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Mining waste dumps – modern monitoring of thermal and gas activities

Introduction

Mining waste inherently accompany coal production and coal preparation processes. They are deposited on the surface to form vast heaps and dumping grounds. In Poland, approximately 123 million Mg of industrial waste was produced in one year (Report 2014), close to 38.5% of the total waste produced in the country was in the Silesian Province, of which, about 80% of the waste was from the extractive mining industry.

The impact assessment of a waste dump on the environment in accordance with the Act on mining waste (Act 2008), requires the conductance of a continuous monitoring of the dump during the exploitation and after its completion for the period of 30 years, to the extent meeting the applicable Regulation of the Minister of the Environment of 18 April 2011 on the monitoring of the extractive mining waste. The main hazards arising from the storage of coal wastes on dumps are as follows:

- groundwater contamination – effects associated with leaching of chemical substances (usually in the form of metal salts) due to rainfalls (Gielisch 2006),
- environment pollution – erosion of a topcoat in the area of the impact of prevention work and wind, leading to increased dustiness of the dump's surroundings.

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- Dump fires:
  - the emission of fumes, dust and flammable gases caused by the existence of active endogenous fire sources in a dump (Chunli et al. 1998; Gumińska and Różański 2005),
  - periodic loss of visibility during the occurrence of extreme conditions, i.e., high emission of flammable gases, dust and the temperature of the dumped material,
  - temperatures occurring in the range of impact of fire sources,
  - the occurrence of caverns beneath the surface, resulting from the burn-out of material in the dump, threatening with a collapse.

The two first of the above-mentioned hazards can be relatively easily reduced. Suitable shaping of the slopes of a dump with surface protection significantly reduces the effects associated with the leaching by rainfalls of chemicals substances (usually in the form of metal salts) as well as the crushing of the surface coating leading to an increase in dustiness of the surroundings of a dump. A fire hazard is the most difficult obstacle to overcome.

In order to assess the impact on the environment of a waste dumping ground during the exploitation and after its completion, it is necessary to carry out continuous monitoring of the dump in terms complying with the provisions on the scope, time and manner as well as the conditions of monitoring a waste dump (Tang 2008; Wasilewski 2009; Wasilewski et al. 2011). Monitoring and assessment of the activity of the heap includes:

The monitoring and the assessment of the activity of a dump cover what follows:

- inspection of piezometers, thereby measuring the depth of occurrence for the water table, specifically for water underground is performed and physical-chemical testing of those waters in accordance with the type of wastes deposited in a dump,
- monitoring drainage water, consisting in physico-chemical studies of sewage water and measurement of their volume at the time of sampling for physico-chemical tests,
- quality control of surface water under the influence of the a dump, consisting of the physical and chemical testing of water and measuring their volume at the time of sampling for physico-chemical testing,
- measurements of rainfalls – with a rain gauge,
- monitoring the gaseous environment (CO, CO_2, O_2) and the thermal condition of the surface and the interior of a dump,
- monitoring the surface ground subsidence of a dump by geodetic methods geodesic performed by authorized persons, based on established benchmarks,
- monitoring the slope stability of a dump – by geotechnical methods.

The complete range of indicator parameters and the minimum test frequency within the framework of the monitoring of the dump (in accordance with the Regulation MS 2011) is shown in Table 1. It is generally assumed that sites of sampling for tests in the after-exploitation phase are the same as in the case of monitoring conducted previously on a dump during the operational phase.

Monitoring within the limits of the above mentioned frequency range should be continued for at least 5 years (Regulation MS 2011). If, after this period, the test results obtained

Table 1. The scope and frequency of monitoring

Tabela 1. Zakres oraz częstotliwość monitoringu

Item	Measured parameter	Frequency of measurements
1.	Volume of surface water flow	Every 6 months
2.	Composition of surface water	Every 6 months
3.	Volume of drainage water	Every 6 months
4.	Composition of drainage water	Every 6 months
5.	Water table of groundwater	Every 6 months
6.	Composition of groundwater	Every 6 months
7.	Gas emissions of a dump site	Every 6 months
8.	Gas Composition of a dump site	Every 6 months
9.	Studies of the volume of rainfall	Every day
10.	Monitoring a dump's surface subsidence	Once a year
11.	Monitoring slopes stability	Once a year

show that the dumping ground does not affect the environment, the body managing the dump may apply for a reduction in the frequency of tests of various indicative parameters, but with no less frequency than once every two years, and in case of the electrolytic conductivity not less than once a year.

1. Fire hazards arising when storing coal wastes

Fire hazards exist for the dumps closed after a period of exploitation, which is most often caused by a significant amount of residual carbon in the deposited waste (Gawenda 2013) and inappropriate technologies in the placement of waste used in the past, and the improper management of this type of area. Mechanisms of thermal and aerological processes are extremely complex. Temperatures rise in a dump as the result of slow, low temperature oxidation of combustibles (Wu i in. 2008; Nowak 2013) contained in a dumped material with the simultaneous inadequate heat removal. Once the heated material reaches a certain temperature, called the critical temperature, a process of ignition of combustible substances contained in the material takes place. The resulting fire source takes oxygen contained in the pores (or the macropores) with air (Gawor and Rysz 2005).

This process enhances the penetration of air into the interior of a dump thanks to the increasing value of the thermal depression. At the same time, the air flowing around the dump causes changes in pressure distribution on its surface. Assuming that the stored material is not uniform, one can determine that one of the main mechanisms of propagation of fire sources in the waste dump is the occurrence of areas characterized by large pressure gradients which cause local aeration of a dump, supplying air to the combustion process of a dumped material.

Due to the fact that the amount of air entering this way is relatively small, the combustion process is incomplete.

The study of phenomena related to the formation and development of the sources of spontaneous heating have been conducted for many years now and include both newly created mining waste dumps as well as those sites after their reclamation. Depending on the exploration, the program is assumed of research focused on locating spontaneous heating sources and monitoring the development of spontaneous heating fires by the gas-thermal monitoring method.

Conducting aerological and thermal supervision on coal waste dumps, according to the methodology developed in the Central Mining Institute, covers a network of measuring points, where measurements of surface high points and slopes are done with specialist instruments as infrared thermometers and digital temperature gauges.

At a place of a determined temperature anomaly a borehole is executed to a depth of about 1 meter in which the following measurements are carried out:

- temperature of the interior of an object,
- concentration of oxygen oxide CO,
- concentration of carbon dioxide CO_2,
- concentration of oxygen O_2.

In depth explorations with point-measurements of temperature and gas composition in the dump are a labor-intensive method that requires performing with great care in making these measurements and additionally they are subject to errors due to the size, heterogeneity of self-heating sources and repeatability of the selection of measurements sites.

2.1. Criteria for the assessment of the thermal condition of a dump

The assessment of a fire hazard of a waste dump is carried out (according to the methodology by the CMI) based on changes in the surface temperature of the dump, and the content of carbon monoxide inside the dump. Four basic thermal conditions are assumed (Gumińska and Różański 2005):

Lack of spontaneous heating of a dump:

$$\Delta t < 3°\mathrm{C}$$

$$\mathrm{CO} \leq 0.002\%\ \mathrm{obj.}$$

↳ Δt – temperature difference between surface temperature of a dump and the ambient temperature,

CO – concentration of oxygen oxide in a gas sample taken from inside of the dump.

Spontaneous heating of a dump:

$$3°\text{C} \le \Delta t \text{ and } \Delta t < 10°\text{C}$$

$$0.002\% \text{ vol.} < \text{CO} \le 0.015\% \text{ vol.}$$

A small intensive dump fire:

$$10°\text{C} \le \Delta t \text{ and } \Delta t < 20°\text{C}$$

$$0.015\% \text{ vol.} < \text{CO} \le 0.05\ \% \text{ vol.}$$

An intensive dump fire:

$$\Delta t \ge 20°\text{C}$$

$$\text{CO} > 0.05\% \text{ vol.}$$

It should be noted that the measurement of the surface temperature, especially during the summer months, does not reflect the actual temperature of the interior. During this period, due to sun exposure a significant increase in surface temperature may occur, and then even at thermally inactive slopes for the value of Δt may considerably exceed 3°C.

In recent times, scientific-research institutions have been searching for effective methods to assess the thermal-gas activity of waste dump with the use of innovative technologies (Łączny, Baran and Ryszko 2012; Wasilewski 2009).

A medium-sized mining waste dumping ground has a volume of about 2 million m^3, so the precise location of the fire source and the effective process of its extinguishment and cooling of the deposited material are a particularly important issue, impeded by its difficulty. (Korski et al. 2004, 2007). An additional difficulty consists of the fact that the development of fire phenomena in the first phase is of latent character until the moment of the appearance of clear and oppressive signs of a fire. It is assumed that this condition could possibly be detected in a continuous or quasi-continuous process of monitoring changes in temperature and gas composition in the massif of the dump. Practice shows that the exploration and analysis carried out at fixed measuring points, make it possible to reach conclusions on the existing fire sources and the development of the spontaneous heating. Hence the idea of the introduction of automatic monitoring, based on selected measurement boreholes, seems to be correct and can become an effective tool for the early detection of a fire hazard in mining waste dumps.

Arguments in favor of the introduction of modern methods of automatic monitoring are now indisputable. Constant supervision of a coal waste dump provides a unique opportunity for rapid and effective intervention in the case at the first signs of spontaneous heating in the object. The lack of an immediate reaction causes the intensification of these phenomena and, consequently, leads to a fire which is very difficult to take control of and requires large financial expenditures, considerably exceeding the cost of fire prevention measures at the early stages of spontaneous heating development.

2. The application of modern monitoring methods in coal waste dumps

The adopted methodology for observing fire hazards in coal waste dumps includes thermal and gas monitoring. In such a vast dumping ground, exploration of a significant area is required and therefore an attempt at the use of the thermal imaging method was undertaken for the exploration of a waste dump by scanning the area during an air raid. Then it was assumed that the identified sites of elevated temperatures should be monitored using thermal-gas monitoring at designated observation boreholes.

The thermal-gas method of monitoring accepted in the project included:

- thermal scanning of the surface of a waste dump during an using precision thermal imaging camera in order to explore and locate sites with elevated temperatures,
- thermal-gas monitoring with the use of a borehole method by drilling boreholes in the massif of the dump and the introduction of pipes to a depth of about 5 m together with installation of measurement probes in pipes and initiation of a continuous monitoring with wireless data acquisition system at a fixed measurement cycle.

A trial of thermal imaging exploration of the thermal condition of a dump by scanning the area with a precision thermal imaging camera during an air raid was performed for the realization of such an adopted methodology. The test thermograms were executed at the Rymer and Skalny dumps, followed by Waleska dump, selected for investigation. Based on the images and thermograms and as a result of agreements reached with people responsible for supervision it was assumed that the identified sites of elevated temperatures should be monitored with the use of measurement probes in the form of continuous thermal-gas monitoring (Raport 2011).

Continuous thermal-gas monitoring was carried out via a borehole method. The boreholes were drilled in the massif of the dump into which the pipes were introduced to a depth of about 5 m with built in heads including measurement probes. The continuous monitoring inside the boreholes, cycling once per hour, recorded the temperature and the concentration of oxygen, carbon monoxide and carbon dioxide through a wireless data collection system. Additionally, the analysis of weather conditions was carried out on an ongoing basis using the data recorded by the nearest weather station located at the Katowice Muchowiec airport, utilizing the so-called wind rose.

The measurement data collected during the observation can also be used as input data for model tests using a computer simulation (Skotniczny 2006; Raport 2011). This way the verification of calculation results is also possible with the results of observations and long-term *in situ* measurements for the changing conditions of the dump's surroundings.

2.1. Application of remote sensing methods in the assessment of the thermal activity of a coal waste dump

The first application of remote sensing methods for the detection and location of spontaneous heating in coal dumps was documented in the United States in 1963 in Scranton in the state of Pennsylvania (Report 2002), in which the thermograms of burning dumps were shown. In the 60s and 70s many American scientists conducted observations of local dumps on fire by using thermal imaging cameras placed aboardplanes. However, the technical capabilities during this period and the resulting density of the thermal scanning allowed only for a rough assessment of areas with elevated temperature and occurring fires. At the beginning of the 80s, studies with the use of remote sensing had already been conducted in several countries with developed mining industries. Remote sensing methods of dump fires based on the spectral scanning in the thermal infrared have been used since 1983 to study coal fires in dumps in Chinese regions of Tażyan Xishan in Shanxi Province (Chunli et al. 1998) and in Jharia (India) where maps of spontaneous heating were developed. This problem has also found its place in the Landsat TM satellite studies. These studies showed that, despite considerable progress, remote sensing and temperature measurements can only be effectively used when large areas are on fire (Wang et al. 2008) due to the low spatial resolution of thermal scanning of the surface.

The development of measurement techniques and technological advances in the fields of electronics and computer information technology also contributed to its development and expansion of the capabilities of non-contact temperature measurement. Given the diversity of the objects and elements in the geographical environment, we are dealing with the thermal differentiation of the substrate, which in turn, determines the absorption, scattering or reflecting of heat energy that reaches the Earth's surface. These phenomena recorded by thermal imaging systems can be placed on thermograms. In order to obtain the contours of the surveyed objects on thermograms additional, parallel with the thermograms, video imaging is required (Sawicki 1999; Tang 2008) in black and white or in natural colors. In this case the data from the GIS system are used, which are recorded simultaneously with the thermal registration in the computer's memory. At the same time, in the state of the art video measurement systems used in the study, advanced methods of processing digital images obtained are becoming the standard, enabling the automation of processing and computer modeling of objects in virtual reality.

In recent years, significant progress in the construction of thermal imaging cameras has been noted as well as tools and software for processing and analyzing thermographs and images, which provides the opportunity to register temperatures on large areas such as waste heaps, waste dumping grounds or the workings of an open pit mine (Dattoma et al. 2001; Gielisch 2006). A precise thermal imaging camera with a digital matrix and cooling within a closed system, equipped with powerful software was used in the research project (Raport 2011) for thermal scanning coal waste dumps during air raids. This very modern research tool provides at present great opportunities for illustration and elaboration of the recorded thermal images (Wasilewski and Choroba 2011).

2.2. Thermal-gas monitoring via a borehole method

Test boreholes, executed in the form of perforated pipes, are used for monitoring purposes (Raport 2011) and at the moment of spontaneous ignition they can be used for preventative measures by utilizing the method of injecting extinguishing agents. Each hole (pipe) is closed on the top with the head, in which the measuring probe is placed with thermometer, sensors, and a power battery, as well as with a data recording system (data logger). Due to the nature of the distribution of boreholes over a large area of a dump, the use of connecting cables with the data acquisition system would be troublesome and therefore the solution of using a radio transmission system was adapted for a mobile data acquisition.

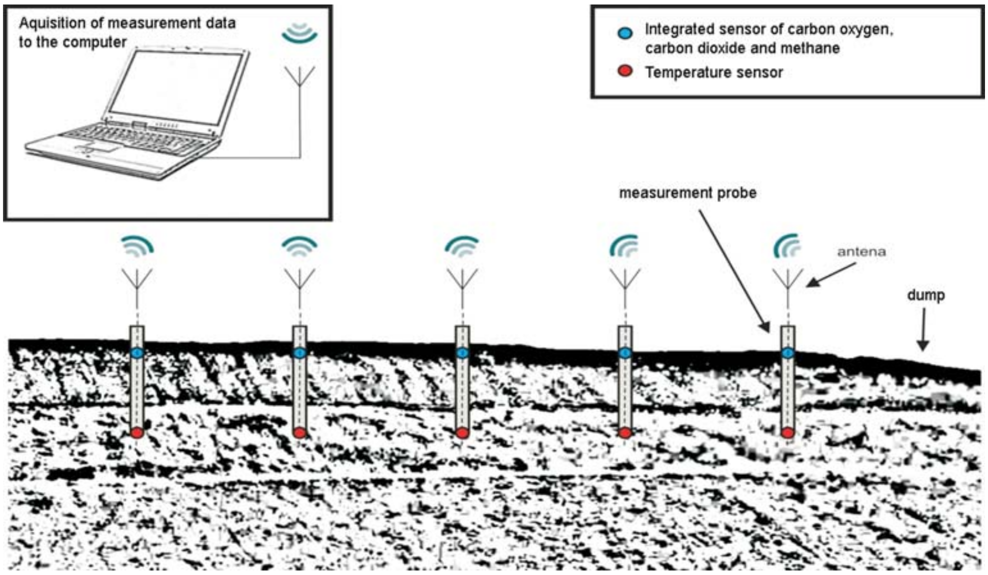

Fig. 1. Diagram of data acquisition system of thermal-gas activity in a dump

Rys. 1. Schemat systemu zbierania danych o aktywności termiczno-gazowej na hałdzie

Technical parameters of a measurement probe

The measuring probe make it possible to measure:

- air temperature, in the range –20 – to at least +2000°C, at the depth of few meters,
- carbon oxide concentration, in the range of 0–1000 ppm,
- carbon dioxide concentration, in the range of: 0–5%,
- oxygen concentration, in the range of: 0–25%.

Measurement frequency was set at once per hour with the possibility of data storing in the non-volatile memory of the buffer for at least two weeks and reading remotely. Simultaneously, the interface of a mobile station allows for reading on request of the data in a wireless system of measurement data collection and acquisition.

3. Waleska dump as a testing ground for checking the assessment methods of thermal activity

Waleska dumping ground in Łaziska Górne was selected as a testing ground for research on a coal dump of Upper Silesia (Raport 2011). This is an area showing thermal activity, although without clear active fire sources.

3.1. Scanning of thermal activity of the dump executed during an air-raid

In order to locate hazardous areas of the dump, pictures were taken by infrared camera of thermal activity by scanning during the air-raid (Raport 2011). During the air-raid thermograms were recorded along the trajectory of the flight, obtaining thus a series of images that allow for the construction of a thermographic map of the area. The registration of thermograms were made using ThermaCAM SC640 thermal imaging camera from FLIR Systems, Inc. This model can detect even small changes in temperature in a wide temperature range. The resulting images are characterized by high sharpness and resolution at the level of 640 × 480 pixels. Thermograms were processed and analyzed, which allowed for the identification of areas with elevated temperatures.

MATLAB software was used for the analysis of thermograms coal waste dump for which the image file representing a thermographic map of the area is a metrological information carrier, constituting at the same time an input datum. Each image is treated as a matrix. Operating on the matrix variable, one can perform transformations, which consequently allow for modifying the base image, and further reading of the information stored in it, being difficult and often even impossible to observe with the naked eye.

Among the transformations that are programmed for the analysis of thermograms, the following can be distinguished:

- transformation of color thermograms into a monochrome one (black and white),
- binarization of the image,
- conversion of a monochromatic thermogram into a temperature intervals image.

Fig. 2. Testing ground of Waleska coal waste dump (source: Google Maps)

Rys. 2. Poligon doświadczalny zwałowisko odpadów powęglowych Waleska (źródło: Google Maps)

For analysis, an algorithm was also developed to estimate the GPS satellite coordinates for any sites with increased thermal activity.

3.2. Thermogram's analysis of Waleska coal waste dump

Waleska coal waste dump is located in Łaziska Górne, on Cardinal Stefan Wyszyński, street, its GPS satellite coordinates are: 50.1425–18.8784. Examples of a satellite image and a thermogram are represented in Figures 3 and 4.

3.3. Analysis of thermal images in a MATLAB environment

Thermographic image analysis was carried out in an the scientific and technical environment of MATLAB. For this purpose, a program was created (Raport 2011) leveraging the advantages of the capabilities and functionality of the Image Processing Toolbox package. A thermogram was an input datum of the software, which was subjected to processing in order to read the information stored within. The verification of the analysis

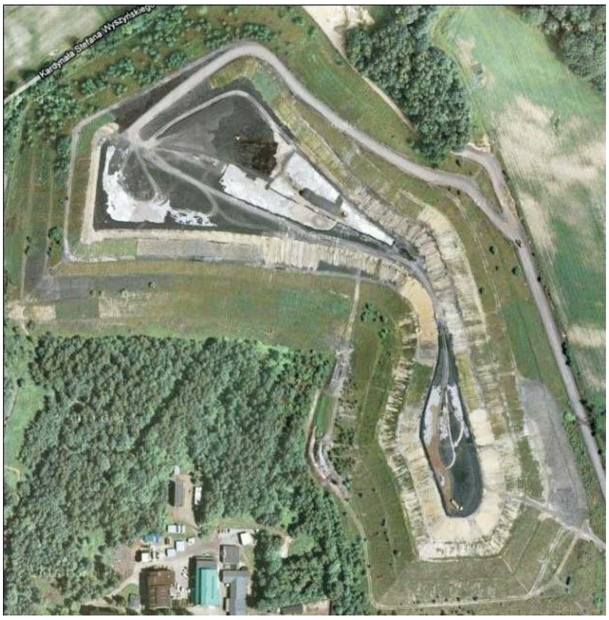

Fig. 3. Waleska coal waste dump – a satellite image

Rys. 3. Hałda Waleska – zdjęcie satelitarne

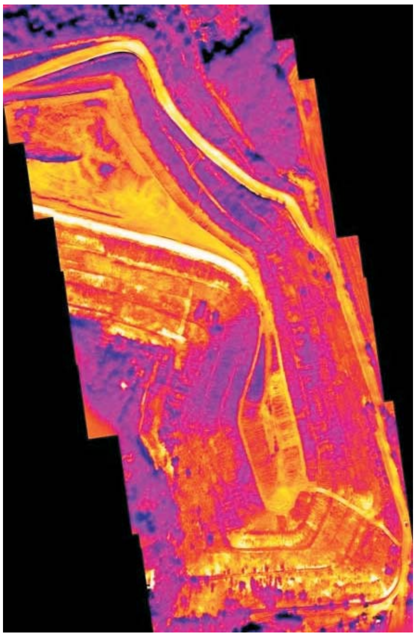

Fig. 4. Waleska coal waste dump – a registered thermogram

Rys. 4. Hałda Waleska – zarejestrowany termogram method of the thermograms together with the software was performed for thermograms obtained previously from twice repeated air-raids over the Rymer dump in Rybnik and Skalny dump in Łaziska Górne. In the measurements taken with the infrared camera, infrared radiation emitted by the body is used; the fourth power of the temperature is directly proportional to the total power of emitted radiation (Wasilewski and Choroba 2011). In this way of recording, we are using one parameter, which allows for the acquisition of a monochrome image. The coloration of the thermogram is accomplished in a programmed way inside the device, in order to improve the quality of the differentiation of temperatures. For numerical analysis a black and white thermogram is a sufficient information carrier, hence the transformation of a color image into a monochrome one.

Binarization is the next step, which consists of converting a monochrome image into an image recorded with the use of two colors, black and white. A threshold on a selected level of greyness is assumed as the criterion of division into the colors mentioned above regarding which pixels become white and which ones black. For thermograms, a 50 percent cut-off threshold was accepted, which corresponds to a temperature in the range of 17°C. This allowed exposure of a site suspected of excessive thermal activity as a result of physical and chemical processes occurring inside the dump.

A monochromatic thermogram was also processed into an image of temperature ranges (quasi-isothermal areas). The following five ranges have been accepted:

- temp. lower or equal to 5°C (background – black color),
- temp. from 5°C to 12.5°C (first area – dark-grey color),
- temp. from 12.5°C to 20°C (second area – grey color),
- temp. from 20°C to 27,5°C (third area – light grey color),
- temp. from 27.5°C to 35°C (fourth area – white color).

As a criterion for the division, the appropriate thresholds for the determined levels of greyness scale were selected.

The estimation of GPS satellite coordinates for sites suspected of excessive thermal activity was programmed at the end. A modified binerized thermogram was a base image on the basis of which calculations were conducted. The modification consisted in filtering a binary image along the rows of the matrix in such a way that pixels adjacent in the column were replaced by a single center pixel. Thanks to such an operation, the points or lines lying within the areas of increased temperature were identified.

In order to estimate the GPS coordinates, the base coordinates were accepted for the characteristic points of a thermogram at the extreme edges of the image (each on the sides of the frame of the thermogram). Subtracting from each other the pair values of coordinates of longitude and latitude and by dividing the obtained distances by respective parameters of the resolution of the image one can determine the value of the step of change of the coordinates in either direction, and thus assign GPS coordinates of the identified points and linesThe original thermogram (Fig. 4) was subsequently converted into a monochrome image in the analysis. On the generated monochrome thermogram (Fig. 5), a binarization operation has been completed (Fig. 6), thanks to which sites could be identified as indicating

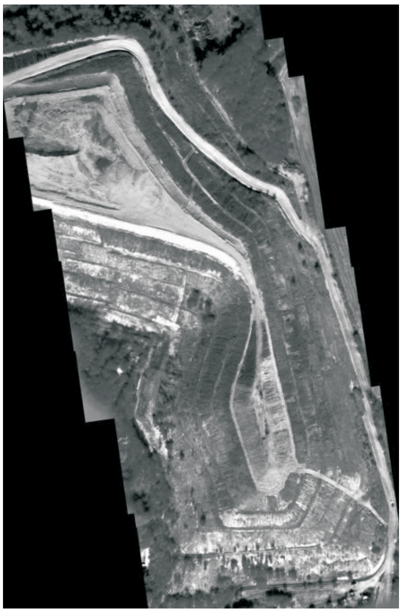

Fig. 5. Waleska dump – a monochromatic thermogram

Rys. 5. Hałda Waleska – termogram monochromatyczny

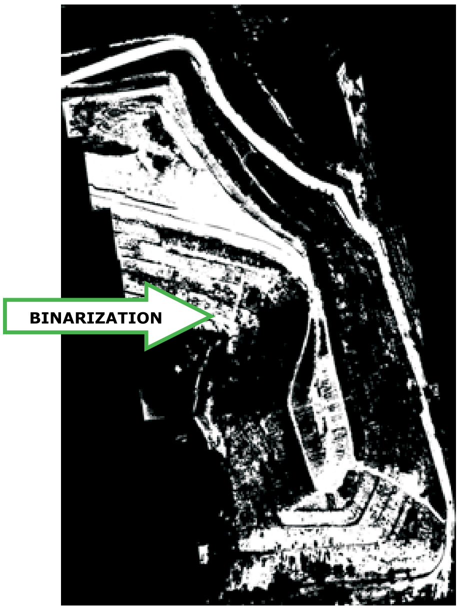

Fig. 6. Waleska dump – a thermogram subjected to binarization

Rys. 6. Hałda Waleska – termogram poddany binaryzacji

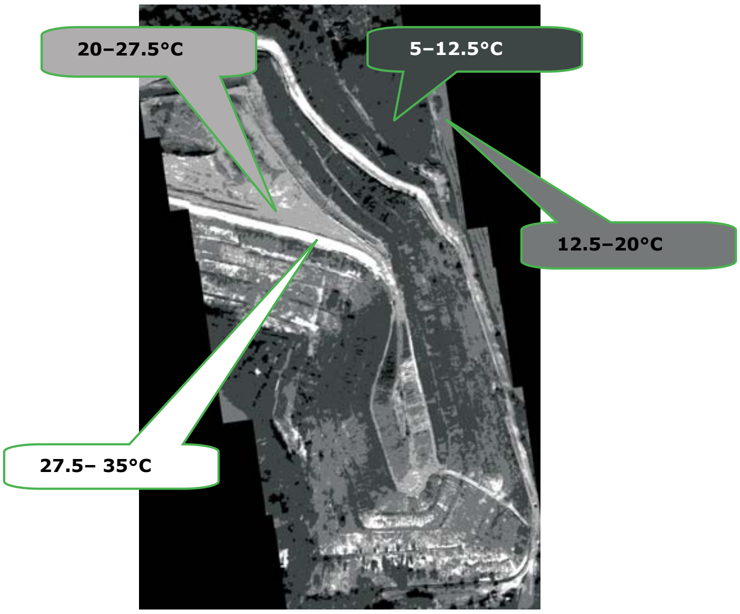

Fig. 7. Waleska dump – an image of temperature ranges (*quasi*-isometric areas)

Rys. 7. Hałda Waleska – obraz przedziałów temperaturowych (obszarów quasi-izotermicznych)

Fig. 8. Waleska dump – a thermogram subjected to binarization

Rys. 8. Hałda Waleska – termogram poddany binaryzacji

Fig. 9. Waleska dump – a modified, binerized image

Rys. 9. Hałda Waleska – zmodyfikowany obraz zbinaryzowany

an elevated thermal activity. The image of the temperature ranges (Fig. 7) illustrates the areas of similar power of emitted thermal radiation. The filtration of the binerized image (Figures 8 and 9) allowed to obtain the points or lines lying within the boundaries of elevated temperature.

3.4. Determining the location of observation boreholes

In order to recognize and identify sites of a higher hazard on a considerable area of a waste dump a local thermal imaging display was done while making the rounds of the surface in addition to the thermal images from an air raid. The experience and previous observations carried out by employees of the Department of Environmental Protection of Bolesław Śmiały mine executing the supervision of the dump were also of meaningful significance. It was assumed that the identified sites with elevated temperatures should be monitored by carrying out thermal-gas monitoring using the borehole method (Raport 2011).

For this purpose, 5 holes were drilled in the massif of the dump (Fig. 10), with a diameter of ϕ100 and depth of 5.20 m, which were equipped with perforated tubes closed from the top by a head with the probe provided with temperature and gas sensors (CO, CO_2, O_2) and a battery, as well as a data transmission system (Fig. 11). A period of continuous

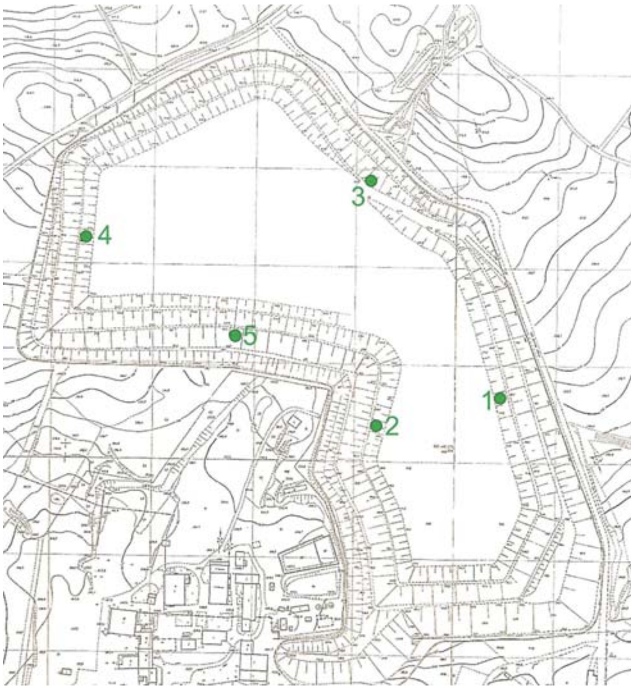

Fig. 10. Location of test boreholes on the surface of the Waleska waste dump

Rys. 10. Lokalizacja otworów badawczych na powierzchni zwałowiska odpadów Waleska

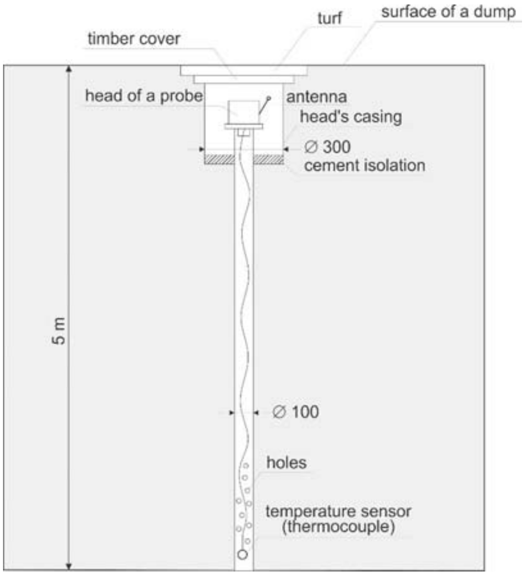

Fig. 11. Technology of installation of measurement heads in test boreholes

Rys. 11. Technologia zabudowy głowic pomiarowych w otworach badawczych monitoring was commenced, in which each measurement point stored measurement data in its memory and sent them wirelessly on request to a mobile data acquisition station.

4. Long-term registration and analysis of the data from test grounds

4.1. Recording of air parameters in test boreholes

Changes in parameters recorded during long-term observation in the hole 1 are shown in Figure 12. The temperature inside the hole had an upward trend to about 19–20°C at the beginning of April 2010 to 27, and even 29°C at the end of September 2010. The concentration of carbon dioxide as well as oxygen concentration was of the variable nature with many fluctuations, while the changes in the concentrations of these gases were clearly of a push-pull character. The concentration of carbon monoxide was recorded only in early April, and then the sensor got damaged (due to high humidity, and even condensation on the measuring head).

Several years of experience has shown that it is precisely the problem of large humidity and condensation of water on the chambers of sensors and measuring systems constituted the greatest difficulty in maintaining of an efficiency of measurement on the testing ground despite the replacement of sensors and electronic circuits several times.

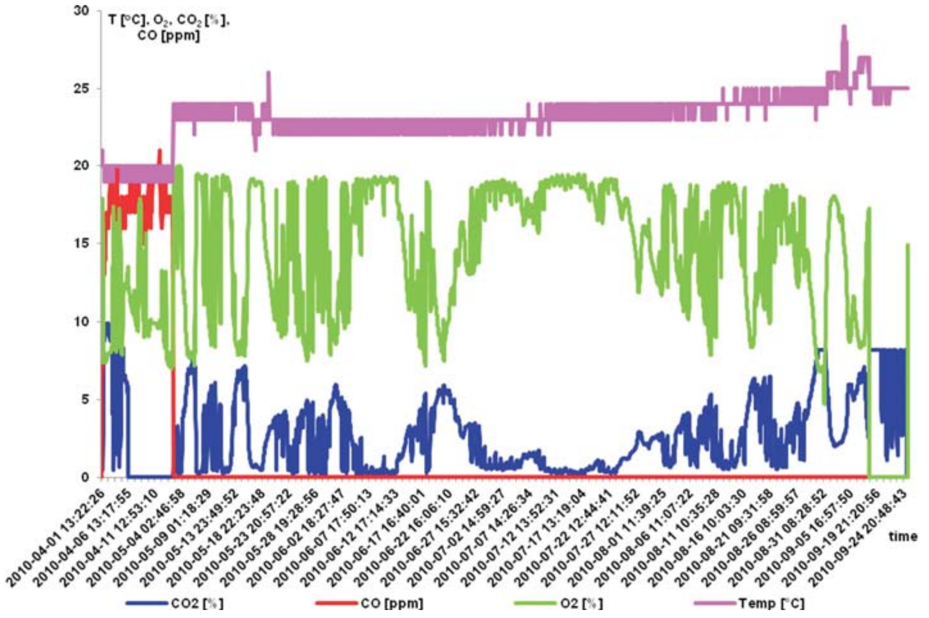

Fig. 12. Recording of air parameters in borehole 1 in 2010

Rys. 12. Rejestracje parametrów w otworze 1 w roku 2010

4.2. Time courses of atmospheric air parameters

Observation and analysis of weather conditions was performed (Raport 2011) based on the measurement data obtained from the weather station located at the Muchowiec airport in Katowice located in a straight line a few kilometers from the Waleska mining waste dump. Figure 13 shows the monthly registrations of atmospheric parameters recorded at the Muchowiec weather station.

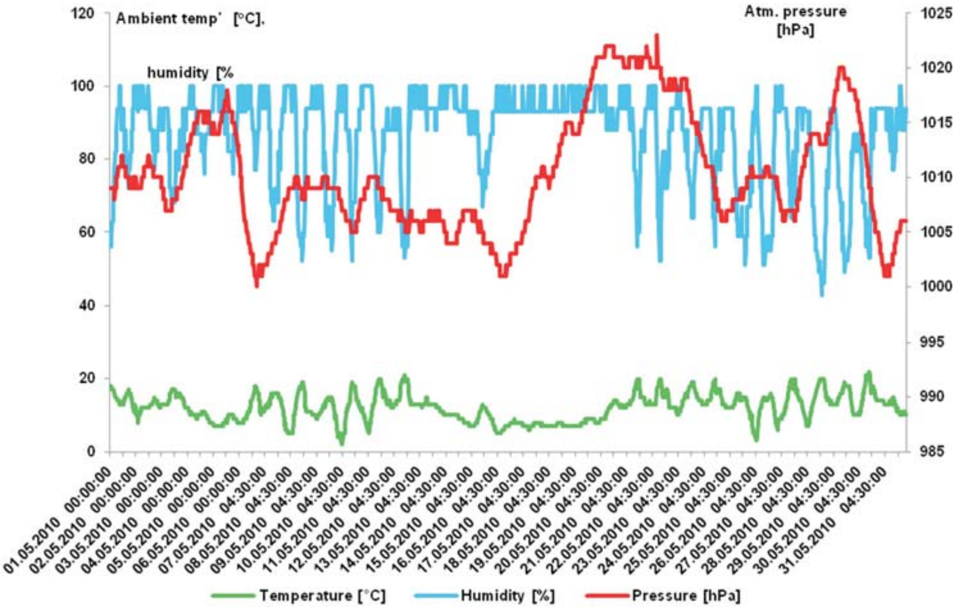

Fig. 13. Weather conditions recorded at Muchowiec station in May

Rys. 13. Warunki atmosferyczne rejestrowane na stacji Muchowiec w maju

Monthly registrations of weather conditions (air pressure, temperature and humidity) show large fluctuations in the daily cycle of temperature and humidity, as well as a definite slowdown for changes in atmospheric pressure. From the point of view of the research, it would be interesting to learn if changing of weather conditions had an impact on the registration of air parameters inside the dump in boreholes.

Wind rose

Registration of wind speed and its direction are shown in radar graphs 13 as a wind rose, during the study period, identifying 12 wind directions, 11 speed classes: 14 = 1, 2, 3, ... 11 m/s (for $\bar{u} < 1$ or > 11 m/s it is assumed that $\bar{u} = 1$ or 11 m/s) and the six states of atmosphere equilibrium. In the diagram (15) the frequency of winds from different directions is characterized with the account of the division of wind speeds U_a. For each speed from 1 m/s to 11 m/s a wind rose was plotted, which provides information about the direction and the share of the winds which were blowing with a determined speed.

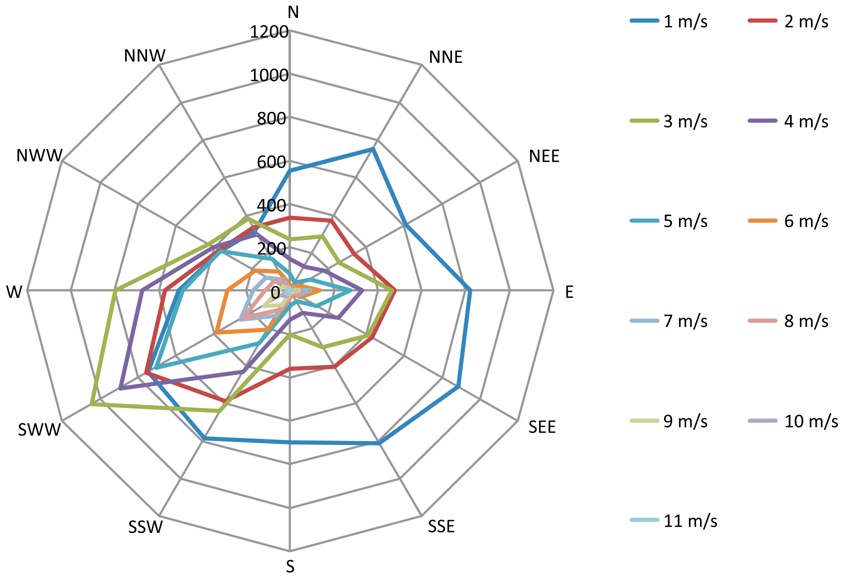

Fig. 14. Wind rose – the share of wind speeds

Rys. 14. Róża wiatrów – udział prędkości wiatru

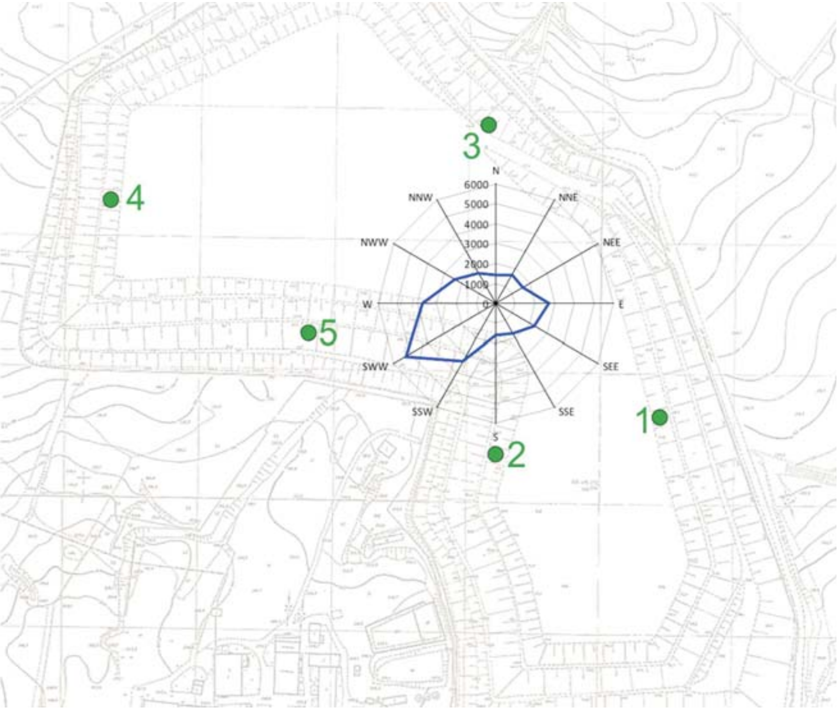

Fig. 15. A cumulative wind rose determined for the conditions of Waleska dump

Rys. 15. Sumaryczna róża wiatrów wyznaczona dla warunków zwałowiska Waleska

The cumulative wind rose plotted against the Waleska dump (Fig. 15), the most often occurring wind direction within the duration of the dump's examination was the South-West (SWW) direction . There is therefore a question about what impact had the wind direction on air parameters recorded inside the dump, i.e. in test boreholes.

5. Correlation of the parameters in boreholes with the conditions of the surroundings

Selected recordings from the period of monthly observations of gas concentrations and temperatures in test boreholes; the conditions of the surroundings in the form of atmospheric pressure and air temperature, as well as the wind direction and speed were used for an attempt to analyze the relationship between these parameters were recorded at this time. The registration from the holes 1, 3 and 2 were taken into account in the analysis. Such a choice resulted from the location of the test boreholes in Waleska dump against the wind rose (Fig. 15) where the boreholes 1 and 3 were on the lee side, and the borehole 2 was located on the side of the highest frequency of occurrence of a wind speed (SSW-S direction).

Recordings of oxygen and carbon dioxide concentration in holes 1 and 3 presented in Figures 16 and 17, 18 and 19 located on the eastern side of the dump (Fig. 15) against the changes of atmospheric conditions changes and particularly changes in atmospheric pressure show a strong influence of the surrounding conditions on the changes in the concentration of gases in the test boreholes. These holes were located on the lee side of the dump and were protected against a direct thrust of the wind. Oxygen concentration was negatively correlated with the atmospheric pressure whereas the carbon dioxide concentration on the contrary was positively correlated with the pressure.

The impact of wind speed from these directions on the changes of gas concentration in the test borehole 3 is not so visible (Fig. 21), because it was located on the north side of the dump that is beyond the reach of impact of the wind from the southern direction.

The dependencies of air parameters in the test bore- hole 2, located on the south side of the dump (Fig. 15), look differently. Changes in the concentrations of gases (oxygen and carbon dioxide) in the test borehole 2 do not have such a strong connection with changes in atmospheric pressure (Fig. 20), but they have a clear link with the changes of wind speed as shown in Figure 21. The impact of changes in wind speed on changes in gas concentration in the test borehole 2 are justified by a location of this test borehole (Fig. 15) against the share of wind speed from SSW direction (Fig. 15).

It should be stressed that the presented recordings (Figs. 17, 19 and 21) show that changes in the conditions of the surroundings, in particular large fluctuations in ambient temperature, do not affect the changes in temperature in test boreholes 1, 2 and 3 and inside the dump.

The presented dependencies confirm that in the case of dominant wind direction to the (SWW) southwest, the western side of the dump (Fig. 15) is intensively aerated, and thus the speed of the wind and its changes have a significant impact on changes in

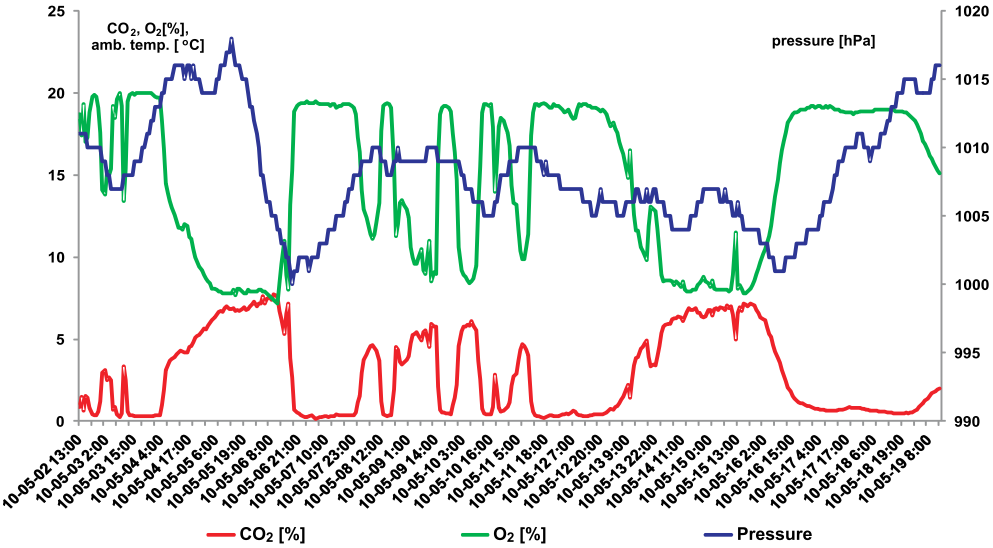

Fig. 16. Recordings of oxygen and carbon dioxide concentration in a test borehole 1 and atmoshperic pressure in May

Rys. 16. Rejestracje stężenia tlenu i ditlenku węgla w otworze 1 i zmian ciśnienia atmosferycznego w maju

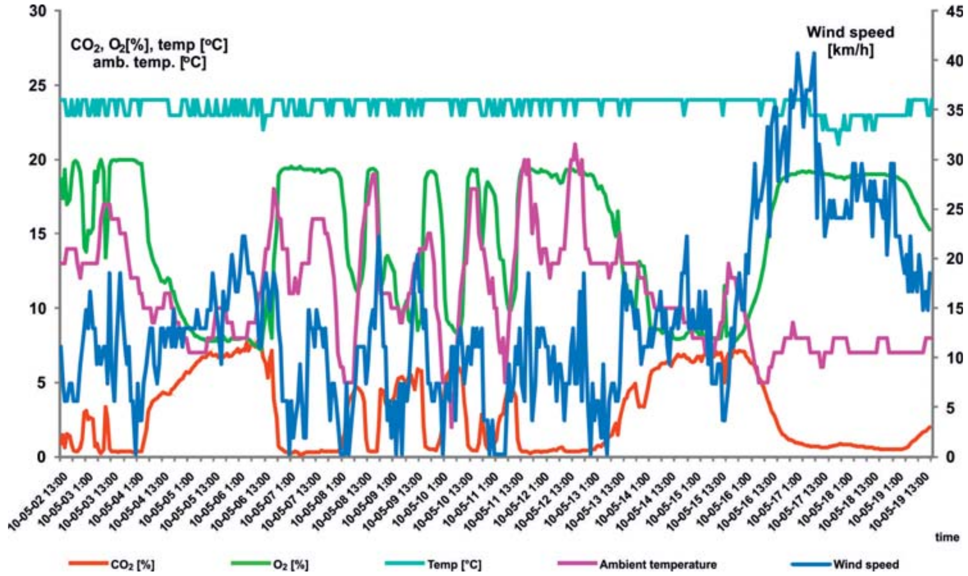

Fig. 17. Recordings of oxygen and carbon dioxide cconcentration as well as temperature in borehole 1 and changes in the conditions of the surroundings of the dump in May

Rys. 17. Rejestracje stężenia tlenu i ditlenku węgla oraz temperatury w otworze 1 i zmian warunków otoczenia hałdy w maju

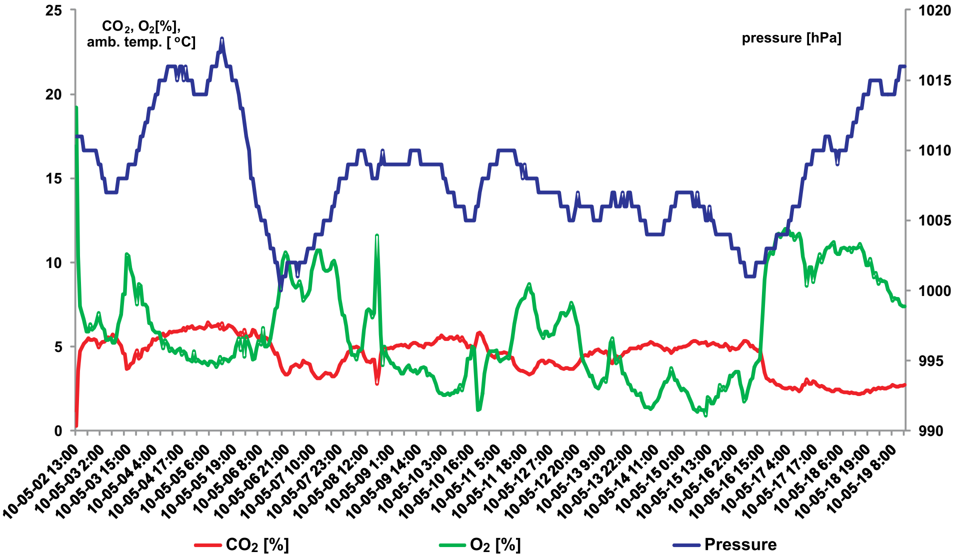

Fig. 18. Recordings of oxygen and carbon dioxide concentration in borehole 3 and atmospheric pressure changes in May

Rys. 18. Rejestracje stężenia tlenu i ditlenku węgla w otworze 3 i zmian ciśnienia atmosferycznego w maju

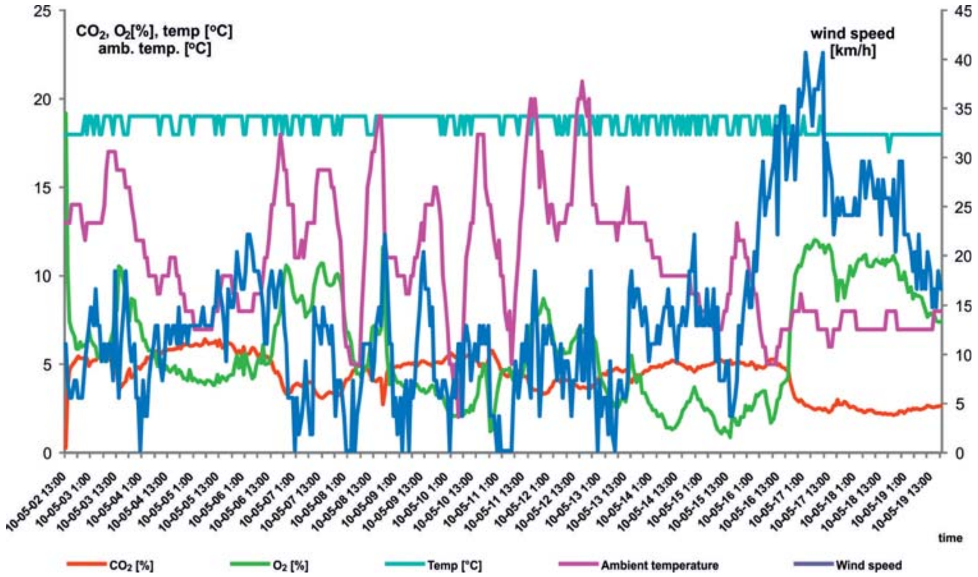

Fig. 19. Recordings of oxygen and carbon dioxide concentration in a test borehole 3 and changes of the conditions of a surroundings of a dump

Rys. 19. Rejestracje stężenia tlenu i ditlenku węgla w otworze 3 i zmian warunków otoczenia hałdy w maju

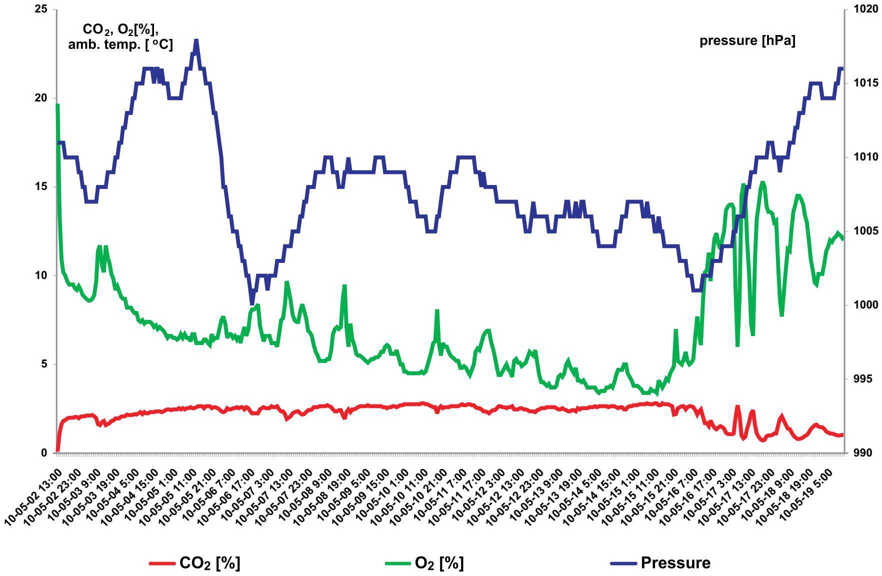

Fig. 20. Recordings of oxygen and carbon dioxide concentration in a test borehole 2 and changes of atmospheric pressure in May

Rys. 20. Rejestracje stężenia tlenu i ditlenku węgla w otworze 2 i zmian ciśnienia atmosferycznego w maju

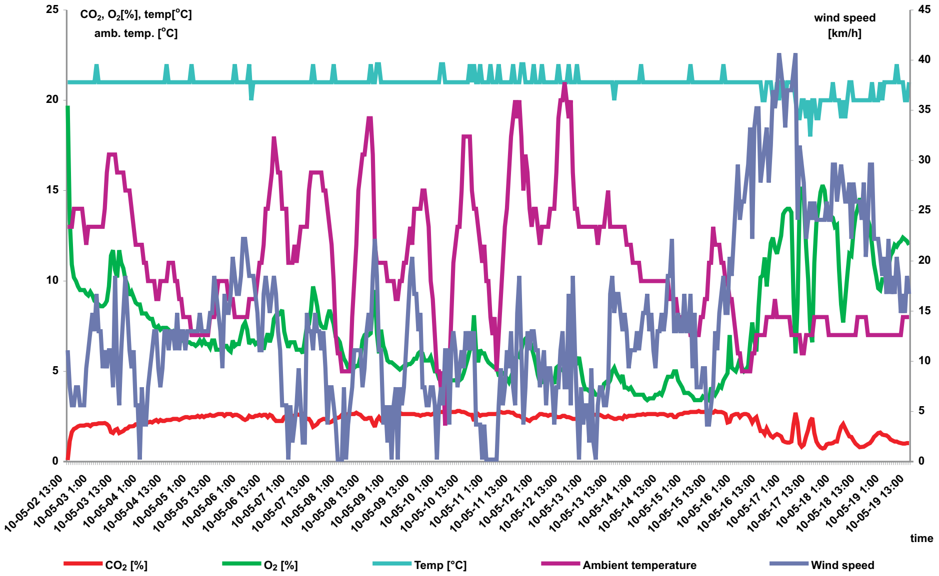

Fig. 21. Recordings of oxygen and carbon dioxide concentration in a test borehole 2 and changes of conditions of the surroundings of the dump in May

Rys. 21. Rejestracje stężenia tlenu i ditlenku węgla w otworze 2 i zmian warunków otoczenia hałdy w maju gas concentrations in test boreholes located on this side. On the other site (eastern) gas concentrations in test boreholes located on the leeside are subjected to the stronger influence of changes in barometric pressure.

Summary

Spontaneous heating of deposited material accompanies the process of placement of coal waste on dumping grounds and results in an initiation of a fire source. This condition can create a serious burden on the natural environment and the threat to human life and health. Monitoring plays an extremely important role in the application of prevention measures against a fire hazard's occurrence on a coal waste dump. The analysis of the activity of newly established waste dump wastes, and on the one under a fire must, in accordance with applicable regulations, be conducted within the framework of monitoring both during the exploitation period as well as for many years afterwards. Continuous supervision over the coal waste dump provides a chance of early and effective intervention in the case of determination of the first signs of spontaneous heating of the object.

The up-to- date methods of monitoring and control, conducted by observers moving along the surface area of a dump, to make measurements of temperature and gas concentrations directly beneath the surface seem to be time consuming and costly. With the current state of the art of technological development, it seems that traditional methods of monitoring can be replaced by using monitoring methods employing modern measurement technology.

The dependence of gas concentrations observed in test boreholes during long-term observation of Waleska dump confirm that in the case of the dominant wind direction (SWW) south-western side of the dump is heavily aerated, and therefore the speed of the wind and its changes have a significant impact on changes in gas concentrations in test boreholes located on this side of the dump. On the other side of the dump (eastern) gas concentrations in test boreholes located on the leeside of the dump were subjected to stronger influences of barometric pressure changes. At the same time, it was found that large variations in the ambient temperature do not affect the temperature changes in the test boreholes, inside the dump.

Conclusions from long-term *in situ* observations confirm the results of a computer simulation for the assumed dominant wind direction (Skotniczny 2006). The results of model testing and their verification with the presented observations will be depicted in a separate article.

Many months observations of thermal-gas parameters of the Waleska dump showed a low level of a fire hazard (Korski et al. 2004, 2007), and even the lack of thermal-gas activity of this object, which confirmed the application of the effective measures of fire hazard combating on coal waste dumps carried out by the Department of Environmental Protection of Boleslaw Śmiały mine the persons responsible for maintenance of the dump during storing and after the storage of the wastes.Many months observations of thermal-gas parameters of the Waleska dump showed a low level of a fire hazard (Korski et al. 2004, 2007), and even the lack of thermal-gas activity of this object, which confirmed the application of the effective measures of fire hazard combating on coal waste dumps carried out by the Department of Environmental Protection of Boleslaw Śmiały mine the persons responsible for maintenance of the dump during storing and after the storage of the wastes.

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ZWAŁOWISKA ODPADÓW WYDOBYWCZYCH – NOWOCZESNE METODY MONITORINGU TERMICZNO-GAZOWEGO

Słowa kluczowe

zwałowiska odpadów wydobywczych, zdalny pomiar rozkładu temperatur,
termografia z pokładu samolotu, wczesne wykrywanie pożarów zwałowisk,
monitoring termiczno-gazowy

Streszczenie

Zwałowiska odpadów wydobywczych wpisują się na trwałe w krajobraz terenów górniczych i oddziaływają na środowisko naturalne w wielu aspektach. Obecność w masywie zwałowiska substancji węglowych prowadzi często do powstawania zagrożeń pożarowych. Niezwykle ważną rolę w profilaktyce przeciwpożarowej odgrywa monitoring aktywności zwałowiska odpadów węglowych nowo powstałych i zapożarowanych. Zgodnie z obowiązującymi przepisami musi on być prowadzony zarówno w czasie eksploatacji jak i przez wiele lat po jej zakończeniu. Monitoring zwałowiska ma na celu m.in. wykrycie anomalii termicznych i gazowych już w początkowym stadium rozwoju i podjęcie działań profilaktycznych w celu usunięcia i minimalizacji wpływu oraz obciążenia zwałowiska dla środowiska oraz zdrowia i życia ludzi.

W artykule przedstawiającym wybrane wyniki projektu badawczego (Raport 2011) zaproponowano metodę monitoringu zagrożeń pożarowych zwałowiska odpadów powęglowych, która obejmuje skaning termiczny oraz monitoring termiczno-gazowy metodą otworową w ustalonych punktach zwałowiska. Monitoring rozległego zwałowiska wymaga rozpoznania stanu termicznego znacznego obszaru, stąd przyjęto skanowanie terenu za pomocą precyzyjnej kamery termowizyjnej w czasie przelotu lotniczego. Następnie w wyznaczonych miejscach zwałowiska prowadzono długookresowe badania poligonowe z wykorzystaniem bezprzewodowego systemu zbierania danych z rozproszonych otworów badawczych, wykonanych z rur perforowanych i wyposażonych w sondy z czujnikami temperatury i gazów (CO, CO_2 O_2). Równocześnie obserwowano zmienne warunki otoczenia i zmiany parametrów stanu atmosfery, tzw. róży wiatrów, wokół zwałowiska na podstawie danych zarejestrowanych przez stację pogodową.

MINING WASTE DUMPS – MODERN MONITORING OF THERMAL AND GAS ACTIVITIES

Key words

mining waste dumps, remote measurements of temperature distribution,
thermo-graphic images taken from an aircraft, early fire detection coal waste dumps,
monitoring of thermal and gas activities

Abstract

Mining waste dumps are permanently incorporated in the landscape of the mining areas and exert an impact on the environment in many ways. The presence in the massif of a dump of carbonaceous substances often leads to the formation of fire hazards. Monitoring the activity of a newly created coal waste dump or of one under fire plays an extremely important role in fire prevention activity. Under the current regulations it must be carried out both during the exploitation process and for many years afterwards. Monitoring a dump is targeted, among others, at detecting thermal and gas anomalies already at the initial stage of development and to undertake preventive measures to eliminate and minimize the impact and load of a dump for the environment and the health and life of humans. In the article selected results of a research project (Raport 2011) are shown; a method of monitoring fire hazards at dump wastes was proposed, which includes thermal scanning and thermal-gas monitoring by a borehole method aimed at fixed points in the dump. Monitoring the large area of a dump requires exploration of the thermal state of a significant area hence the accepted scanning of the area is with a precision thermal imaging camera during an air raid. Then at selected sites of the dump, long-term in-field studies were conducted using the wireless data collection system from scattered test holes, made of perforated pipes and equipped with temperature and gas probes (CO, CO_2, O_2). At the same time the changes of environmental conditions and changes in atmospheric state parameters were observed around the dump, the so-called wind rose, based on data recorded by the weather station.