The use of computer programs to solve ventilation issues in Vietnamese coal mines

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Abstract. Having enjoyed an economic upsurge in recent years, Vietnam is now recording increased demand for electrical energy. Its production, for the most part, relies on the coal mining industry, thus resulting in a strong upward trend in mining volumes. Being geologically complex, Vietnamese mines are characterised by a complicated structure of their headings. The local ventilation systems are also affected by there being very few automatic dams and an by increases in airflows delivered to the mine. For this reason, in order to analyse airflows and maintain the proper control of ventilation systems, computer software is required. The article offers a comparison of computer programs – Kazemaru, VentGraph and VentSim – as employed for use in Vietnamese mines. The assessment covered the manner in which these programs are used and how their output data are presented, as well as their range of applications in the conditions of Vietnamese coal mines.

1. Introduction

In recent years, the economy of Vietnam has been growing at a rate of 6-7% (with 6.8% recorded in 2017) [1]. The primary source of energy security is coal mining. Up to 2011, open-pit mines had served as the primary source of coal production [2]. At present, open-pit mining accounts for approx. 40% of the entire coal production and continues to drop. This results from the maximum depth being reached up to which mining is profitable. The hard coal production in the years 2017-2018 and the volume to be mined by 2030 are presented in Table 1.

Table 1. Hard coal production volume in Vietnam in 2017-2018 and the volume to be mined by 2030

Year	2017	2018	2020	2025	2030
Volume (million Mg)	35.6	40.0	47-50	51-54	55-57

The main coal producer in Vietnam is Vinacomin, which expects coal production to reach 40 million Mg in 2019 [3]. Detailed information on Vinacomin's coal production from 2011 to 2017 is presented in Table 2.

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Table 2. Vinacomin's coal production in 2011-2017 [4].

Year	2011	2012	2013	2014	2015	2016	2017
Production (million Mg)	48.232	44.512	42.687	37.430	37.384	34.791	35.037

The planned increase in extraction and the mining of lower coalbeds are connected with problems related to ventilation, transport, operational systems used, occupational safety and natural hazards. Ventilation plays a very important role in underground mining activities, as it is used not only for aerification and air-conditioning, but also for combating fires and underground explosions. The main purpose of ventilation is to provide adequate air parameters, achieve the required air flow velocity and remove gases harmful to humans.

2. Ventilation in Vietnamese mines

The Vinacomin Group, which is responsible for the majority of coal extraction in Vietnam, assumes its continuous growth. Therefore, modernisation and increased mining mechanisation are being introduced, which is connected with the implementation of more efficient machinery and equipment for underground coal mining. This, however, results in higher amounts of combustion engine gases and more heat generated by engines, machinery and heavy-duty equipment. For the above reasons, the issue of ventilation has taken on an increasingly important role.

Due to their specific nature, Vietnamese mines are facing more and more ventilation problems:

- The complex geological structure makes it necessary to build irregular pathway grids, which further complicates the ventilation system and the calculation of ventilation parameters.
- Despite mining depths still being relatively low (up to 300 m), there are problems with high temperatures. This is mainly due to high temperatures outside in the summer and high humidity, but also the continuous development of mechanisation. These factors necessitate increasing the ventilation airflow or, in extreme cases, ceasing coal production.
- Central air conditioning systems have not yet found their place in coal mines. The first on-site air-conditioning units appeared in the Halam mine in Halong.
- The limited number of automatic dams used there contributes to difficulties with airflow and its control.
- Problems also result from dust generated during mining works, transport and processing of coal.
- Coal blasting is often used, which further increases the temperature in the heading and is a source of toxic gases. It was only recently that a long-wall coal cutter was introduced in the Halam mine – Figure 1.

Fig. 1. A long-wall cutter in the Halam mine in Halong.

- The absence of a filling method leads to the occurrence of numerous voids in the excavation areas.
- While increasing their ventilation airflows, many mines have failed to accordingly adapt shafts and ventilation ducts. This has led to problems with airflow, in addition to difficulties in controlling the distribution of air.

With so many changes at hand, the knowledge of airflows and proper control of ventilation systems is necessary. Determining airflow routes, values of resultant resistance, and air distribution requires that calculations for the ventilation system be made. At present, simulations and analyses of such systems in coal mines require the use of computer software.

3. Computer programs used to simulate ventilation systems in underground mines

Computer software has come to be widely used in the simulation and analysis of ventilation systems. A general comparison of such programs can be found in [5], and more detailed descriptions, including analyses of the applied mathematical models, are presented in [6]. Computer software mainly serves as a tool assisting engineers in charge of mine ventilation. Their main duties include:

- developing a digital model of all headings;
- performing ventilation simulations both in normal conditions and during emergency;
- including in simulations disturbances such as fires, sudden methane influxes, gas ejections, and rock bursts;
- ensuring compatibility with sensors of mine monitoring systems;
- forecasting ventilation following changes made to the ventilation system.

Many of these programs provide some additional options:

- simulation of weather conditions;
- simulation of demethanation systems;
- employee records;
- financial calculations.

The most popular programs used by coal mines include: VentSim, VentGraph, Vuma3D, Vnet, ICAMPS MineVent, Kazemaru, 3D-CANVENT^{2000}, AutoWENT and AERO 2010d. The article focuses on Kazemaru, VentGraph and VentSim – three programs which have been most commonly used in the analyses of Vietnam's ventilation systems.

3.1 Kazemaru

"Kazemaru", a program developed by Prof. Masahiro Inoue from the Kyushu University, Japan, is now used in the majority of Japanese coal mines. Its sample modes of usage are described in [7]. The program is characterised by features such as:

- simplicity and user-friendliness;
- data editing using a ventilation diagram;
- maximum number of nodes: 1000, maximum number of ventilation pathways: 1500;
- calculation time of less than one minute for systems consisting of around 100 nodes and 150 pathways;
- inclusion of natural ventilation parameters and ventilator specifications;
- graphic simulation of the distribution of air;
- the possibility of including fires;
- simulation of temperature distribution, gas concentration, and smoke distribution during a fire.

The main program window with a fragment of the ventilation system is shown in Fig. 2; the ventilator specification window is presented in Fig. 3.

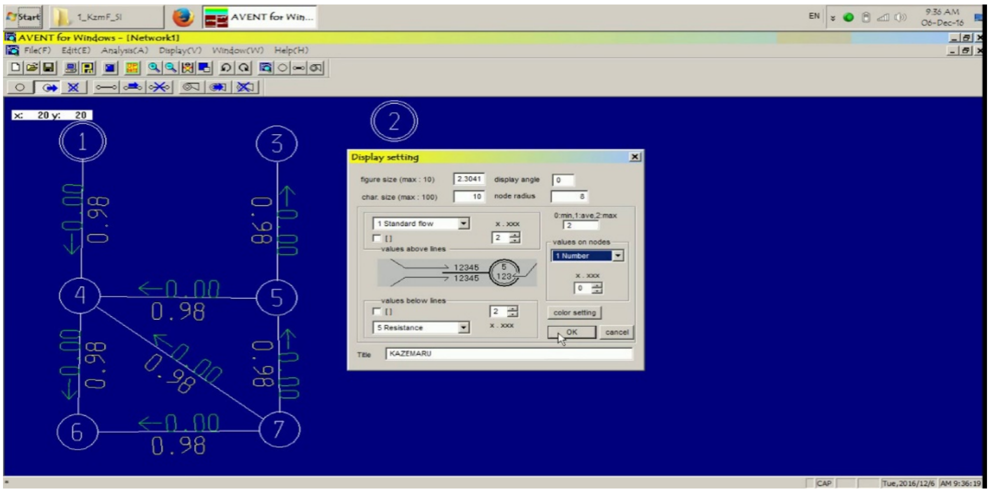

Fig. 2. A fragment of the ventilation system in Kazemaru software.

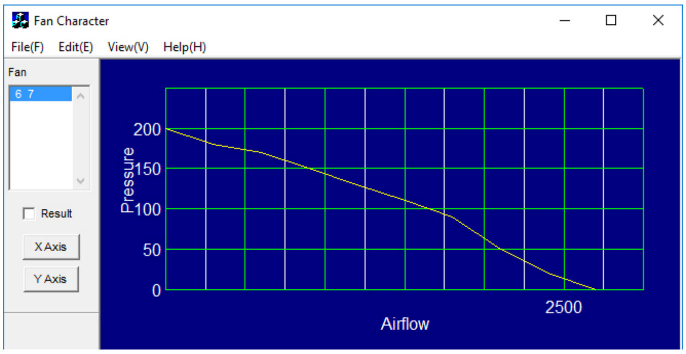

Fig. 3. Ventilator specification window in Kazemaru software.

3.2 VentGraph

VentGraph is a program consisting of combined modules, designed to solve complex problems in mine ventilation systems. It includes the following calculation modules [6, 8, 9]:

- GRAS – determining the set distribution of air in a network of headings in normal conditions and during emergency. The module makes it possible to change the resistance of a selected heading, add a dam with a specific resistance, apply fire depression, change the type of siding, modify ventilator specifications, change the delivery rate of air, methane or carbon dioxide, etc.
- FIRE – calculations to determine the impact of the seat of fire on the level of ventilation. A module which simulates unspecified air and gas distribution in a network of headings following an underground fire. It therefore makes it possible, by simulating various fire variants, to predict how the ventilation system will behave during the fire.
- VentZroby – calculates airflows in the ventilation system and the adjacent goaves, accounting for the impact of fire on ventilation.
- VentWilg – simulates the impact of fire on the distribution of humid air in a network of headings.
- ESCWIN – a module cooperating with the monitoring network to provide support in fire prevention. This module can collect data on the status of an actual ventilation system by leveraging data collected by the sensors of the mine's monitoring system. This provides the mine dispatcher with a quick overview of the available outposts and escape routes and allows them to separate the area subject to fire smoke hazard.

VentGraph has found broad application in Polish and foreign mines. It has been numerously validated [10-12] and used in the analysis of ventilation systems and simulations not related to coal mine ventilation [13-21]. Fig. 4 shows the VentGraph interface with the ventilator specifications and ventilation system structure windows.

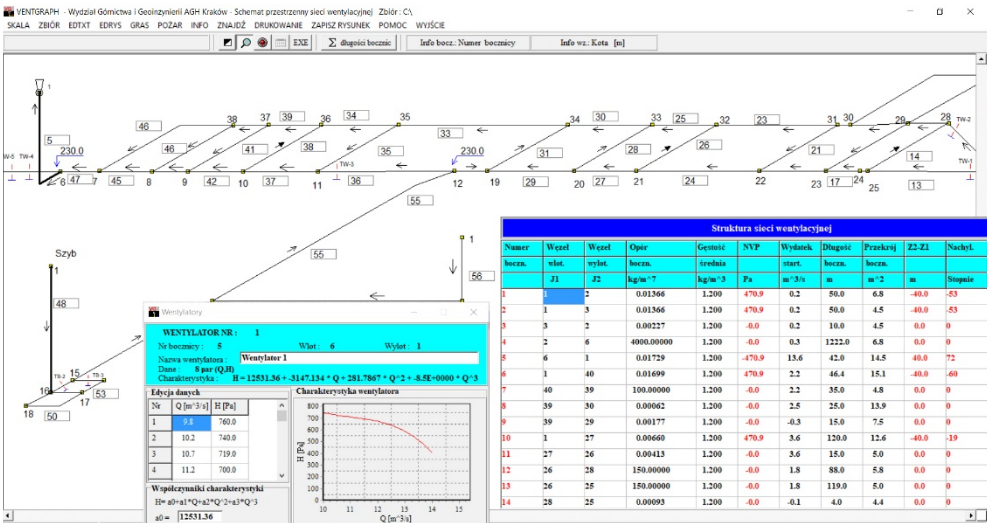

Fig. 4. The ventilation system, the ventilator specifications, and the structure of the ventilation system in VentGraph.

3.3 VentSim

Developed in 1993, in 2009 the program received the 3D simulation functionality. It is now used all over the world, including, since recently, selected mines in Poland. Its enhanced, Premium, version features the following functionalities [22, 23]:

- 3D presentation with accurate object sizes;
- animations of the airflow in the ventilation system;
- maximum number of ventilation pathways: 60000;
- calculations for variable air density;
- inclusion of changes to the ventilators' rotational speeds and ventilator reversions;
- simulations of thermodynamic parameters (cooling and heating, thermal properties of rocks, sources of heat, natural ventilation);
- transport of contaminants (distribution of smoke and contaminants, concentration of contaminants, coal blasting smoke, diesel engines);
- detection of flow recirculation;
- financial calculations.

Similarly to VentGraph, VentSim has many applications, also outside the mining industry. Study [24] describes how the VentSim program is used for the analysis of the ventilation system in the Donghai mine, China. The manner in which VentSim can be applied to analyse the behaviour of a ventilation system after the introduction of mine pit sealing is presented in article [25]. [26] discusses the results of modelling of a ventilation system in the Romanian mines of Lupeni and Uricani. Brake [27] addresses modelling in three fire scenarios: in an underground diesel installation, an underground explosive storage magazine, and on an ore belt conveyor. The simulations of various solutions to increase air flow in the Rosh Pinah mine, Namibia, are described in [28]. The software has also been used to optimise and analyse the ventilation system in the Redeemer [29] and Bronzewing Gold Mines [30] in Australia, the Majiagou mine in China [31], the Western-Razmja mine in Iran [32], and the Konkola Copper Mine in Zambia [33]. [34] presents changes made to the ventilation system to reduce the costs of ventilation in the Zhangcun mine, China.

VentSim was used to perform an analysis of the ventilation system in the Mông Duong mine in Vietnam. Figures 5-7 provide a view of the ventilation system as 2D (Fig. 5) and 3D (Fig. 6) images and as fragments depicting the complex layout of pathways (Fig. 7).

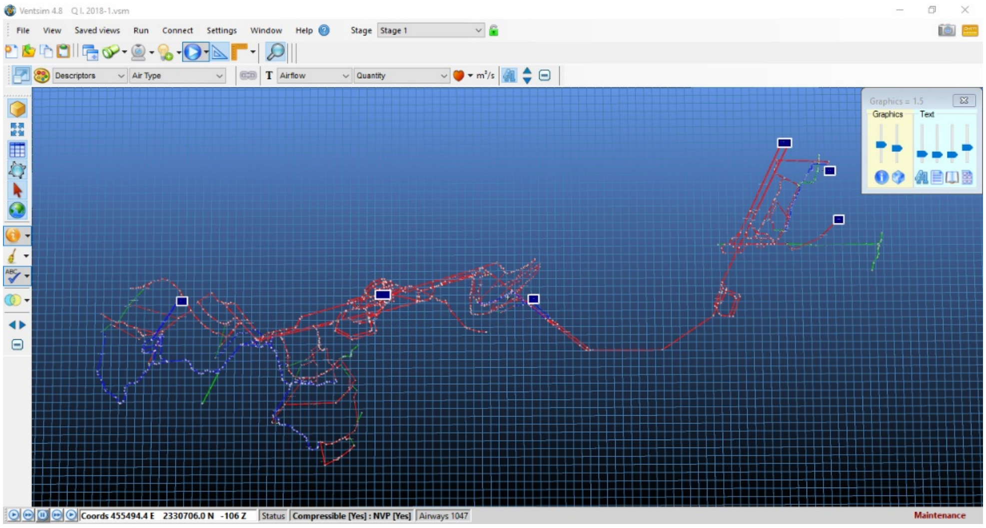

Fig. 5. A 2D diagram of the ventilation system in the Mông Duong mine.

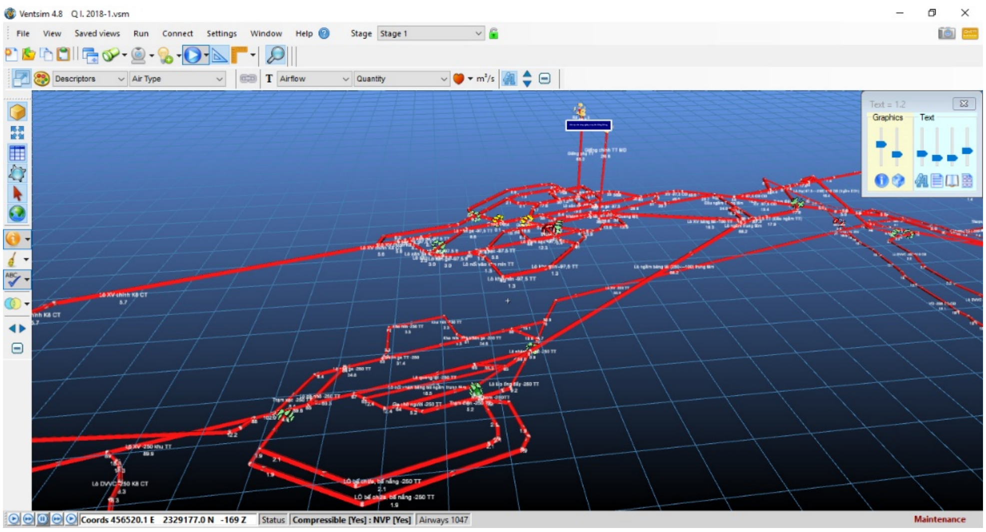

Fig. 6. A 3D diagram of the ventilation system in the Mông Duong mine.

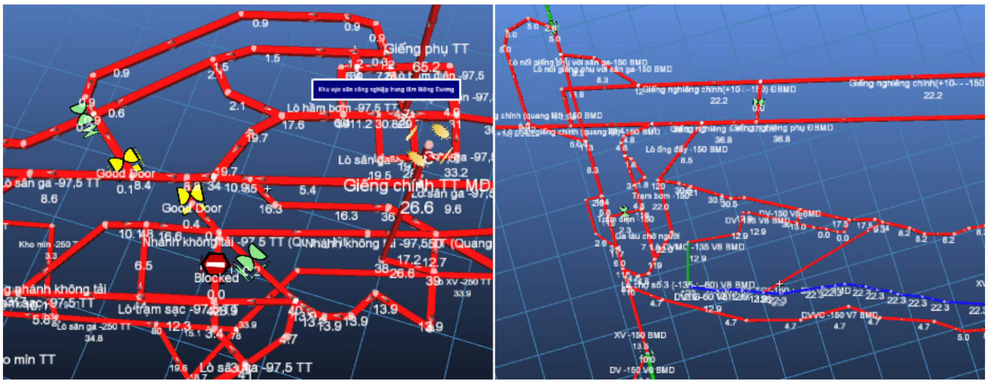

Fig. 7. A fragment of the ventilation system in the Mông Duong mine.

4. Summary

A ventilation system is indispensable in every underground mine, not only contributing to the comfort of work, but also, and primarily, enhancing worker safety. For the purpose of analysis, optimisation or planning of ventilation systems, specifically designed software is used. Vietnamese coal mines use the following three programs: Kazemaru (in the Campha region), VentGraph (selected mines) and VentSim (in the regions of Uongbi and Halong). Having worked with them, the authors could formulate a subjective assessment of these programs (the more stars, the better), as presented in Table 3.

Table 3. Comparison of Kazemaru, VentGraph and VentSim software in Vietnamese mines

Assessment criterion	Kazemaru	VentGraph	VentSim
Computing speed	★★★	★★★	★★★
Data entry speed	★★	★	★
Graphical user interface	★	★★	★★★
Production tracking	-	★★	★★★
Ventilation planning	★★★	★★	★
Calculations for a duct line ventilation system	-	-	★★★
Connectivity with the monitoring network	-	★★	★★

The assessment pertains exclusively to the specific conditions of the Vietnamese mining industry. Currently the computer programs are mostly used to verify the correctness of calculations, not for production tracking or the monitoring of ventilation systems. As coal production and work mechanisation are growing, however, computer software is gaining in popularity and is being deployed on an increasingly broad basis.

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