the mine area. This study should estimate how much water is available for the ground water system recharge, and how much water can be released from storage during the mining operation. The presence of major surface water bodies in the mine area should be analyzed, and the potential for hydraulic connection between the source of surface water and the mine should be assessed. The mining method being considered for application and the depth of the mine are important factors in the assessment of potential seepage into the mine from a surface water source. Important factors for the estimation of subsidence effects on hydraulic connection between surface water resources and an underground mine include mining methods, whether the mine is caved or backfilled, and the type and method of backfill placement. Hydro-geologic characteristics of the mine area have a great impact on the selection of water control methods. The presence of major aquifers in the mine overburden, or the existence of a highly conductive water-bearing ore body should be considered. Sudden inrushes of water into an underground mine are often caused by the presence of major geological structures. An investigation of the hydraulic characteristics of major structures, and faults in particular, is necessary for the selection of a water control method. Faults often act as hydraulic conduits in the shear zone along the fault, but can also act as hydraulic barriers perpendicular to the fault due to the presence of mylonite and clay particles.

Calculation of the probable water inflow into the mine should be a part of any study for mine water control. Analytical methods, as for example the "Large Well" method adapted for the mining application by Russian hydro-geologists (Klimentov et al, 1957 and others), are a good first step in the mine inflow assessment. For some mines with relatively simple hydro-geologic conditions, analytical methods may be adequate for the mine water inflow estimates. In more complex hydro-geologic conditions, where significant aquifers and major faults are present, or where potential impacts of mine drainage on surface and/or ground water resources is of the concern, the application of numerical computer models should be considered. Simulation of ground water inflow into a mine should indicate from which strata and how much water would be flowing into the mine workings at various stages of the mining activities. Potential environmental impacts of mine drainage on surface streams, including depletion of stream flows, and impacts on adjudicated water rights, are of great concern in the arid climatic conditions of the western United States. The aspects of potential impacts should be considered in the selection of water control methods. Protection of major aquifers which are used by others for water supply is an important consideration in the selection of a water control method. Extensive pumping from a major aquifer can cause substantial drawdown in a large area and impact numerous water users.

This may substantially increase the cost of the mining operation, and can be a difficult obstacle in the mine permitting process. The estimated volume of water which will need to be pumped has to balance the development of conditions for efficient and safe mining while limiting impacts on surface and ground water resources. Included in the evaluation of impacts to surface and ground water resources should be an estimation of the potential water quality of discharge from the mine, and the post-mining ground water quality. This type of study would be based on background water quality data, the geology of the deposit, geochemical testing (Humidity Cell, Acid-Base Accounting, and Meteoric Water Mobility Tests) and prediction modeling. Several software packages are available for geochemical modeling including PHREEQE and MINTEQA2 which have been widely accepted by regulatory agencies in the United States.

4.0 CASE HISTORIES OF VENTIALTION SYSYTEM AND GROUND WATER CONTROL IN UNDERGROUND MINING

4.1 Ventilation System

Rowland (2011) demonstrated the ventilation survey techniques and the execution of ventilation modeling out of the survey results and suggested some outputs for the same. He have emphasized that the level of survey detail required is totally dependent on the end use of the data and the accuracy of the data set for safety and viability of working operations. He formulates a strategy to carry out the appropriate ventilation survey and highlights the nature of report outputs. He had advocated for fabrication of a properly tuned ventilation model which are intricate components of the modern underground safety management systems and emphasis for utilizing the ventilation modeling software as a key tool in ventilation circuit designs and ventilation changes.

Brian & Loomis (2004) measured the frictional pressure differential during a ventilation survey. They compares the two basic methods of frictional pressure drop measurements; the barometer and the gauge & tube regarding applicability and conditions favoring each method and believed that in both metal and coal mines the gauge & tube method is more preferable than the barometric pressure techniques owing to rapid evaluation and more accurate results.

Hinsley (1966) demonstrated that when a ventilation system is changed from forcing to exhaust the inbye portions of the workings are reduced below the barometric pressure of the air by an amount equal to half the fan pressure.

Akande (2013) developed a model for the calculation of mine airflow distribution as a part of comprehensive study for underground coal mine of Okaba coal deposits. Calculated the air pressure, fan power and airflow rate to maintain the safety levels of methane in underground mine for workers protection against harmful substances.

Calizaya (2010) computed quantity and pressure readings for monitoring and developing a booster fan selection method.

S K Ray (2002) carried out pressure quantity survey on 1 & 2 incline of Jhanjhra area of Raniganj coalfields at RVII & RVIIA seam by hose & trailing method, inclined manometer, pitot tubes etc. and quantity by anemometer at more than 20 strategic locations to ascertain air quantity distribution in mine for introducing a chamber method of ventilation arrangement which is superimposed on main ventilator system to reduce cumulative pressure in a desired area without affecting the main fan pressure and ventilation in other part of the mine.

Varma (2009) conducted ventilation survey which comprises of pressure survey, quantity survey, study of performance of main fan and fire area stoppings behaviour as a part of investigation in Sindra Banjara colliery a unit of Sijua area, BCCL on VI seam of pit no.3.

Morla (2012) presented a detailed case study of the pressure survey of the ventilation network and the simulation results of the GDK-11 incline in RG-I area of SCCL for bord and pillar mines with an objective of increasing the ventilation quantity with low operating pressure and effective utilization of main mechanical ventilator and observed that, the alteration of the intake air shaft into a return shaft will increase overall resistance of the mine.

Sahay (2003) conducted pressure survey, air quantity survey, temperature survey, performance study of fans, computer simulation studies and studied pressure behaviour of stoppings at Kacchi Balihari colliery of Bharat Coking Coal Limited (BCCL), India for controlling fire in the sealed panel.

4.2 Ground Water Control

Ground surface impermeabilization is not a common method of mine water inflow control in the arid conditions of the western United States, because major surface water streams are typically not present. However, this method was used with success in several mines worldwide.

In the Neves-Corvo Mine in Portugal (Carvalho, et al, 1990) sealing of a river course with concrete, reinforced with steel mesh and anchors, and protection of river banks by shotcrete substantially reduced water inflow to the mine. Another successful impermeabilization of river course flowing over a subsidence impacted area was reported at the Konkola Mine in Zambia (Freeman, 1970). At this mine, a sublevel caving mining method was used, and local stream beds were filled with tailings to seal the cracks developed by subsidence. Later, more environmental friendly methods for surface stream sealing were proposed for this mine (Mulenga, 1993). However, the prohibitive cost and uncertainty as to how efficient the sealing would be prevented the completion of the project. Ground freezing can be a very efficient method of ground water control in certain hydro-geologic conditions.

Ground freezing has been successfully used on many shaft sinking projects, especially for coal and potash mines. Recently, an extensive ground freezing program has been proposed for ground water control at an open pit mine in Canada, but the project was not realized for economic reasons (Placquet, 1997). To our knowledge, this method has not been used for ground water control in underground mines, with the exception of shaft sinking.

Grouting practices for soil and rock stabilization and ground water control have a long history. From the simple injection of bentonite and lime slurry for soil stabilization in the first part of the 19''' century to the sophisticated injection of chemical grouts for historical building restoration and ground water control. Most of the applications of grouting technology in the mining and tunneling industry use cement, and cement - clay grouts. There are many technical papers describing the successful application of grouting methods in mining and tunneling (Kipkoat, 1993., Heinz, 1997., Nel, 1997). However, only a few describe the limitations or failures of grouting methods.

The application of cement-based grouts is more common in the mining and tunneling industry than use of other types of grouts. Numerous vertical shafts have been sunk under the cover of grouting. Methods of pre-cementation have been used extensively in South Africa, the United Kingdom, the former USSR, and also on several coal mine shafts in the eastern United States. Grouting from the bottom of shafts during sinking is a common practice in the industry for overcoming sections with poor ground conditions or excessive ground water inflow. Mine dewatering is the most common method of water control in underground mines.

Dewatering methods for underground mines can range from the relatively simple collection of water seeping into the mine from fractures or roof bolts, to more complex drilling of dewatering wells from the ground surface, drilling of drainage boreholes from within the mine, or mining of drainage galleries. Dewatering of mines by the use of vertical wells drilled from the surface is a common practice, especially in open pit mines. The advantage of this system of dewatering is drainage ahead of mining, discharge of clean water, and practically no interference with the mining operation. Disadvantages of this method are the cost of drilling and pumping, limitations in drawdown achieved, and cost-effectiveness in dewatering both aquifers of low permeability, and prevalently vertical-fractured rock masses. Dewatering wells from the surface could not effectively dewater several underground mines in Nevada, where this method of dewatering was tried and could be used only in combination with the in-mine drilled drainage boreholes. The drilling of deep dewatering wells from the ground surface which are capable of pumping large volumes of water has become quite common in the last several years in the western United States. There are at least three new underground gold mines in the western United States where deep dewatering wells drilled from the ground surface are the main drainage system. These mines, located in Nevada (Meikle, West Leeville, and Turquoise Ridge), use large diameter wells (25 to 40 cm) and submersible pumps capable of pumping up to I 00 I/sec from depths greater than 700 meters.

Drainage boreholes drilled above the stopes, or into the hanging wall from the access drifts are very probably the most common method of mine drainage. These boreholes, if combined with delineation or definition drilling, can be the most cost effective dewatering method.

Drainage boreholes are typically drilled up to an angle of + 10 to +55 degrees and the orientation of the boreholes should be based on mining plans, orientation of main fracture systems, and the size of stopes. Boreholes can be drilled with coring or percussion bits. In strongly fractured or weathered zones, it may be necessary to insert plastic or steel casing into the boreholes to prevent caving. Most of the drainage boreholes are installed with a 4 to 5-cm diameter plastic (PVC) casing. This type of mine drainage has been quite successful in Deep Star and Rosebud underground gold mines in Nevada, and the Lame foot and K 2 mines in Washington State. In-mine drainage boreholes are also the main method of dewatering in the Konkola Mine in Zambia, which is considered to be one of the wettest mines in the world. Drainage galleries have not been used extensively for mine dewatering in last 10 years, mainly because of the cost. A very unique drainage tunnel was completed at the tum of the century in western Colorado. This tunnel, the Yak Tunnel, is about 6 km long and drains the entire section (10km2) of the Leadville historical mining district. The continuing discharge from this tunnel of about 20 l/sec of highly acidic water brought serious environmental impacts.

Similar tunnel was completed in Idaho Springs, Colorado (Argo Tunnel). The longest drainage adit is very probably the Ferdinand adit in Kremnica, Slovakia, which is 18 km long (Straskraba, 1983) .

Cases of Water Control Methods

The water control methods for an underground mine should be selected in the stages of pre-feasibility and feasibility studies. Mine water control can contribute substantial costs to the mining operation, and the environmental consequences for poorly designed water control can be costly for many years after mine closure. The following text presents several cases of well thought out and designed water control methods for a few mines already in production, and for several mines in the development and planning stages:

i. Deep Star Underground Gold Mine in Nevada:

This relatively small mine is located on the Carlin Trend in Nevada, near the Post/Betze open pit where more than 4,100 I/sec Use of water is pumped from surface perimeter wells. Because of the proximity of the Deep Star Mine to the highly water-bearing strata in the open pit area, some hydro-geologists believed that dewatering wells from the surface would be necessary for the underground mine drainage, although available packer test permeability data performed in geotechnical boreholes indicated much lower hydraulic conductivity in the underground mine area. The first deep dewatering well had a low yield and pumping from this well was abandoned. The underground mine is being adequately dewatered by in-mine drainage boreholes and the total mine inflow is less than 10 I/sec (Clode, 1997). Analytical calculations of probable ground water inflow into the mine proved to be more accurate than finite-element computer modeling performed for this mine.

ii. Turquoise Ridge Underground Gold Mine in Nevada:

This mine is in the first phase of production. Two shafts were sunk through highly permeable (3x10^-3 cm/sec) basalt up to 180 meters deep, and through moderately permeable (l.5x10^4 cm/sec) hornfel and marble to 350 meters depth, and completed in metamorphic sediments with low permeability (5.0x10^-5 cm/sec) at a depth over 700 meters. Shaft sinking was completed under the cover of three dewatering wells, without any significant ground water inflow into the shafts during the sinking (Barker et al, 1997). The dewatering wells were up to 700 meters deep and pumped initially up to 86 I/sec. It seems that the surface dewatering wells are not able to lower the water table adequately in the lower permeable strata for the initiation of the ore production on the 900 Level (274 meters). Grouting above the stopes and drilling of angled or vertical boreholes is being tested and considered for additional dewatering. Recommendations for mine dewatering, and for the shaft sinking phase of the project in particular, were based on finite-difference (MOD FLOW) computer simulation.

iii. Meikle Underground Gold Mine in Nevada:

This mine is in an early stage of development, and the mine drainage was so far accomplished by dewatering wells from the surface. In mine drainage boreholes are considered at a later stage of mining.

iv. West-Leeville Underground Gold Mine in Nevada:

Proposed mine with a consideration of mine drainage by wells from the surface. Test well was completed and tested for permeability of water bearing strata. Packer permeability tests were performed at the shaft pilot borehole.

Rosebud Underground Gold Mine in Nevada: Ground water inflow calculations for this mine were based on an analytical method ("Large Well" Method), and on a water balance analysis. The potential inrush of ground water where the decline crossed a major fault was accurately predicted and the pilot boreholes drilled ahead of decline drifting were adequate for water control. Mine dewatering is handled by the drilling of drainage/definition boreholes and no major problems have been encountered during mine development and production. In-mine drainage by gravity flow from boreholes is facilitated by pumping of water from several water supply wells in the general mine area, even though these wells are located on the other side of a major structure from the mine.

v. Kensington Underground Gold Mine in Alaska:

This mine is in a development stage and production is likely to be initiated in the near future. Calculations of the probable water inflow into the mine during production were based on a water balance method and on analytical calculations of the potential inflow along major faults. The current mine dewatering program is based on the drilling of drainage/definition boreholes into the hanging wall and into several water-bearing structures. Grouting of fracture zones and several major water-bearing structures was recommended and is being considered.

vi. Lamefoot and K2 Underground Gold Mines in Washington State:

These two mines have relatively low ground water inflow, and water control is handled by drilling drainage boreholes and grouting. Grouting of boreholes with a discharge of water of more than 0.06 I/sec per borehole was imposed on the mining company by a federal regulatory agency for environmental protection. Calculations of the inflow of water into these two mines was based on a water balance analysis and on analytical methods.

vii. Crandon Underground Zinc-Copper Mine, in Wisconsin:

This mine is in a feasibility study and permitting stage, and is located in a state with the strictest environmental law in the United States. Extensive computer modeling has been performed to support the conclusion that mining and mine dewatering would have minimal impact on the local surface and ground water resources. The overburden of this deposit is formed by a regional aquifer in glacial materials. These materials are underlain by low permeable clays and saprolite at the top of the bedrock. The predicted inflow into the mine is only about 37 to 80 I/sec, and the mine drainage would not create any insurmountable difficulties. However, the potential environmental consequence of impacting the glacial aquifer, the streams, lakes, and wetlands, and the need to treat and discharge the water pumped from the mine at a distant location, led to an interesting water control system. The potential reduction of permeability by extensive grouting of the weathered top of the bedrock (which is located within the proposed crown pillar) was proposed and tested. Boreholes drilled from the ground surface to a depth of 80 meters were used for grouting a cement curtain, approximately 10 meters thick, at the top of the bedrock. Results of test grouting, with the use of Portland cement for primary grouting, and with the application of ultrafine cement grout for the secondary grouting, indicated that grouting boreholes at a distance of 3 meters from each other could reduce the original hydraulic conductivity of 2 x 10^-3 em/sec to 9 x l0^-5cm/sec, and could reduce the calculated vertical seepage by up to 95 percent. It is anticipated that the drilling and grouting from the underground drift will be even more efficient than grouting from the ground surface because of the mostly vertical fracture systems. The verification of the reduced permeability was accomplished by repeated packer permeability testing before and after grouting, and by drilling of several verification boreholes, from which core samples were recovered.

5.0 CONCLUSION

Effective ventilation system control and ground water management are essential for ensuring miner safety and health, preventing environmental pollution, protecting nearby water resources, maintaining mine stability and productivity, complying with regulations and standards. Underground mining operations must prioritize these aspects to minimize risks and hazards, promote sustainable mining practices, and protect ecosystems and communities, Ensuring long term environmental stewardship.

By implementing robust ventilation, pollution control, and ground water management systems, underground mining can be conducted safely, responsibly, and with minimal environmental impacts.

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