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A GIS-based approach: Influence of the ventilation layout to the environmental conditions in an underground mine

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Abstract

Gases such as CO, CO₂ or NO_x are constantly generated by the equipment in any underground mine and the ventilation layout can play an important role in keeping low concentrations in the working faces. Hence, a method able to control the workplace environment is crucial. This paper proposes a geographical information system (GIS) for such goal. The system created provides the necessary tools to manage and analyse an underground environment, connecting pollutants and temperatures with the ventilation characteristics over time. Data concerning the ventilation system, in a case study, has been taken every month since 2009 and integrated into the management system, which has quantified the gasses concentration throughout the mine due to the characteristics and evolution of the ventilation layout. Three different zones concerning CO, CO₂, NO_x and effective temperature have been found as well as some variations among workplaces within the same zone that suggest local airflow recirculations. The system proposed could be a useful tool to improve the workplace conditions and efficiency levels.

Keywords: Underground environment; pollutant; safe workplace; ventilation layout; GIS.

1. Introduction

A safe underground environment is crucial for a correct operation of the mine and the sake of its employees. This issue has been extensively studied, taking different approaches such as controlling airflow leakages (Widiatmojo, et al., 2015), improving the underground environment conditions in coal mines to reduce the level of dust and methane (Su et al., 2008; Xi et al., 2014; Zhang et al., 2015) or focused on underground gases and finding out more efficient ventilation designs (Kurnia et al., 2014).

One of the main functions of the ventilation system is to remove and dilute gases. Unfortunately, it becomes more difficult as the mine spreads out and the ventilation circuit gains complexity. The origin of gases generated in a mine can be a consequence of the mineralization or exploitation method –mainly mining equipment and blasting–. Carbon monoxide and dioxide can also be spontaneously released in potash mines with some particular geological conditions (Carrasco et al., 2011; Hedlund, 2012).

The control of pollutant levels is currently mandatory, because their toxicity affect the health of the employees in the short and long term (Rundell et al., 1996). For this reason, it is very important to provide tools to design a proper underground ventilation system able to manage this hazard and keep the environmental conditions within the maximum levels established by law. Several investigations have been carried out in this field, especially in coal mining (Cheng et al., 2015; Noack, 1998; Sasmito et al., 2013). Despite that, the relationship among ventilation layout, gas concentrations and temperatures remains unstudied.

This paper gives insight into the airflow recirculation influence in the level of pollutants and effective temperature in the working faces from a case study and how this recirculation is affected by the ventilation layout. A geographical information system –GIS– is proposed to manage and analyse the data collected due to its capacity to provide the adequate tools, frameworks and understanding of the real situation inside a mine (Saleh and Cummings, 2011). The objectives of the study are as follows:

- To create a system able to manage, store and manipulate ventilation data to assess the ventilation circuit.
- To evaluate the relationship among gas concentration, effective temperature and airflow in the working faces depending on the ventilation layout.

2. Methods and materials

2.1. Location of the mine

The research was undertaken in a mine located in the centre of Catalonia, Spain. The company has produced potash and salt over the last few decades through several shafts. The case study is focused in one of the largest mining activity in the zone.

2.2. Considered pollutants

Although the source of gases can be diverse in a mining activity, diesel combustion is the main cause in the case analysed. Diesel fuel –during an ideal combustion process– would produce only carbon dioxide and water vapour, as is exposed in Eq. 1. However, combustion processes are non-ideal and other pollutants are also generated, such as CO or NO_x (Carrasco et al., 2011).



Table 1 details the pollutants studied by the mining activity and their threshold limit values (TLV), either time weighted average (TWA) or short-term exposure limit (STEL), according to the current Spanish legislation, Royal Decree 863/1985.

Table 1. Effects of the pollutants and TLVs in parts per million (ppm).

Gas	Physical risk	Hygienic risk	Principal origin	TLV TWA (ppm)	TLV STEAL (ppm)
CO	Explosive Inflammable	Asphyxiating Toxic	Engine combustion	50	100
CO ₂		Asphyxiating	Engine combustion	5000	12500
NO _x		Toxic	Engine combustion	10	25

Gas concentration and temperature levels increase as the ventilation drifts lengthen, since airflow stays a longer time in the ventilation circuit interacting with the surrounding rock and mining equipment. Therefore, an increase over time can be considered, dn_g/dt , as in Eq. 2.

$$n_g(t) = n_{g0} + \frac{\delta n_g}{\delta t} \delta t \quad (2)$$

Where n_g is the pollutant concentration as a function of time (ppm), n_{g0} is the initial concentration at the beginning of the intake (ppm). However, n_{g0} value is considered as zero,

because the beginning of the intake is considered as a base value for the gas detector, see section 2.3.

Temperature would also have a similar behaviour, but strata and equipment heat inputs should be included. However, determination of the different heat sources is not the purpose of this study, but the influence of airflow recirculation to effective temperatures.

2.3. Case study and data collection

The mine is exploited using a room and pillar method. Potash and salt are extracted by continuous mining machines, the material mined is subsequently carried by a fleet of trucks and loaders to a conveyor belt system and finally it is taken out to the surface through a shaft.

Heat load and pollutants generated are removed by a system of ducts and auxiliary fans that exhaust air from the working areas. This airflow is conducted again to the intake and/or return airways depending on the operational planning. Thus, there is a partial recirculation system in which an air fraction returns from the working face and goes back into the intake again. This method has the advantage to be more economical, but airflow needs to be monitored to control pollutant concentrations. Unfortunately, there is no real time data and the ventilation layout is established on past experience without considering the appropriate ratio of air recirculated.

The GIS proposed will be able to estimate this recirculation over time and its impact to the environmental conditions through several control points located on the most relevant places of the ventilation system, particularly the auxiliary circuit, which has the worse conditions in the case study. In consequence, each working face is going to have a measuring point.

Turbulent flow conditions are found along the principal and auxiliary ventilation circuit, either in ducts or airways, while transitional and laminar regimes would be more common in leakages (McPherson, 1993). Pollutant and temperature measurements have been done in the miner operator position, whereas velocity is gauged in the duct system as well as entries and exits of the main ventilation circuit.

Data is collected manually every month, gathering 265 points from 2009 to 2014, and the equipment is systematically calibrated to keep data accuracy. Parameters measured are based on: the exploitation characteristics, Spanish law (Royal Decree 863/1985) and procedures exposed by McPherson (1993) and Carrasco et al. (2011):

- Control point: Coordinates of the point. The chosen location is away from bends, turns and other possible obstructions.
- Date: Day and hour of the measurement. They are done within the same period of the shift to ensure its representativeness.
- Air velocity (m/s): A vane anemometer is used. It is the most accurate option for moderate air speeds, 2 and 15 m/s, doing a traverse (Brake, 2013; McPherson,

1993).

- Dry and wet temperature (°C): They are measured by a sling psychrometer, which has to be swung rapidly for at least 30 seconds (McPherson, 1993).
- Pollutants: Carbon monoxide (CO), carbon dioxide (CO₂), nitric oxide (NO) and nitrogen dioxide (NO₂) in ppm. Readings are obtained by a gas detector.
- Cross section (m²): Using a laser distance measurer. Several vertical and horizontal measures are carried out in the cross section of each control point in the drift, whereas the diameter of the ducts is known.

Airflow and temperature are calculated by means of the GIS, some parameters described above and Eq. 3-4.

$$Q = v \cdot A \quad (3)$$

Where, v= air velocity (m/s), Q= Airflow (m³/s), A= cross section (m²). According to the Spanish law, temperature analysis has to be done by means of the following expression.

$$te = 0.9 \cdot tw + 0.1 \cdot td \quad (4)$$

Where, te= effective temperature (°C), tw= wet temperature (°C), td= dry temperature (°C). On the other hand, nitric oxide and nitrogen dioxide have to be summarized and analysed together (NO_x) to verify if values are below TLVs established by law.

2.4. GIS creation

All the data, described in previous section, have been stored in a GIS created to manage the ventilation parameters with the different ventilation layouts of the mine over the years. This connection will allow better ventilation system assessments and knowledge of any variation in the environmental conditions. The ArcGIS software has been chosen because of its user-friendly interface and widespread use.

Fig. 1 displays the steps followed to create the GIS file. It starts with the ventilation layouts, in CAD format, and data gathered in a spreadsheet. Subsequently, both files are merged in a single one by means of the ArcGIS tools. This creation gives the possibility to connect graphical and numerical information about the auxiliary ventilation system and taking into account the ventilation circuit evolution over time.

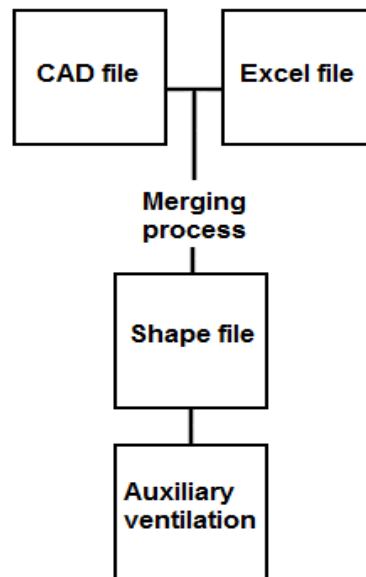


Fig. 1. Scheme of the process followed to create the GIS file.

Fig. 2 stands for the main ventilation layouts regarding its evolution over time, while each layer has the miner locations with their corresponding data. On the other hand, the layer called mine workings helps to obtain an easier understanding of the mine development. Every configuration can be analysed and inquired concerning gases, temperature and airflow.

Layers

- Configuration_1_(April2009-September2009)
- Configuration_2_(October2009-September2010)
- Configuration_3_(October2010-February2011)
- Configuration_4_(March2011-January2012)
- Configuration_5_(February2012-October2012)
- Configuration_6_(November2012)
- Configuration_7_(December2012)
- Mine workings

Fig 2. Auxiliary ventilation layers.

2.5. Ventilation layout

The ventilation system is inquired to find potential weaknesses in the case study once all data is stored in the GIS. In this regard, three different groups have been found considering clearness of the air that arrives to the working faces. Every working face has one miner and the number of continuous miners per group varies depending on the configuration, see Fig. 2.

- Group 1: Provided with clean air.
- Group 2: Partially provided with clean air, as well as recirculated from group 1.
- Group 3: Mainly provided with recirculated air. A small fraction of clean air and then recirculated from groups 1 and 2.

The intake is split before arriving to group 1 and then there is a mixture of clean and recirculated air in different proportions depending on the evolution of the mine, because the air used in the miners is returned to the intake. Thus, it is vital to measure the airflow at the entries and exists of each group to determine the recirculation ratios in groups 2 and 3. Fig. 3 details part of the ventilation circuit with the three groups mentioned above.

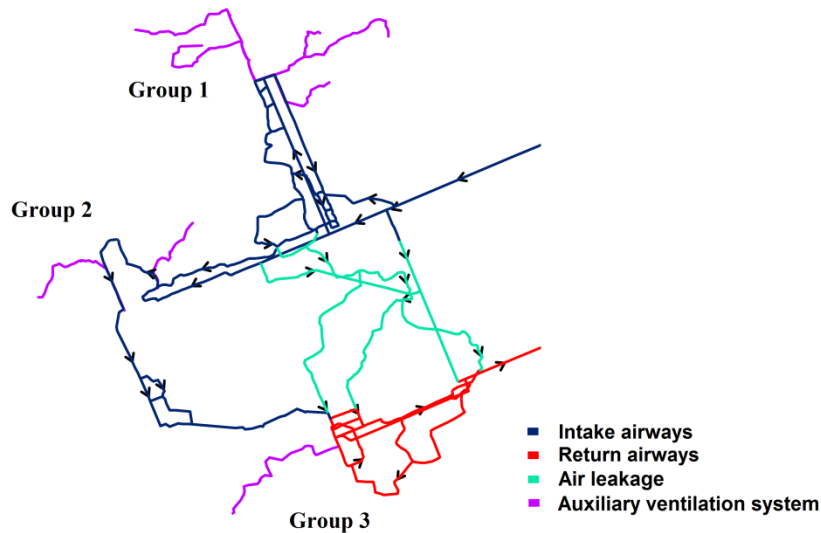


Fig. 3. Scheme of the ventilation circuit in the case study.

As can be deduced from Fig. 3, the ventilation layout is going to have a crucial impact on the recirculation rate and subsequently to the current and future workplace environmental conditions. For the purpose of this analysis, it is assumed that all airflow in each group is used in the workshops.

2.6. Data processing

Data have been analysed by group and working face. First, all measurements have been split in groups based on their ventilation characteristics, having each one 126, 70 and 69 measurements respectively. Afterwards, mean values of airflow, effective temperature, CO, CO₂,

NO and NO₂ have been calculated per group and miner. These distinctions allow analysing the situation individually and per group.

The time factor is really important in the system proposed due to the geographical position of control points and ventilation layout varies over time. Fig. 4 shows an example of a workplace, called M8, and how its position changes between April 2009 and September 2010, moving from group 1 to group 2. Thus, the knowledge of its variation, from clean air to a partially recirculated situation, is very important to analyse the environmental conditions.

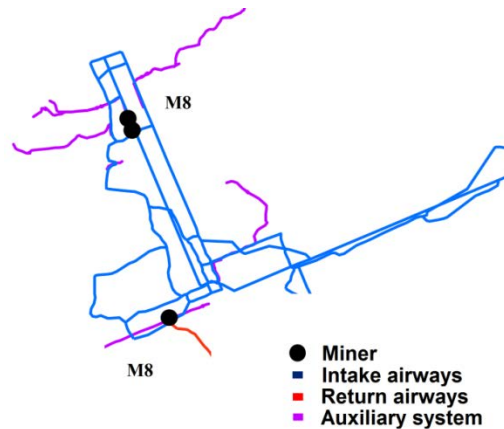


Fig. 4. Miner M8 position changes.

It would have been more difficult to discriminate this information among the three groups without the usage of the GIS, especially when the data collected is from a long time ago.

Fig. 5 displays the effective temperatures in miners 1 and 2 from group 2 between April 2008 and February 2009. This assessment can be done if the layout remains the same, but the approach has to be different when it varies due to a very long period analysed, as done in section 3.

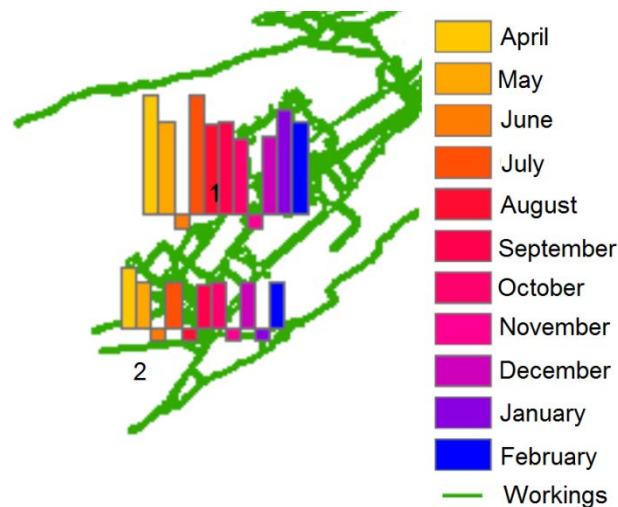


Fig. 5. Effective temperatures of two miners over a year.

3. Results and discussion

The GIS created analyses the working conditions evolution in an underground mine based on: the ventilation layout, its evolution over time and airflow recirculation ratio. Table 2 shows the proportion of recirculated airflow through mean values at the entry of each group. In addition, the configuration, Fig. 2, with the maximum and minimum mean recirculated airflow is also included.

Table 2. Airflow analysis at the entry of each group.

	Mean clean air (%)	Mean recirculated air (%)	Maximum recirculated air (%)	Minimum recirculated air (%)
Group 1	100	0	0	0
Group 2	81	19	21	18
Group 3	17	83	85	82

Despite different ventilation layouts, recirculation ratios are quite steady over time. The portion of recirculated airflow at the entry of group 3 is proportionally much higher than in the others. Hence, it is necessary to figure out how this difference determines the environmental conditions.

Mean values of airflow (m^3/s), effective temperature –EfTemp– (C°), CO, CO₂ and NO_x (ppm) are gathered in Table 3 with their corresponding sample size –n– standard deviation –StDev– and 95% confidence level. In addition, Table 4 compares the percentage variation among different underground conditions. The null hypothesis is supported in the majority of the cases as can be seen in Table 3. Besides, the sample size allows rejecting the null hypothesis and supports the alternative hypothesis (Box et al., 2005).

Table 3. Mean values from the groups.

	Group 1				Group 2				Group 3			
	Mean	St. Dev	P 0.95	n	Mean	St. Dev	P 0.95	n	Mean	St. Dev	P 0.95	n
Airflow	10.59	3.01	0.010	125	10.03	3.61	0.018	66	11.32	4.24	0.085	69
EfTemp	27.99	1.97	0.101	125	28.17	2.51	0.036	69	29.19	1.73	0.122	71
CO	6.18	3.78	0.205	124	5.81	4.98	0.005	69	8.43	4.93	0.135	71
CO ₂	1819	981	0.062	124	1641	921	0.433	69	1883	995	0.135	71
NO _x	7.97	4.09	0.112	125	8.28	6.18	0.105	69	9.31	5.14	0.005	71

Table 4. Percentage variation using group 1 as reference.

	Airflow (%)	Effective temperature (%)	CO (%)	CO ₂ (%)	NO _x (%)
Group 1	0.00	0.00	0.00	0.00	0.00
Group 2	-5.29	0.64	-5.99	-9.76	3.84
Group 3	6.89	4.29	36.41	3.53	16.70

Previous tables show that there is an increase in pollutants concentration and effective temperatures between group 1 and 3 despite similar airflow, especially in CO and NO_x values. On the other hand, the comparison between group 1 and 2 provides mixed results. Therefore, recirculation rate in group 2 does not influence the working conditions as much as in group 3.

Individual analysis by miner is displayed in next Tables and Figures, where each miner stands for a column in Table 5 and a bar in Fig. 6 to 10. However, the same miner changes from one group to another in some cases, such as miners 2 and 3 from group 1, which are physically the same as miners 2 and 3 from group 2, because at some point they were moved to another part of the mine. Hence, they are considered as different miners for the study of the environmental factors. Their identification names will be very important to manage the database in the GIS. The null hypothesis is supported again in most cases from Table 5 according to their confidence level.

Table 5. Name and number of the measurements from each miner with their corresponding P 0.95.

Miner	Group 1						Group 2				Group 3		
	1	2	3	4	5	6	1	2	3	4	1	2	3
n	21	15	17	27	21	23	17	21	14	18	24	27	18
Airflow	0.083	0.331	0.155	0.402	0.079	0.023	0.574	0.346	0.058	0.047	0.371	0.013	0.578
EfTemp	0.186	0.067	0.191	0.404	0.354	0.132	0.041	0.302	0.284	0.544	0.038	0.272	0.496
CO	0.058	0.225	0.005	0.225	0.089	0.280	0.309	0.028	0.656	0.529	0.313	0.726	0.050
CO ₂	0.015	0.274	0.841	0.953	0.197	0.650	0.243	0.375	0.666	0.910	0.172	0.821	0.214
NO _x	0.091	0.889	0.472	0.107	0.453	0.510	0.068	0.005	0.059	0.104	0.005	0.072	0.151

Table 6 compares the minimum and maximum values of the parameters analysed among miners. The percentage variation of the conditions showed in Table 5 has been linked to information from Table 4 by the last column, called Group-miner, which identify the group and then the miner having the maximum and minimum value of each condition respectively.

Table 6. Difference between maximum and minimum values in the working faces.

	Maximum Value	Minimum value	Difference (%)	Group-miner
Airflow (m ³ /s)	12.92	9.74	32.65	3.2-2.4
Effective temperature (°C)	29.75	26.74	11.26	3.1-1.1

CO (ppm)	8.96	5.60	60.00	3.2-2.2
CO ₂ (ppm)	2400.00	1291.88	85.78	1.3-2.1
NO _x (ppm)	10.94	7.39	48.04	3.1-1.1

The analysis of maximum and minimum values of effective temperature and pollutants are in accordance with the recirculation ratios. Apart from CO₂, group 3 has worse conditions than the other two groups.

Individual mean values from each miner, exposed in Fig. 6 to 10, distinguish the three groups in different coloured bars. The quantity of continuous miners per group is different; having groups 1, 2 and 3 a quantity of 6, 4 and 3 miners respectively. This difference is just a matter of mine planning.

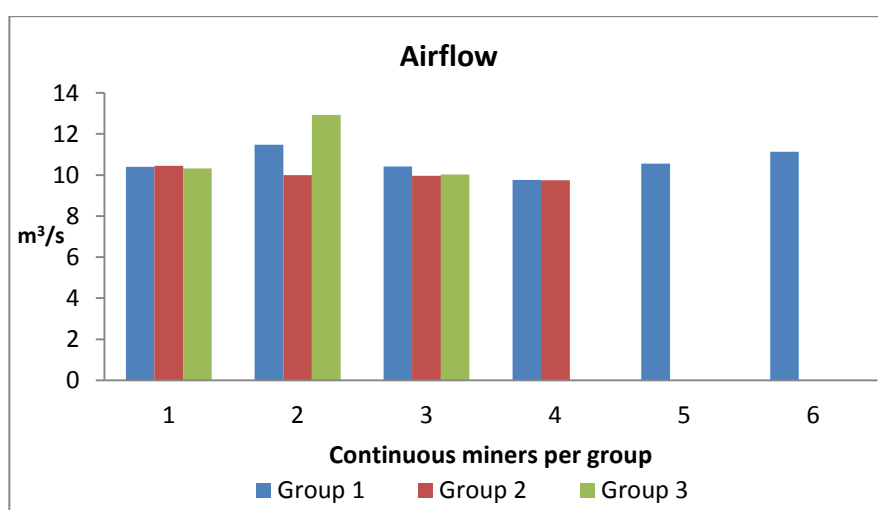


Fig. 6. Airflow per continuous miner.

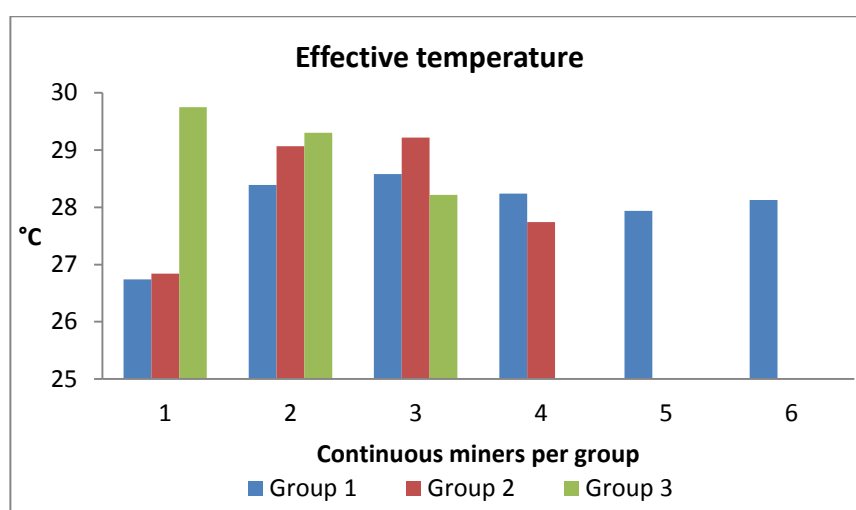


Fig. 7. Effective temperature in each continuous miner.

Airflow per continuous miner fluctuates around 10 m³/s in all cases, regardless of the ventilation layout and the presence of recirculation. Pearson and Spearman correlation coefficients have been calculated, attributing very low correlation airflow-temperatures and airflow-pollutants. Therefore, the workplace condition variation is mainly caused by the recirculation rate instead of airflow supply.

With respect to effective temperatures, mean values oscillate between 27 and 30 °C, finding the highest difference, 11.26%, between miner 1 from Group 1 and miner 1 from Group 3 according to Table 6, which is in accordance with groups of clean and recirculated airflow respectively. When location of both miners is examined individually using the GIS tools, it can be appreciated that the one with the lowest effective temperature is placed very close to the service tunnels and hence, it has less heat input to the ventilation system than other miners.

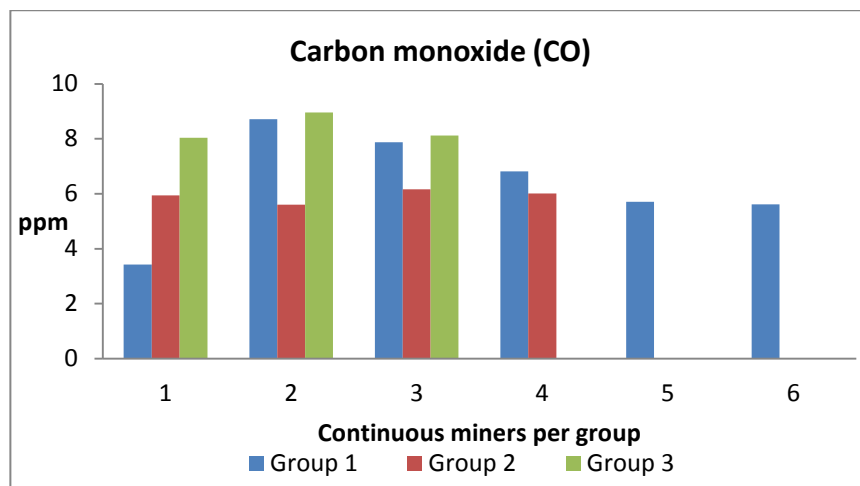


Fig. 8. Carbon monoxide concentration per continuous miner.

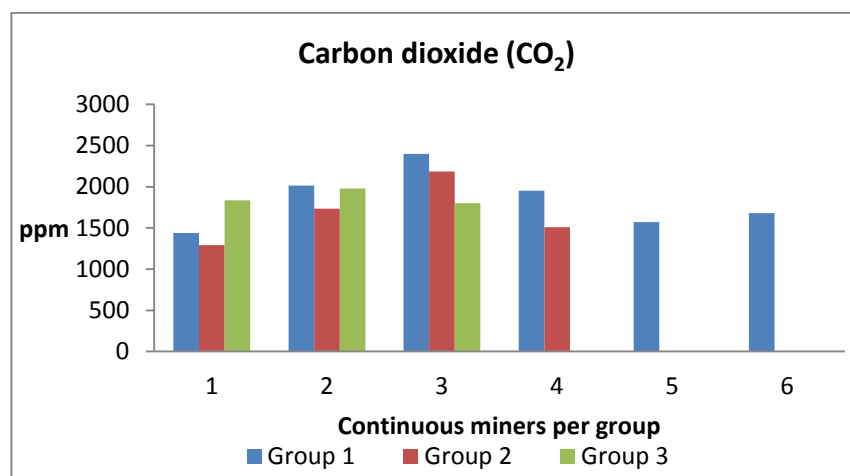


Fig. 9. Carbon dioxide concentration per continuous miner.

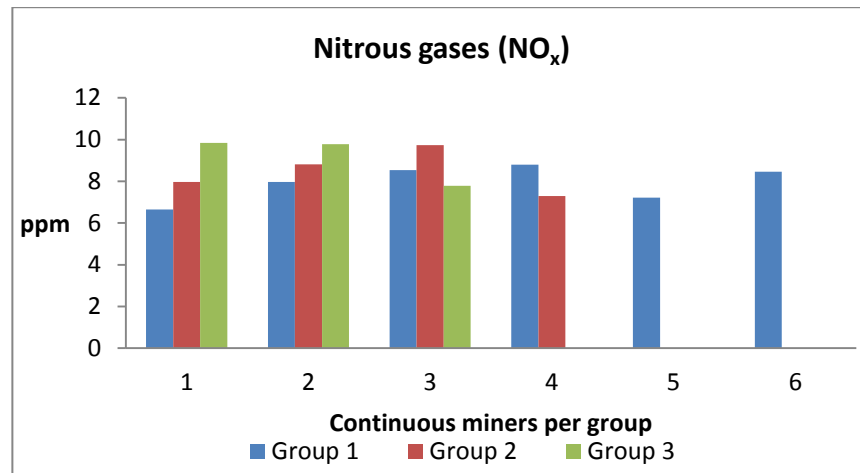


Fig. 10. Nitrous gases concentration per continuous miner.

Despite the lack of a clear trend in individual values of CO, CO₂ and NO_x regarding their corresponding group, miners from group 3 show higher concentrations in almost all working faces. In some cases, the difference within the same group is considerable, such as CO₂ in group 1, where the difference between the highest and lowest concentration reaches a 56.47% variation while they should be much lower given the airflow is clean.

These deviations among groups come from the recirculation rate, whereas the difference among miners from the same group suggest there are local recirculations caused by leakages or inadequate auxiliary ventilation system. This situation is reflected in some miners from group 1, which should have much lower pollutant concentrations.

Information related to the auxiliary ventilation circuit such as leakages or discharge zone of the duct should be included in the GIS in order to clarify these divergences within the same group. The system would also increase its potential if it was fed with real time data.

4. Conclusions

The geographical information system has proved to be a proper tool to analyse the environmental conditions of the workings in an underground mine over the time, as well as inquire the data in many different ways to take decisions concerning the ventilation circuit. Individual and global results extracted from the GIS have given insight of the pollutants and temperature evolution throughout the mine and the influence of the airflow recirculation to the underground environmental conditions.

The analysis unfold two main characteristics of the ventilation circuit. The first is three different groups regarding the environmental conditions directly related to the ventilation

layout used in the mine. The second one is an important deviation among the working conditions within the same group.

Despite all miners have similar airflow, there is a considerable deterioration in conditions between group 1 and 3 due to airflow recirculated, while in group 2 remain acceptable, because it does not have significant influence in a range of 20% of the total airflow. Therefore, recirculation will be the main influence to environmental conditions and consequently the ventilation layout. Although all working faces comply with the current legislation, group 3 displays a considerable increase in terms of temperature and pollutants compared to the situation with clean air, there is an increase of around 36% in CO, 4% CO₂, 17% NO_x and 4% effective temperature. Hence, it would be advisable to partially change the ventilation layout in group 3 to provide air with a lower ratio of contaminants and heat load. Adding more airflow per miner could reduce the effective temperature, but the problem with pollutants would remain unless the recirculation ratio is reduced.

Moreover, the individual approach suggests that there are local airflow recirculations within each group that could be the source of the divergence between the miners from the same group. The knowledge of their specific characteristics would help to plan better auxiliary ventilation circuits, which in turn would impact positively on the efficiency rates of the employees and workplace conditions. Even though more parameters are needed to determine local problems within each group and automatic measurements would increase the potential of the system, the GIS functioning and utility would remain the same.

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