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# Assessing and Improving Compressed Air Network in Underground Mines (A Case Study in Iran)

**Mohammad Javad Rahimdel[1*]; Farzad Zafarzadeh[2]**

[1] *Department of Mining Engineering, Faculty of Engineering, University of Birjand, Birjand, Iran, https://orcid.org/0000-0002-7980-6212*
[2] *Department of Mining Engineering, Faculty of Engineering, University of Birjand, Birjand, Iran*

**Abstract**

Compressed air is one of the most common methods of energy transfer in industrial and mining systems. Compressed air has numerous applications in underground mines to ensure safety (ventilation fans), carry out extraction operations (compressed air equipment and machines), and manage technical services like dewatering and the operating of spare equipment. Therefore, it is necessary to investigate the compressed air supply systems in mines to assess the sufficiency of compressed air, reduce energy consumption, and lower operating costs. Considering the significance of utilizing compressed air in underground mines, it is essential to verify the adequacy of the flow rate and permissible pressure of compressed air for all mine air consumers. This requires proper design and adjustment of the compressed air distribution network. In this paper, the compressed air network in the main compressor house of the Qaleh-Zari copper mine in Iran was investigated. To achieve this goal, the compressed air consumption in various mining operation conditions was investigated and discussed after surveying the airflow transmission lines. The pressure drops in each line were estimated as well. Regarding the results, the airflow consumption in regular mining operations is about 36 cubic meters per second. The drop in air pressure within the network lines is below the permissible limit, but the overall pressure drop is significant. In this approach, practical adjustments such as changing the diameter of the pipes, increasing the airflow pressure, and utilizing local compressors near consumers' locations were proposed and investigated.

**Keywords:**
underground mining; compressed air network; pneumatic equipment; Qaleh-Zari copper mine

## 1. Introduction

Compressed air is one of the most popular energy sources used in industries due to its excellent transportability, safety, purity, cleanliness, storage capacity, and ease of use (**Hernández-Herrera, 2020**). Compressors use electric energy, and many countries such as Australia, Italy, France, China, and the USA contribute approximately 10% of the total electricity consumption (**Castellanos et al., 2019**). In underground mining operations, compressed air is used in various equipment, systems, and machines such as jackhammers (**Vardhan and Murthy, 2007**), drilling equipment (**Rahimdel et al., 2020**), blowers (**Marchildon and Mody, 2006**), pneumatic loaders (**Jonker, 2016**), tunnel boring machines (**Afradi et al., 2021; Afradi et al., 2022; Mikaeil et al., 2022; Afradi et al., 2024**), and auxiliary devices like ventilation doors and water sprays (**Mutagwaba et al., 1997; MIMI, 2012**). Moreover, pneumatic motors are widely used for dewatering, material transportation, and processing. They are also utilized in operating railway machinery, ventilation doors, steering brakes, railroad switches, and auxiliary ventilation systems. However, the energy consumption of compressed air systems accounted for about 18% of the total energy used in mining operations. Therefore, inefficient compressed air systems in underground mines reduce energy efficiency and, consequently, increase operational costs (**Zietsman, 2020; Merwe et al., 2022**).

Nowadays, the compressed air distribution network has been studied in surface and underground mines by various researchers. **Liebenberg et al. (2012)** implemented an automatic compressor control system in a South African gold mine to reduce electrical energy consumption. In the mentioned study, a compressor control strategy was implemented with a maximum allowed pressure of 520 kPa to ensure the correct pressure and airflow requirements for the mine at all times. In the proposed strategy, if the air pressure of the system increased above the set-point pressure, the controller would be prompted to stop at least one compressor. The results of the mentioned study showed that the proposed strategy saved 1.25 MW during the evening peak period, which reduced 17.3% of the electrical power consumption. **Cloete et al. (2013)** stated that rock drill operators often

Corresponding author: Mohammad Javad Rahimdel
*e-mail address: rahimdel@birjand.ac.ir*

leave manifold valves open due to negligence. This habit causes a pressure drop at the drills, which consequently extends the drilling time. Therefore, the reviewed paper examined the potential and viability of replacing manual air-closing valves with automatic ones. In the mentioned study, the effects of the proposed air-closing valve on a typical underground platinum mine in South Africa are analyzed. The results of this study showed that the proposed valves reduce compressed air wastage and increase production by boosting drill supply pressures. **Faramarz** and **Zarei Darmian (2015)** designed and modified compressed air network in the development panels of the Tabas Parvadeh Coal Mine in Iran. In this research, the volume of the compressed air consumption was determined based on the airflow consumption of each pneumatic equipment. The appropriate diameter for the compressed air transmission pipes was obtained according to the permissible pressure drop of the airflow. **Friedenstein et al. (2018)** simulated the compressed air system of a gold mine in South Africa and studied various scenarios to reduce operating costs. According to the results of the reviewed study, reducing the pressure of the emergency compressed air chambers led to an average energy consumption reduction to 0.9 megawatts. **Hallajian** and **Farrokhi (2018)** optimized the compressed air consumption in the Glendrood Coal Mine, Iran with the aim of reducing costs and improving the efficiency of the compressed air supply operations. In this research, the volume of compressed airflow required for the pneumatic machinery and equipment was estimated by taking into account the daily extraction of 900 tons of coal from two levels of the mine. According to the results, the necessary compressed airflow was estimated to be 72 cubic meters per minute. **Merwe et al. (2022)** enhanced the air-compressed system to create a zero-waste compressed air demand. In the reviewed paper, actual data was compared with the zero-waste baselines for pneumatic drilling equipment in a deep mine in South Africa. The results of the study showed that surface operations were the source of approximately 80 MWh of waste. Moreover, a total of 153 MWh of energy was wasted in the deep-level mine.

All pneumatic equipment and machines require compressed air at a specific pressure level. In other words, the diameter of the pipelines should be determined based on the pressure created by the compressor to ensure that the air pressure at the consumers' location is not lower than the pressure required by the device. Moreover, any interruption in the production and distribution of compressed air results in the cessation of pneumatic equipment operation, ultimately halting mining activities. Therefore, it is necessary to verify the compressed air consumption in various operational conditions and to monitor the pressure drop in the compressed air distribution lines.

A significant amount of time has elapsed since the installation and implementation of pneumatic equipment and devices at the Qaleh-Zari copper mine in Iran. The compressed air distribution system in this mine has deteriorated, leading to increased operating costs and energy prices. Hence, it is essential to examine the adequacy of the current compressors. By implementing this approach and designing a suitable compressed air distribution network, while optimizing the compressed air consumption, not only can operating costs and energy consumption be reduced, but also the environmental conditions of the mine can be improved.

The main purpose of this paper is to investigate and optimize the compressed air distribution network in the Qaleh-Zari copper mine. To achieve this, first the operational consumption of compressed air by the pneumatic equipment and machinery of the mine is investigated. The pressure drop of the airflow from the mine compressor houses to the consumer locations in the mine is then calculated and compared with the permissible level as outlined in the technical guidelines for distributing compressed air in Iranian mines. Furthermore, practical approaches are proposed to ensure an adequate supply of compressed air for the pneumatic equipment in accordance with the mine production plan.

This paper is organized as follows. In section 2, the research methodology discusses the concepts and definitions related to compressed air distribution networks, as well as the methodology for calculating the required amount of compressed air and compressed air drops. In Section 3, after introducing the studied area, the compressed air transmission network is monitored. The compressed air consumption and pressure drop in the network are investigated and discussed.

## 2. Methods

The compressed air produced in the mining compressor house is transferred to the consumption network through seamless steel pipes, which are typically designed to withstand a pressure of 7 bar or slightly more. In the mining stopes and secondary gates, rubber hoses with the shortest possible length are also utilized. The compressed air transmission pipes are connected by flanges and bushings. Along the path of compressed air transmission, various branches (such as tee sockets) are utilized to alter the direction of air movement. Auxiliary tools like stopcocks, valves, and pressure gauges are also employed. To prevent the infiltration of groundwater into the compressed air network and avoid potential damage, compressed air pipes are typically suspended from the walls of tunnels and galleries. In the compressed air network, it is usually recommended to use at least two air lines. In this scenario, if any defects occur in the network, the faulty part is isolated from the circuit for the required repairs to be conducted. In this scenario, conducting the repair operation will not interrupt the mining operation. Therefore, it is crucial to select the most appropriate pipes to ensure sufficient airflow for the pneumatic equipment while minimizing the pressure drop.

**Table 1:** The height coefficient regarding the height installation of the compressor (**MIMI, 2012**)

| **Height of compressor installation above sea level (m)** | 0 | 300 | 600 | 900 | 1200 | 1500 | 1800 | 2100 | 2400 |
|---|---|---|---|---|---|---|---|---|---|
| **Height coefficient** | 1 | 1.03 | 1.07 | 1.10 | 1.14 | 1.17 | 1.20 | 1.23 | 1.26 |

This section is dedicated to calculating the appropriate amount of compressed air for different areas of the mine, selecting the correct hose diameter, and estimating compressed air drop and losses according to the technical guidelines for distributing compressed air in Iranian mines **(MIMI, 2012)**. The first step involves selecting the appropriate pipe diameter for the compressed air distribution network, which is then presented and discussed. The calculation of the operational consumption of pneumatic equipment and the pressure drop in the compressed air network is presented and discussed.

## *2.1. Pipe selection for the compressed air distribution network*

If the diameter of the compressed air transmission pipe is incorrectly selected, the pressure at the end of the pipeline may decrease to a level that is insufficient for the proper operation of the equipment. In this case, the efficiency of the equipment is greatly reduced, leading to an increase in energy consumption. Therefore, the diameter of the compressed air distribution pipes should be selected so that the pressure drop along them does not exceed the permissible limit. For this purpose, the initial diameter is first selected based on criteria such as the permitted speed, technical and economic considerations, and then the pressure drop along the pipeline is calculated. If the pressure drop is within the permissible limit, the selected diameter will be suitable. Otherwise, pipes with larger diameters must be used. It should be mentioned that when selecting the diameter of the pipe based on the permissible speed, the pipeline's diameter should be chosen so that the velocity of the compressed air falls within the range of 6 to 7.5 meters per second. To achieve this, first, the rate of the compressed air flow is calculated as follows **(MIMI, 2012)**.

$$P_1 Q_1^{1.4} = P_2 Q_2^{1.4} \quad (1)$$

Where, $P_1$ is the absolute pressure of the atmospheric air, $P_2$ is the absolute pressure of the compressed air inside the pipe (obtained from the sum of the absolute pressure and the relative pressure of the compressed air), $Q_1$ is the predicted rate of the free airflow in the pipe, and $Q_2$ is the rate of airflow in the pipe.

After determining $Q_2$, the diameter of the pipe can be obtained from **Equations 1** and **2** (**MIMI, 2012**).

$$Q_2 = \left(\frac{\pi}{4} d^2\right) V \quad (2)$$

$$d = \sqrt{\frac{4Q^2}{\pi V}} \quad (3)$$

Where $Q_2$ is the rate of the airflow in the pipe, $V$ is the compressed air speed in the pipe and d is the pipe diameter.

In general, to determine the diameter of the pipe, the closest diameter to the standard pipes is selected, and then the pressure drop of the pipeline is calculated. To do this, first, the smallest standard diameter whose pressure drop is within the permissible limit is selected. It should be noted that according to **MIMI (2012)**, in the secondary lines branched from the main pipe, the selected diameter should be such that the maximum speed of the compressed airflow is between 12 to 15 meters per second.

## *2.2. Calculation of the compressed air flow rate*

After calculating the nominal consumption of each pneumatic equipment, it is necessary to determine the actual consumption of the equipment by taking into account correction coefficients. It is worth noting that the appropriate compressor is selected based on the total operational consumption of equipment. Regarding the **MIMI (2012)**, the most important correction coefficients are height, leakage, and synchronicity coefficients.

The remainder of this section is devoted to introducing these coefficients.

### 2.2.1. Height coefficient

The altitude of the compressor above sea level significantly affects the rate of airflow production. Therefore, the correct rate of the compressed airflow should be calculated by multiplying the initial airflow produced by the compressor by the height correction coefficient. The height coefficient can be obtained from **Table 1 (MIMI, 2012)**.

### 2.2.2. Simultaneity coefficient

In general, not all pneumatic consumers work simultaneously. Therefore, according to the location and the number of active consumers, a coefficient known as the simultaneity coefficient should be taken into account. In this approach, if there are two pneumatic devices, only one of them is active at a time. The device consuming the most air is considered for calculating airflow consumption. For example, if there is an active jackhammer and loader in the working stopes, only the most air-consuming equipment is considered because only the hammer or loader is in operation at the same time. To achieve this, the simultaneity coefficients are taken into account. According to **MIMI (2012)**, the synchronicity coefficient for the active hammers and loaders is obtained from **Table 2**.

**Table 2:** Simultaneity coefficient based on the number of drilling machines on loaders (**MIMI, 2012**)

| No. of drilling equipment or loader | Simultaneity coefficient | No. of drilling equipment or loader | Simultaneity coefficient |
|---|---|---|---|
| 1 | 1 | 10 | 0.71 |
| 2 | 0.9 | 11 | 0.67 |
| 3 | 0.87 | 12 | 0.63 |
| 4 | 0.85 | 13 | 0.58 |
| 5 | 0.82 | 14 | 0.55 |
| 6 | 0.80 | 15 | 0.53 |
| 7 | 0.77 | 16 | 0.52 |
| 8 | 0.75 | 17 | 0.51 |
| 9 | 0.74 | 18 | 0.49 |

#### 2.2.3. Leakage coefficient

The compressed air in the air distribution network passes through pipeline connections. Therefore, depending on the type of connections and pipelines, there may be air leakages. In this scenario, to guarantee sufficient airflow, the operational airflow consumption should be calculated based on the leakage coefficient. According to the **MIMI (2012)** report, the leakage coefficient ranges from 1.1 to 1.15. In addition, if there is no accurate information about the details of the pipelines, the leakage coefficient is considered as 1.15.

### *2.3. Pressure drops in the compressed air distribution network*

Nowadays, various relationships, tables, and experimental diagrams have been developed to calculate the pressure drop in compressed air networks. In this section, the relationships introduced by Harris and Atlas Copco, which are the most common relations used in the calculation of pressure drop, are presented. The compressed air pressure drop, as per the Harris formula, is as follows **(MIMI, 2012)**.

$$\Delta p = \frac{800LQ^2}{rd^{5.3}} \quad (4)$$

Where $\Delta p$ is the pressure drop (bar), $L$ is the effective length of the pipe (m), $Q$ is the volume flow rate (in liters per second, l/s), $r$ is the average pressure or the ratio of the absolute pressure of the compressed air to the absolute pressure of the atmospheric air, and $d$ is the internal diameter of the pipe (mm).

The pressure drop, according to the **Atlas Copco (1975)** formula, can be obtained as follows:

$$\Delta p = \frac{fLQ^{1.58}}{p_1 d^5} \quad (5)$$

Where $\Delta p$ is the pressure drop along the pipeline (bar), $L$ is the effective length of the pipe (m), $f$ is the dimensionless friction coefficient which is considered as $1.6 \times 10^8$ for normal pipes, $Q$ is the volume flow rate (liters per second), $P_1$ is the absolute air pressure at the beginning of the pipeline (bar), and $d$ is the internal diameter of the pipe (mm).

### *2.4. Compressed air losses*

The compressed air network consists of various connections. At the beginning of the network installation, these connections have no defects. However, as time passes, the connections wear out, causing air to escape from them. For this reason, the volume of air consumed by the equipment differs from the amount of air produced by compressors. The pressure drops caused by the connections are usually expressed as the equivalent length of the pipe. In this approach, the pressure drops through the fitting/valve are equivalent to the pressure lost through a certain length of piping at the corresponding flow rate. For many common fittings found in piping systems, such as expansions, contractions, elbows, and valves, equivalent length data are available to estimate the losses **(Green and Southard, 2019)**. In a compressed air distribution network, the equivalent length is added to the length of the subsequent pipe. In other words, the effective length of compressed air equals the pipe length plus the equivalent length.

## 3. Compressed air distribution network in the Qaleh-Zari Copper Mine

In this section, the compressed air distribution network following the introduction of the Qaleh-Zari copper mine is examined. The Qaleh-Zari underground copper mine, covering an area of approximately 6 km$^2$, is situated 180 km south of Birjand city in the Southern Khorasan Province of Iran. The Qala-Zari copper mine is located at an altitude of 1450 meters above sea level. The Qaleh-Zari copper mine is the only underground mine in Iran where extraction is carried out using shrinkage-stopping methods. The width of the mineralization area ranges from 0.5 to 7 meters and is extracted using the drilling and blasting method. The blast holes are drilled using pneumatic drilling picks. Pneumatic loaders are used to

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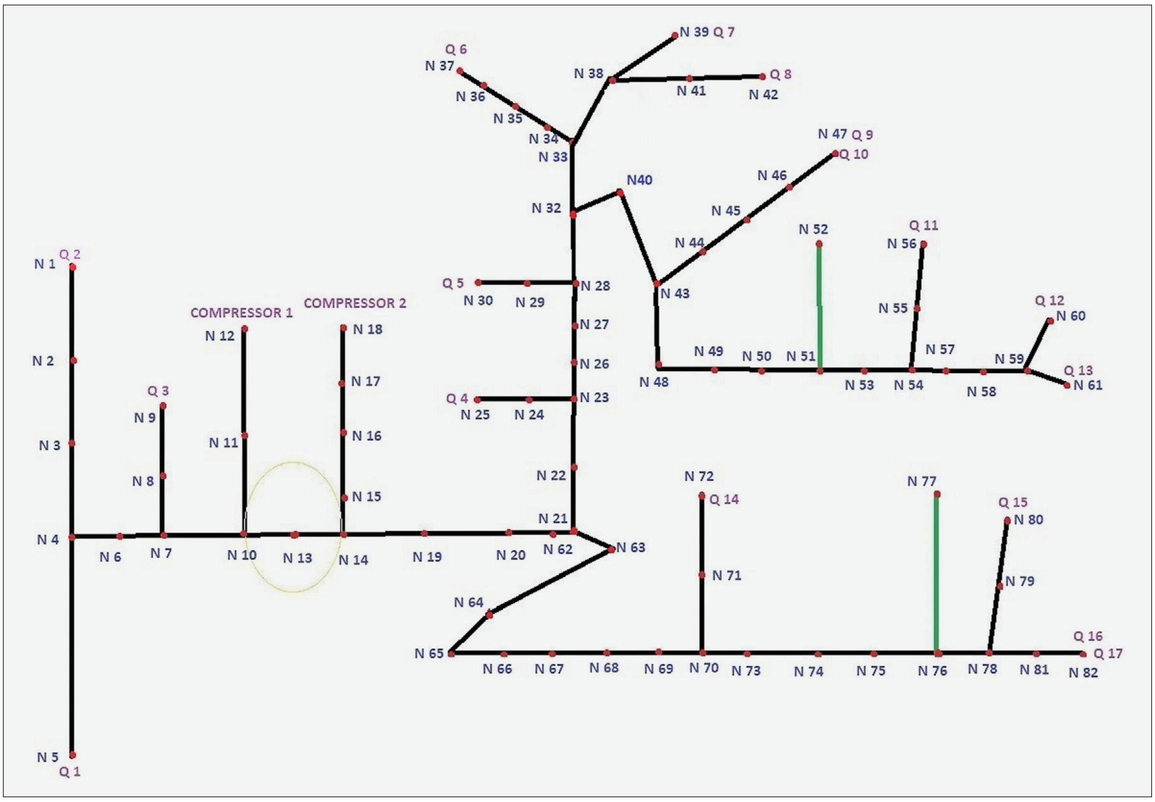


**Figure 1:** The simplified compressed air distribution network of the Qaleh-Zari copper mine

load the extracted ores into wagons. The extracted ores are then moved to the surface through six vertical shafts and one inclined (or main) shaft. The total production of the mine is approximately 450 tonnes per day. All shafts have their own compressor house to manage all pneumatic equipment. It should be noted that the compressor house of the main shaft (the incline shaft) handles both the pneumatic equipment in the underground mining operation and the mineral prospecting plant (**Rahimdel, 2023; Rahimdel and Ghodrati, 2023**).

### *3.1. Survey and measurement of the characteristics of compressed air network*

To measure the loss of compressed air at the mine consumers' location, the first step involved surveying the compressed air distribution network from the mine compressor house to the consumers' location. The main compressor house of the mine has three similar piston compressors. Two compressors are always active as the main compressors, while one compressor is designated as a reserve compressor. The main compressors operate in three working cycles. If any of the main compressors stops due to failure or any other reason, the reserve compressor will come into operation and be used until the main compressor is repaired. According to the extractive map of the mine, the compressed air transmission lines from the main compressor house of the mine were surveyed, and the compressed air distribution network was drawn. Figure 1 shows the compressed air distribution network of the mine. Each line in Figure 1 represents the compressed air transmission lines. The distance between each point represents the air transmission line, taking into account the effective length of the pipe or hose. It should be noted that the impact point of two series compressors is considered as point N13. It is worth noting that as long as the diameter or type of the pipe has not changed, the lines are drawn in a straight line. The diameter of the pipes in the compressed air distribution network was calculated and is provided in Table 3.

**Table 3:** Specification of the pipes and hoses in the compressed air distribution network

| Pipe/hoses type | External diameter (mm) | Internal diameter (mm) |
|---|---|---|
| Seamless iron | 219.075 | 202.717 |
| Seamless iron | 168.275 | 154.051 |
| Seamless iron | 323.850 | 303.225 |
| Seamless iron | 114.300 | 102.260 |
| Seamless iron | 60.325 | 52.502 |
| Seamless iron | 33.401 | 26.645 |
| Cast iron | 175.260 | 152.908 |
| Galvanized | 33.401 | 27.559 |
| Polyethylene | 88.900 | 77.927 |
| Polyethylene | 73.025 | 62.713 |
| Polyethylene | 60.325 | 49.251 |
| Polyethylene | 26.670 | 20.930 |

**Table 4:** Correction coefficient and actual air consumption for pneumatic consumers

| Consumer | Nominal consumption ($m^3$/min) | Actual consumption ($m^3$/min) |
|---|---|---|
| Q1 | 12 | 13.8 |
| Q2 | 0.0004 | 0.0004 |
| Q3 | 0.0017 | 0.0019 |
| Q4 | 0.0002 | 0.0003 |
| Q5 | 0.0024 | 0.0032 |
| Q6 | 0.0002 | 0.0003 |
| Q7 | 0.0002 | 0.0003 |
| Q8 | 0.0002 | 0.0003 |
| Q9 | 5 | 5.792 |
| Q10 | 2 | 0 |
| Q11 | 2 | 2.397 |
| Q12 | 5 | 5.792 |
| Q13 | 2 | 0 |
| Q14 | 0.0002 | 0.0003 |
| Q15 | 2 | 2.397 |
| Q16 | 2 | 0 |
| Q17 | 5 | 5.792 |

**Table 5:** The pressure drops in the placement of consumers

| Consumer | $P_{Harris}$ (bar) | $P_{AtlasCopco}$ (bar) | $P_{Average}$ (bar) |
|---|---|---|---|
| Q1 | 6.435 | 6.456 | 6.446 |
| Q2 | 6.869 | 6.872 | 6.870 |
| Q3 | 6.929 | 6.929 | 6.929 |
| Q4 | 6.863 | 6.858 | 6.860 |
| Q5 | 6.632 | 6.615 | 6.624 |
| Q6 | 6.605 | 6.588 | 6.597 |
| Q7 | 6.605 | 6.588 | 6.597 |
| Q8 | 6.605 | 6.588 | 6.597 |
| Q9 | 4.523 | 4.515 | 4.419 |
| Q10 | 4.523 | 4.515 | 4.419 |
| Q11 | 5.702 | 5.643 | 5.673 |
| Q12 | 5.613 | 5.545 | 5.579 |
| Q13 | 5.666 | 5.606 | 5.636 |
| Q14 | 6.139 | 6.097 | 6.118 |
| Q15 | 5.470 | 4.294 | 5.382 |
| Q16 | 5.729 | 5.621 | 5.675 |
| Q17 | 5.729 | 5.621 | 6.675 |

### *3.2. Actual consumption and pressure drop estimation*

Compressed air equipment, used in the Qaleh-Zari copper mine, includes drill bit sharpeners, tunnel loaders, and perforators. The operational compressed air consumption of each pneumatic equipment was calculated according to the nominal consumption and the correction coefficients, mentioned in sections 2-2. The results are given in **Table 4**. It should be noted that, since the mine compressor house is 1377 meters above sea level, the height coefficient was considered from Table 1 to be 1.15. The simultaneity coefficient of each network line was calculated based on the number of active consumers in each line, as shown in the **Table 2**. Furthermore, based on expert opinion and in accordance with the **MIMI (2012)** instructions, the pipe leakage coefficient was determined to be 1.15 due to the wear and decay of the network pipes.

In the rest of this section, the pressure drop in each line of the studied network is calculated. The relative pressure of the compressed air produced by the compressors was measured by reading the pressure gauge installed in the compressor house of the mine, which showed 88 psi (6 bar). Considering the ambient air pressure as 86 psi, the absolute pressure of the compressed air produced by the compressors was calculated to be 100 psi (6.9 bar). Subsequently, the pressure drop in all lines was calculated using the Harris formula (Equation 4) and the Atlas Copco formula (**Equation 5**). The results are presented in **Table 5**.

## 4. Discussion

The operational compressed air consumption of pneumatic equipment (see **Table 4**) indicates that the total consumption of compressed air is 35.97 cubic meters per second. It should be noted that the mineral processing plant, with a consumption rate of 13.8 cubic meters per second, is the largest consumer of compressed air in the network. Regarding the pressure drop values obtained for each line of the studied network, although the pressure drop in all lines of the network is within the permissible limits of the **MIMI (2012)**, the pressure drop at the location of consumers Q9 and Q10 is approximately 1.8 bar below the permissible limit. It is necessary to mention that, according to **MIMI (2012)**, the maximum allowable pressure drop is 10% of the initial pressure in the pipeline. The significant pressure drop adversely affects the performance of pneumatic equipment at the locations of Q9 and Q10. Therefore, it is necessary to adjust the network and implement control measures to reduce the pressure drop, especially in the lines supplying consumers Q9 and Q10.

The remainder of this section is devoted to presenting some practical adjustments to keep the pressure drop at permissible levels. In the first scenario, the pressure drops at the locations of consumers Q9, Q10, Q15, Q16, and Q17 were studied when the diameter of the pipes supplying these consumers was increased. Since the acceptable pressure for compressed air pipes is typically considered to be 7 bars **(MIMI, 2012)**, one practical solution worth exploring is increasing the diameter of the pipes to reduce critical pressure drops. If the diameter of the compressed air pipes in the N23-N40, N40-N43, and N43-N44 pipelines changes from 2 to 3 inches, the di-

**Table 6:** The average pressure at the consumer's location (compressor relative pressure: 7.5 bar or 109 psi)

| Consumer | Pressure (bar) | Consumer | Pressure (bar) | Consumer | Pressure (bar) | Consumer | Pressure (bar) |
|---|---|---|---|---|---|---|---|
| Q1 | 7.053 | Q5 | 7.218 | Q9 | 5.295 | Q13 | 6.311 |
| Q2 | 7.445 | Q6 | 7.193 | Q10 | 5.295 | Q14 | 6.752 |
| Q3 | 7.500 | Q7 | 7.193 | Q11 | 6.345 | Q15 | 6.082 |
| Q4 | 7.436 | Q8 | 7.193 | Q12 | 6.260 | Q16, Q17 | 6.348 |

ameter of the N45-46 pipeline changes from 2½ to 3 inches, and the diameter of the N46-N47 pipeline changes from ¾ to 1¼ inches, the pressure at Q9 and Q10 reaches 6.36 bar, which is within the permissible level. Moreover, if the diameter of the pipelines N68-N69, N69-N70, and N70-N73 increases from 2 to 3 inches, and the polyethylene pipes in lines N73-N74, N75-N76, N76-N78, and N78-N79 are replaced with seamless iron pipes with a diameter of 2 inches, the pressure at consumer Q15 and consumers Q16 and Q17 will reach 5.81 and 6 bar, respectively. Although these adjustments mentioned above lead to a reduction in the pressure drop at the consumers' location, a technical and economic study of implementing and adjusting the proposed pipelines is necessary. Regarding these results, the pipe diameter has a significant effect on the pressure drop at the consumer's location, which is inconsistent with previous studies (**Zarei Darmian et al., 2014; Faramarz and Zarei Darmian, 2015; Maleki et al., 2018**).

In the second scenario, the pressure drop at the consumer's location was investigated when the relative pressure of compressors was increased. If the relative pressure of the compressed air in the main compressor house of the mine is increased to 7.5 bar (or 109 PSI), the pressure drop at the consumer sites will decrease significantly. The results are presented in **Table 6**. In this case, the pressure drop at the locations of consumers Q9 and Q10 is reduced by 17%. Since a considerable amount of time has elapsed since the construction of the compressed air network in the Qaleh-Zari copper mine, it is crucial to monitor all sections of the network to assess the capacity to withstand the pressure in the compressed air tanks, pipes, and hoses.

The **MIMI (2012)** guideline-based procedure for calculating the compressed airflow consumption was successfully applied in designing the compressed air network in various underground coal mines in Iran, such as the Parvadeh Tabas mine (**Zarei Darmian et al., 2014; Faramarz and Zarei Darmian, 2015**), Razmja (**Maleki et al., 2018**), and Glendrood (**Hallajian and Farrokhi, 2018**) mines. Given the considerable time that has elapsed since the compressed air network was established in the Qaleh-Zari copper mine, raising the airflow pressure could potentially result in unfavorable outcomes. Hence, deploying auxiliary compressors near consumers experiencing significant pressure drops can be deemed a practical solution. Future studies could focus on the economic implications of the proposed solutions and their effects on the overall energy consumption and operational costs.

## 5. Conclusions

Designing the compressed air distribution network is one of the most vital stages in underground mining. Compressed air plays an important role in ensuring safety, technical services, and operations. Any delay in providing an adequate supply of compressed air not only results in financial losses but also jeopardizes the health and safety of the workers and operators. Therefore, it is necessary to check the volume of the compressed air flow and pressure drop for the optimal operation of pneumatic equipment and machines. In this paper, the airflow consumption and pressure drop in the compressed air distribution network of the Qaleh-Zari copper mine in Iran were studied and discussed. Furthermore, practical solutions are proposed to maintain pneumatic equipment at the desired level in accordance with the design standards of compressed air systems in mines.

Regarding the results, the total volume of the compressed airflow consumption network under study is 36 $m^3/s$, with the mineral processing plant having an airflow volume of 13.8 $m^3/s$, making it the most significant consumer in the network. In the current mining conditions, the pressure drop at the location of consumers Q9 (loader) and Q10 (jackhammer) at a depth of 175 meters in the mine is approximately 1.8 bar, significantly impacting the equipment's performance. By increasing the diameter of the compressed air pipes in the N23-N40, N40-N43, and N43-N44 routes from 2 inches to 3 inches, enlarging the diameter of the N45-46 pipeline from 2½ inches to 3 inches, and expanding the diameter of the N46-N47 pipeline from ¾ inch to 1¼ inches, the pressure at consumer locations Q9 and Q10 will reach 6.36 bar, falling within the acceptable pressure drop range. Furthermore, if the relative pressure in the main compressor house of the mine increases to 7.5 bar, the pressure drop at the location of these consumers decreases by 17%.

The results of this study are beneficial for mine managers and contractors to ensure an adequate supply of compressed air at the required pressure level.

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## SAŽETAK

### Procjena i poboljšanje sustava stlačenoga zraka u podzemnim rudnicima (studija slučaja u Iranu)

Prijenos energije pomoću stlačenoga zraka jedna je od najčešće primjenjivanih metodologija prijenosa energije u industriji i rudarstvu. Ona ima brojne primjene u podzemnim rudnicima, kao na primjer kod omogućavanja sigurne ventilacije, izvođenja radova na eksploataciji (oprema i strojevi za komprimirani zrak) i upravljanja tehničkim uređajima kod odvodnjavanja i rada rezervne opreme. Zbog toga je potrebno istraživati svojstva sustava opskrbe sa stlačenim zrakom kako bi se procijenila dostatnost stlačenoga zraka, smanjila potrošnja energije i smanjili operativni troškovi u rudnicima. S obzirom na važnost upotrebe stlačenoga zraka u podzemnim rudnicima, nužno je provjeriti primjerenost protoka i razinu dopuštenoga tlaka za sve potrošače rudničkoga zraka. Sve to zahtijeva pravilno projektiranje i usklađivanje distribucijske mreže stlačenoga zraka. U ovoj studiji istražena je mreža stlačenoga zraka povezana s glavnom kompresorskom stanicom rudnika bakra Qaleh-Zari u Iranu. Istražena je i raspravljena potrošnja stlačenoga zraka u različitim rudarskim uvjetima nakon što su pregledani postojeći vodovi za protok zraka. Također su procijenjeni padovi tlaka u svakoj liniji. Rezultati su pokazali da protok zraka u redovitome rudarskom radu iznosi oko 36 kubnih metara u sekundi. Pad tlaka zraka unutar vodova u mreži ispod je dopuštene granice, a znatan je i ukupni pad tlaka. Na osnovi toga predložene su i istražene praktične prilagodbe u sustavu poput promjene promjera cijevi, povećanja tlaka protoka zraka i korištenje lokalnih kompresora u blizini lokacija potrošača.



**Ključne riječi:**
podzemna eksploatacija, mreža komprimiranoga zraka, pneumatska oprema, rudnik bakra Qaleh-Zari


## Author's contribution

**Mohammad Javad Rahimdel (1)** (Associate Professor of Mining Engineering at the Department of Mining Engineering, University of Birjand, Iran) contributed to the paper by supervising, providing methodology, conducting data analysis, writing, reviewing, and editing the paper. **Farzad Zafarzadeh (2)** (B.Sc. graduated in Mining Engineering, Department of Mining Engineering at the University of Birjand, Iran), performed the field work and data analysis.