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Climatic hazard assessment in selected underground hard coal mines in Vietnam

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Abstract. The article discusses the possibility of improving the microclimate in underground hard coal mines in Vietnam. Vietnamese underground mines are shallow mines which extract coal deposits accumulated up to 500 m below ground. According to the current Vietnamese laws, coal deposits can be mined if air temperature does not exceed 30ºC, although this rule is not always observed, especially during summer. This article analyses the impact of air parameters on the climatic conditions in headings and the use of the air temperature reduction method in selected underground mines in Vietnam.

1. Introduction

Working conditions in underground mines have their specific characteristics differing from opencast mines. Underground mines are primarily characterised by working sites scattered across a large area and human-unfriendly working environment. In addition to technical hazards arising from technological processes, there are also natural threats related to the rock mass surrounding the headings (water, gas, gas and rock ejections, gas and dust explosions, rock bursts, and climatic hazards).

In underground headings there are natural and technological sources of heat reaching the flowing air. This results in high temperatures in the headings, which, in combination with high humidity, leads to a considerable deterioration of climatic conditions. These cause a decline in bodily functions, having a negative impact on perception, concentration, and attention, and causing fatigue. This unfavourable impact of temperature and humidity on the human body is referred to as 'climatic hazard'.

In underground mining, climate is determined by the physical parameters of the air and the environment, such as the chemical composition of air, temperature, humidity, air velocity and the average radiation temperature of the heading's walls. This article analyses and assesses the impact of temperature, humidity and air velocity on the climatic conditions in the headings of selected Vietnamese mines.

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2. Microclimate parameters in underground hard coal mines in Vietnam

In Vietnam hard coal is found mainly in the northern part of the country, in the regions Quang Ninh, Thai Nguyen, Bac Kan, North Path, Nong Son, Ba River, Da River, Ca River and Nghe Tinh, marked in Fig. 1.

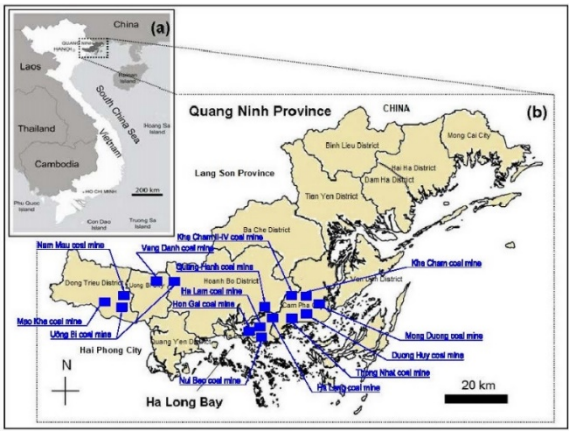

Fig. 1. Vietnamese coal mining districts [1]

Fig. 2. Underground hard coal mines in the Quang Ninh Coal Mining District [1]

The largest hard coal mining district is located in the Quang Ninh province, in the north-eastern part of Vietnam (Fig. 2). Most coal mines in Vietnam belong to the Vietnam National Coal – Mineral Industries Holding Corporation Limited (VINACOMIN).

By the end of 2018 most VINACOMIN's underground mines had completed the mining of deposits over the sea level and began mining deposits found below sea level. The annual average production in these mines is around 1,500,000 Mg. Vietnamese underground mines are shallow mines which extract coal deposits up to 300 m below ground, e.g. Nui Beo, Ha Lam, Mao Khe and Khe Cham III. Deeper mines include Khe Cham II-IV, reaching 500 m below ground.

Now and in the next few years, VINACOMIN will accelerate the mechanisation of coal deposits mining by introducing roadheaders, self-propelled drilling rigs and rockbolt supports with sprayed concrete. Mechanisation will also be applied to longwall headings, where mechanised supports will be used, with wooden supports replaced with hydraulic props. In the Khe Cham, Khe Tam, Ha Lam, Mao Khe, Vang Danh and Nam Mau in which conditions of coal deposit accumulation are favourable, longwall shearers will be used and the system of transporting the excavated material with belt conveyors will be upgraded.

2.1 Air velocity in headings

Vietnamese underground mines use a ventilation system based on main ventilation fans, the so-called central suction system. In addition, in extraction areas supplementary fans are used.

Software used for modelling air flow through mining headings, which are highly scattered, with an irregular network of headings due to their complex geological structure includes such programs as Kazamaru, Ventgraph and Ventsim.

In Vietnam, mining operations are governed by Regulation No. 03/2011/TT-BCT of the Ministry of Industry and Trade, according to which the air velocity in the wall and heading faces cannot be less than 0.25 m/s. In mines with methane hazard categories III and IV air current speed cannot be below 0.5 m/s (in faces with an 15° incline or coal deposits thicker than 2 m as well as face headings with a length up to 100 m). Air velocity cannot exceed: 4 m/s in coal excavations, 8 m/s for tunnel headings, 10 m/s – for air crossings, 12 m/s in shafts and fore-shafts while transporting people and 15 m/s in air ducts. Table 1 presents the volumetric air stream and its velocity in selected underground mines in Vietnam.

Table 1. Examples of air velocity and volumetric air delivery in selected mines in Vietnam

No.	Heading name	Volumetric air stream [m^3/s]	Cross-sectional area of the heading [m^2]	Air velocity [m/s]
A	**Ha Lam mine**			
1	Wall -150 / -160, zone III, coalbed 11	6.9	5.2	1.33
2	Wall 10-2, zone III, coalbed 10	6.0	5.1	1.18
3	Wall CGH 7-2.1	27.0	8.5	3.18
B	**Vang Danh mine**			
1	Bottom gate of wall CII-8-3, coalbed 8, Canh Ga zone	4.6	4.5	1.02
2	Air-heading of wall CII-8A-2, coalbed 8A, Canh Ga zone	5.4	4.8	1.13
3	Air-heading level +106, coalbed 6, Gieng Vang Danh zone	13.2	5.5	2.40
C	**Thong Nhat mine**			
1	Bottom gate of wall KT7	6.7	4.8	1.40
2	Air-heading of wall KT8	11.0	8.5	1.29
3	Bottom gate of wall KT9	2.3	5.7	0.40

Ventilation in underground mines in Vietnam must meet the requirements of the above mentioned regulation regarding air flow and velocity in headings.

2.2 Air temperature and humidity

Air temperature in mine headings depends on the temperature of fresh air supplied from the surface, rock mass temperature, ventilation intensity, mining depth, chemical reactions taking place in the rock mass and other factors caused by people or machines working, and blasting works. In line with Vietnamese regulations (03/2011/TT-BCT), air temperature at the working site cannot exceed 30°C. In underground mines in Vietnam in most cases air temperature is maintained at the level meeting the above standards. However, during summer, when the external air temperature exceeds 35°C, hot air is supplied to the working site through the ventilation system, resulting in air temperature higher than 30°C. In addition, increases in air temperature in headings are caused by technological sources of heat and the operation of mining machines. Another factor contributing to the decline of climatic

conditions is air humidity, which often exceeds 85%. Table 2 presents air temperature and relative humidity values in selected Vietnamese mines.

Table 2. Air temperature and humidity in selected headings of underground mines in Vietnam

No.	Heading name	Air parameters	
		Temperature [ºC]	Relative humidity [%]
A	**Mao Khe mine**		
1	Air-heading, level -80, coalbed 8	29.0	83
2	Carrying gangway, level -80 of wall I, coalbed 8, east	30.6	87
B	**Vang Danh mine**		
1	Carrying cross-heading, level -50 F11-F12, zone II - Gieng Canh Ga	28.9	88
2	Carrying gangway, level +60 of wall CIII-8A-2 - Gieng Vang Danh	28.0	88
C	**Nam Mau mine**		
1	Air-heading of wall I-9-5	29.5	94
D	**Ha Lam mine**		
1	Carrying inclined drift of wall CGH 7-2-2	31.0	93
E	**Thong Nhat mine**		
1	Cross-heading, level +18	29.9	94
2	Carrying gangway, level +8, PV4C	29.2	93
F	**Ha Long mine**		
1	Roadway -50 - V11B -CB Cam Thanh	28.6	88
2	Wall -20/+40 V11B -Cam Thanh	28.8	88
G	**Khe Cham mine**		
1	Carrying gangway of wall 14.5.2.A, coalbed 14.5	28.5	75
2	Air-heading, level -152 of wall 14.5.3.1, coalbed 14.5	29.0	82

As demonstrated in Table 2, air temperature above 30ºC is found in several headings of the Ha Lam and Mao Khe mines, in which a mechanised complex was used for extracting coal from walls. This equipment has high electric power and emits a lot of heat to the ambient air. In order to lower the air temperature in the heading of Vietnamese mines ventilation tools are used, which often are not able to sufficiently lower the temperature at working sites.

3. Air temperature lowering options in underground hard coal mines

In order to improve climatic conditions in underground headings, mining companies mainly use traditional methods of headings ventilation, with artificial air cooling methods being used in selected mines and operating areas. The traditional methods of improving climatic conditions in mines are such that do not require cooling equipment. Effective ventilation of headings may improve climatic conditions, taking the following into account [2, 3, 4]:

- limiting fresh air humidification in downcast shafts and at the upper levels,
- simplification of the ventilation network and, consequently, directing a broader stream of fresh air to walls and driven headings,

- proper exposure and cutting of the deposit, shortening the air supply paths and spoil haulage,
- whenever possible, using dip or descending ventilation in extraction areas,
- performing preparatory works on the side where fresh air transported to longwall headings is available,
- selecting an optimum longwall heading ventilation system,
- tight insulation of cave-in goaves (limiting air flow through goaves),
- avoiding serial ventilation of longwall headings,
- locating the spoil haulage from the longwall in the used air current,
- proper design of heading length, especially of longwalls, to account for the ventilation system's efficiency.

With the rising extraction depth and production concentration, traditional methods of improving climatic conditions may prove insufficient. Thus, there is a necessity to use other methods involving the application of cooling devices. There are three tendencies in the mine air conditioning technology used to artificially lower air temperature at working sites through the use of local, group-based or central air conditioning [5].

Local air conditioning, the diagram of which is presented in Fig. 3, is used to cool air in one heading, in which several air coolers can operate arranged, e.g. in a series.

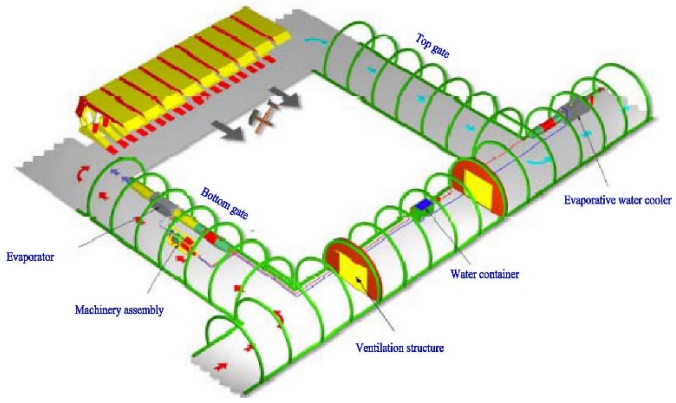

Fig. 3. Local air conditioning diagram [5]

Air conditioning equipment can operate in the indirect or direct system. These devices include an evaporator, which is an air cooler, combined with a machinery assembly consisting of an air-cooled condenser, an expansion valve and an air compressor. The evaporator and the condenser are connected with elastic wires to the coolant circulation. Direct action chillers cool the air stream with an evaporator located directly in the cooled air stream, while heat is collected from the condenser in an open or closed system with the use of technological water. Underground hard coal mines use local direct action chillers with a cooling capacity of 150-450 kW for the air conditioning of face works, driven roadways, cuts and longwalls [2, 5]. In the direct action air conditioning (cooling capacity of 300-900 kW), the evaporator cools the water pumped to the hydraulic air cooler placed in a given heading. The condenser is cooled in a similar way as in direct action systems.

If it is necessary to locate several air coolers in a heading or there is a need to cool the air on a large extraction area, stationary cooling aggregates are used instead of individual

devices. Cooling aggregates supply cold water to air coolers, which is called group air conditioning [5].

Group air conditioning systems (Fig. 4) make use of one or two cooling aggregates combined in a series. The total cooling capacity of the aggregates is from 1000 to 3000 kW. The aggregates are usually located near extraction areas, and the condensation heat is released through evaporative water coolers.

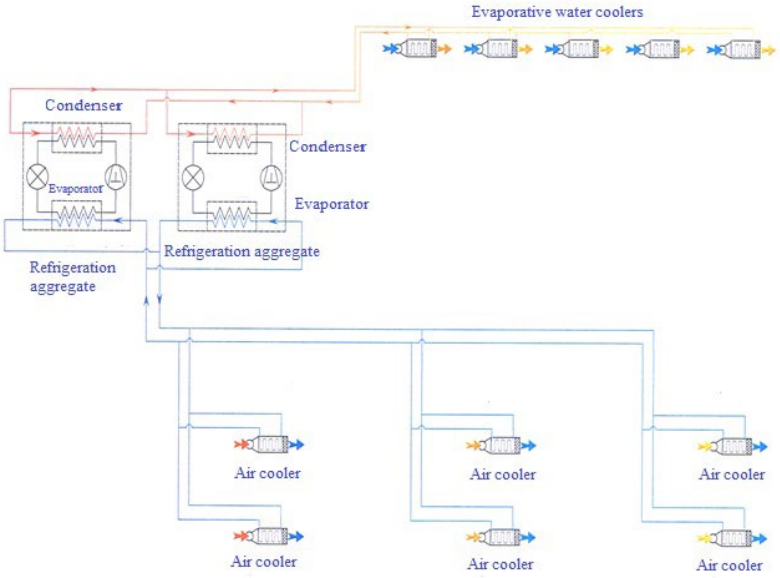

Fig. 4. Group air conditioning diagram [5]

Cooling aggregates, depending on the conditions in a given mine, are usually located near downcast shafts, from which cooled water is transported through isolated pipelines to regional air coolers [4]. In Polish mining, very often group air conditioning systems are used in combination with local air coolers.

In central air conditioning systems (Fig. 5) cooling aggregates with their cooling system can be located on the surface or under ground, or both. Central air conditioning systems use water cooling aggregates, with water pumped to local hydraulic air coolers. In Poland central air conditioning systems are used, for instance, in the Pniówek, Rudna, Budryk and KGHM mines.

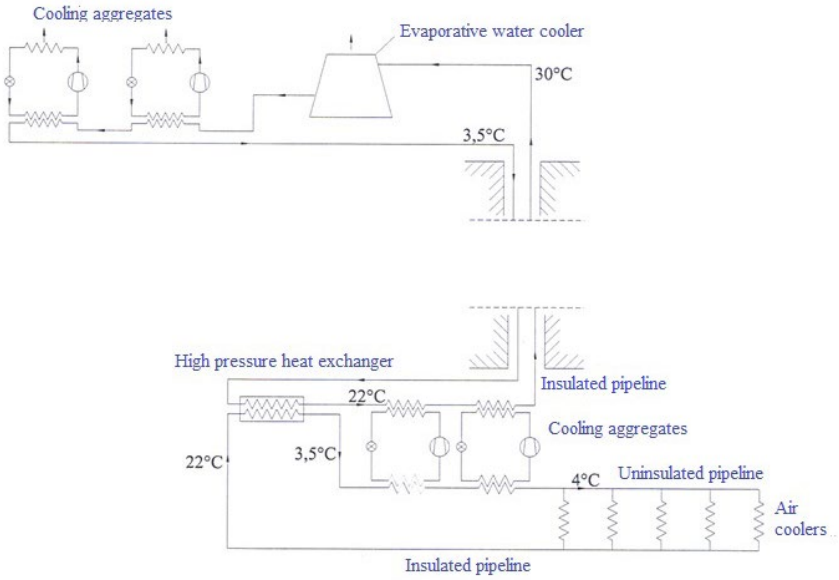

Fig. 5. Central air conditioning diagram [5]

4. Possibilities of applying local air conditioning in the Ha Lam mine in Vietnam

In longwall heading CGH 11-1.14, coalbed 11 in the Ha Lam mine temperature in the summer often exceeds 30°C (Table 3).

Table 3. The air temperature measures in wall 11-1.14 of the Ha Lam mine before installing a local air conditioning system.

Heading name		Months										
		February	March	April	May	June	July	August	September	October	November	December
Bottom gate CGH 11-1-14	°C	28.2	28.7	29	29.5	30.5	31.5	31.5	32	32	29.6	29.1
Wall CGH 11-1-14	°C	29.7	30	30.5	31	31.5	32.5	32.5	32.5	32.5	30.6	30.2
Top gate CGH 11-1-14	°C	30.3	30.7	31	32.5	32.2	33.8	33.5	33.5	33	31.9	30.6
Air stream	m^3/s	22.8	22.3	22.6	24.2	20.5	19.8	21.1	22.7	22.1	22.8	22.3
Surface air temperature	°C	24.2	28.8	32.9	35	36.2	34.8	35.2	32.6	28.6	26.5	24.6

In order to provide appropriate working conditions, in June 2016 a local air conditioning system was installed based on direct action coolers MK300 made in Poland. The air cooler made it possible to reduce air temperature in the heading to 29.4°C. Table 4 contains basic working parameters of the MK-300 cooling device.

Fig. 6 presents air temperature distribution at the surface and in wall CGH 11-1.14 before installing local air conditioning. As can be observed, wall air temperature is below 30°C only at the turn of February.

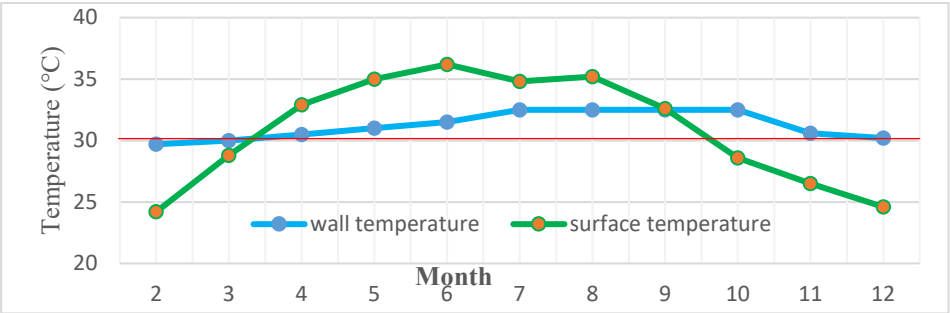

Fig. 6. Air temperature change diagram for wall CGH 11-1.14.

Table 4 contains catalogue data for MK-300 direct action cooler presented in Fig. 7 installed on wall CGH 11-1.14.

Table 4. Basic technical parameters of cooler MK-300 [6]

No.	Item	Parameter
1	Nominal cooling capacity	300 kW
2	Evaporation temperature	(0 ÷ 7°C) T_p = 3.3°C
3	Condensation temperature	(40 ÷ 48°C) T_k = 42°C
4	Volumetric air stream	V_l = 400 ÷ 6700 m^3/min
5	Air temperature at the evaporator inlet	T_{pi} = 31.0°C
6	Air temperature at the evaporator outlet	T_{Ao} = 19.0°C
7	Water temperature at the condenser inlet	T_{wi} = 27°C
8	Water temperature at the condenser outlet	T_{Wo} = 40°C
9	Volume of water cooling the condenser	V_w = 20.0 m^3/h
10	Roadway cooling area (from the evaporator outlet)	150 ÷ 200 m
11	Nominal cooling capacity of the condenser	450 kW

Fig. 6. The MK-300 air cooler used in the Ha Lam mine

5. Conclusions

Ventilation in underground mines in Vietnam meets the requirements regarding air flow and velocity in headings in line with the regulations of the Ministry of Industry and Trade. In line with the regulation, temperature at the working site in an underground mine should not exceed 30°C. In the summer however, in Vietnam external air temperature is high, exceeding 35°C. Also the operation of underground mining equipment and the progressing

automation of coal excavation (the use of mechanised complexes on walls) lead to unfavourable air temperature increases in underground headings.

In order to minimise the negative impact of climatic conditions on production in underground hard coal mines, ventilation methods are used, which do not always prove sufficient. For the purpose of lowering air temperature at working sites, Vietnamese mines have begun to use artificial air cooling in the form of direct action local air coolers.

In the Ha Lam mine, to reduce air temperature on wall 11-1.14, MK300 air coolers made in Poland were used with a nominal capacity of 300 kW. The application of an air compressor system made it possible to reduce the temperature to 29.4°C and thus improve climatic conditions in the heading.

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