Searching for dependent air currents in a mine ventilation network using the connected graph disconnection method

To cite this article: Grzegorz Pach 2018 IOP Conf. Ser.: Earth Environ. Sci. 174 012010

View the article online for updates and enhancements.

You may also like

- Research on Mine Ventilation Optimization Based on 3D Simulation System
  Aiwei Jiang, Bo Zhou, Hao Hu et al.

- Safe and energy-efficient ventilation in mines – application of the golden ratio method in designing forced air distribution for ventilation networks
  Grzegorz Pach

- Quantification of ventilation distribution in regional lung injury by electrical impedance tomography and xenon computed tomography
  Gunnar Elke, Matthew K Fuld, Ahmed F Halaweish et al.
Searching for dependent air currents in a mine ventilation network using the connected graph disconnection method

Grzegorz Pach
Faculty of Mining and Geology, Silesian University of Technology, Akademicka 2, 44-100 Gliwice, Poland
grzegorz.pach@polsl.pl

Abstract. Ventilation networks in underground hard coal and copper ore mines are usually designed with branches with dependent air currents. Among these, branches connecting sub-networks of main fans may be distinguished. In view of ventilation hazards: fire hazard, gas hazard, thermal hazard and coal dust explosion hazard, the presence of dependent air-currents may be both desirable and adverse. Information regarding the possible presence and character of the dependent air currents in the mining plant’s ventilation network is thus significant. The paper presents a method, based on graph theory, allowing to determine the presence of dependent air currents and their affiliation with the supplied (fresh) air or the removed (used) air. This allows to obtain information whether air currents connecting the main fan sub-networks exist in a ventilation network. The method is applicable in all ventilation networks under the condition of the previous reduction of parallel connections. The paper presents an example of a ventilation network with three main fans, where the method in concern was applied. The algorithm presented in the article allowed to determine the existence of dependent currents in each of the air zones. Additionally, it allowed to identify the main ventilator sub-networks that are interconnected.

1. Introduction
The Polish hard coal mining industry is continuously subject to restructuring. As a part of this process, not only unprofitable mines are being shut down, but also mining plants are being merged [1]. The effects of such undertakings include significant changes in the structure of the mines’ ventilation networks. Differences occurring in the structure of these networks are significant in the management of the ventilation of an underground mining plant [2], especially in the analysis and prevention of ventilation hazards: fire hazard, methane hazard, thermal hazard and coal dust explosion hazard [3]. The structure of an underground mining plant's ventilation system also impacts the distribution of smoke and gas produced in fire in headings, being thus decisive for the area of the zone with smoke conditions or the applicability of reverse ventilation [2, 3, 4]. In case of methane hazard, methane removal efficiency and the supply of adequate amounts of air to the exploitation areas is highly dependent on the size and the complexity of the ventilation network [5]. One of the preventive methods applied in cases of thermal hazard is to ensure an increased air flow through workings [6, 7]. The possibility to reach an increased airflow is dependent on the structure of the ventilation network.

In cases where mining plants are merged, the newly formed ventilation network may and usually does exhibit a complex structure. In such networks, dependent air currents may occur both in the supplied (fresh) and the removed (used) air zones. Among these, currents which connect the sub-networks of the main ventilation fans may appear. Due to the ventilation hazards in mining plants,
information regarding the presence of dependent air currents and the type of the currents in the ventilation network is highly significant.

The purpose of this paper is to present a method allowing for the determination whether dependent air currents occur in the analyzed underground mining plant as well as to determine the type of the currents. The presented method is applicable for ventilation networks with all structures.

2. Types of air currents in mining plant ventilation networks

Workings of underground mining plants are interconnected, thus forming a mine ventilation network. The network includes: nodes, branches, fans and other ventilation devices (e.g. various types of dams) [8]. A division is known (due to the number of incoming and outgoing air streams) into the following types of nodes: separating, combining and mixing (figures 1a-1c) [9]. In mining practice, the application of the so-called semi-node is also known (figure 1d).

![Figure 1. Types of nodes in a mine ventilation network: a) combining node b) separating node c) mixing node d) semi-node.](image)

A working or a series of workings connecting two nodes is called the ventilation branch. The air current flowing in a branch may be normal (with single direction of flow) or diagonal (the direction depends on the aerodynamic resistance in neighbouring branches). A. Krach [10] has presented one of the methods to determine the diagonal character of a branch.

Branches through which the air flows to the so-called take-off points (e.g. longwalls, functional chambers) are called branches with supplied air (fresh), while branches through which the air flows out from the take-off points up to the surface are called the branches with removed air (used). Due to the above, all branches in a mine ventilation network may be divided into:

- branches with supplied air currents (fresh),
- branches with air take-off points,
- branches with removed air currents (used),
- branches representing the atmosphere.

All branches with supplied air current form a zone of supplied (fresh) air while the branches with the removed air constitute a removed (used) air zone. A similar division may also be applied to the nodes of the ventilation network. After distinguishing such zones, another division of air currents may be made:

- independent air currents – separating from the supplied air current, ventilating the branches with take-off points and joining the removed air current,
- dependent air currents – connecting two different supplied air currents or connecting two different removed air currents.
Figure 2 presents a canonical diagram of the mine ventilation network. The green p-c line denotes the full section through the ventilation network, passing through all branches with take-off points (4 mining regions and 1 functional chamber). The section divides the ventilation network into two zones: the supplied air zone (branches with red-coloured arrows) and the removed air zone (branches with blue-coloured arrows). The broken line connecting the nodes 1-12, 9-12 and 11-12 represents branches symbolizing the earth’s atmosphere. While analyzing the above canonical diagram, it may be concluded that the air current in the 7-13 branch (based on the node numbers) is diagonal, while the current in the 1-2 branch is normal. The air current in the 22-7 branch is an independent current, ventilating the mining region, while the air current in the 12-8 branch is a dependent current. Due to the location in given zones, the air current in the branch 4-6 is a dependent air current in the supplied air zone, while the air current in the branch 12-10 is a current in the removed air zone. Additionally, air current in the branch 12-10 connects the sub-networks of the main ventilation fans. It should be noted that each dependent air current is a diagonal current.

Figure 2. Example of a ventilation network with dependent currents in the supplied (fresh) and removed (used) air zones.

3. Advantages and disadvantages of the occurrence of dependent currents in ventilation networks of mines

In mining practice, ventilation networks containing only branches with normal air currents are very rare. In the Polish hard coal and copper ore mining industry, ventilation networks almost always include branches with a diagonal character and dependent air currents.

The advantages of the existence of dependent air currents include:
- shortening of escape routes,
- increased possibilities of establishing transport routes for the mined material, staff and materials,
- the possibility to decrease the main ventilation costs [11].
In case of a fire in the mining region in the 25-10 branch (figure 2) due to the existence of the 12-10 dependent current, it is sufficient for an employee of that division to move to node 10, where air, which does not contain smoke, flows from node 12.

On the other hand, the disadvantages of the dependent currents are:

- the possible increase of the area of the direct smoke zone,
- difficulties in the design of mining plant ventilation systems,
- increase of the costs related to the maintenance of additional workings.

In case of a fire in the branch 2-4, due to the presence of the branch with dependent current 4-6, all mining regions as well as the functional chamber are affected by smoke and not only the regions 23-7, 25-10 and the 24-10 functional chamber.

4. Method for searching for dependent air currents

Solutions applying the graph theory for solving problems related to a mining plant’s ventilation system are known in source literature. Such activities are substantiated and allow to apply mathematical means offered by the theory [12]. The theory finds its application also in the problem in concern.

The proposed method allows to answer the following questions:

- Are there branches with dependent currents in the investigated ventilation network of the underground mining plant?
- In which air zone are the branches located?
- Does the ventilation network contain branches connecting sub-networks of the main ventilation fans?

The liquidation of parallel connections in a ventilation network is a prerequisite to apply the method. The presented method consists in the disconnection (disintegration) of a connected graph representing a ventilation network into independent sub-graphs. The determination of the cyclomatic number [12] for each of the sub-graphs makes it possible to answer the above questions.

The algorithm of the method consists in a series of subsequent operations.

1. Removal of branches with air take-offs (or, generally, branches contained within the full section passing through the air take-offs) and branches representing the atmosphere from the structural representation of the network. Such an operation will disjoin the graph representing the ventilation network into several disconnected subgraphs.
2. Assignment of nodes and remaining branches to individual subgraphs and adding them up.
3. The determination of the cyclomatic number value $\nu$ for each of the subgraphs based on the dependence 1.

$$\nu = m - n + 1$$

where: $m$ – number of branches in a zone, $n$ – number of nodes in a zone.

Interpretation of results of the algorithm.

1. If the cyclomatic number in the supplied/removed air zone is more than 0, this indicates the existence of dependent current in these zones. The 0 value denotes that no such currents exist in the tested network.
2. Assuming that a $lw$ number of main fans exist in a ventilation network, the following cases are possible after the disconnection of the graph representing the ventilation network:
   a) Two subgraphs were formed, one for the supplied air zone and the second for the removed air zone. This indicates the interconnection of all main fan subnetworks with dependent currents.
   b) $lw+1$ subgraphs were formed. It may then be concluded that no currents connecting any of the main fan subnetworks occur.
   c) At least 3, but not more than $lw$ subgraphs were formed. In relation to the above, this is an intermediate situation – some but not all subnetworks of the main fans are connected.

5. Example of searching for dependent currents

The example of the operation of the method shall be presented with the ventilation network presented in figure 3. In the analyzed network, 6 branches with take-off points exist (4 mining regions –
branches 6-8, 6-7, 5-7 and 4-10 as well as two functional chambers – branches 5-13, 5-10). Branches representing the atmosphere are the branches: 9-12, 14-12, 11-12 and 12-1. In line with the first step of the algorithm, all the mentioned branches shall be removed. After the removal of these branches, a transition matrix representing the ventilation network is developed – presented in table 1.

**Table 1.** Transition matrix for the A mine ventilation network.

|   | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 | 11 | 12 | 13 | 14 |
|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| 1 | 0  | 1  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| 2 | -1 | 0  | 1  | 1  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| 3 | 0  | -1 | 0  | 0  | 1  | 1  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| 4 | 0  | -1 | 0  | 0  | 1  | 1  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| 5 | 0  | 0  | -1 | -1 | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| 6 | 0  | 0  | -1 | -1 | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| 7 | 0  | 0  | 0  | 0  | 0  | 0  | 1  | 0  | 0  | 0  | 0  | 0  | 0  | 1  |
| 8 | 0  | 0  | 0  | 0  | 0  | 0  | -1 | 0  | 1  | 0  | 0  | 0  | 0  | -1  |
| 9 | 0  | 0  | 0  | 0  | 0  | 0  | -1 | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| 10| 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 1  | 0  | 0  | 0  | 0  |
| 11| 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 1  | 0  | 0  | 0  | 0  |
| 12| 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| 13| 0  | 0  | 0  | 0  | 0  | 0  | -1 | 0  | 1  | 0  | 0  | 0  | 0  | 0  |
| 14| 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | -1  |

Bold font indicated the zeroed cells of the transition matrix, corresponding to the removed branches with air take-off points, while cursive denotes the zeroed cells corresponding to the removed branches representing the atmosphere.

Subsequently, in line with the second step of the algorithm, the first subgraph is formed, in which node 1 is included. While analyzing the first row of the matrix (table 1), one may note that node 1 is connected to node 2. Node 2 is thus included in the first subgraph. Subsequently, the row of the matrix characteristic to the node 2 is considered. Here, it is found that the node 2 is connected to nodes 3 and 4. Thus, the nodes 3 and 4 are included in the first subgraph. Subsequently, the rows of the matrix corresponding to nodes 3 and 4 are analyzed and nodes 5 and 6 are added to the first subgraph. During
the analysis of the rows corresponding to nodes 5 and 6, no new nodes may be found that could be attributed to the first subgraph. The first subgraph shall thus contain the nodes: 1, 2, 3, 4, 5 and 6. After another analysis of the matrix, it may be found that the following branches are related to the nodes: 1-2, 2-3, 2-4, 3-5, 3-6, 4-5 and 4-6. The number of nodes in the first subgraph shall thus amount to 6 while the number of branches shall be 7.

Subsequently, a second subgraph is formed starting with the next “free” node (in this case, node 7) and the procedure presented above is repeated. The second subgraph includes the nodes and branches 7-8, 7-13, 8-9, 8-13 and 13-14. The number of nodes and graphs in the second subgraph is identical and amounts to 5.

Next, a third subgraph is formed. This subgraph includes nodes 10 and 11 and the 10-11 branch.

Node 12 may not be included in any of the subgraphs as it is not connected to any other node (table 1).

Based on the formula 1, values of the cyclomatic number are determined for each of the subgraphs. These amount to: for the first subgraph – 2, for the second subgraph – 1, for the third subgraph – 0.

5.1. Analysis of the obtained results
The cyclomatic number of the first subgraph is 2 and, simultaneously the node 1 (intake to the shaft) is in the supplied air zone – thus dependent currents exist in this zone.

The cyclomatic number of the second subgraph is 1 and nodes 9 and 14 are connected with branches to fans W1 and W2 (figure 3), thus dependent air currents also occur in the removed air zone.

The number of the formed subgraphs is 3, while the number of the main fans is also 3. Thus a situation presented in subsection c (chapter 4) occurs. Some of the main fan subnetworks are interconnected. The second subgraph includes nodes 9 and 14 (nodes with fans W1 and W2), so the subnetworks of these two fans are interconnected.

To confirm the analysis of the results, figure 4 presents the subgraphs that were formed after the removal of branches with air take-off points and branches representing the atmosphere.

![Subgraphs](Figure 4)

**Figure 4.** Subgraphs that were formed after the disconnection of the graph representing the A mine ventilation network.

6. Conclusions
1. The method using elements of the graph theory presented in the paper is applicable to any mine ventilation network, under the condition that the parallel connections of branches are previously reduced.
2. The method allows to determine whether dependent currents occur in a mine ventilation network and to specify their location in the supplied (fresh) and removed (used) air zones.
3. By comparing the number of subgraphs formed after the disconnection of the graph representing the ventilation network of the mine with the number of main fans, information is obtained regarding the existence or non-existence of a connection between the main fan subnetworks.

4. The information regarding the presence of dependent air currents, including currents which connect subnetworks of main fans is significant in the prevention practices applied for ventilation hazards. The presence of such currents may be both beneficial and disadvantageous.

References

[1] Kugiel M 2010 Efekty procesów restrukturyzacyjnych w Kompanii Węglowej S.A. Kwartałnik Górnictwo i Geologia 5(3) pp 59–73
[2] Wacławik J 2010 Wentylacja kopalń - tom 1 (Kraków: Wydawnictwa AGH) pp 282–318
[3] Szlązak N and Zając K 1998 Ocena możliwości wykonania rewersji wentylacji głównej w kopalniach węgla kamiennego (Kraków: Biblioteka Szkoły Eksploatacji Podziemnej)
[4] Strumiński A 1996 Zwalczanie pożarów w kopalniach głębinnych (Katowice: Wydawnictwo „Ślask”)
[5] Krause E and Łukowicz K 2012 Wpływ struktury kopalnianej sieci wentylacyjnej na skuteczność ujęcia metanu Prace naukowe Głównego Instytutu Górnictwa, Kwartałnik Górnictwo i Środowisko 4 pp 95–108
[6] Drenda J, Sułkowski J, Różański Z, Pach G and Wrona P 2016 Two stage assessment of thermal hazard in an underground mine Archives of Mining Science 61 pp 309–22
[7] Drenda J, Pach G, Różański Z, Wrona P and Sułkowski J 2018 Safe working conditions in hot mine environment – the analysis of different indices Archives of Mining Science 63 pp 93–106
[8] Musioł D and Pach G 2014 Projektowanie rozpływów powietrza w sieciach wentylacyjnych przykłady obliczeniowe (Gliwice: Wydawnictwo Politechniki Śląskiej)
[9] Kolarczyk M 1993 Wpływ struktury kopalnianej sieci wentylacyjnej na wrażliwości prądów powietrza przy zmianach oporów bocznic Zeszyty Naukowe Politechniki Śląskiej 214
[10] Krach A 2014 Determining diagonal branches In mine ventilation networks Archives of Mining Science 59 pp 1097–105
[11] Pach G, Sułkowski J, Różański Z and Wrona P 2018 Costs reduction of main fans operation according to safety ventilation in mines - a case study Archives of Mining Science 63 pp 43–60
[12] Wilson R 2017 Wprowadzenie do teorii grafów (Warszawa: Wydawnictwo Naukowe PWN)