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Testing the equipment used in ventilation of mine workings

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Abstract

The article gives a short presentation of three basic test types of equipment used in ventilation of mine workings, such as dust collectors, fans and vortex ventubes.
The procedure for measurements preparation and tests realization as well as how to present the test results, is given. In addition, the article contains information on the regulations to be met for proper tests realization. The mentioned tests concern equipment operating in the forced or sucking-forced ventilation systems. Furthermore, the article presents the design and layouts of measuring stands used in KOMAG. It also specifies the parameters to be measured along with their read out places.

Streszczenie

Artykuł zawiera krótką prezentację trzech podstawowych rodzajów badań urządzeń wykorzystywanych przy przewietrzaniu i odpylaniu wyrobisk kopalnianych, jakimi są: odpylacze, wentylatory i lutnie wirowe.
W opracowaniu określono zasadnicze cele poszczególnych badań, zaprezentowano procedurę przygotowania pomiarów, tok postępowania podczas badań oraz sposób przedstawiania wyników. Dodatkowo zostały w nim zawarte informacje dotyczące przepisów do jakich należy się dostosować w celu prawidłowego przeprowadzenia danych pomiarów. Wymienione w artykule badania dotyczą urządzeń pracujących w najczęściej stosowanych na kopalniach układach przewietrzania tj. w układzie wentylacji ssącej lub ssąco tłoczącej. Ponadto w publikacji przedstawiono budowę oraz schematy stanowisk pomiarowych wykorzystywanych do badań w ITG KOMAG, a także zostały określone parametry jakie należy mierzyć wraz z miejscem ich sczytywania.

1. Introduction

Currently, mining the hard coal seams using the state-of the-art technologies causes generation of coal dust, what has a negative impact on miners health and poses serious threat of coal dust explosion. Hazards related to the explosive properties of coal dust in underground mine workings belong to the earliest identified and most dangerous ones and are listed as one of the primary hazards identified in hard coal mines both in Europe and in the USA [1, 2]. There are the following main sources of dust: longwall coal mining, including advance of powered roof supports, development of roadways by roadheaders, using the blasting method as well as run-of-mine transportation and crushing [3]. Also, technological processes in coal processing plants can be a source of dust, posing a threat to health and explosion hazard [4].

In this case the following equipment may be a source of dust emissions:

- machines - point and surface sources,
- containers - surface sources,
- transportation routes - line sources.

Therefore, it is important to eliminate these hazards by applying appropriate technical measures.

Depending on the characteristics of the technological lines, three types of dust control installations can be used:

- local - limited to one source of emission,

- technological – covering the whole technological line or its bigger part,
- structural - covering entire buildings or rooms.

Regardless of the type of technological or structural dust control method used, there will always be places of increased dust concentration [5].

Vortex ventubes as well as dust collectors have been used for several years in hard coal mines for dust control and roadways ventilation. In accordance with additional restrictions applicable in the Polish mining industry regarding work safety and environmental protection, use of these devices in a roadway which is under development by a roadheader is mandatory [6].

The equipment placed on the market meet the requirements of the regulations, both in terms of meeting the requirements for ventilation, as well as air quality and formal requirements, covering the devices operating in underground mines. Research and development work is constantly being carried out to improve the operational reliability of the ventilation and dust control systems in mine workings as well as to ensure proper conditions of work safety [7].

These devices are certified for compliance with the general requirements of the directives [8, 9], as well as the requirements of the applicable standards, specifying the requirements and scope of tests for dust collectors and vortex ventubes.

The test results confirm compliance of the required parameters of the devices with the requirements and their effectiveness, what allows their use in combined, sucking and forcing ventilation systems in the hard coal mines underground. At the same time, the universal nature of the equipment, in particular dust collecting devices, allows to broaden the spectrum of their use, e.g. for dust collecting in coal processing plants or in other industries [6].

2. Procedures for testing the equipment used for mine workings ventilation

For each of the discussed devices, the measurements have to verify their operational parameters specific to the given type of device, to check compliance with the requirements for safe use and to test the structure strength.

- during dust collector tests, the primary objective is to determine the dust collection efficiency using the dust meter (including the respirable fraction), in which the ventube pipeline conditions are simulated and a sample is taken to check the device efficiency.
- measurements of ventubes operation have to check if they do not exceed the permissible operational parameters and to determine the proper range of their operation.
- during tests of vortex ventubes, adjustment of the device and determination of output of air flowing through the ventube, is the main objective.

Problems of the research projects on testing the devices used in ventilation of mine workings, carried out at the KOMAG Institute of Mining Technology are presented on the example of testing the dust collectors, ventubes and vortex ventubes.

2.1 Tests of dust collecting equipment

The dust collector's testing process includes mainly checking the functionality of each unit and their components, as well as determining the efficiency of dust control.

Due to the fact that the dust collector's testing process was not standardized at both global and European level, the PN-G-52002:2009 Polish Standard was developed in the Polish Committee for Standardization, which regulates the principles of testing in this case. The test stand built at KOMAG meets the requirements specified in the Polish Standard [10].

The constructed stand is used for testing wet type dust collectors. The basic operating parameters are as follows:

- flow rate range from 120 to 1000 m^3/min,
- measuring ventube diameter ∅ 630, ∅800, ∅1000 mm.

The main part of the stand is the measuring ventube in which the tested air flows. Additionally, devices used to induce the air flow, such as:

- auxiliary fans,
- airborne dust blowing fans,

are installed within the stand.

The test stand consists of the following components:

- dosing scale,
- inlet cone,
- tested dust controlling device,
- fan,
- measuring ventube,
- gravimetric dust meter.

General outline of the test stand is presented in Figure 1.

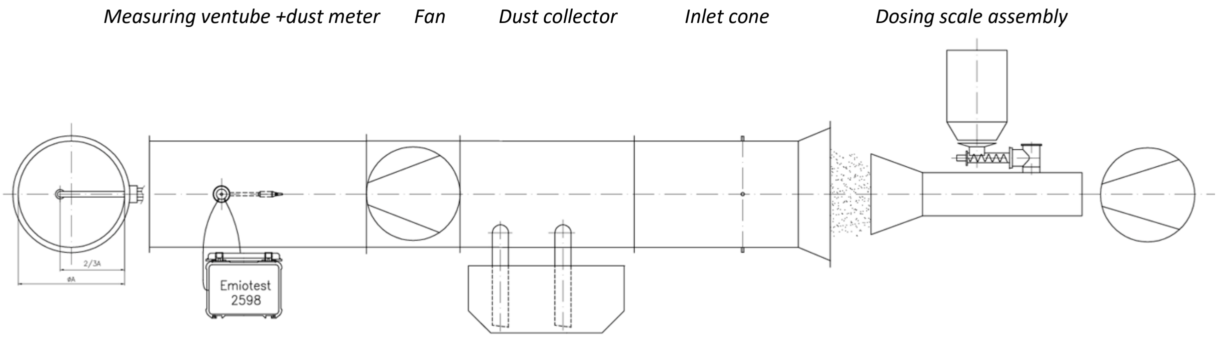

Fig. 1. Schematic diagram of the stand for testing dust collecting equipment

The scope of testing the dust collector

During dust collector tests, the most important issue is to define dust collection efficiency as the basic parameter. Before starting the tests it is necessary to determine the following initial parameters:

- water system efficiency,
- efficiency of transported air,

with active water supply system.

Efficiency of the water system

To measure the efficiency of the water system, it is necessary to assembly a measuring system consisting of a nozzle (nozzle assembly or water distributor), pump and connection hoses, and then measure the time required to fill up the tank of known volume.

The volume of water stream flowing through the water system is calculated using the following formula:

$$\dot{V}_w = \frac{V_{zp}}{t_n} \tag{1}$$

where:

$\dot{V}_w$ – volume of water stream flowing through the water system, m^3/s

V_{zp} – volume measured in the measuring tank, m^3

t_n – average time of filling the tank to the volume V_{zp}, s

In turn, the mass of water flowing through the water system is calculated in relation to the density of water at temperature at which the measurement was made.

Output of air flowing through the dust collecting device

To determine the efficiency of the air flowing through the dust collecting device, a system, in which inlet cone is installed at to the device entry according to ISO 5221:1984 [11], is used.

After assembling the system, it is necessary to determine the fan lowest and the highest point of operation, at those points fan output should be determined. For that purpose, after switching on the driving system of the device or the fan, under the load of water, it is important to throttle the dust control device at the outlet by the gate valve until the fan enters the pumping state, in which its operation is irregular and with power variability.

Parameters for the lowest point of fan operation at which the minimum flowrate should be determined should be close to the pumping point, but without entering this state, and the parameters for the highest point of operation refer to the maximum flowrate obtained in the device.

After determining the operational parameters, it is important to measure the power of the nozzle or drive assembly motor and check if it does not exceed the rated value, when the water load is too high.

The parameters listed in Table 1, read from the scale of the measuring instruments are the input data for calculations.

Table 1. Parameters to be measured for calculation of air volume flowing through the dust collecting device

Parameter	Symbol	Unit	Measuring instrument
Barometric pressure	b_{at}	[Pa]	barometer
Relative humidity	φ	[%]	hygrometer
Temperature	t_1	[°C]	thermometer
Pressure drop on Venturi tube (differential pressure)	Δp	[Pa] (inlet cone ISO)	micromanometer

Stream of fed dust mass

At first, to determine mass of dust fed to the system, output of air flowing through the system should be determined and then dust concentration in flowing air. It was assumed that dust concentration in air is c_p = 500 mg/m^3, and mass of dust fed to the system is calculated according to the following formula:

$$\dot{m}_p = c_p \cdot \dot{V} \tag{2}$$

where:

c_p – dust concentration in flowing air, kg/m^3

$\dot{V}$ – output of air flowing through the system, m^3/h

$\dot{m}_p$ – stream of fed dust mass, kg/h

Measuring instruments and testing procedure

Automatic dust meter, configured according to the needs, was the basic component included in the stand for testing the dust control devices. Disposable filters are used for measurements, the type of which depends on the filtration method. For internal filtration, so-called thimbles, mini-bags or flat paper filters are used. After drying in a desiccator, the filter is weighed just before the test with an accuracy of 0.001 mg on a laboratory scale. Then the filter is placed in the dust separator (Fig. 2a) and then the dust removal device tests are carried out. After completion, the filter is again dried for 24 hours in a desiccator and weighed "dry". The filter masses before testing the dust control device (i.e. without dust) and after the test (with caught dust) are used to determine the dust control efficiency of the device.

Fig. 2a. Separator and dust filter prepared for installation

Fig. 2b. Measuring probe with the filter installed in the tested ventube pipeline

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The air-dust mixture was prepared in the dosing scale assembly and blown by an auxiliary fan to the tested dust control device. After passing through the dust collector, the gas stream flows through to the aspiration probe being a part of the dust meter. The probe should be installed in the appropriate socket of the measuring ventube section (Fig. 2b) so that the dust separator with the aspiration end, where dust particles are caught on the measuring filter, is in the axis of the flowing air stream in 2/3 of the channel diameter.

Dust control efficiency

The following parameters should be determined for calculation of dust control efficiency:
- m_0 [mg]– initial mass of dried filter,
- m_k[mg] – final mass of dried filter after the test,
- m_p[mg] – mass of dust collected on the filter,
- τ [min]– duration of measurement,
- Vv [m^3/h] – air flowrate through dust separator

Dust control efficiency is determined according the following formula:

$$\eta = \frac{C_p - C_k}{C_k} \cdot 100[\%] \tag{3}$$

where:

C_p – initial concentration, mg/m^3

C_k – final concentration, mg/m^3

$$C_k = \frac{m_p}{\tau \cdot V_V} \tag{4}$$

Assuming that big dust particles are completely removed and only respirable fraction of size from 0 to 5μm passes the device, we can determine dust control efficiency of this fraction as not less than:

$$\eta_{5-0} = \frac{x_{5-0} - (100 - \eta)}{x_{5-0}} \cdot 100[\%] \tag{5}$$

where:

$\eta_{5\text{-}0}$ – dust control efficiency of respirable fraction of size from 0 to 5 μm, %

η – total dust control efficiency, %

$x_{5\text{-}0}$ – share of fraction from 0 to 5 μm, %

When interpreting the results of dust collector tests, the following factors should be borne in mind:
- dust control efficiencies should be compared using the same inlet concentration of particles in the gas.
- change in concentration of solid particles at the inlet to the dust collector has negligible impact on change in flow resistance through the device.
- dust control efficiency is the same for dust collectors of the same energy consumption and increases with pressure drop, especially for pressures above 2500 Pa [12].

Additional tests and measurements

In addition to the tests related to the dust control process, the noise emitted by the device (especially the drive unit or fan) was measured.

In the case of devices containing components that operate in a pulsating manner, the vibrations produced during the operation of the device should be tested additionally.

If necessary, also check the rotor rotational speed**.**

2.2 Testing the ventube fans

Ventube fan tests are carried out according to the procedure given in the EN ISO 5801:2017-12 standard [13], and the result is the relationship between the fan capacity $\dot{V}$ [m^3/min] and:
- ram effect ΔP_F [Pa], recalculated for air density ρ_0 = 1.2 kg/m^3,
- electric power in [kW] recalculated for air density ρ_0 = 1.2 kg/m,

- total efficiency of the fan set η_e [%].

In addition, it is necessary to check if the recalculated electric power of the tested ventube motor does not exceed the permissible power calculated according to information from the motor's nameplate.

The standard presents testing procedures for four types of measuring channels:
- type A – free inlet and free outlet,
- type B – free inlet and a channel at the outlet side,
- type C – channel at the inlet side and free outlet,
- type D – channel at the inlet side and channel at the outlet side.

The most popular operating system for ventubes used in mines are relevant to the C-type stand with the measuring channel at the inlet side and the free outlet, the design of which is schematically shown in Fig. 3.

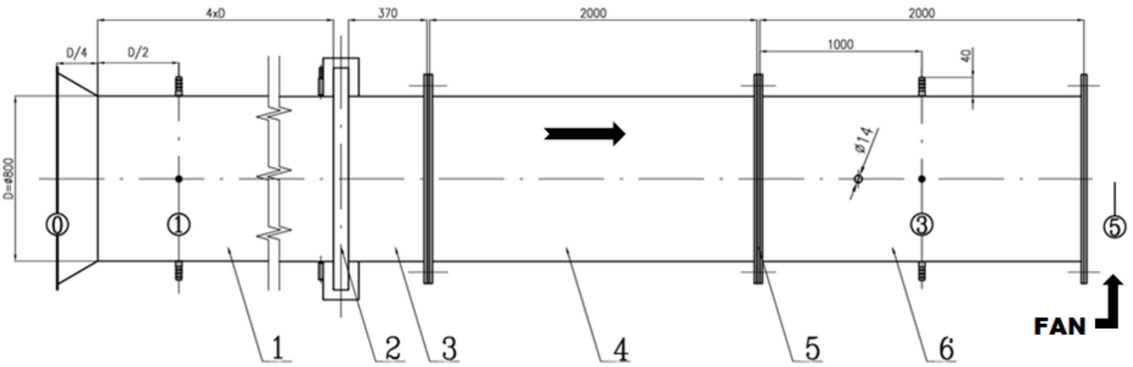

Fig. 3. Diagram of the testing facility type C

Explanations:
1. Inlet cone ∅800* with four measuring ends ∅11.
2. Mesh gland.
3. Stream straightener.
4. Spacer ventube ∅800x2000.
5. Gaskets ∅810x∅900 2 pcs.
6. Measuring ventube ∅800x2000 with four measuring ends ∅11 and opening ∅14.

Measuring cross-sections acc. to PN-EN ISO 5801:2017-12 were marked as follows:
0 – inlet (environment parameters),
1 – stream contraction zone,
3 – measuring cross-section in the channel at the side of fan inlet,
5 – fan outlet.

* *other measuring cones can be used e.g. ∅630, ∅320 mm.*

The tested ventube fan is connected to the outlet of the measuring channel and draws in air through this channel. The air flows first through the inflow cone (position 1), creating a difference between the negative pressure caused by air stream contraction and the surrounding pressure. On this basis, the air flow rate through the fan is determined. In the further part of the test stand, using a mesh gland (position 2), the resistances of the network cooperating with the fan are simulated. This unit is equipped with a perforated metal sheet, on which throttling nets of the standard mesh sizes are placed one on another to create air flow resistance. In this way, by reading out the below mentioned parameters for each number of nets, the fan characteristic points are obtained. The air then flows through the cell straightener of air stream (position 3). Next, the air flows through the distance ventube (position 4) to stabilize the air stream and then through the measuring ventube (position 6), where the vacuum generated by the fan connected to the measuring ventube outlet as well as air stream temperature are measured. Each test stand assembly is flange connected using gaskets (position 5).

Testing and test results

According to the calculation procedure, the following parameters should be measured and recorded on the measurements sheet:
- ambient temperature t_0 [°C] – ahead of the measuring inlet,
- ambient humidity φ_0 [%] - ahead of the measuring inlet,

- atmospheric pressure P_b [%] – around the measuring inlet,
- pressure drop on inlet in relation to atmospheric pressure h_1 [mm H_2O],
- temperature in the measuring channel t_3 [°C],
- pressure drop in the measuring channel h_3 [mm H_2O],
- air stream temperature on the fan outlet or behind the noise dumpers and diffusor (if the fan has such equipment) t_5 [°C],
- motor (or motors) power N_1 (N_2) kW.

The measurement results and the results of calculations are presented in tabular form and in graphical form in the form of graphs of fan characteristics (Fig. 4), showing the relationships of total ram effect, electrical power and total efficiency in a function of fan output. It is also important to interpret the measurement results regarding the correct fan operation, i.e. whether the mechanical power limit for the motor is not exceeded and to determine the scope of correct operation and a pumping range.

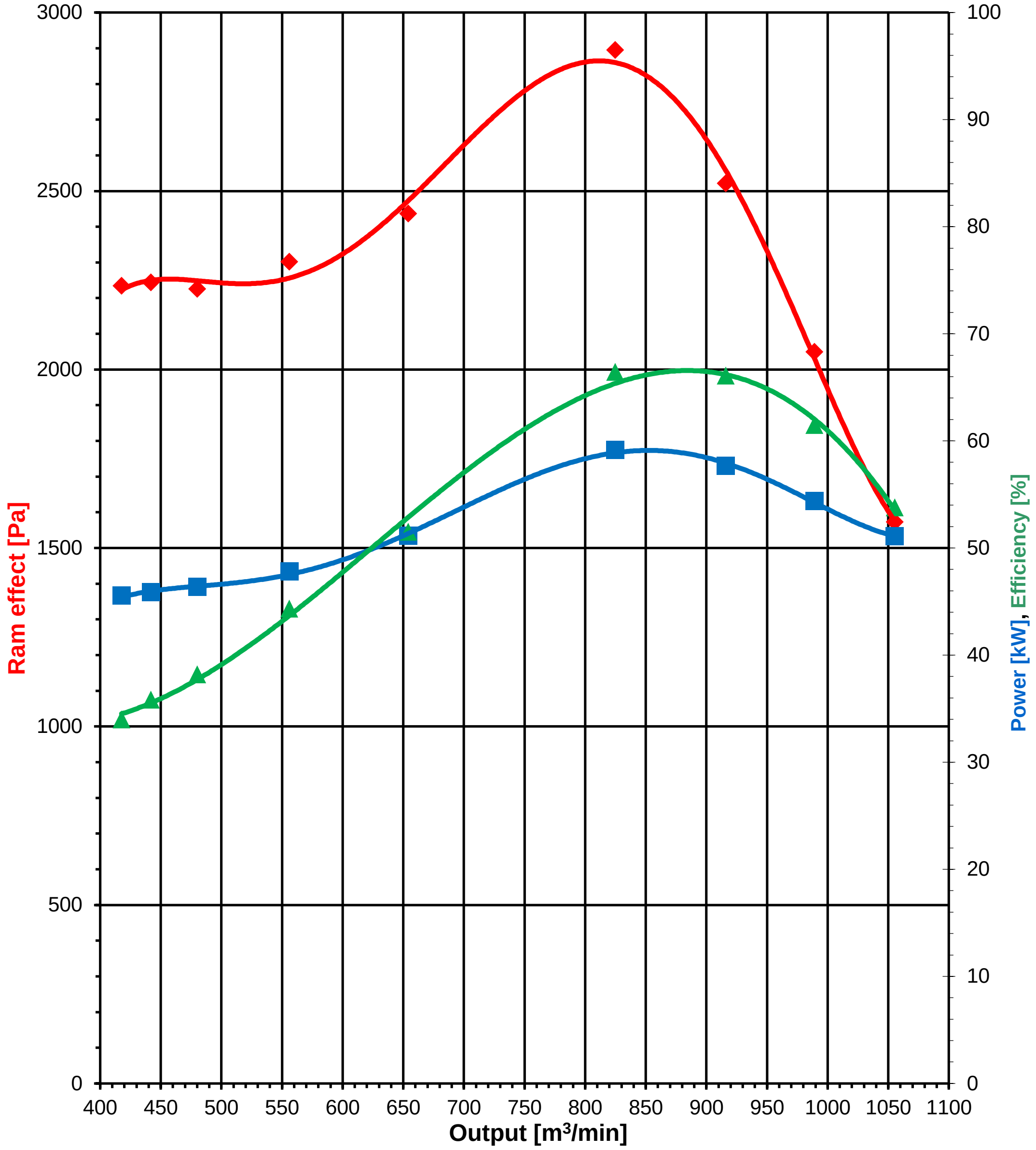

Fig. 4. Sample fan characteristics for air density 1.2 kg/m^3

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Additional tests and measurements

Apart of the basic tests, the tests of noise and vibrations were conducted and the calculated electric power was recalculated for other air densities, i.e. $\rho_o = 1.3\ kg/m^3$ or $\rho_o = 1.4\ kg/m^3$ to determine the device ability to operate in tough (not typical) conditions.

2.3 Testing the vortex ventubes

Vortex ventube is another device subjected to testing in the KOMAG laboratories for analysis of effectiveness of air vortices generation.

Similarly as in the case of dust collectors, the testing methodology for the mentioned devices was not standardized at European and at global level, therefore in Poland the national standard PN-G 43042: 2011 [14] is the basis for the uniform testing methodology. This standard specifies the requirements, as well as the types and methods for testing the vortex ventubes intended for use in underground roadways drilled with roadheaders in hard coal and other minerals mines.

Testing the vortex ventubes covers the following procedures:

- determination of output of air flowing through the ventube,
- measurements of distribution of air outflow rates from the ventube gaps,
- adjustment of ventube gaps width,
- measurements of the driving motor power.

Test stand structure and characteristics

Structure of the test stand together with measured parameters is schematically presented in Figure 5. The KOMAG stand for testing the vortex ventubes consists of the following components:

1. an inflow cone,
2. a ventube fan,
3. a vortex ventube driving unit,
4. segments of tested vortex ventube, where total length of the ventube gap should be 10 m,
5. a flap.

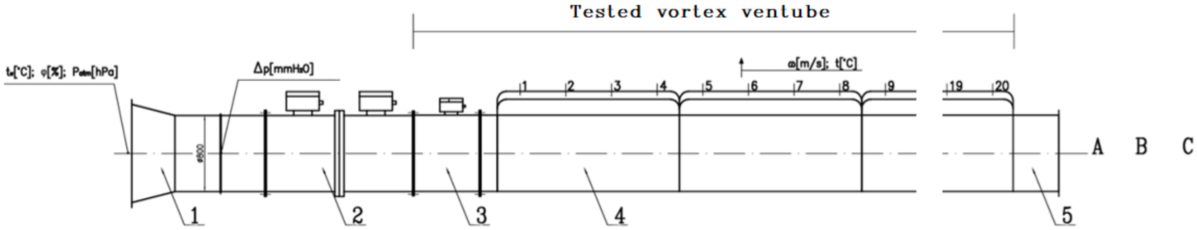

Fig. 5. Schematic diagram of the stand for testing the vortex ventubes together with the tested device

According to the testing procedure, 20 measuring points are evenly deployed on vortex ventube segments along the outlet gap. According to Figure 3, the following parameters are measured in points A, B, C:

- in point A – air flowrate in the ventube axis in a distance of 30 cm from the outlet,
- in point B – air flowrate in the ventube axis in a distance of 60 cm from the outlet,
- in point C – air flowrate in the ventube axis in a distance of 100 cm from the outlet.

The tested vortex ventube is connected from the inlet side to a measuring system constructed according to ISO 5221: 1984 [11], consisting of an ISO inflow cone (position 1) and to a ventube fan (position 2), whose task is to force gas flow through the test stand. In the inflow cone, the air flow rate through the entire vortex ventube (and the test stand) is determined on the basis of readout of the gas stream pressure drop (Δp). Then, in the case of non-flap vortex ventubes, the air flows through the vortex ventube driving unit (position 3), causing a gas outflow from the ventube segments gaps (position 4), where the gas outflow rate and temperature are measured at the specified points 1 - 20. In the case of a flap vortex ventubes, the flow through the vortex gaps is forced by completely closing the flap located at the outlet from the last ventube segment (position 5).

Testing procedure and test results

The vortex ventube air output is determined in the same way as in the case of the fan tests, while the outlet gap width is adjusted with screws for the maximum possible lifting up the control ribbons as in Fig. 6 and the smallest possible air outflow rate from the ventube's outlet.

Fig. 6. Correctly adjusted vortex ventube

Distribution of output air flow rate from a vortex ventube's gap

The air flow rate ω and temperature *t* should be tested with a thermo-hygrometer, whose measurement error does not exceed 5%, at a distance of not more than 5 cm from the edge of the outlet gap, at least at 20 points, deployed evenly along the length of the outlet gap.

The measurement results should be tabulated and interpreted graphically using a polynomial curve from 2 to 6 degrees selecting the curve for which the coefficient of concordance is closest to one. Examples are shown in Fig. 7.

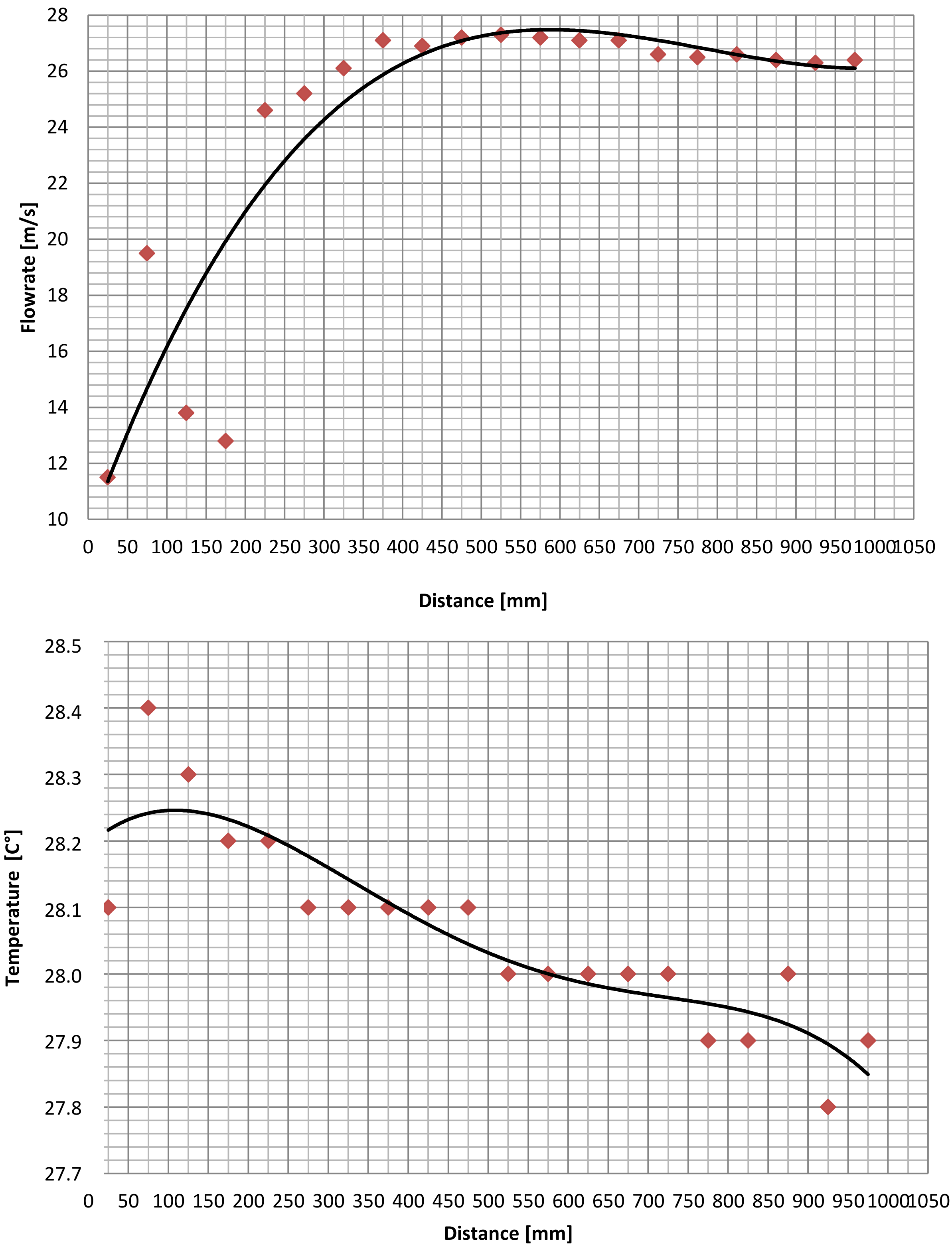

Fig 7. Graphical presentation of flowrate and temperature measurement results in a function of distance

Additional tests and measurements

In addition, compliance with the requirements for operation in potentially explosive atmospheres was tested on the basis of certificates and declarations of compliance for materials and devices, as well as the working media consumption (e.g. compressed air) was measured with instruments which measurement error does not exceed 5%.

Additionally, a continuous operation test can be conducted by turning on all ventube's sub-assemblies, in the gap air flow mode, for at least 20 min checking the correctness of the vortex ventube operation.

3. Summary

Dust control equipment and ventilation devices used in the mining industry enables eliminating the dust particles (coal dust, rock dust) significantly reducing dust hazard during solid coal mining. Due to the increasing expansion of mine networks there is a subsequent increase in ventilation network size and complexity, making fresh air distribution and management of the ventilation network challenging and energy intensive [15] Selection or designing the devices for dust control depends on many factors, first of all on local conditions and characteristics of dust source and dust itself [16]. Conducted tests enable gaining information on parameters, the scope of use and usability of the devices operating in mine ventilation and dust control systems. This knowledge is especially important for potential purchasers to decide about selecting the devices best suited for their needs.

Sample tests discussed in this article are based on guidelines given in the standards relevant to a given type of equipment. Knowledge about the most characteristic parameters and principles of the safe use of tested devices, is the tests result. In the case of dust collectors it is dust control efficiency, in the case of fans, it is very important to check if the power recalculated for air density of 1.2 kg/m^3 does not exceed the permissible power and to gain knowledge on their operational characteristics. Determination of effectiveness of the air vortex process in the vortex ventube was the objective of the vortex ventube tests.

It should also be noticed that for all tests the same principles of safe operation of the test stand apply, where special attention should be paid to the following:

- noise (exposure to mechanical vibrations of fan components and its motor as well as aerodynamic vibrations of the pumped gas),
- power supply (possibility of electric shock),
- air stream (possibility of entering the air stream of high flowrate),
- mechanical hazard (moving parts of the fan).

Information gained during the tests is very important not only as it concerns equipment used in hazardous conditions but also health and even life of people working in underground workings which depend on their reliable operation. In addition, expert opinions based on data collected during tests are the documents required for granting the certificate of compliance with the ATEX directive.

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