SEARCHING UNGROUND FAN INDUCED RECIRCULATION IN A COMPLICATED MINE VENTILATION NETWORK

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ABSTRACT

Due to the difficulty of finding recirculation of airflows in a complicated ventilation system, a searching strategy is proposed based on depth-first search method for searching recirculation in complicated ventilation networks. The depth first method is introduced briefly while the searching strategy for tracing recirculation in a network is introduced in detail. The proposed method is then used in a copper mine for searching the recirculation of airflows. The mine ventilation system is solved by VENTSIM software first for getting all the airflows information, i.e. the nodes and directions. Then the data of ventilation system is stored in the matrix for tracing the recirculation in the network. A few of recirculation of airflows are found and are compared with the VENTSIM solving results. It is found that the searched results agree with the VENTSIM solving results of the ventilation system. It is concluded that the proposed method has the capabilities of tracing airflow for finding recirculation.

KEYWORDS

Recirculation of airflow, Searching strategy, Mine ventilation

INTRODUCTION

Ventilation is an essential component of underground mining, which provides adequate airflow to create safe environment for mining workers[1]. The main purposes of ventilation in a mine are to dilute mine gases and combustion products including gases and particles, to remove dust and to control air temperature[1]. Therefore, the quantity and quality of airflow in a ventilation systems are of significant importance. However, the complexity of the ventilation network, such as metal mine ventilation system, reduce the basis function of the system and the volumetric efficiency of the ventilation system. For example, the widely used booster fans in underground mining can induce recirculation of airflow in a few connected airways. As for a complicated mine ventilation system, with dozens of fans installed in underground mine and hundreds or thousands of airways, it is quite difficult to find recirculation of airflows. Therefore, in order to control or eliminate the recirculation of airflows in a complicated mine ventilation system, it is empirical to develop a searching method for finding the recirculation in complicated mine ventilation systems.

In last two decades, many researches were done on the recirculation of airflows in mine ventilation system [1-5]. These researches focused on the characterization of air recirculation in multiple fan ventilation system, controlled recirculation and the simulation of air recirculation. However, there are rare study focusing on tracing the airflows for finding recirculation of airflows. Thus, on the one hand, it is necessary to study the recirculation in term of finding the positions, since it is hard to find the recirculation in a complicated mine ventilation system. On the other hand, it is imperative to study the searching strategy for finding the recirculation of airflows in order to control or eliminate them.

METHODS

Since most of the recirculation of airflows are induced by fans installed underground, in our research we focus on finding the recirculation induced by underground fans. For the recirculation induced by underground fan, the airflow begins from the fan and flows in a few airways. Finally, it flows back to the airway where the same fan is installed. Therefore, for finding the recirculation, we can search the recirculation from a fan and follows the direction of the airflow. If the airflow finally flows back to the fan position, we find a recirculation.

In this section, a modified depth first search method is introduced to search recirculation of airflows induced by underground fans.

Depth-first search method

Depth first search method has been widely used in may field [6-11]. However, there are rare applications in mine ventilation. Since the depth first method has been introduced in detail in the literature [8], herein we only introduce this method briefly.

Depth-first search method is used to traverse a graph and uses a stack to store the visited vertex, i.e. node. Eventually, all the vertices in the graph will be visited. The searching strategy is as follows.

The idea of the depth first search method is to travel as deep as possible from one node to node before backtracking. The travel will follow edges and no nodes cannot be visited twice. The travel rules are as follows.

- The travel will begin from given nodes, i.e. initial node.

- Travel will visit the adjacent nodes of the given node and marked the visited nodes. Then the numbers of the visited nodes are put into a stack.

- If no unvisited adjacent node is found, the travel will pop back.

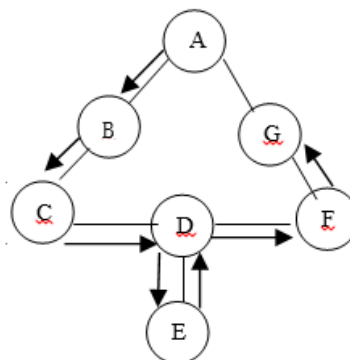- The travel will repeat rule 2 and 3 until the stack is empty.

Fig. 1 - An example for depth first search method

Figure 1 gives a simple example for the searching procedure of depth first search method. As can be seen, there are 7 nodes and some nodes are connected together. Suppose Node A is the initial node. There are two adjacent nodes for node A, e.g. Node B and Node G. In this graph, there are not different for the two nodes. The depth first search method starts from initial node, i.e. Node A, and then visit Node B according to the alphabet order. The Node A and Node B are put in the stack. Following Node B, the Node C, D and E are visited successively. Therefore, there are five nodes in stack, i.e. A, B, C D and E. Since there are not adjacent node fore Node E, the

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search will pop back to D. At this moment, there are four nodes in the stack, i.e. A, B, C and D. As there is one unvisited node for Node D, i.e. Node F, the Depth first search method visits Node F and marks it as visited. After that, the Node G is visited and there are no adjacent unvisited nodes for Node G. At this time, there are six nodes in the stack, i.e. Node A, B, C, D, F and G. The search pops backward and finally pops back to Node A. Since Node A has no unvisited adjacent node, the A is also taken off from the stack. Now, there are no nodes in the stack. Thus, according the rules mentioned in this section, the depth first search method has finished its searching procedure.

Implementation of the depth first method for finding recirculation in network

For finding the recirculation in the network on the basis of the depth first search method, the searching strategy has been changed as follows:

- The search follows the direction of the line, i.e. the direction of airflows in a ventilation system.

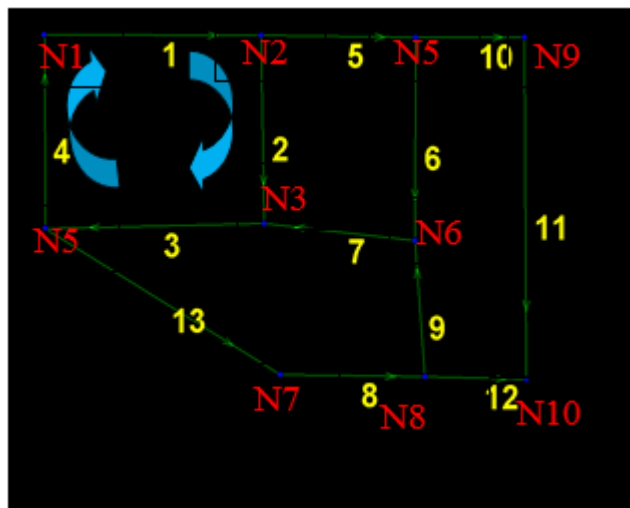- If the travel traces back to the initials nodes, a recirculation is found.

Fig. 2 - A simple network

The modified depth first search method is implemented by MATLAB. In order to explain how to use the method in MATLAB, a simple example is given. Figure 2 illustrates a network. It could be part of a ventilation network or any network. All lines are vector and the arrows represent the direction. Then we number all the nodes. As can be seen, each line with two nodes and the number order according to the directions of the line. For example, line 1 has two nodes, i.e. node 1 and node 2, and the direction of the line is from node 1 to node 2, i.e. from the smaller number to bigger number. There are 13 lines and 10 nodes. The coordinates of every nodes are shown in Table 1.

Therefore, according to the coordinates, the figure can be drawn in MATLAB, as shown in Figure 3. For easily tracking the recirculation, all the graph information, i.e. nodes and lines, is stored in a matrix. The matrix is made according to Equation 1. Equation 2 shows the matrix for all the graph information. In the matrix, the numbers on the horizontal direction show nodes information while the numbers on the vertical direction show the line information. Taking line 4 as an example, there are one "-1"on the line1 which means node 1 is on the line and it is the beginning node while node 4 is also on the line and it is the end node.

$$a_{ij} = \begin{cases} 1 & node\ i\ is\ the\ begining\ node\ of\ line\ j \\ -1 & node\ i\ is\ the\ ending\ node\ of\ line\ j \\ 0 & node\ i\ is\ not\ belong\ to\ line\ j \end{cases} \qquad (1)$$

Tab. 1 - The coordinates for the simple network of fFgure 2

| Line	Coordinates of beginning nodes			Coordinates of ending nodes		
	X	Y	Z	X	Y	Z
1	781	835	490	1024	836	490
2	1024	836	490	1027	1034	490
3	1027	1034	490	782	1039	490
4	782	1039	490	781	835	490
5	1024	836	490	1197	838	490
6	1197	838	490	1196	1052	490
7	1196	1052	490	1027	1034	490
8	1045	1193	490	1207	1195	490
10	1207	1195	490	1196	1052	490
11	1197	838	490	1319	838	490
12	1319	838	490	1321	1198	490
13	1207	1195	490	1321	1198	490
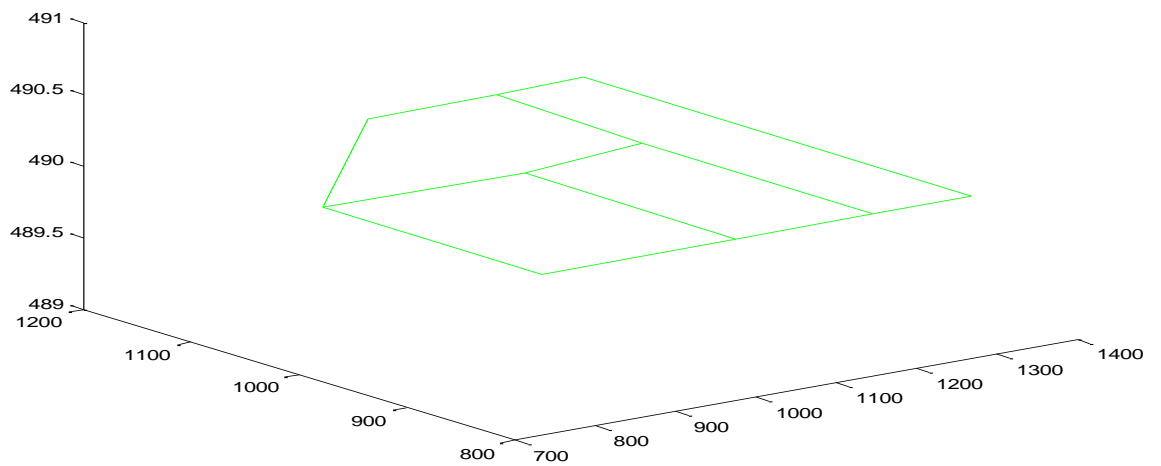
Fig. 3 - Plotted figure according to coordinates in Table 1

$$
M = \begin{vmatrix}
1 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
-1 & 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & -1 & 1 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & -1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\
0 & 0 & 0 & 0 & -1 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & -1 & 1 & 0 & -1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & -1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 1 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 1 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & -1 & 0
\end{vmatrix}
\tag{2}
$$

The traveling of the graph, i.e. Figure 2, follows the rules mentioned both on the Section 2.1 and Section 2.2. The implementation of the depth first search method, travelling on the graph, is through the data on the matrix of the graph.
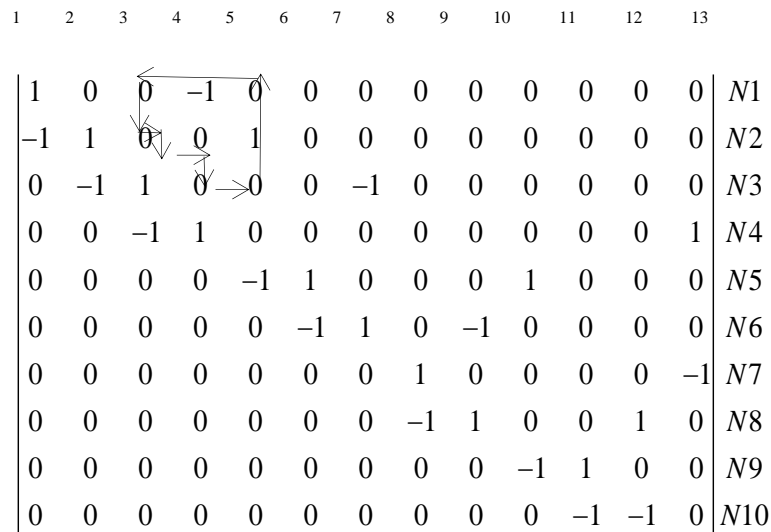
	1	2	3	4	5	6	7	8	9	10	11	12	13	
	1	0	0	-1	0	0	0	0	0	0	0	0	0	N1
	-1	1	0	0	1	0	0	0	0	0	0	0	0	N2
	0	-1	1	0	0	0	-1	0	0	0	0	0	0	N3
	0	0	-1	1	0	0	0	0	0	0	0	0	1	N4
	0	0	0	0	-1	1	0	0	0	1	0	0	0	N5
	0	0	0	0	0	-1	1	0	-1	0	0	0	0	N6
	0	0	0	0	0	0	0	1	0	0	0	0	-1	N7
	0	0	0	0	0	0	0	-1	1	0	0	1	0	N8
	0	0	0	0	0	0	0	0	0	-1	1	0	0	N9
	0	0	0	0	0	0	0	0	0	0	-1	-1	0	N10

Fig. 4 - Graph tracing on matrix

As shown in Figure 2, the lines 1, 2, 3 and 4 are comprised of a recirculation. We take searching this recirculation as an example. The initial node is Node 1, i.e. A_{11} of the matrix, i.e. Figure 4. The search firstly travel on the vertically direction to find the ending node on the line 1. Then we find Node 2, i.e. A_{21}. We continue to search on the horizontal direction to find if Node 2 is also on another line. Then we find that Node 2 is the beginning node of the Line 2, i.e. A_{22}. We repeat the travelling and put the visited nodes in a stack. We found that, we travelled back to node 1, i.e. A_{11}, as shown in Figure 3. Thus, we found a recirculation. It should be noted that line 1, 5, 6, 7, 3 and 4 also form a recirculation, and line 9, 7, 3, 13 and 8 consist of another recirculation. They also can be find using the method mentioned above.

Application the strategy on a mine ventilation system for finding the recirculation of airflows

Yunnan Dahongshan Copper is taken as an example for searching recirculation of airflows. The copper mine is located in Yunnan province, west of China. Figure 5 shows the ventilation system of the copper mine, which has hundreds of airways distributed in 19 levels and 38 fans installed underground. As shown in Figure 5, three slops and one downcast shaft connected with a drift open from where the fresh air flows into the mine. On the right side of the Figure 5, there are slops and shaft for polluted air flowing out of the mine.
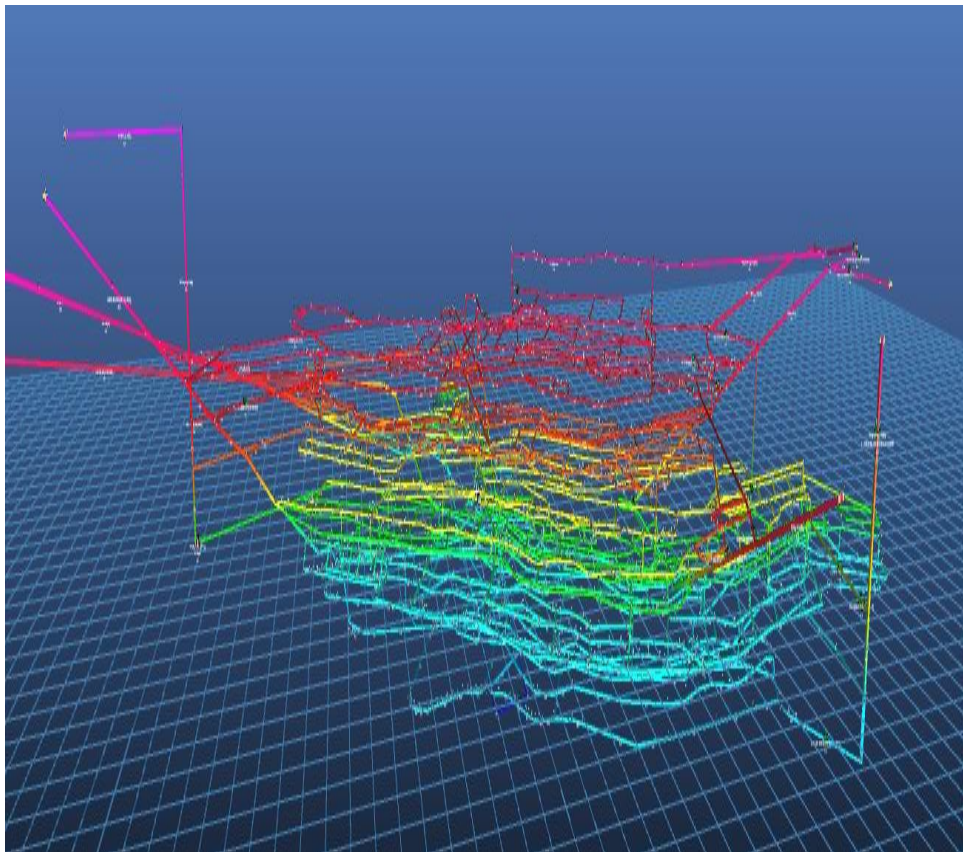
Fig. 5 - Ventilation system of a copper mine

In this ventilation system, the fresh air passes though the intake air shafts and are taken to all the airways underground. Then the fresh air will pass to the working face area to dilute the contaminated air, including methane and heat. Eventually, the contaminated air will be carried out though the return shafts, i.e. shaft and slops on the right side of Figure 5.

It is obvious that, the mine ventilation system is extremely complicated with five downcast shafts and four up-cast shafts as well as 38 booster fans underground. Although, the ventilation system can be solve by some ventilation solving software, it is still very difficult to find the recirculation of airflows in such a complicated ventilation system. Therefore it is necessary to study how to track along the airflows to find the recirculation. In order to apply the depth first method to find recirculation of airflows in the copper mine ventilation system, the ventilation solving software, i.e. VENTSIM, is employ to achieve the coordinates of all the airways of the copper mine ventilation system. Table 2 contains all the coordinates of each airway, i.e. the coordinates of the beginning and end nodes of airways.

Tab. 2 - The coordinates for the network of Figure 4

No.	Flow	Vel	Pdrop	Resistance	K-Factor	Height	X1	Y1	Z1	X2	Y2	Z2
1	.1.237	4.2	6.6	0.0038539	0.01503	3.2	1187	855	435	1198	845	435
2	.1.237	4.2	21.7	0.0127703	0.01503	3.2	1198	845	435	1258	835	435
3	.1.237	4.2	35.3	0.0207509	0.01503	3.2	1258	835	435	1359	821	435
4	7.17	0.7	0.7	0.0130742	0.01503	3.2	1359	821	435	1336	879	435
5	15.7	1.6	1.4	0.0055975	0.01503	3.2	1336	879	435	1349	899	435
6	8.53	0.9	0.2	0.0031389	0.01503	3.2	1331	889	435	1336	879	435
7	15.7	1.6	7.2	0.0292496	0.01503	3.2	1349	899	435	1484	954	435
8	15.7	1.6	5.9	0.0237437	0.01503	3.2	1484	954	435	1594	913	435
9	!1.963	2.2	4.8	0.0098706	0.01503	3.2	1594	913	435	1610	870	435
10	!1.963	2.2	6.7	0.0138148	0.01503	3.2	1610	870	435	1582	810	435
11	0.441	1.1	0.8	0.0069963	0.01503	3.2	1582	810	435	1565	784	435
12	2.731	0.3	0.0	0.0060621	0.01503	3.2	1565	784	435	1540	776	435
13	7.709	0.8	0.3	0.0058546	0.01503	3.2	1565	784	435	1568	759	435
14	6.425	0.6	0.3	0.0073246	0.01503	3.2	1540	776	435	1568	759	435
15	!4.067	3.4	13.9	0.0119732	0.01503	3.2	1359	821	435	1415	812	435
16	1.268	1.1	0.2	0.0015186	0.01503	3.2	1415	812	435	1413	810	435
17	1.268	1.1	0.2	0.0014037	0.01503	3.2	1413	810	435	1411	809	435
18	1.268	1.1	0.2	0.0012443	0.01503	3.2	1411	809	435	1410	808	435
19	1.268	1.1	0.2	0.0018375	0.01503	3.2	1410	808	435	1406	806	435
20	1.268	1.1	0.2	0.0016694	0.01503	3.2	1406	806	435	1403	804	435
21	1.268	1.1	0.2	0.0015186	0.01503	3.2	1403	804	435	1401	802	435
22	1.268	1.1	0.2	0.0015186	0.01503	3.2	1401	802	435	1399	800	435
23	1.268	1.1	0.2	0.0016694	0.01503	3.2	1399	800	435	1397	797	435
24	1.268	1.1	0.2	0.0012443	0.01503	3.2	1397	797	435	1396	796	435
25	1.268	1.1	4.1	0.0326633	0.01503	3.2	1396	796	435	1317	653	435

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3358	7.822	1.8	3.0	0.0094394	0.01503	3.2	1496	1278	500	1455	1263	500
3359	2.794	0.3	0.1	0.0076	0.01503	3.2	1484	1246	500	1496	1278	500
3362	!4.208	10.3	105.7	0.0256432	0.01840	2.6	2439	269	550	2432	241	550
3363	!2.203	4.5	21.4	0.0055212	0.00900	4.5	2762	733	741	2763	630	759
3365	.6.485	2.9	0.6	0.0002752	0.00900	5.0	2743	743	740	2762	733	741
3366	5.717	1.0	0.1	0.0005927	0.00900	5.0	2760	785	740	2762	733	741
3370	!0.047	11.3	67.7	0.0105679	0.00800	5.0	2622	588	750	2711	582	758
3371	!0.047	11.3	18.6	0.0029084	0.00800	5.0	2711	582	758	2732	581	758

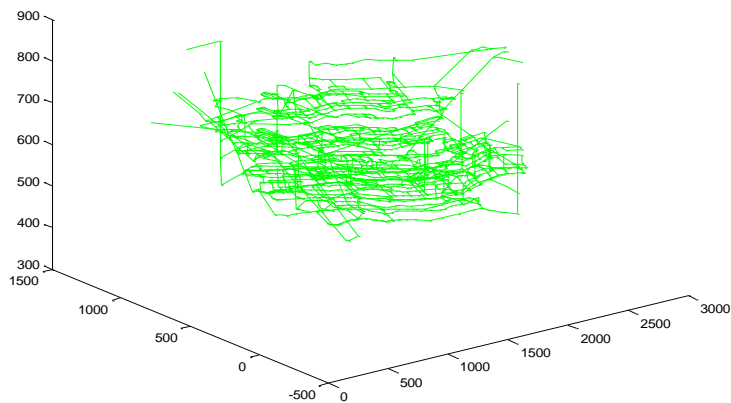Therefore, according to coordinates in Table 1, the ventilation system can be plot through on as shown in Figure 6.

Fig. 6 - Ventilation of the copper mine plotted in MATLAB

Then we search the recirculation of the airflows from a given node where a fan is there. The found airflows are marked as red colour. The results are shown in Figure 7 in which the recirculation of the airflows are marked in red colour.
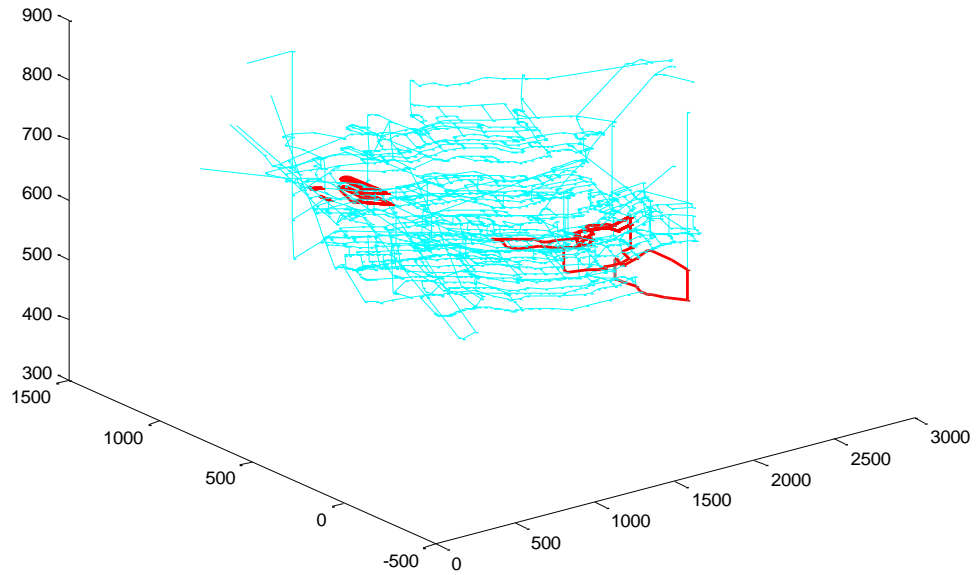

Fig. 7 - Ventilation system and the recirculation of airflows (marked using red colour) of the copper mine
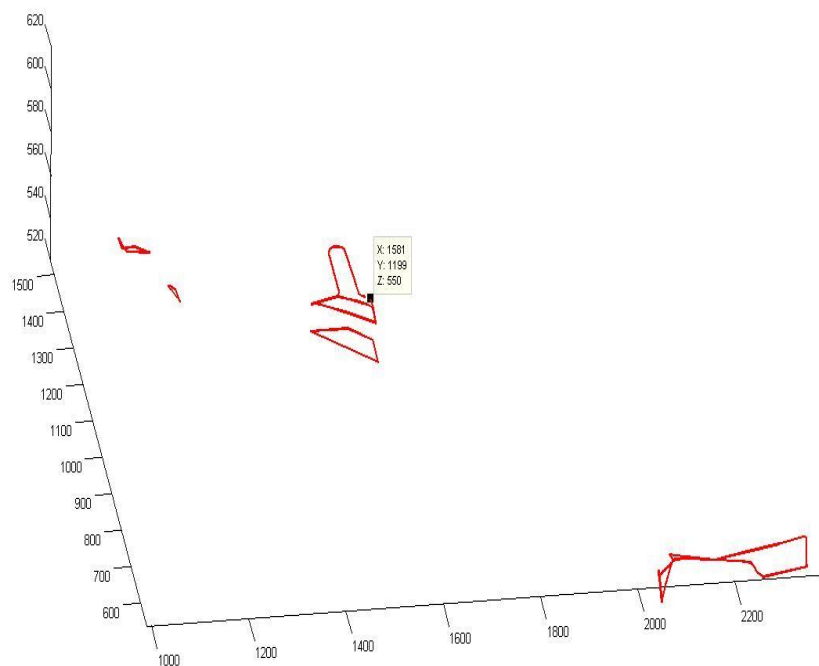

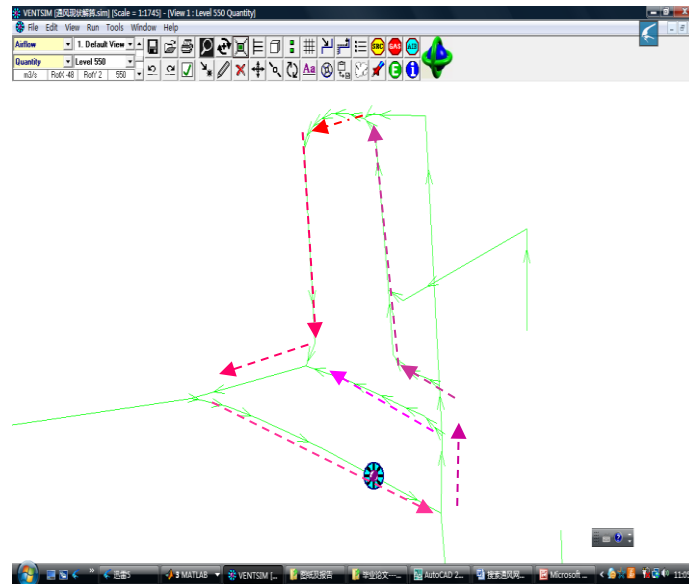*Fig. 8 - Recirculation of airflows in the copper mine*

Fig. 9 - The corresponding recirculation of Figure 7

The found recirculation of airflow as indicated in the red colour (Figure 8) is compared with the simulation result by VENTSIM as shown in Figure 9. It is found that the recirculation found by depth first search method is confirmed by the ventilation simulation result.

CONCLUSION

The recirculation of airflows in a mine ventilation system can reduce the volumetric efficiency and induce the concentration of contaminated air. Therefore, it is necessary to find the recirculation of airflows and control them. However, it is difficult to find the recirculation of airflows in a complicated mine ventilation system. Moreover, the recirculation of airflows is mainly induced by fan installed in underground mine. Thus a searching strategy is proposed on the basis of depth first search method for finding the recirculation of airflows which is mainly induced by unground fans. The depth first search method is introduced briefly since there are many studies on the method, while the searching strategy for the finding recirculation of airflows, i.e. the modified depth first search method, is introduced in detail. The proposed method is implemented by MATLAB. A simple example of applying the proposed method by MATLAB is introduced step by step. Then the proposed searching strategy is used to find the recirculation of airflows induced by booster fans in a complicated copper mine ventilation system. The found recirculation of airflows are marked using red colour and are compared with the ventilation simulation results. It is found that the recirculation of airflows found by the searching strategy agree with the simulation results. It is concluded that:

- The searching strategy is able to find recirculation of airflows induced by fan installed underground in a complicated mine ventilation system.

- The searching strategy could be easy implemented through MATLAB by storing all the network information in matrix and searching the data in the matrix.

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