Acta Technica 62 No. 1A/2017, 179–190

Design and key technology of coal mine safety monitoring system based on analytic hierarchy process (AHP)[1]

Gao Xiaoxu[2,3]

Abstract. The paper aims at analyzing the causes for coal mine safety accidents dishonesty and verifying the applicability of coal mine safety monitoring system. The analytic hierarchy process (AHP) is used to establish the dishonesty model of gas explosion. In addition, combined with the current situation of coal mine safety monitoring system and the development trend of wireless sensor network technology, the design scheme of coal mine comprehensive monitoring system based on wireless sensor network technology is put forward. What is more, on the basis of theoretical research, based on CC2430/CC2431 node design, the safety monitoring system in a wireless sensor network is achieved, and the test of the system in the simulated mine is carried out. The test results showed that when the layout distance of wireless nodes is 10 m, it meets the communications needs of the system. In conclusion, the coal mine safety monitoring system is of great significance in reducing coal mine accidents, which has good performance and applicability.

Key words. Analytic hierarchy process, wireless sensor, coal mine safety, monitoring system
.

1. Introduction

Coal is the foundation of our national economy and social development. Our country belongs to the country poor in oil but rich in coal. At present, the coal energy accounts for about 73 % of energy production and consumption in China. Moreover, for a long time in the future, the status of coal as the major energy will not change. As a result, the coal still is a basic industry related to sustainable development of national economy, and this situation will not change in the long historical period. Safety is very important for coal production. At present, the

[1]The study was Supported by National Natural Science Foundation of China (51504183).

[2]School of Energy Science and Engineering, Xi'an University of Science and Technology, Xi'an Shaanxi 710054, China

[3]Key Laboratory of Western Mine & Hazard Prevention, China Ministry of Education, Xi'an Shaanxi 710054, China

production of coal mine in our country is mainly using the method of well drilling, and the production environment is complex, so it is essential to ensure the safe production of coal mine [1]. After years of development, the security situation of China's coal industry has been significantly improved. However, the underground casualty accident is still very serious, and major accidents occurred sometimes, which has become a "bottleneck" problem that constraints the development of China's coal industry.

Since that China's coal seam conditions and geological structure are complex, spontaneous combustion, high gas, coal and gas outburst coal seam are various. As a result, it resulted in the complex safety problems in the production of coal mine. In addition, with the increase of mining depth and development of high yield and high efficiency coal mine, it put forward many new security technology problems for the safety production of coal mine in China. Therefore, it is an inevitable trend of loss of historical development and the urgent problem in the coal industry safety needed to be solved to take scientific, systematic, and complete measures to change the coal security situation in our country and the backwardness, and to strengthen the research and application of the safety management and safety science and technology. In addition, it is quite urgent to effectively prevent and control all kinds of accidents, and reduce the casualties and economic loss caused by all kinds of accidents.

From the causes of coal mine accidents in China in recent years, in China's coal mine accidents, the vast majority are caused by responsibility accidents. In consequence, to simply improve the coal mine safety control technology is not enough to solve the present situation of mining accidents in our country [2]. Instead, only by comprehensively and systematically analyzing coal mine accident causes, finding the root cause of coal mine accidents, establishing effective accident model, and taking effective measures and countermeasures from two aspects of technology and management, can we effectively prevent and reduce the occurrence of coal mine accidents and the hazards brought about. This paper starts from research on the dishonesty factors resulting in all kinds of typical coal mine safety accidents, and uses AHP method to construct the coal mine safety accidents dishonesty model. In addition, we make a systematic analysis of the causes of coal mine safety accidents by the importance degree of influence of various dishonesty factors on the accidents. What is more, on this basis, for the existing problems of coal mine safety monitoring system, according to the development trend of wireless sensor network technology, we put forward the solution for the coal mine safety monitoring system based on wireless sensor network.

2. Methodology

According to statistics of the State Administration of Work Safety, in the past five years, gas accidents accounted for a half of the coal mine safety accidents with more than 10 people died. And the gas explosion accident accounted for the first in all gas accidents. As a result, this paper only selects the representative top 45 gas explosion typical coal mine safety accident with high occurrence percentage and frequency for the analysis.

2.1. *Accident cause statistics*

First of all, according to the necessary conditions of the controllable gas explosion, we make a classification statistics of the direct causes of the 45 accidents: the fire source causing the occurrence of accidents and the reason of the gas concentration overrun, and the data in Table 1 are obtained.

Table 1. Statistical analysis of gas explosion accident

Necessary conditions for gas explosion	Reasons	Frequency
Source of fire	Electric spark	17
	Blasting spark	17
	Others	11
Gas concentration overrun	Ventilation system	27
	Mined out area	6
	Others	12

2.2. *Establishment of the hierarchy model of dishonesty factors*

Through the investigation report of the 45 cases of heavy gas explosion accidents, we can see that these accidents are all the responsibility accidents, so they can be attributed to the personnel dishonesty factors and the equipment dishonesty factors. For the personnel dishonesty factors, they include managers' dishonesty and staff dishonesty.

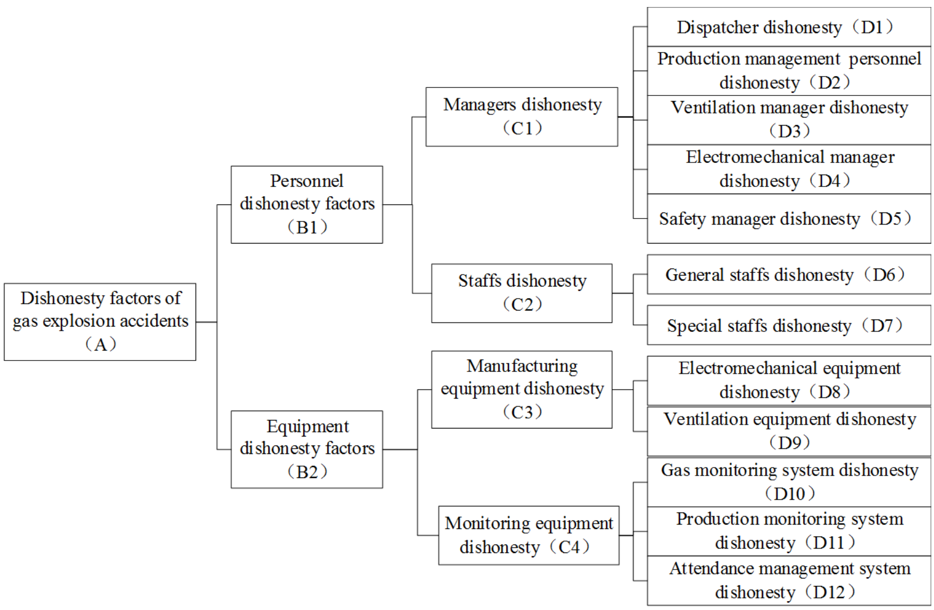

Fig. 1. Hierarchy structure model of dishonest factors in gas explosion accident

For equipment dishonesty factors, they include the production equipment dishonesty and monitoring equipment dishonesty. Through the dishonesty analysis of the gas accident, the dishonest factors in the gas accident are decomposed into several sub factors, and the hierarchical structure model is constructed according to the relationship among these factors, as shown in Fig. 1.

2.3. Construction of judgment matrix

The analytic hierarchy process uses 1∼9 scaling to assign the importance degree of various factors, and the value of each factor we get is the number for them appearing in the accident. In consequence, the differences between various factors are used as the basis for determining 1∼9 scaling. Set the difference of each factor value to be $a_x = u_i - u_j,\ x = 1, 2, ..., n$, where n indicates the number of lower indicators [3]. And for the lower level indicators u_i and u_j corresponding to the higher level indicators, the meaning of corresponding 1∼9 scales are shown in Table 2. According to the meaning of scales in Table 2, the comparison judgment matrix under different criteria can be obtained.

Table 2. Meaning of 1∼9 scaling

Scaling	Difference (a_x)	Meaning
1	0∼4	It represents that u_i and u_j have the same importance.
3	6∼9	u_i is slightly more important than u_j
5	11∼14	u_i is more important than u_j
7	16∼19	u_i is quite important than u_j
9	above 20	u_i is extremely important than u_j
2,4,6,8	5,10,15,20	The adjacent intermediate values of above judgments
1,1/2,1/3,. . . ,1/9	The negative values	The importance ratio of u_i to u_j is a_{ij}, then the importance ratio of u_j to u_i is $1/a_{ij}$

According to Table 2, we can obtain the judgment matrix W between managers and the subordinate personnel in the form

$$W = \begin{bmatrix} C_1 & D_1 & D_2 & D_3 & D_4 & D_5 \\ D_1 & 1 & 9 & 1 & 1/5 & 1/7 \\ D_2 & 1/9 & 1 & 5 & 3 & 2 \\ D_3 & 1 & 1/5 & 1 & 1/5 & 1/7 \\ D_4 & 5 & 1/3 & 5 & 1 & 1/2 \\ D_5 & 7 & 1/2 & 7 & 2 & 1 \end{bmatrix}$$

The vector of characteristics values of the matrix is $W = (0.0426, 0.4285, 0.05, 0.1823, 0.2965)$.

Matrix W refers to the weights of four kinds of personnel dishonesty, including dispatcher, production managers, ventilation managers, electromechanical managers, and safety managers. Similarly, we can get the various judgment matrices under other criteria. We calculate and obtain the comprehensive weights of various dishonesty factors, and thus get the dishonesty model of gas accidents.

According to the dishonesty model of gas accidents, the weight of personnel dishonesty accounted for 0.9, while the weight of equipment dishonesty is only 0.1 [4]. And in the staffs' dishonesty, what accounted for the larger weight are the special personnel dishonesty, production management personnel dishonesty and safety management personnel dishonesty.

3. Result analysis and discussion

In view of defects and shortcomings in the coal mine safety monitoring and control system, and underground dishonesty factors, we put forward the coal mine safety monitoring system based on wireless communication technology and the multimedia wireless sensor network technology. It is composed of sensing and detecting system, security information network and communication system, security management information system, safety warning decision and decision support system, and rescue information support system, as shown in Fig. 2.

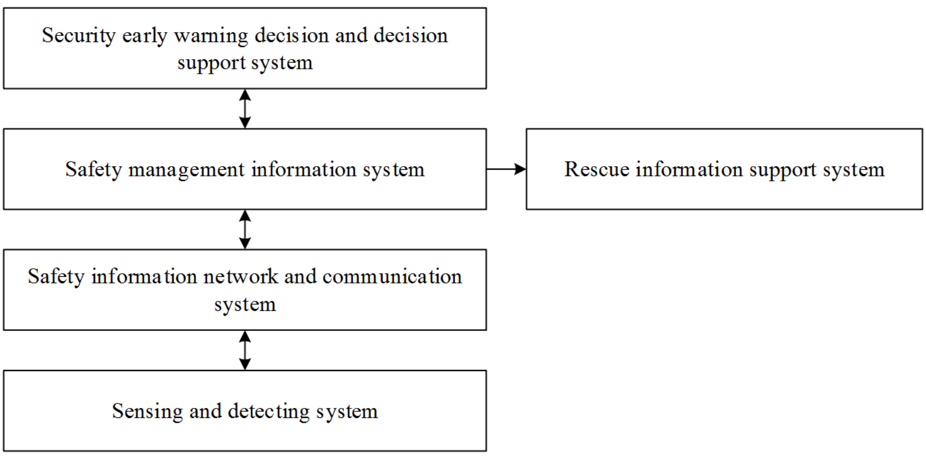

Fig. 2. Structure of coal mine safety monitoring system

3.1. Sensing and detection system

Sensing and detection system is the bottom support system of a coal mine safety comprehensive monitoring system. It is composed of a large number of sensors underground and wireless sensor network nodes, to realize the collection of underground basic data, and to upload it to the upper system for processing. Sensor is the terminal equipment for underground data acquisition, which can acquire the underground environment and equipment data. In accordance with the needs of underground production safety monitoring, sensors usually include environmental sensors, equipment sensors, video sensors, audio sensors and vital signs sensors.

Each sensor is connected with the underground wireless sensor network nodes through the interface. Each underground sensor node has the function of calculation, storage, and wireless communication, with embedded operating system inside. According to the monitoring needs, write the monitoring program [5]. Each sensor node has the intelligent interface identification function. It can automatically identify the connected sensor types and models, and automatically call the corresponding monitoring program to drive the sensor to work.

3.2. Safety information network and communication system

The system is mainly used for data transmission of safety monitoring system. Wireless sensor network (WSN) is a network composed of a large number of micro mobile sensor nodes, which can monitor, perceive and collect environmental information, process the data and transmit to the monitoring center. It combines sensor technology, remote control technology, embedded computing technology, distributed information processing technology and wireless communication technology. It can be widely used in coal mine harmful gas monitoring, moving target tracking, environmental state changes monitoring and so on.

The underground wireless sensor network is composed of three parts: wireless gateway, wireless sensor node and sensor. The gateway is the connection and conversion equipment between wireless sensor networks and wired LAN, with computing and storage capacity. It is the data export of wireless sensor network, responsible for data transmission acquired by wireless sensor network to the wired network, and transmission of the control command to the wireless sensor network.

The overall structure of the integrated monitoring system of mine is shown in Fig. 3. The system is mainly composed of integrated ground control station, intrinsically safe network intelligent substation, flameproof and intrinsically safe network switches, intrinsically safe network video server, intrinsically safe mobile communication base station, intrinsically safe network camera, cable or coaxial cable, wireless sensor network convergence device, sensor nodes and so on. The system is interconnected with the local area network and the Coal Mining Group Corporation (Bureau) wide area network [6].

3.3. Safety management information system

The safety management information system is used to deal with the state data of the environment, equipment, personnel, vehicles and so on acquired underground, and to issue various control commands according to the needs of safety control. Mine information is the dynamic and active information that is closely related to spatial location information. The safety monitoring information with location information is meaningful. And the coal mine safety monitoring information is dispersing in positions and unified in types. The data content collected by different monitoring systems has different types and the forms are dispersing, necessary for effective integration. Only in this way can it provide complete, comprehensive and unified safety information for coal mine safety managers [3]. Therefore, based on the coal mine geographic information system (GIS), the platform of safety management information system is constructed which organically integrates various monitoring information systems.

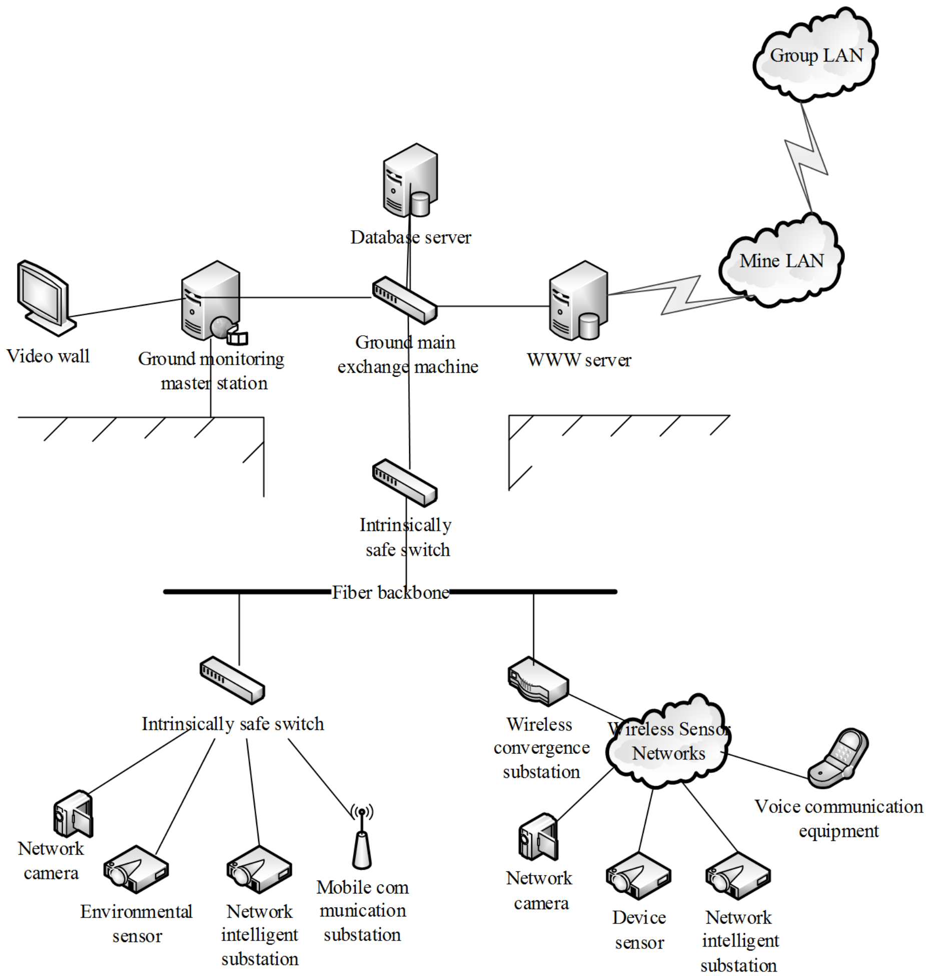

Fig. 3. The overall structure of the system

3.4. Security early warning decision and decision support system

Safety early warning decision and decision support system, based on coal mine safety production needs, combined with geological conditions of coal mines, establishes a variety of security early warning models and realizes the online identification of security risks. The system is able to in time identify the major hazard sources that may be of high risk, to send out early warning signals, and to start early warning response action plan according to the environment, equipment and production data. At the same time, it can be used to evaluate the changing process of the hazard degree of high risk source in real time, and to continuously change the level of the early warning, so as to adapt to the complex coal mine production environment. The decision support system shall carry out uninterrupted continuous monitoring on all kinds of underground dangerous source. According to the enterprise development, the critical value or the critical environmental parameters Approved by industry authorities make a dynamic monitoring of the dangerous source. As long as there is a danger source reaching the set value, enterprises have entered into early warning management period.

3.5. Rescue information support system

The rescue information security system can extract the information needed by the rescue from the security information management system after the occurrence of the mine disaster, which can be used for rescue decision makers to facilitate the timely rescue. Rescue information security system can extract the number of personnel underground and distribution information when the accidents occur from the underground personnel positioning system. In addition, it can extract various environmental data from underground mine environment information system when the accidents occur. Moreover, it can extract the state of various equipment information from the equipment information system when accidents occur. At last, it can extract underground geological data, distribution of roadway information from the underground GIS system. Rescue information security system, based on the extracted information, can use virtual reality technology to generate three-dimensional tunnels real map information and simulate the effect graph of underground mine accidents. What is more, it can analyze the possible personnel moving track and distribution after the mine accidents occurred, and based on virtual reality technology, simulate the effects of various rescue scheme, so as to determine the best rescue plan.

3.6. Data analysis

The beacon node of the wireless sensor network node of the system uses the CC2430 node, the unknown node uses the CC2431 node, and the sink node uses the C51RF-CC2431-ZDK network expansion board. The software development environment of CC2430/CC2431 node is composed of IAR Embedded Workbench and C51RF-CC2431-ZDK emulator. PC control software is running on the PC control computer, and making data exchange with the sink node through the RS232 interface. It is mainly responsible for the deployment of nodes in the wireless sensor network, network data receiving, storage and graphical display.

In order to verify the change of network signal of the coal mine safety monitoring system based on wireless sensor network with the distance, we design the experiments that the underground signal intensity changes with the distance. First of all, according to the wireless sensor network test platform constructed, the acquisition and test of the RSSI value between the nodes with the distance in the tunnel is carried out. The two nodes are deployed in the underground roadway and the transportation lane, one is the transmitter, and the other is the receiving end. Continuously change the distance between the nodes and record the RSSI value of the communication between the two nodes.

The results of the experiments are shown in Figs. 4 and 5.

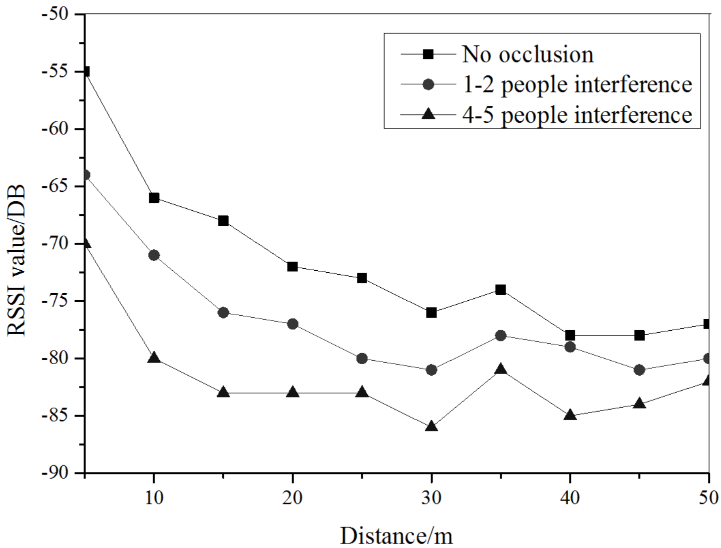

Fig. 4. RSSI test data in main lane

As can be seen from the results, with the increase of distance between the transmitter node and the receiving end node, the change of distance will result in that the RSSI values between nodes produce greater change. The closer the two nodes distance, the stronger the received signal strength, and the greater the RSSI value; the farther the distance, the weaker the received signal strength, and the smaller the RSSI value. In the case of the same distance, with the narrowing of the tunnel width, the attenuation degree of wireless signal is increasing, and the narrower the roadway is, the smaller the RSSI value received in the same distance will be. Because the width of the roadway is larger than the width of the lane, the signal attenuation in the traffic lane is worse than that in the lane. When there is no barrier between the nodes, the change of RSSI value with the distance is relatively smooth; when the nodes are shielded, the change curve of RSSI value with the distance is relatively fast, and with the increase of disturbance, the degree of signal attenuation increases.

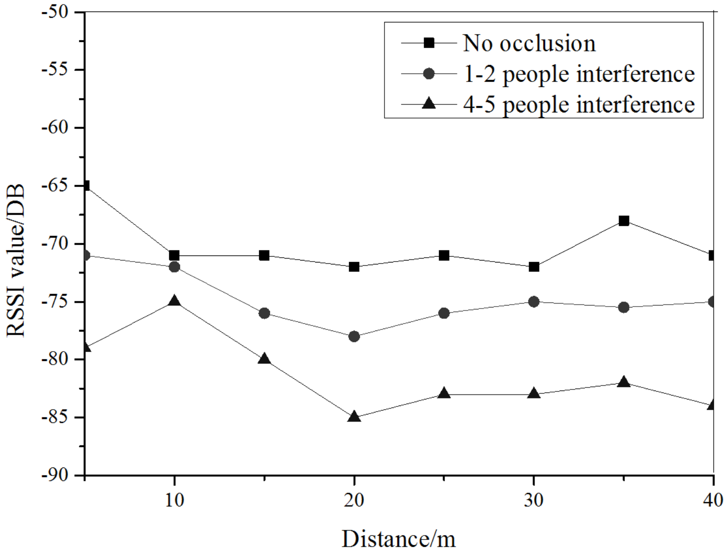

Fig. 5. RSSI test data in the transport lane

The experimental results showed that when the distance between nodes is 10 m, the intensity of the signal meets the needs of the system

4. Conclusion

According to the present situation of coal mine accidents in our country, this paper analyses the causes of the typical coal mine safety accidents from the perspective of dishonesty by the statistics and analysis of the typical coal mine safety accidents in recent years. Using AHP method, we establish the dishonesty model of the typical gas explosion accidents. In addition, on this basis, in view of the existing problems of coal mine safety monitoring system, combining with the development trend of wireless sensor network technology, we put forward the solution of coal mine safety monitoring system based on wireless sensor network. It is composed of five parts: a sensing and detection system, security information network and communication system, safety management information system, safety early warning decision and decision support system, and rescue information support system. The experimental results showed that when the distance between the nodes is 10 m, the signal strength of the underground wireless network meets the needs of system data transmission.

References

[1] T. L. Saaty: *Decision making with the analytic hierarchy process*. International Journal of Services Sciences *1* (2008), No. 1, 83–98.

[2] O. S. Vaidya, S. Kumar: *Analytic hierarchy process: An overview of applications.* European Journal of Operational Research *169* (2006), No. 1, 1–29.

[3] G. Sun, H. Zhou, K. Sun: *Coal mine safety evaluation method based on incomplete labeled data stream classification.* Open Cybernetics & Systemics Journal *8* (2014), No. 1, 918–923.

[4] D. Mondal, P. N. S. Roy, PP. K. Behera: *Use of correlation fractal dimension signatures for understanding the overlying strata dynamics in longwall coal mines.* International Journal of Rock Mechanics and Mining Sciences *91* (2017), 210–221.

[5] S. Han, H. Chen, R. Long, H. Qi, X. Cui: *Evaluation of the derivative environment in coal mine safety production systems: Case study in China.* Journal of Cleaner Production *134* (2017), 377–387.

[6] L. Xin, Z. T. Wang, G. Wang, W. Nie, G. Zhou, W. M. Cheng, J. Xie: *Technological aspects for underground coal gasification in steeply inclined thin coal seams at Zhongliangshan coal mine in China.* Fuel *191* (2017) 486–494.

Received May 22, 2017