Ventilation systems in Brazilian underground miners: an overview

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Abstract: In the past Brazil starred in relevant ventilation and innovative projects for temperature control and improvement of underground working conditions in mines, such as the large-scale surface cooling plant for underground air conditioning projected by George Chalmers and Eric Davies at the historical Morro Velho gold mine, approximately 2.4 km deep, in 1920 in Minas Gerais. Currently, although mining is mainly open-pit, underground mining remains quite significant, and with a great expansion trend, demonstrated by the expressive number of underground mines and relevant new projects with underground mining. Despite the remarkable increase in the number of ventilation studies in recent years, it is verified that compared to other mining traditional countries there is still a considerable research gap about the ventilation and cooling systems employed in the country. This work aims, therefore, to present a current panorama of ventilation systems in Brazilian mines, highlighting not only basic data of the main and auxiliary ventilation, such as types of systems and fans more adopted, but also design specifics. From a list of the Brazilian National Mining Agency, extensive bibliographic research and a comprehensive survey were carried out with the mining companies. In addition to interesting generic conclusions, the analysis of the obtained data revealed a marked heterogeneity between the ventilation systems employed, depending on the mines' sizes, allowing the identification of three distinct patterns. Although still a minority, it is also observed that there have been significant technological advances in medium/large- scale mines recently, from the use of intelligent systems for automation and ventilation control, measures for energy consumption reduction, and ventilation systems efficiency increase. Although the mines' average depth is not very high, currently there are already 4 Brazilian mines with refrigeration systems.

Keywords: Mine ventilation systems · Mine refrigeration systems · Brazilian mines · Ventilation on demand

1. Introduction

In the past Brazil starred in relevant ventilation and innovative projects for temperature control and improvement of underground working conditions in mines, such as the large-scale surface cooling plant for underground air conditioning projected by George Chalmers and Eric Davies at the historical Morro Velho gold mine, approximately 2.4 km deep, in 1920 in Minas Gerais [1,2].

Currently, although mining is mainly open-pit, underground mining remains quite significant, and with a great expansion trend, demonstrated by the expressive number of underground mines (more than 75) located mainly in the country midwest, southeast, south and northeast regions and relevant new projects with underground mining recently implemented, such as the Aripuanã Project, for the extraction and processing of zinc (the main product), copper and lead in Serra do Expedito (Mato Grosso), which started operations in July this year [3–5]. There are also important projects that provide for underground mining under discussion in the country, such as the implementation of the Autazes potash mine in Amazonas to produce potassium chloride for fertilizers, which must employ the Room-and-Pillar Mining Method and have refrigeration systems [6–8]. In addition, it is worth remembering that some mines that are currently paralyzed show great potential for reactivation in the future, and that new geophysical prospecting methods will certainly stimulate new research and identification of promising targets in several depleted underground mines, such as several smaller mines. of fluorite and lead in the states of Paraná and Santa Catarina and of tungsten in the state of Rio Grande do Norte [5].

Despite the remarkable increase in the number of ventilation studies in recent years [9–17], it is verified that compared to other mining traditional countries there is still a considerable research gap about the ventilation and cooling systems employed in the country. This work aims, therefore, to present a current panorama of ventilation systems in Brazilian mines, highlighting not only basic data of the main and auxiliary ventilation, such as types of systems and fans more adopted, but also design specifics.

2. Materials and Methods

For this purpose, the methodology applied in this research was divided in two stages.

The first consisted of extensive bibliographic research in digital libraries and varied bibliographic databases to collect information on the ventilation systems currently used in Brazilian mines, which, as mentioned above, confirmed the lack of publications on this topic. The second step was to perform a thorough survey carried out with the Brazilian mining companies to obtain or eventually confirm data on their ventilation systems, through a form to be filled out via Google Forms and sent by email, in addition to telephone contacts.

From the publication of Heider [5] and contact with the Brazilian National Mining Agency (ANM),it was possible to make a list with the 76 underground mines in the country, which served as a starting point for the research development.

After the data collection phase, all the information obtained was compiled in an Excel database and its analysis through Dynamic Tables.

It is observed that it was possible to contact approximately 78% of the listed underground mines. Despite intensive research and effort, 17 of the listed mines could not be reached as their current email addresses or telephone numbers could not be located. Twenty-six of the 59 mines contacted did not want to provide information about their ventilation systems and 6 of the mines listed were deactivated. In this way, the study focused and can be developed from the data collected in 27 underground mines in operation.

For reasons of confidentiality, the names of most companies and their respective mines involved in the research will not be disclosed.

3. Results and Discussions

For a better characterization of the studied mines (14 metallic, 6 non-metallic and 7 coal), they were initially classified according to the mining method used and their maximum depth, as shown in Figure 1.

It is observed that within the Room-and-Pillar mining method group, mines are included that mine gems by a more artisanal method, which is similar to Room-and-Pillar. Also, in the Sublevel Stopping mining method group are mines that employ this method with long holes with or without backfill.

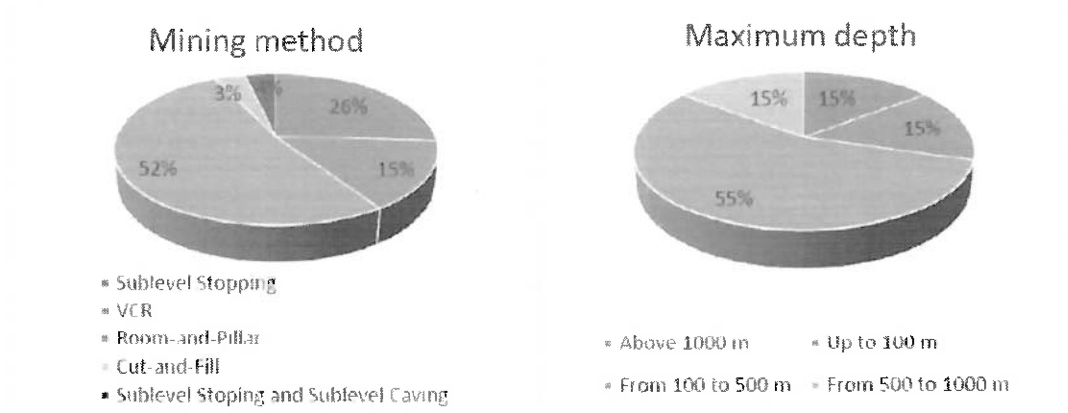

Figure 1. Distribution of mines according to the mining method and maximun depth

Item 3.1 presents the basic characteristics of the ventilation systems of the mines surveyed, such as their types and the types of fans used, both in the main ventilation (MV) and in the auxiliary ventilation (AV), among other parameters.

The analysis of the results revealed a marked heterogeneity between the ventilation systems employed, depending on the mines' sizes, allowing the identification of three distinct patterns, denominated in this work as pattern A, pattern B and pattern C and which are presented in items 3.2, 3.3 and 3.4 respectively.

3.1. Basic features of ventilation systems

3.1.1. Main Ventilation

Figure 2 shows the distribution of the types of main ventilation used in mines. It is observed that main ventilation systems that work in exhaustion predominate (with 63%), which was expected since, globally, most underground mines operate in this way [1,18]. According to Tuck [18] gas control during falls of barometer and fan stoppage favors exhausting systems. Twenty-two % of the main fan systems are a combination of the blowing (or forcing) and exhausting systems ("Push-pull ventilation"). It is important to mention, however, that approximately 11% of the mines studied do not have a mechanized main ventilation system depending, therefore, for the dilution of contaminants, only on natural ventilation complemented by auxiliary ventilation.

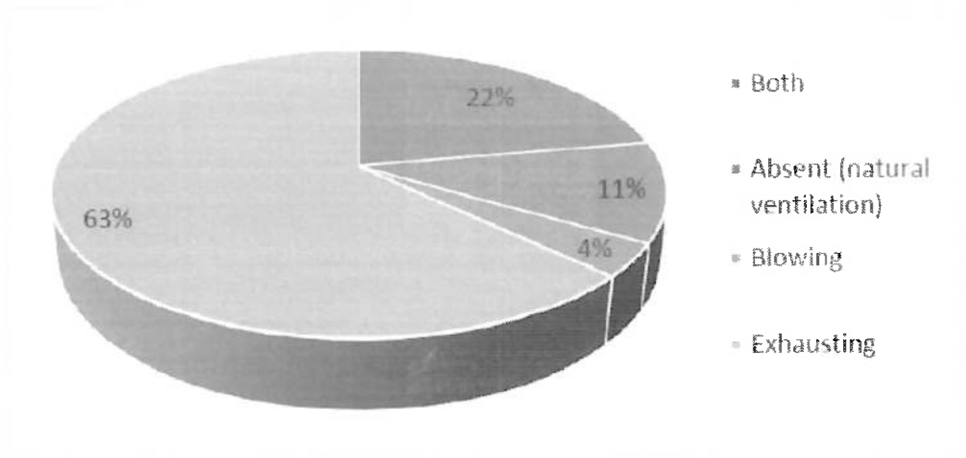

Figure 2. Main ventilation types distribution

Among the fans used in MV systems, axial fans stand out (70%), as shown in Figure 3. This significant percentage can be explained by its overall lower cost and compactness, in addition to its versatility and potential to generate a significant amount of airflow, which makes it ideal in most underground mines [1,19].

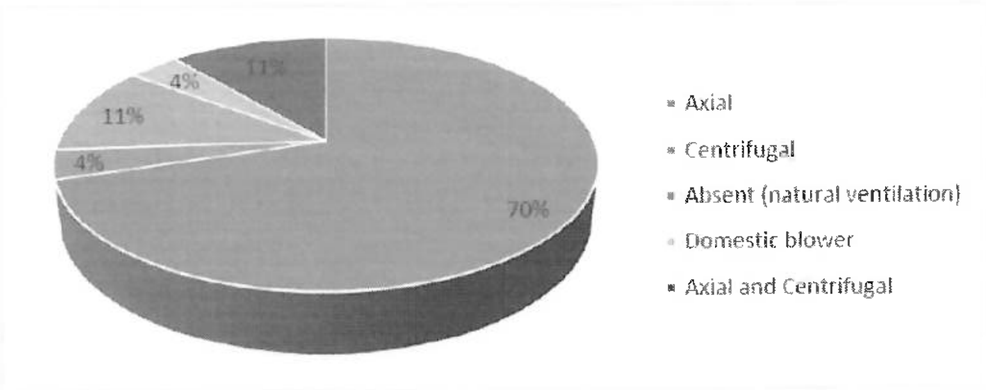

Figure 3. Main fan types distribution

Regarding the use of main fans in association, although most fans are associated in parallel, the results showed a high percentage (33%) of non-associated fans Figure 4.

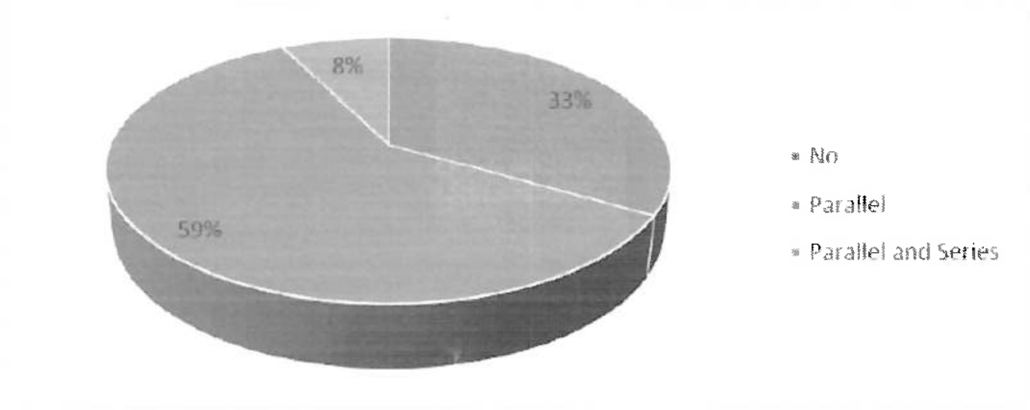

Figure 4. Use of main fans in combination

Approximately 15% of the mines have boosters as well to boost airflow in specific parts in underground, improving pressure and energy control, and saving operating cost [18] (Figure 5).

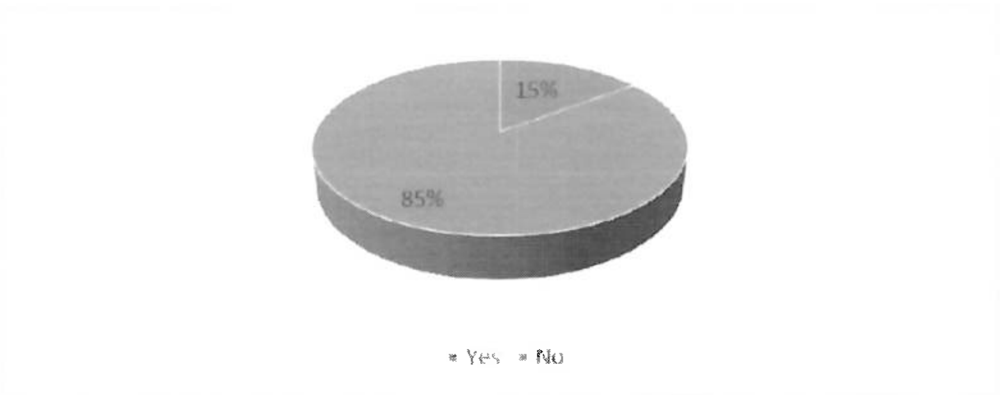

Figure 5. Presence of boosters

3.1.2. Auxiliary Ventilation

The presence of ducts and fans in the AV systems of the mines surveyed is practically unanimous, as shown in Figure 6. Another alternative of secondary ventilation system is the use of jet fans (ductless fans) (4%).

If properly designed and installed, ventilation ducts and fans, are normally the main means to complement the main ventilation, providing a more positive and controlled ventilating effect at the face [1].

Depending on the mine studied, the ducts have different diameters, from 0.3 m to 1.6 m. The material for its manufacture also varies, the most common being flexible resistant braided PVC ducts (commercially known as "ráfia"); PVC vinyl canvas ducts reinforced with high tenacity polyester mesh and laminated polypropylene ducts.

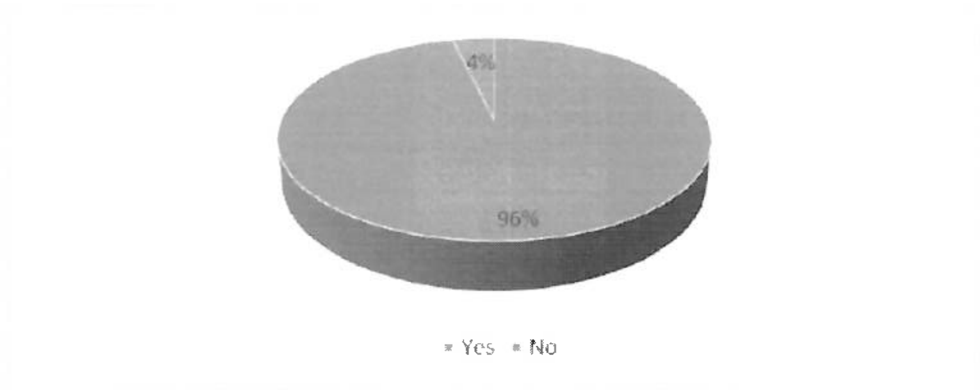

Figure 6. Use of ducts for auxiliary ventilation

Unlike the MV, the AV adopted in the mines is predominantly by blowing. One of the main reasons listed for the use of this type of system is the high speed of airflow, which reaches great distances [1,19]. Furthermore, it is well-known that the higher velocity emerging from the exit of a blowing duct provides a scouring action which efficiently sweeps the area [18,19]. Hence, it is good to remove gases by delivering turbulent mixing and to enhance air cooling power as well, by providing high airflows. The blowing system, different from the exhausting systems, also does not require the use of rigid or reinforced ducting, which usually are more expensive than flexible ones [18].

Overlap systems are also significant in the mines investigated with 33%, as illustrated in Figure 7.

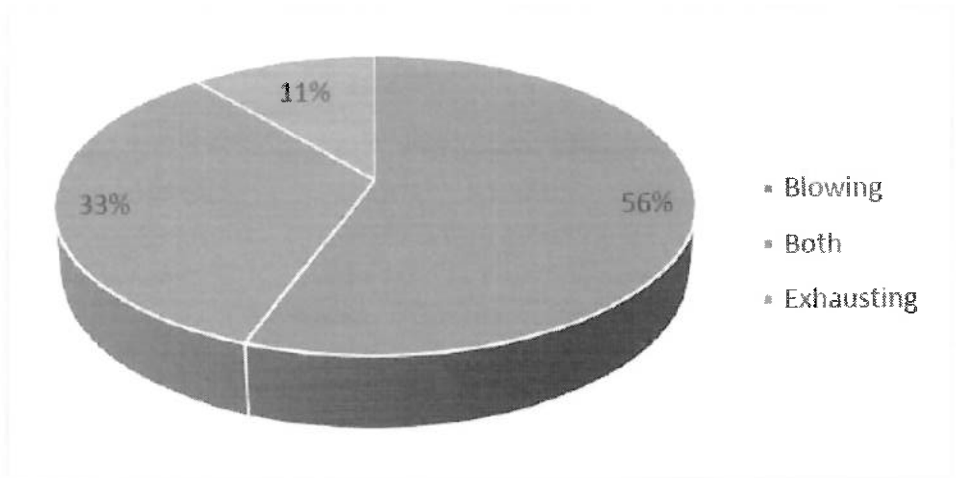

Figure 7. Auxiliary ventilation types distribution

Regarding the types of fans used in auxiliary ventilation systems, the axial fan is the most used, as expected, either "alone" or with other centrifugal fans, as shown in Figure 8.

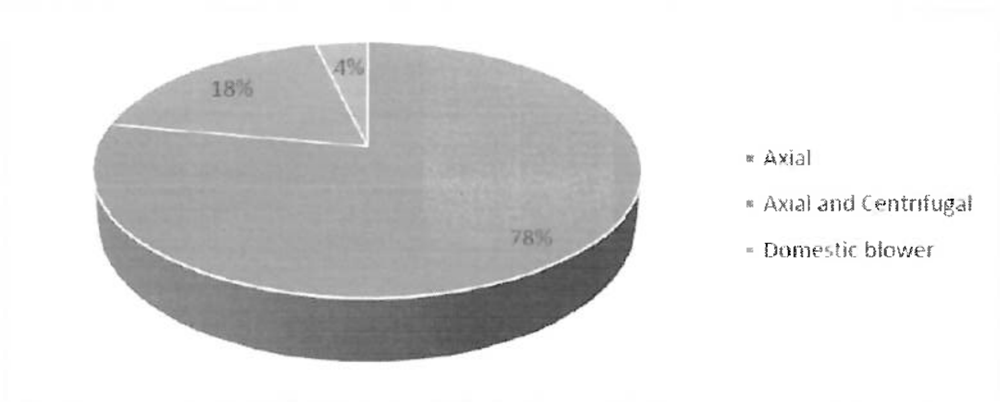

Figure 8. Auxiliary fan types distribution

Regarding the combination of auxiliary fans in the mines, most of the fans are not combined (56%), according to Figure 9. However, there is still emphasis on arrangements in parallel and in series.

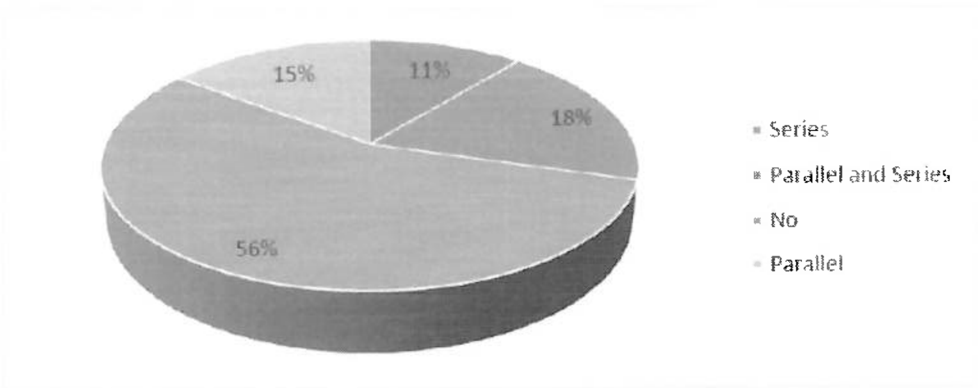

Figure 9. Use of main fans in combination

3.1.3. *Additional control devices and methods*

In addition to the components of the main and auxiliary ventilation systems presented in the previous items, the research sought to investigate whether the mines have airflow control devices; additional methods of controlling underground contaminants, such as refrigeration systems and/or some automated ventilation control system (the popular and established Ventilation on Demand, VOD).

Most mines have passive airflow control devices, as shown in Figure 10. The devices vary greatly depending on the mine, with doors (metal, steel, and wood), stoppings and seals being more common, followed by brattices, airflow regulators and air crossings. Few mines have automated regulators. Stoppings are usually fixed (masonry sidings) or mobile (metal or plastic sidings).

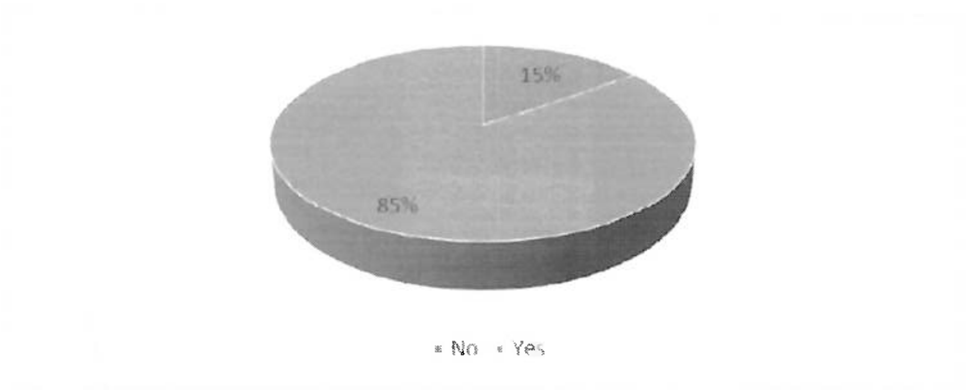

Figure 10. Use of airflow control devices

According to the survey with mining companies, only 4 Brazilian mines currently have refrigeration systems. Most of the mines studied have only a ventilation system to dilute the heat underground (85%). However, when analyzing mines with a depth greater than 500m, the percentage of mines with cooling systems rises from 15% to 50% (Figure 11), mainly evidencing the influence of the geothermal gradient for the increase of heat in the subsoil.

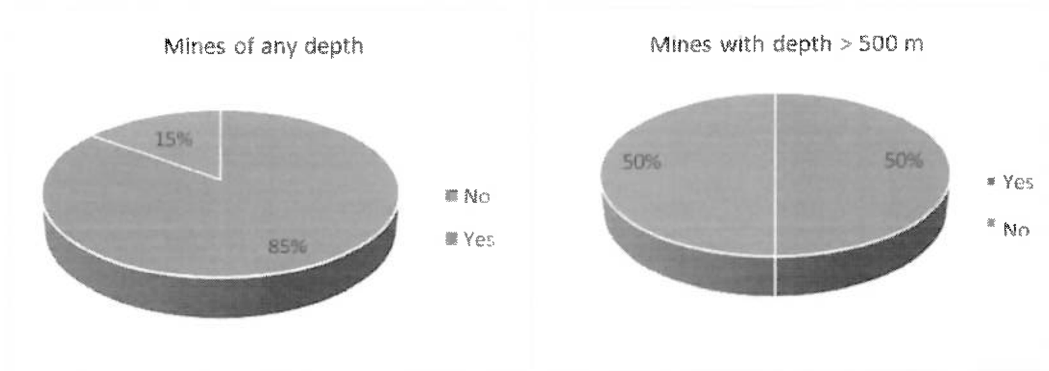

Figure 11. Presence of a refrigeration system

The use of automated ventilation control systems was also investigated in the research. Figure 12 shows that VOD systems have been gaining ground in the Brazilian mineral industry, since in 41% of mines this type of technology has been used.

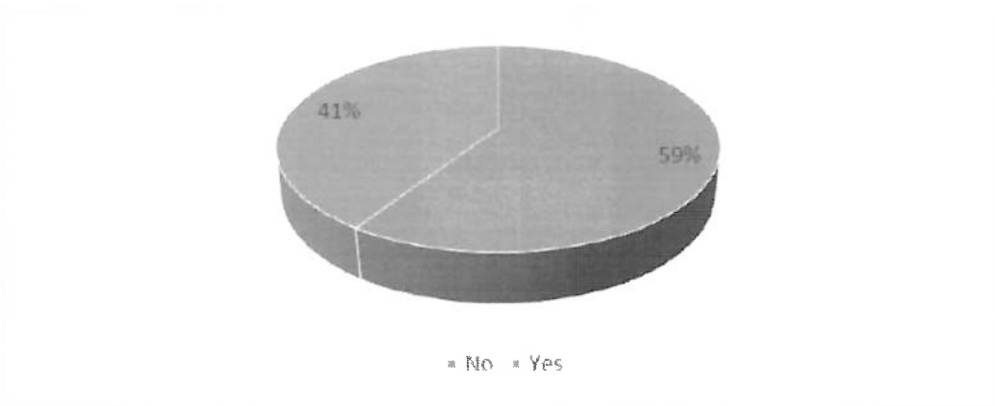

Figure 12. VOD Employment

3.2. Pattern A

The analysis of the results revealed a remarkable heterogeneity between the ventilation systems employed, allowing the identification of three distinct patterns in terms of technological evolution: pattern A, pattern B and pattern C.

Mines that feature mechanized main and auxiliary ventilation systems, airflow control devices and that have already started using more recent technologies for automation and ventilation control, such as VOD, can be fitted into pattern A. Such mines, as identified, are generally medium to large-sized metal mines, according to the ANM classification based on annual run-of-mine production [20] and totaled about 41% of the mines surveyed.

An example of pattern A can be illustrated by the Ipueira mine of the Brazilian company Cia de Ferro Ligas da Bahia (Ferbasa), which mines chromium ore using the Sublevel open stopping and Sublevel caving mining methods [21]. According to Costa [22], an automation project for the main ventilation of the mine was implemented in 2013 and developed for approximately three years, with which it was possible to observe a considerable reduction in the energy consumption of its ventilation system. According to Oliveira et al. [23], the VOD system generated energy savings of around 71% compared to the classic system, equivalent to 8,290,648 kWh/year. The fans are driven by a variable frequency drive, also allowing the adjustment of the rotation speed and consequently the amount of fresh air supplied according to the calculated required flow. During shift intervals and in the period corresponding to "peak hours", the fans are programmed to work with lower rotations, depending on the lower intensity of activities during this period. In 2016, there was an expansion of the automation project of underground stationary equipment for the secondary ventilation, compressed air and pumping system, making the mine more integrated, and also enabling the reduction of the secondary fans rotation when convenient and the consequent reduction of their consumption energetic. In specific locations in the mine, there are sensors for detecting carbon monoxide and controlling it [22– 24].

3.3. Pattern B

In pattern B, mines that also have mechanized main and auxiliary ventilation systems and airflow control devices can be framed. However, they do not usually have automation systems and control of ventilation assets. These are generally medium-sized non-metallic and coal mines. In the survey, they totaled approximately 48% of the mines studied.

3.4. Pattern C

Mines that could be allocated to pattern C are those that have only mechanized auxiliary ventilationsystems. They make use of natural ventilation and do not have airflow control devices. They are usually mines of non-metallic and metallic ores, but of smaller size and corresponded to 11% of the mines studied.

4. Conclusions

Although not all mines have made their ventilation data available, it was possible to know better and draw a current overview of the ventilation systems used in Brazilian underground mines.

Most of the mines surveyed employ the Room-and-Pillar mining method (52%) and can be considered medium-depth mines (with maximum depth between 100 and 500 m) (55%).

Approximately 89% of mines have mechanized main ventilation, with most main fans working only on exhaustion (63%) and axial type (total of 81%). It is observed that mixed flow or axial-centrifugal fans are not used, as in other countries. As expected, most of the main fans are combined in parallel (total of 67%), increasing the system flow when desired and avoiding downtime problems in case of failure/maintenance of one of the component fans. However, there is also a high percentage (33%) of singly fans. Approximately 15% of mines have also booster fans underground to boost a portion of the whole mine airflow.

Most mines use passive airflow control devices, the most common being doors (metal, steel and wood), stoppings (fixed or mobile) and seals. Brattices, airflow regulators and air crossings are less frequent.

The type of auxiliary ventilation system most used is the one with fan and duct (96%), with the ducts having diameters in the range of 0.3 to 1.6 m and different materials. Unlike MV, the AV adopted in mines is predominantly by blowing (56%). However, the type of fan used in secondary ventilation is also axial (total of 96%), as expected. It is observed that most of them are not combined (56%). Another alternative of secondary ventilation system is the use of jet fans (ductless fans) (4%).

Only 4 Brazilian mines currently have refrigeration systems.

Approximately 41% of the mines surveyed use automated ventilation control systems, demonstrating that VOD technology is gaining more and more space, especially in medium/large-sized metal mines.

In addition to these generic conclusions, the analysis of the data revealed a remarkable heterogeneity between the mines regarding their ventilation systems, depending on the mines' sizes and the type of ore extracted. Three distinct patterns could be identified in terms of technological evolution: pattern A (mines with mechanized main/auxiliary ventilation systems, airflow control devices and VOD technology), pattern B (mines with mechanized main/auxiliary ventilation systems and airflow control devices) and pattern C (mines with mechanized auxiliary ventilation systems and natural ventilation).

About 41% of the surveyed mines fit into pattern A, 48% into B and 11% into C. It is observed, however, that part of the mines surveyed did not want to make their ventilation data available and that illegal mines were not part of the research, as they are not registered in the Brazilian Ministry of Mines and Energy and are excluded from official statistics. In these illegal mines, focused on subsistence, rudimentary and artisanal mining techniques are usually used without a proper ventilation system [25]. Therefore, if such mines were considered in the study, it is believed that the percentage of mines categorized as B and C would tend to increase, as well, the percentage of mines grouped in category A would certainly be lower.

Acknowledgment

We would like to thank the mining companies that contributed to the development of this research.

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Contenido

Ingeniería de ventilación

Automatización y análisis computacional