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Analyzing the effects of natural ventilation caused by excavating the waste pass on the ventilation network of the Anguran mine

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ABSTRACT

One of the operating costs of exploiting underground mines is related to ventilation operations. The development of the underground mining network during the process of mining and the necessity for additional excavations, will require a repeatedly redesign of the ventilation plan. Excavating the waste pass in the Anguran underground lead and zinc mine and expanding new ways to transfer cement filling requisites from the surface, necessitates a comprehensive reassessment of the ventilation network plan. The present research aims to analyze the efficiency of the mine ventilation network through simulation with considering the effects of waste pass based on the consequences of natural ventilation. For this purpose, based on the assessment conducted on the needed parameters of the underground development plan, the required airflow intensity of this mine was 57.5 m3/sec and the air pressure drop was estimated to be a value of 116.79 millimeters of the hydrological column. The dataset related to underground mine network was imported into the Ventsim software. Furthermore, the simulation and delineation of each branch have been included as well. Subsequently, considering the benefits of natural ventilation within different seasons, various placements of the primary fan were analyzed in accordance with the positioning of the mine entrance and air passages. Ultimately, an optimal ventilation design was proposed. The investigation of modeling natural ventilation comprised two distinct phases: pre-excavation of waste/ore pass and post-excavation. This study was conducted using Ventsim software, considering variables such as temperature, pressure, and varying levels of humidity. Based on the outcomes of the simulation, the mining network necessitates a minimum natural ventilation flow of 14 m3/sec during the winter season, leading to energy savings of 16.02 Kwh.

Keywords: *Natural ventilation, Mine ventilation network, Mine ventilation simulation, Ventsim, Anguran lead and zinc mine.*

1. Introduction

Providing the required airflow in different locations of the mining network and creating a suitable environment to provide essential requirements in order to make the exploitation operation of underground mines possible. Therefore, ventilation design is one of the most indispensable operations in the exploitation of underground mines. Mine ventilation design is a dynamic activity based on the mine life and it should be assessed in different conditions based on the underground network development. A prerequisite for the natural draught flow within the mine is the establishment of a minimum of two connections between the mine network and the external atmosphere. In this scenario, the temperature disparity between the interior and exterior of the mine gives rise to variations in the specific air density, subsequently generating differential pressures and fostering the movement of airflow from regions of higher pressure to regions of lower pressure. These factors contribute to the intricacy of the ventilation element. Recently, the increasing integration of computer applications in mining-related research has led to the emergence of software-based ventilation design as a dependable and extensively employed methodology. Various software has been developed to analyze mining networks so that complex networks can be stimulated.

Anguran lead and zinc mine is located in Anguran region, Zanjan province, Iran. The study area is located approximately 125 kilometers southwest of Zanjan city. Because of the expansion of the underground operations of the Anguran mine and also the excavation of new underground Prospects such as waste passes, it is necessary to provide a suitable ventilation plan to provide more productivity. Conversely, the excavation of waste passes is necessary to facilitate the backfilling of underground stopes, which ultimately connect to the ground surface and serve as outlets for the open-pit mine. Due to the inherent airflow direction within the mining network, these structures will induce varied impacts across different seasons. Based on new excavations employed, the ventilation plan of the mining network should be redesigned and the airflow production of the fan should be recalculated by considering the effects on the new natural flow during different seasons. Moreover, the

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need to develop a computer model of the ventilation network of the underground Anguran mine to control the ventilation parameters caused the research presented in this article.

Because of the size and complexity of the underground networks, the manual design of mine ventilation is time-consuming and it is involvs some errors. Computer simulation of mine ventilation network has been able to be a suitable alternative to manual design as a result of ease of use. Ventsim, Minevent, and Ventpac software tools are specific examples in this regard[1-3]. Computer simulation has been used for ventilation design in several kinds of research[1]. To select the suitable tools for simulating the ventilation network of the Anguran mine, firstly the background of computer simulation of mine ventilation is briefly studied.

In 2001, Capehart and Watson simulated the ventilation network of an underground gold mine in Australia. This deposit was mined to a depth of 600 metersin form ofn an underground mine. According to the fact that the exploration of mineral reserves indicated the presence of minerals observed at greater depths, so to exploit the lower horizons, it was essential to upgrade the ventilation system and achieve this goal. Several ventilation schemes were modeled in Ventsim software[3-5].The Dongi mine in China is another mine whose ventilation network has been simulated by Ventsim software. This research was conducted in 2011. The reason for this research was the complexity of the mine ventilation network and operational problems. . Some airways had very high resistance. Pollutants simulation, economic evaluation, and thermal simulation have been done for this mine and the efficiency of this computer simulation tool perfectly demonstrated accurate and fast modeling of current ventilation status, design and long-term planning [6]. In 2012, Lilic et al. simulated the ventilation system of the Omarler coal mine in Turkey. The extraction system simulation in this mine is completed in both computerized and traditional methods. Long-term planning for mine ventilation and, finally optimization of mine network have been performed [7]. In a study conducted by Elahi in 2012, the ventilation design of the East Takht coal mine was examined. In this study, the analysis of natural ventilation effects as a result of the environment climatic conditions with mechanical ventilation in regards to ventilation airflow costs was performed. Ventsim software was applied to modeling in this research[8]. In another study, Pazin 2013 optimized the Anguran lead and zinc mine ventilation network by Ventsim software [9]. In 2014, Stewart simulated the ventilation of underground blasting operations through Ventsim software and calculated the volume of gases from the explosion and the optimal time to discharge the explosive gases[10]. In 2014, Cioclea et al. presented the hazards of explosions and fire gases in a study based on a computer simulation of a ventilation network by Ventsim software. After developing a computer model of the mine, the explosion system was simulated in one of these branches. Lastly, the effects of fire and its harmful gases have been inspected and the basic solutions and measures have been described in case of hazards[11]. In 2015, Sethi designed a computer model of the Nandira underground coal mine to survey the amount of pressure and air quality in the mine's ventilation system. Ventilation required from the mine has been done with the contribution of appropriate tools in forty stations. Simulation and analysis were done by Ventsim software and the results were compared with the Observed and real data acquisited of the mine [12]. In another study, Acona and Wallace selected a mineral deposit in Chile and designed its ventilation network using computer modeling. The preparation of this mine was scheduled in two phases. The second phase of the project started in 2015 and ended by 2020. This research was directed in 2015, ventilation design and sensitivity analysis were done on the maximum and minimum airflow intensities at the inlets and outlets[13]. In 2016, Zhang and Su reviewed the Miyago Coal Mine Ventilation System and and again the simulation conducted using Ventism Software. In this investigation, the application of this software has been examined in long-term and short-term mining plan as well as facilitating the mine ventilation management system [14]. In 2019, Jiang et al. modeled coal mine ventilation in China using Ventsim software. In this research, the analysis of the air distribution in different branches of the mine ventilation network is probed. This research aims to enhance an reduce energy consumption with seasonal changes[15]. In 2014, Elahi deliberated on the ventilation of the Zemestan-Yurt mine located in Golestan province and evaluated the effect of natural ventilation on the ventilation mechanism of this mine. The simulation has been done using Ventsim software [16]. The majority of preceding studies have been conducted through computer software simulations. The examination of the research background highlights the importance of computer simulation and the aptitude of Ventsim software in effectively simulating mine ventilation networks, thereby facilitating enhanced management practices. [2-4, 9, 14, 16-20].

The primary objective of this research is to assess the impact of waste pass excavation on the natural ventilation of the Anguran mine. With consideration given to the mine's natural ventilation, the study reevaluates the ventilation plan and investigates the influence of waste passes on the mining network. To achieve this aim, it is essential to initially examine the methodology employed in Ventsim software and the underground network of the Anguran mine, followed by a comprehensive review of the simulation results pertaining to its ventilation network. Recognized as a highly efficient ventilation simulation software, Ventsim has gained extensive popularity within the field of mine ventilation simulation. Its robust graphical interface and user-friendly functionality set it apart from other software options, contributing to its widespread adoptionThis software possesses notable attributes, including the ability to simulate and visualize the distribution of airflow intensity within a designated network, facilitate both short-term and long-term ventilation system planning, enable the simulation and calculation of natural ventilation, conduct financial analysis of ventilation alternatives, address concerns related to dust and hazardous gases, and provide emergency control measures for events such as mine fires. Additionally, it offers the capability to select an appropriate fan for mining operations. Input parameters in Ventsim software include specification of the branch, beginning and the end of the nodes related to branch, branch resistance (should get defined by the user or it can be calculated by the software), airflow (by the user in branches), pressure drop (if available), coefficient Friction (manual entry or software calculation), the local drop calculated by the system, the cross-sectional area, section shape, and type of spaces (Gusat, 2011). The Hardy Cross theory is acknowledged as the principal theoretical framework employed in Ventsim software, much like other numerous air conditioning softwares. Developed in 1936, Hardy Cross introduced a mathematical model to estimate airflow by establishing mathematical relationships [21]. This approach relies on iterative mathematical computations, persisting until the error becomes equal to or smaller than the precision of the mathematical calculations. The equations delineating the estimation of airflow error for each loop within the Hardy Cross theory are illustrated in Equations (1) to (6) [21-25].

$$\Delta P = rQ^n = r\,(Q_0 + \Delta)^n \tag{1}$$

$$rQ^n = r\,(Q_0^n + n\Delta Q_0^{n-1} + \ldots) \cong rQ_0^n + nr\Delta Q_0 + nr\Delta Q_0^{n-1} \tag{2}$$

$$\sum rQ^n = \sum nrQ_0^n + \Delta \sum nrQ_0^{n-1} \tag{3}$$

$$\sum rQ^n = 0 = -\Delta \sum nrQ_0^{n-1} \tag{4}$$

$$\Delta = -\frac{\sum rQ_0^n}{\sum nrQ_0^{n-1}} \qquad n = 2 \rightarrow \Delta = -\frac{\sum rQ_0^2}{2\sum rQ_0} \tag{5}$$

$$\Delta = -\frac{\sum \pm \Delta P_i}{2\sum r_i Q_i} = -\frac{\sum \pm r_i Q_i^2}{2\sum r_i Q_i} \tag{6}$$

In the above equations:

Q: Actual airflow (m^3/sec)

Q0: Hypothetical or initial airflow (m^3/sec)

Δ: Loop airflow error (m^3/sec)

r: Air resistance of each branch (kmorg)

P: Air pressure drop of each branch (mm water)

According to the equations mentioned above, to implement the Hardy Cross method, first according to the law of nodes, a hypothetical current flow with a hypothetical direction for each branch of the ventilation network is considered. Afterwards, the useful loops in the ventilation network are identified and a hypothetical direction is selected for them. In the next step, the air pressure drop is calculated for each of the branches in the loops. Then, the flow error of each loop is considered in line with Equation (5). At this stage, if the direction of airflow in a branch is in the same direction as the direction of ring flow, then the pressure drop of that branch will appear to be a positive value, otherwise will appear in the equation with a negative sign. As well, the denominator of the fraction in the equation without specifying its sign will always have a positive sign. Then, the new flows of different branches of the ventilation network are assigned. To do this, it is primarily tested that each branch is affected by several loops and then the positive or negative sign of the error of each effective loop is determined. Lastly, the new flow of each branch in the ventilation network can be calculated by the algebraic sum of the current flows of the intended branch with the amount of minimum error of the effective loops[15, 25-28]. It should be noted that if the direction of the loop is in the same direction as the flow direction of the branch, the error value of the loop should be multiplied by the positive sign and otherwise by the negative sign. Moreover, if the amount of new airflow of the branches becomes negative, the direction of airflow in the purposed branch should be reversed. The above operations are repeated until the calculation error is less than or equal to the accuracy of the calculations[1, 18, 29].

2. Case study

The Anguran lead and zinc mine is located within Zanjan province, approximately 125 kilometers southwest of Zanjan city. This mine is nestled in a mountainous region characterized by an average altitude of 2950 meters above sea level. Dandy is the nearest town to this mine. The region experiences significant temperature variations between day and night, as well as distinct hot and cold seasons. Generally, the spring and autumn seasons are relatively brief, while the transition from summer to winter occurs rapidly. Regarding the geographical location, topography, and mineable reserves, the transition from open pit to underground limit has been set to 2750m and the final underground level is set at 2700 m above sea level. The current extraction capacity of the underground part of the mine is 120,000 tons per year. According to Figure (1), The access to the main mineral deposit is through two horizontal drifts. Drift No.1 (main haulage drift) is located at the level of 2700 and Is employed for the transportation of extracted ore. Currently, the transportation system relies on railway wagons; however, it will be replaced by a roof conveyor system within this specific drift. A significant portion of this drift, which traverses compact limestone, remains without support. This drift is used as an inlet of fresh air to the mining network. The main jet fan in a side corridor near drift 1 is responsible for ventilating the mining network. The drift's overall length turns to be 1190 meters, with a predominant cross-sectional area of 7.9 m^2 throughout the majority of its length. However, in certain sections, the cross-sectional area expands to 13.6 m^2 due to the inclusion of two lanes from the existing railway line. Drift No.2 is located at level 2775 with 1119 m length, whose main task is to transport the cement material to the batch mixer unit situated at the end of this drift. The total slope of this drift is five per thousand. The excavation of underground spaces is implemented with a modified cut and fill method to extract the high-sulfur zone. In this method, parallel sections are drilled and then, extractions are filled with cement materials. The extraction direction is underhand stopping, that means the lower horizons will be extracted after exploitation of the upper level. Extraction drifts are also drilled along the reserve to divide them into two parts at each reserve level. In the event of a substantial deposit thickness, it may be necessary to implement multiple extraction drifts. Thereafter, handles are excavated in the direction perpendicular to the deposit from the extraction drift. Its cross-section area will be nearly 20 m^2. The galleries are sequentially excavated, and the terminations of these galleries are interconnected at two consecutive horizons. The extraction process will be conducted in a retreat manner. After extracting the stopes, the filling operation will be commenced. In this method, several stopes can be extracted together. After the stopes get extracted, the extraction of the remaining pillars will take place. Figure (2) shows the status of the extraction stopes, ramps, access drifts, transfer winze, and ventilation raise [9, 30-32].

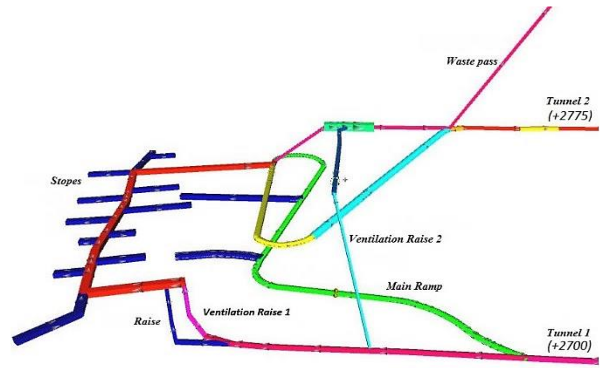


Figure 1: The underground mining network of Anguran lead and zinc mine[30].

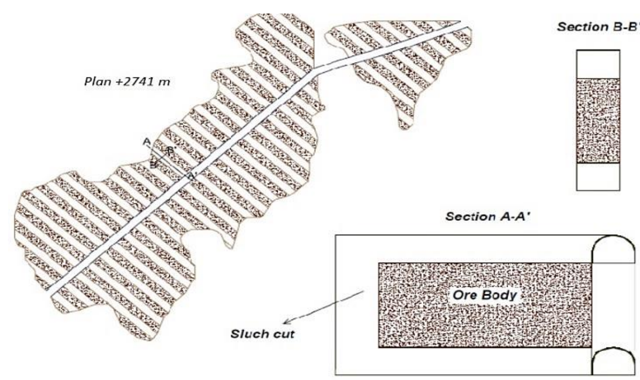


Figure2. Status of extraction stopes.

Furthermore, the main ramp is put into joining different levels of the mine as well as the movement of workforces to the stopes and to linking the two drifts. The main ramp has been excavated with a cross-section area of 9 m^2 and a length of 681 meters. The ramp on each level is connected to the extraction galleries through an access drift. The access drifts of the horizons, branch off from the ramp and spread perpendicular to the reserve. The estimated cross-section of these drifts is 20 m^2. At every level, a drift has been excavated to facilitate the transportation of extracted ore to the raises. Extraction galleries are excavated at different levels while extraction stopes are located on both sides. After the extraction operation in each level, these drifts are filled like extraction stopes. A 39-meter-long ore raise with a cross-section of 4.9 m^2 has been constructed to haulage the extracted ores out of the mine through drift 1. In the mine network, ventilation is used to transfer clean air from the end of drift 1 to the excavated galleries, with a cross-sectional area of 4.9 m^2. The total length of this raise is 47.5 meters. In the underground network, the primary ventilation access with a length of 135 meters is located at the end of the batch mixer, which is almost horizontal and has a cross-sectional area of 7 m^2. The end of this drift is linked to drift 1 by a raise. There is also an (old) ventilation raise connecting the ventilation access to the transport drift. It is responsible for transferring clean air to the batch mixer and cleaning the batch mixer dust. The length of this raise is 104.6 meters with a cross-section of 2.3 m^2. The required materials to fill the extracted stopes are supplied in two ways. In the Anguran mine, the initial and most ancient approach involves the provision of materials via a batch mixer situated at the terminus of drift No. 2. Subsequently, the materials traverse through the pump chamber before being transferred to the extracted stopes. The cross-section area of this excavation is 2 m^2 and its length is about 61 meters. To address the challenges associated with stope filling and the limited capacity of the aforementioned batch mixer, a raise has been recently excavated as a waste pass for the transportation of concrete from the ground to the mine. The length of this raise spans 125.4 meters. The cross-sectional area of this square-shaped raise is 2.5 × 2.5 meters. The entry point of this raise is positioned at the surface ground level and, from beneath, it intersects with the ramp and drift No. 2. Waste pass is significant in that it reaches the ground and facilitates natural ventilation. Nevertheless, the presentation of natural ventilation can be different as a result of the alterations in temperature of the region [30].

3. Simulation and analysis of the ventilation system in Anguran underground mine

As previously stated, the primary objective of this study is to simulate the ventilation impacts associated with the inclusion of a waste pass within the Anguran underground network. This waste pass affects the natural ventilation of the mine and consequently the ventilation design by increasing the access of the underground network to the ground surface. For this purpose, the location of the main fan was considered outside the mine, because in addition to easier maintenance, it is cheaper to supply energy on the ground, and also in case of mine fire, the fan will not be damaged. Then, the required airflow was calculated. Consistent with the mine ventilation design criteria and conditions of the Anguran mine, the airflow was calculated based on the personnel, the amount of explosives consumed, diesel machinery, and also dust removal. Table 1 features the required airflow of each section. In both forced and exhaust ventilation scenarios, the maximum theoretical airflow is determined by the summation of the total required airflow values provided in Table 1. Specifically, these values are recorded as 67.2 m^3/Sec and 91.25 m^3/Sec, respectively. Considering the arrangement of series, parallel, and combined branches as depicted in Figure (1) of the mine diagram, the minimum necessary airflow is determined for both forced and exhaust ventilation. Specifically, the minimum required airflow values are 57.2 m^3/Sec and 86.87 m^3/Sec, respectively.

The optimum value should be in such a way that in all branches of the mine ventilation network, the standards related to the removal of pollution are taken into account. In the Ventsim software, the minimum air flow is considered and then it is controlled and adjusted while the pollution removal standards taking into account. In this case, the estimated optimum required airflow of this network in the forcing and exhaust ventilation mode are equal to 57.5 and 87.5 m3/Sec. Therefore, these values are determined as the base values of essential airflow required in each of forcing and exhaust ventilation states.

Furthermore, the frictional resistance of the initial mine network with the characteristics of each branch considering a coefficient of 1.1 for local and meander loss was calculated to be equal to 0.017545 N.Sec^2/m^8.

At this stage, different ventilation layouts are designed according to the operational considerations of excavating the waste pass to select the suitable ventilation plan and the appropriate location for installing the main fan, and likely scenarios are defined as follows: The simplified depiction of the ventilation network and the corresponding airflow pathways for each of the potential scenarios are presented in the subsequent Figures.

1. In scenario 1, the main ventilation fan is installed at the portal of drift 2 and the fan operates as an exhausting system. The intake of fresh air into the mine ventilation network occurs through drift 1, subsequently providing ventilation to the stopes and ramps. Finally, the air exits the network through drift 2 (Figure 3).

2. In Scenario 2, the fan is located at the waste pass opening and the main ventilation fan operates as an exhaust at the opening of the ventilation raise. The ingress of fresh air into the mining network takes place via drift 1 and drift 2, effectively ventilating the stopes. Eventually, the air is expelled from the mine using a waste pass. (Figure 4).

3. In Scenario 3, the primary ventilation fan is positioned at the entrance of drift 1. Fresh air is introduced into the ventilation network through drift 2 and a waste pass. Subsequently, the mine air undergoes purification, and the contaminated air is expelled through drift 1. (Figure 5).

4. In Scenario 4, a fan is installed at the entrance of drift 2 to facilitate forced ventilation. Through drift 2, as well as the drifts, ventilation shaft, and ramps, clean air is introduced into the airways, resulting in the ventilation of the stopes. Subsequently, the contaminated air exits through drift 1 (Figure 6).

5. In Scenario 5, the fan infrastructure is positioned at the waste pass, while fresh air is compelled from the utmost elevation of the mine to the mining network via a ventilation system that gradually diminishes. The entry of air into the network occurs through the ramp and batch mixer station, where it undergoes ventilation before exiting drift 1. Additionally, a portion of the air is expelled through drift 2. (Figure 7).

6. In Scenario 6, the main ventilation fan is installed at the portal of drift 1 and operates by the forcing method. Fresh air enters the airways through drift 1 and the airways cause ventilation of the stopes and polluted air leaves through the waste pass as well as drift 2 (Figure 8).

After importing the required data, each of the 6 possible scenarios was simulated in Ventsim software. The simulation results and airway resistance curve are illustrated in Figure 9. The pressure drop and airflow required for the network in each ventilation scenario were compared by the simulation.

Table 1. Calculation of required airflow for each section.

Situation	Cross section Area (m2)	Work force		Explosives		Equipment (m3/sec)	Dust Cleaning (m3/Sec)		Maximum Airflow (m3/Sec)		Safety Factor	Required Airflow (m3/sec)	
		Numbers	Airflow (m3/sec)	Consumption (Kg/shift)	Airflow (m3/sec)		Forcing	Exhaust	Forcing	Exhaust		Forcing	Exhaust
Stopes	16	10	1	42	7.77	–	3.2	9.6	7.77	9.6	1.25	9.7	12
Gallery	20	30	3	-	–	24	4	12	24	24		30	30
Drift 1	13.1	20	2	–	–	4	2.62	7.9	4	7.9		5	9.87
Drift2	13.1	15	1.5	–	–	4	2.62	7.9	4	7.9		5	9.87
Ramps	9	20	2	–	–	6	1.8	5.4	6	6		7.5	7.5
Batch Mixer	44	15	1.5	–	–	–	8	24	8	24		10	30

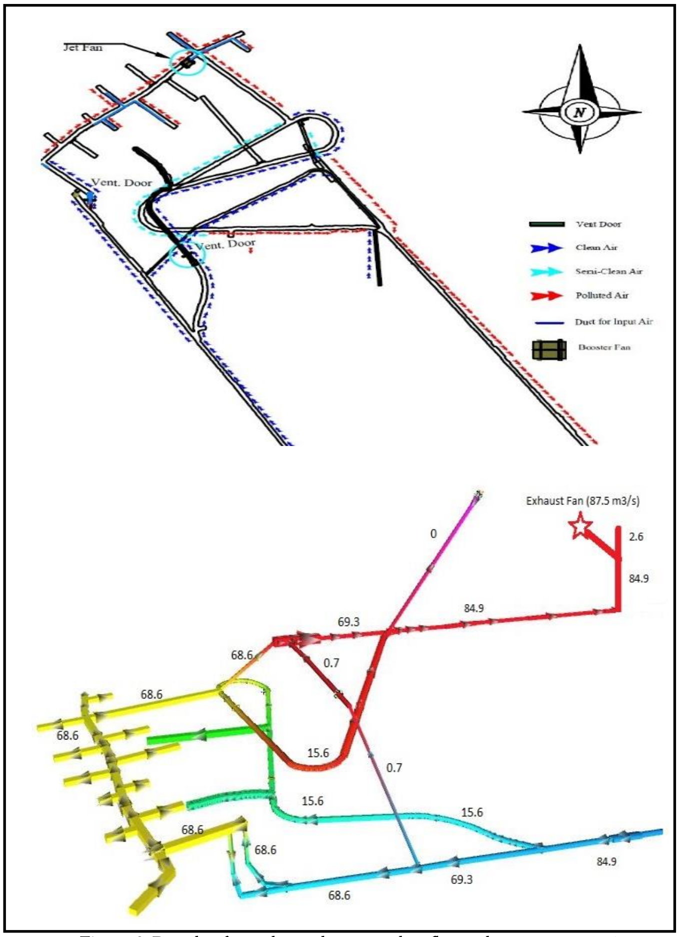


Figure 3. Details of ventilation layout and airflow values in scenario 1.

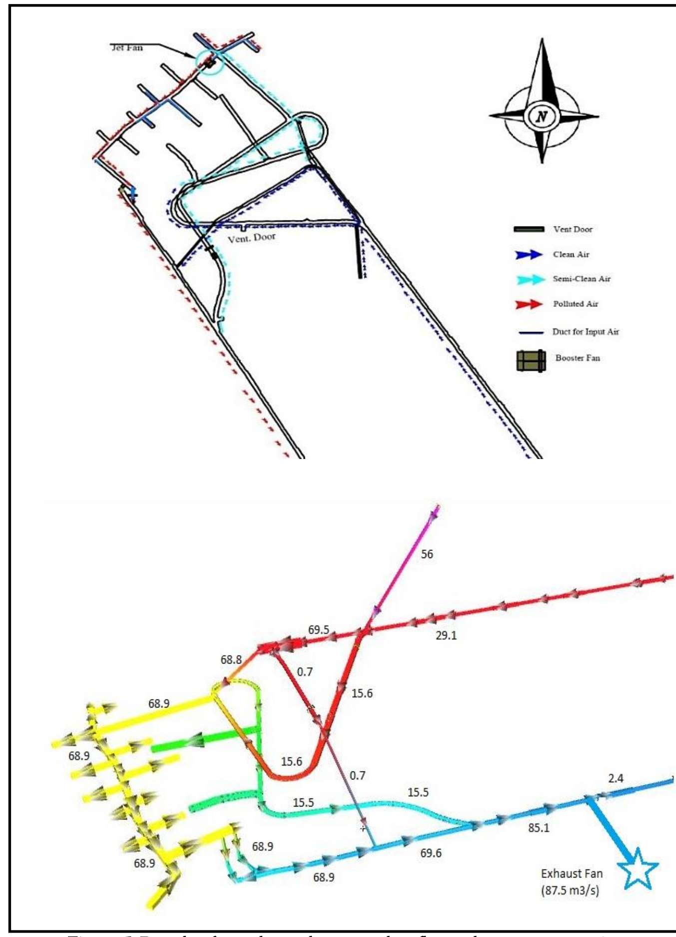


Figure 5. Details of ventilation layout and airflow values in scenario 3.

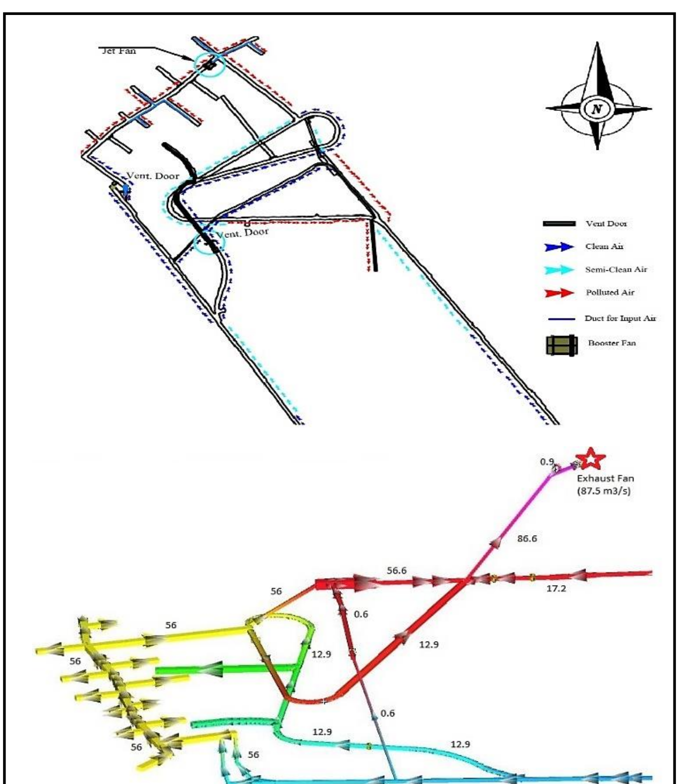


Figure 4. Details of ventilation layout and airflow values in scenario 2.

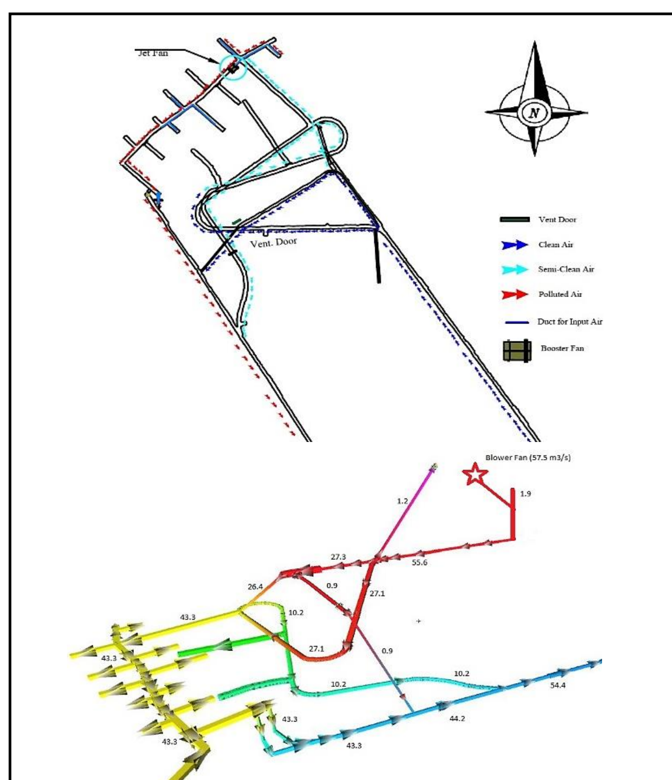


Figure 6. Details of ventilation layout and airflow values in scenario 4.

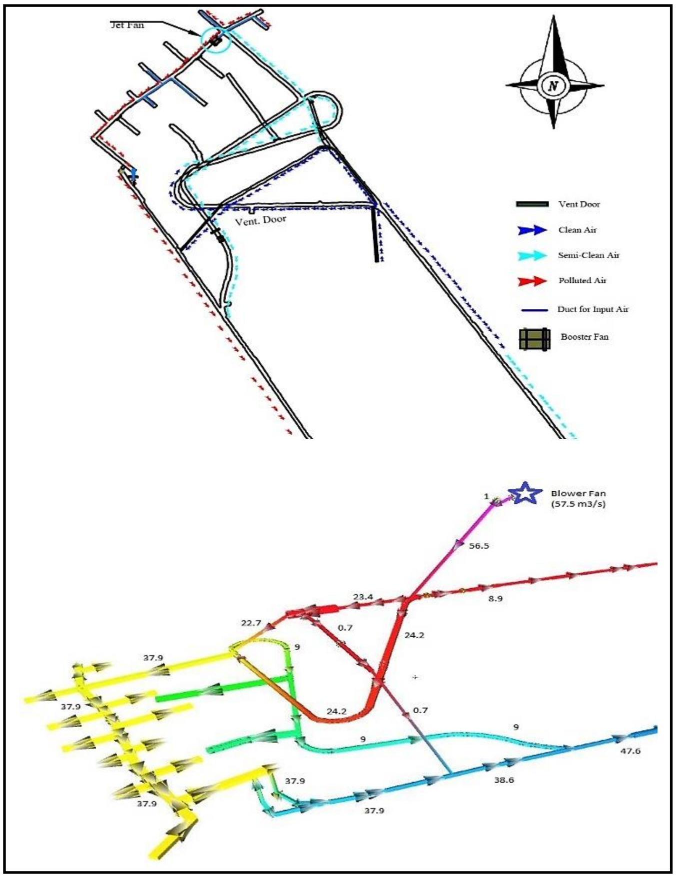


Figure 7. Details of ventilation layout and airflow values in scenario 5.

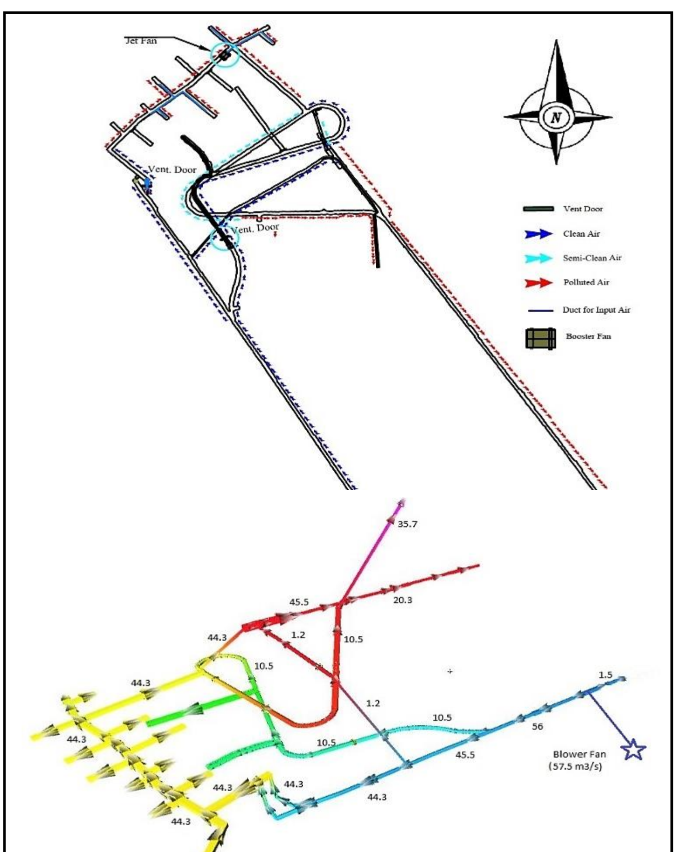
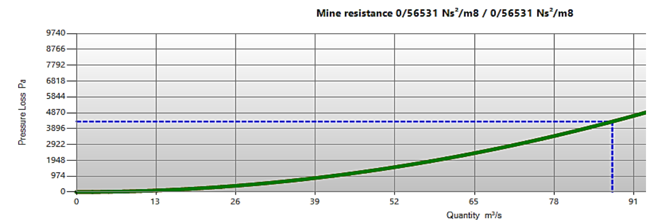
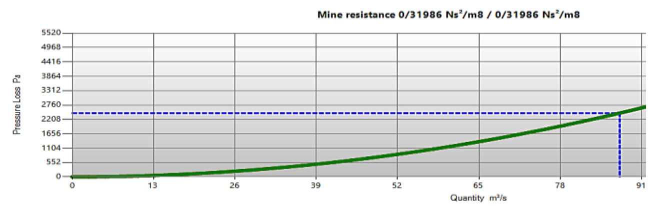


Figure 8. Details of ventilation layout and airflow values in scenario 6.

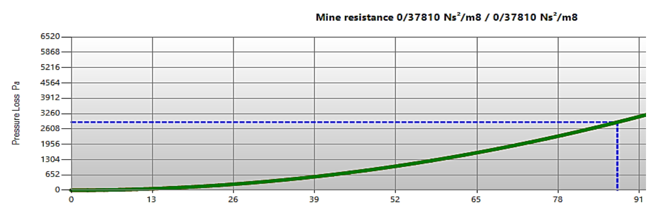
In accordance with previous statements, conducting simulations involves the comparison of different scenarios from a technical standpoint, while assessing their respective advantages and disadvantages. Table (2) presents a technical comparison of different scenarios. After employing the comparison of possible scenarios related to main fan location based on technical and operational considerations, lastly, ventilation from drift 1 (Scenario 6) is selected as the most suitable mine ventilation system.



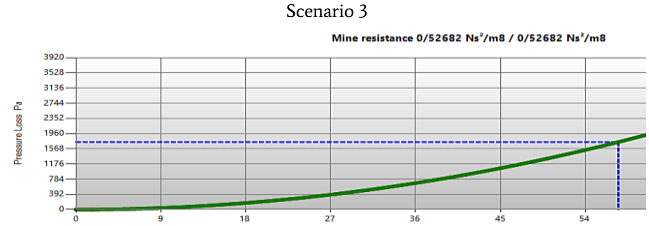
Scenario 1



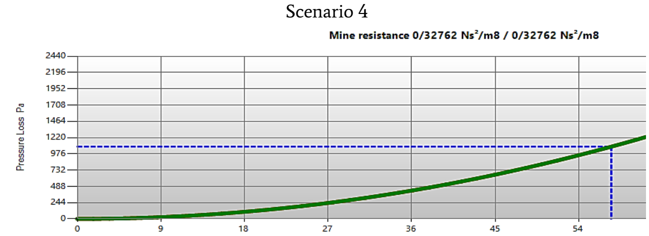
Scenario 2



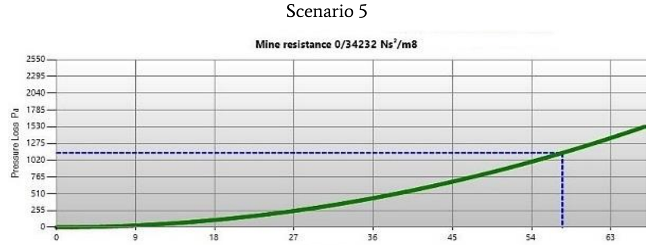
Scenario 3



Scenario 4



Scenario 5



Scenario 6

Figure 9. Airway resistance curve of different scenarios.

Table 2. Comparison of different scenarios for selecting the location of the main fan and the airflow direction.

Scenario	Ventilation Mode	Advantages	Disadvantages and Considerations
1	Exhaust	• Ascending ventilation • Same direction with natural ventilation • Natural draught in winter	• Excavating an airway near the main drift • Installing airlock at the beginning of drift 2 • Installation of two regulating doors with 0.9 m2 valve on the ramp • Installation of stopping without air leakage at the beginning of the waste-ore pass raise • Increasing the resistance of the mining network • Increasing the pressure and airflow • Closing the waste/ore pass raise and using all ways to access the ground surface as intake or return airways.
2	Exhaust	• Ascending ventilation • Same direction with natural ventilation • Natural draught in winter	• Lack of quick access to the main fan • Installing two regulating doors with 0.8 m2 valve on the ramp at a distance from each other to pass the locomotives (one of these doors should be closed) • Installation of regulating door with 0.9 m2 valve on the ramp • Installing a regulating door in the ventilation drift • High pressure and airflow • High energy consumption and high cost
3	Exhaust		• Descending ventilation and opposite direction with natural draught • Installing an airlock at the beginning of drift 1 • Installation of a regulating door with 0.9m2 valve in the ramp • Installing a ventilation door in the ventilation drift
4	Forcing	• Same direction with natural draught in summer	• Descending ventilation and opposite direction with natural draught in most seasons • Installation of high-resistance stopping in the waste pass to prevent air leakage • Installing an airlock at the beginning Drift 2 • Installing the regulating door with 1 m2 valve in the ramp • Installation of ventilation door in the ventilation drift • using all airways as intake or return airways
5	Forcing		• Descending ventilation and opposite direction with natural draught • Insufficient access in emergencies to the fan place • Installing two regulating doors with 0.5 m2 valve near the intersection of drift 2 and ramp • Installation of air regulating door with 0.9 m2 in ramp • installation of ventilation door in ventilation drift
6	Forcing	• Ascending ventilation and same direction with natural draught in most seasons	• Installation of an airlock in drift 1 • Installing a regulating door with 0.9 m2 in the ramp • Installation of a ventilation door in the ventilation drift

Based on the assessment of the mine ventilation network in scenario 6, the subsequent facilities were integrated into the network:

- Installing the airlock at the beginning of drift No. 1 to stop short circuit.
- Installing the ventilation door with an air-adjustable trapdoor in the ramp.
- Installing a ventilation door with an adjustable trapdoor in the ventilation drift.

Adding trapdoors and airlocks to the mine ventilation network increases the overall resistance of the network and more pressure is required to circulate the air, but the presence of these facilities is essential for suitable circulating air in the proper direction and air conditioning. Thus, by installing ventilation facilities such as an airlock, trapdoor, and regulators, the resistance of the mine network increases from 0.01754 $Nsec^2/m^8$ value to 0.34618 $Nsec^2/m^8$ as the final resistance of the underground network of the Anguran mine. Regarding the airflow and final resistance of the mining network, the pressure required for airflow is equal to 116.79 mm.H_2O (1145.319Pa) and the power of the main ventilation fan is equal to 65.81 kW. Therefore, the equation of the airway resistance curve in the Anguran mine was predicted as following equation:

$$\Delta P = 0.34323 * Q^2 \quad (7)$$

In the subsequent step, the ventilation network simulation parameters were adjusted to enhance the performance of the model. To achieve this objective, the selected scenario from the previous section was simulated as a new network using Ventsim software. A 3D grid was created, and all mine data were meticulously adjusted for this model. Initially, the mining network was simulated with a constant airflow, without the utilization of regulating valves.

It was observed that the intended airflow could not meet the needs of the mining network, so the simulation was performed again by installing regulating doors. This model can be used as a suitable model for mine ventilation management and is also able to calculate the ventilation features of different parts of the mine. The next step is to check the natural draught flow. Subsequently, utilizing the Ventsim software, the natural flow of ventilation was simulated at various temperatures, taking into account the pre-construction data obtained from the mine. This simulation was performed to validate and analyze the network behavior in the case of natural draught flow in excavated waste pass. To simulate the airflow, data regarding temperature, humidity, and air pressure in various locations of the mine network were gathered as inputs, as presented in Table 3. Subsequently, these data were imported into the Ventsim software for analysis and modeling purposes. Figure (5) illustrates the natural airflow in the mine, represented by the blue line, which is influenced by temperature variations. Additionally, the simulated current airflow is depicted by the orange line. It is evident from the graph that the simulated airflow aligns reasonably well with the actual data, showcasing a minimal prediction error within the model.

Table 3. Validation of natural airflow simulation results in different locations.

Row	Humidity (%)		Air Pressure	Temperature		Natural Airflow		Prediction Error (%)
	Inside the Mine Network	Out of Mine		Inside the Mine Network	Out of Mine	Collected	Simulation Results	
1	85.4	59.5	765.3	9.6	•	8.832	7.9	-10.55
2	91.1	39.2	761.1	9.4	1.1	7.74	7.8	0.77
3	86.8	60.8	762.7	9.5	2	9.216	8.9	-3.42
4	83.7	71.1	757.3	10	3.9	6.912	6.5	-5.96
5	91	39.3	763.1	9.8	4.4	7.424	7.1	-4.36
6	89.5	36.2	758.6	10.1	5.4	7.936	7.3	-8.01
7	80.1	70.4	764.5	10.7	6	8.576	8.2	-4.38
8	86.2	54.2	759.2	9.5	7.1	8.960	8.6	-4.01
9	82.7	57	763.3	9.5	8.1	9.728	8.7	-11.81
10	83.7	58.8	765.2	9.7	9.1	8.896	8.5	-4.38

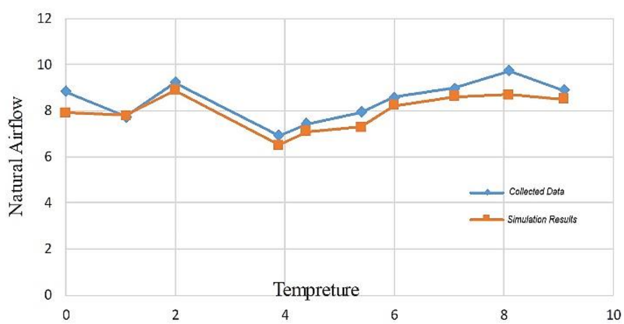


Figure 5. Comparison between Observed and Simulated Natural Airflow Values.

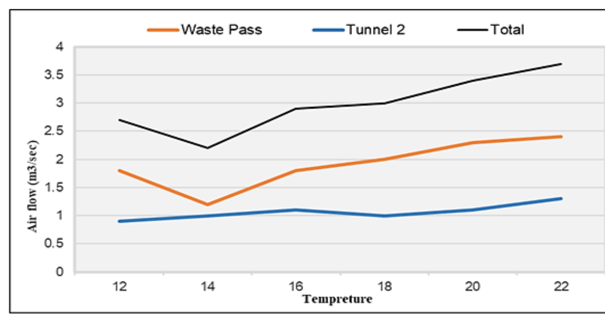


Figure 6. Natural airflow simulation in summer.

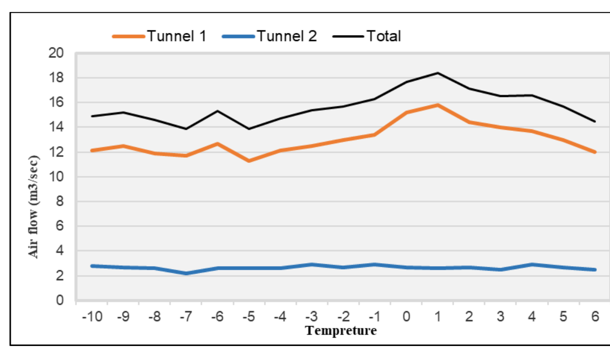


Figure 7: Natural airflow simulation in winter.

After validating the output of the model, the effect of excavating the waste pass on the natural ventilation flow is explored. To achieve this goal, waste pass specifications are added to the model and its effect on natural ventilation should be considered. The opening of this raise is located at surface ground level and from below at the intersection of the ramp and drift No. 2. The square-shaped raise possesses a cross-sectional area measuring 2.5 × 2.5 meters and extends a length of 125.4 meters. Using previous data about climatic conditions in the Anguran mine, it is anticipated that in winter, natural ventilation provides significant airflow in the mining network that aids in reducing mine ventilation costs. Significantly, the natural airflow reaches its peak during winter and its minimum during summer. Moreover, the airflow nearly ceases in spring and autumn, attributed to the average temperatures observed in these seasons. The simulation encompassed winter and summer conditions, incorporating the corresponding temperatures and pressures. Therefore, the natural airflow created in the mining network usually reaches its lowest value in summer. The mine's behavior, influenced by factors such as its geographical location, climatic conditions, and depth, conforms to this pattern during summer as well. Simulations were conducted under various temperature and pressure conditions, and the outcomes regarding natural airflow (measured in m^3/sec) for both summer and winter are displayed in Figures (6) and (7), respectively. During winter, the natural airflow penetrates the mine through tunnel 2 and waste passes, whereas in summer, it predominantly enters through tunnels 1 and 2. Simulations including diverse temperature, pressure, and humidity conditions were conducted throughout the year for the mine ventilation network. The amount of natural airflow entering the mining network is not a constant flow and is affected by various factors. Therefore, it cannot be used as a reliable flow. Natural ventilation simulation shows the fact that a significant amount of fresh air enters the mine naturally in winter and if act wisely, can be used to reduce mining costs.

To increase the incoming airflow to the mine ventilation network, the minimum value obtained from the simulation will be measured as the basis for the natural airflow to the mining network. The minimum inlet airflow to the mining network in winter is a value of 14 m^3/sec, which can greatly support the main ventilation fan of the mine. Based on the energy consumption calculations, it is determined that the energy savings resulting from natural airflow amount to 16.024 kWh, accounting for the overall pressure loss of the network, measured at 1.14 kPa. However, during other seasons, this value may be negligible due to the limited natural airflow within the mine. Nonetheless, it remains feasible to utilize this airflow to enhance the quality of the mine air.

4. Conclusion

This research involved the simulation of the ventilation network in a specific underground section of the Anguran lead and zinc mine using

Ventsim software. The study specifically took into account the impact of natural ventilation resulting from the excavation of the waste pass, which served as a newly established airway. Using the real data taken from this mine and ventilation calculations, the amount of airflow required for all parts of the mine was determined, and based on that, the total airflow of the network was assessed. The total required airflow in the mine network was adjusted by installing valves and seals. The total current required by the mine network was 57.5 m^3/Sec and the required pressure was estimated to be a number of 116.79 mm H_2O (1145.319 Pa). Six possible scenarios were defined and examined in order to define the location of the main fan and the airflow direction. To summarize, the optimal solution identified in scenario 6 was ventilation via drift 1. In this particular scenario, fresh air enters the ventilation network through drift 1, subsequently ventilating various sections of the mine through the waste pass and drift 2, while polluted air exits the mine network. Subsequently, the mine underwent natural ventilation simulations under various temperature and pressure conditions during both summer and winter seasons. During winter, the minimum influx of natural airflow into the mine was estimated at 14 m3/Sec, resulting in an energy saving of 16.024 kWh. Implementation of this approach during the initial three months of winter can potentially reduce electricity consumption by approximately 124,603 MJ, thereby impacting mining costs due to the significant expenses associated with energy supply in mines. Another outcome of this research was the development of a comprehensive model for the management of ventilation by using an integration of the natural and mechanical ventilation in the field of mining.

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