ELECTRONICS AND ELECTRICAL ENGINEERING
ISSN 1392 – 1215 2012. No. 6(122)
ELEKTRONIKA IR ELEKTROTECHNIKA

T 010 ELECTRONIC MEASUREMENTS
ELEKTRONINIAI MATAVIMAI

Complex Measuring System for Longtime Monitoring and Visualization of Temperature and Toxic Gases Concentration

R. Hajovsky, M. Pies
Department of Cybernetics and Biomedical Engineering, VSB-Technical University of Ostrava, 17. listopadu 2172/15, 70833 Ostrava, Czech Republic, phone: +420 597 324 221, e-mails: radovan.hajovsky@vsb.cz, martin.pies@vsb.cz

crossref http://dx.doi.org/10.5755/j01.eee.122.6.1838

Introduction

Deep coal mining has always been accompanied by an array of negative effects. One of the most significant is the occurrence of mining dumps in the vicinity of mining companies. Mining dumps (also dumps) are natural mounds where collateral rocks from the surroundings of coal seams that cannot be further industrially used were stored during mining. Concurrently, coal substance was also stored in dumps, either in its pure form or as an individual layer of the loose rock mass or as a part of the collateral rock (mostly clay stone) that contained variously thick layers of coal that could not be separated during the mining process. It is the most dangerous material of the mining dump that creates and spreads thermal processes, virtually in the entire volume of each and every dump.

The amount of coal being stored together with collateral rock depends on the technology of separation and processing the product of a coal factory. Various analyses of the coal dump samples declare that percentage of combustible substances usually reaches 30%, while even 50% is not an exception.

There are many old mining dumps in the Moravian-Silesian Region. Several of them have been exposed to a very intense thermal process. The thermal processes, such as auto-oxidizing heating, endogenous as well as surface fires, occurred more or less constantly in mining dumps during last century. The occurring thermal processes represent a whole range of risks at a various degree of danger, some of which imminently threaten the lives of people. Last but not least, these processes also have a negative impact on the environment. The most serious risks arising from the existence of burning dumps include:

- *Development of heat.* The burning of the combustible parts of a dump releases considerable heat. The heat then uselessly leaks into the atmosphere and contributes to the disturbance in the natural balance of the given location;
- *Releasing toxic substances***.** Each mining dump contains a non-homogenous mix of carbon rock, coal as well as household and industrial waste that also used to be uncontrollably dumped at mining dumps during the operation of a coal factory. During fires, not only coal substances, but also all organic substances in the dump and illegally dumped chemicals in the last resort burn. The production of extremely toxic CO that is created as the product of imperfect combustion with the lack of oxygen is the most severe and extensive danger as the CO concentrations may become lethal, particularly in the immediate vicinity of gas outlets in burning dumps. CH_4 methane is another highly toxic gas [4];
- Generation and spread of fine dust;
- Creation of burnt-out space within the dumps;
- Risk of a surface fire;
- Negative impact on ecosystems.

Monitoring temperatures and gas concentrations in mining dumps

The aforementioned facts imply that it is absolutely essential to carry out long-term measurements of temperatures as well as concentrations of hazardous gases (CO, CH_4) in thermally impacted mining dumps. The monitoring of the quantities may be divided into two basic groups. The first one includes regular manual measurements of temperatures and gas concentrations in special probes with the use of manual portable measuring instruments. The second option, considerably quantitatively and qualitatively better, is to use special measuring systems that will ensure regular measurements of temperatures and gas concentrations as well as other quantities in defined time intervals and their subsequent transmission to a dispatching station. The first measurement method has a whole array of disadvantages, the major one being the necessity to manually measure and read values of specific quantities in regular intervals. Measurements are often executed in a dangerous and inaccessible terrain where there is a risk of injury or poisoning by the measured gases. Another disadvantage is the danger of falling in the created burnt-out spaces within the dump and thus threat to human life. Last but not least, manual measurement is inaccurate, namely with regard to the error in reading the measured data. All the disadvantages of manual measurement described above as well as other are solved by the second method of long-term monitoring, based on the use of specially developed measuring systems that consist of a sensory part, telemetric station and visualization (dispatching) station. Figure 1 shows the basic block diagram of such a system [2].

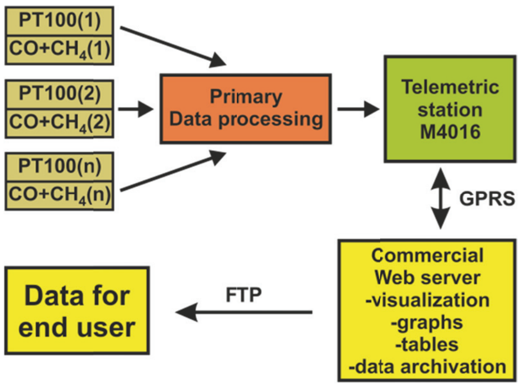

Fig. 1. Basic block diagram of the measurement system

The causes of a dump fire vary and apart from the physical and chemical properties of the particular type of the combustible, they also largely depend on the development and method of the creation of the dump in time. The progressing fire (thermal process) of the dump and the presence of other negative impacts of the environment, hazardous gases are also created and released, CO, CO_2 and CH_4 in particular. The release of methane, which virtually always accompanies the coal substance, is another adverse factor. There is a risk of explosion at higher concentrations (from 4.0 %) in such territories. This is closely connected to the necessity to monitor and evaluate boundary situations (values) of specified quantities on the basis of measurement. A limit value is a value that requires an inevitable redevelopment action since the continuing increase of such a value could lead to inadmissible conditions – the creation of an explosive gas concentration, toxic gas concentrations harmful to health, the creation of an endogenous and subsequent surface fire [3].

CO concentrations

Carbon monoxide is a colorless gas without any taste and odor, lighter than air, not irritating. It is little soluble in water. It is contained in coal gas, in generator and water gas and it has strong reduction properties. In nature, it is fractionally present in the atmosphere where it is namely created by the photolysis of carbon dioxide affected by ultraviolet radiation as a product of imperfect combustion of fossil fuels as well as biomass. It is also contained in volcanic gases. With regard to its toxicity, it is one of the significant pollutants. It is created by imperfect combustion of carbon and organic substances and it is emitted, for example, by automobiles, local furnaces, energetic and metallurgical industry.

Carbon monoxide blocks the transfer of oxygen by blood as its binding with hemoglobin is by 200 – 300 times stronger than that of oxygen. CO poisoning occurs, for example, in closed spaces where internal-combustion engines are running, or where ventilation of gas appliances is insufficient. Long-term CO concentrations above 30 ppm are considered to be hazardous for people. Concentrations above 100 ppm are life-threatening.

The aforementioned implies that the warning state must be set at the concentration of 0.003 % and the limit value at the concentration of 0.013 %, whereas the immediate CO concentration must be measured in determined intervals [1].

CH_4 Concentration

Methane naturally occurs under natural conditions, that is:

- In atmosphere where it gets namely as a product of the decomposition of substances with biogenic origin (biogas) or as a product of the metabolism of large ruminants, as well as from termitaries or rice fields;
- Under the ground:
  - As the main substance of gas bound to the coal substance;
  - As a part of the mine gas released from free spaces;
  - Dissolved in crude oil.

Natural gas is the main source of methane. At room temperature, it is non-toxic gas without any color and odor, lighter than air (relative density: 0.55 kg.m^{-3} at 20°C). Methane represents a highly explosive mixture when mixed with air. The self-ignition point is very high (595°C, the ignition temperature at the concentration of 8.5 % is 537°C) but it only takes an electric spark or open flame to explode the mix of methane and air (the minimal initiation energy is 0.28 mJ). It is a highly explosive gas and its explosion limits are considerably large, from 4.4 to 15 volume percent. The Decree of the Czech Mining Authority No. 22/1981 Coll., Section 83, permits a usual concentration of 1 %, with 2 % being the exception. With regard to the risk of methane explosion, the limit value is 1 %.

Gas sensors

The aforementioned developed measuring system that provides continuous monitoring of the temperature and concentrations of CO and CH_4 is fitted with sensors by FIGARO Sensors, namely TGS2442 [5] CO sensor and TGS2611 [6] CH_4 sensor. Both sensors are heated semiconducting. A glass layer for thermal insulation is printed between a ruthenium oxide (RuO2) heater and an alumina substrate. This heater heats the gas for analysis. The sensing layer has a defined electrical resistance R_0 at the exposure of the gas sensor to the specified concentration (typically 100 ppm for CO or 5,000 ppm for

CH_4). The sensing layer in both sensors is separated by a carbon filter and the sensors are stored in a stainless case.

The signal processing from the CO sensor is more complicated. The sensor has to be heated for the precisely determined period of 14 ms. At the end of the heating impulse, the temperature inside the sensor is approximately 350°C. After additional 984 ms, the sensor signal is connected to the A/D microprocessor input. The voltage value V_S of the sensor at this moment corresponds with the CO gas concentration at the room temperature of 25°C. Fig. 2 shows a diagram of signal processing.

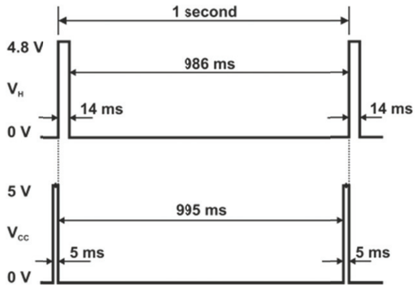

Fig. 2. Timing of the signal for CO sensor data processing

Voltage V_S is dependent on the value of the sensing resistance and the load resistance R_L. Load R_L is selected so that is approximates resistance R_0 as much as possible. In this case, the voltage of the sensor will have the value of $V_{CC}/2$, where V_{CC} = 5V. Furthermore, voltage V_S is dependent on the ambient temperature of the sensor. The value of resistance R_0 is tabulated; however, we were not able to find suitable resistance R_L for our sensor series. The sensors were calibrated using two reference meters: CEM CO-110 and GD500 with CO gas probe PS56. The correction of ambient temperature was executed by NTC thermal resistor which is placed as close to the sensor case as possible.

Fig. 3 shows the CO and CH_4 measuring unit in the development stage. MC908JL16CPE micro-controller was selected for signal processing. The CO and CH_4 concentration data are led out via PWM outputs. The PWM signals are filtered by a low-pass filter and amplified to 0 – 10 V. To connect them to the telemetric station, the outputs had to be transferred to current outputs of 4 – 20 mA. The resulting gas concentration is recalculated according to full scale of the gas sensors.

The results of measurements mainly depend on temperature of particular gas. Due to this reason, our own developed system includes thermal compensation of the sensor. The measured values were compared with the once obtained by calibration instrument GD500. The deviation is about 30 ppm. The reliability of sensors measurement is up to 50 °C.

The signal processing of the CH_4 gas sensor is simpler than the CO sensor. The sensing element in the CH_4 gas sensor is heated permanently. This would lead to a substantially high consumption if the unit was operated by batteries. Again, the voltage at the sensor output that corresponds with the gas concentration is influenced by the value of the load resistance R_L. However, the value of R_L for our production series is known in this case and it is selected according to the considered working concentration of CH_4. The table in the data sheet includes the LEL parameter (lower explosion limit of methane = 50,000 ppm). The value of R_L is 2.49 kΩ for 10 % LEL (i.e. 5,000 ppm of methane) and our sensor ID #14. Also, the CH_4 gas sensor requires a temperature compensation of the ambient temperature.

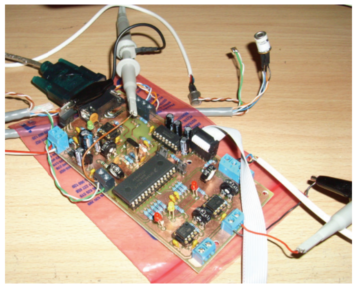
Fig. 3. CO and CH_4 measuring unit

Measuring system

As Fig. 4 shows, the basic feature of the measuring system is a telemetric station, to which temperature sensors as well as current signals from a special embedded system for measuring gas concentrations (CO, CH_4) are connected. The system was completely developed for these applications at the Department of Cybernetics and Biomedical Engineering. Fig. 4 shows the sensor (electrical signals) connection block diagram.

Fig. 4. CO, CH_4 measurement block diagram

The telemetric station continually measures all the required quantities (temperatures, gas concentrations). It stores the measured data in its internal memory in selected intervals (most frequently: every 10 minutes) and it sends the data to the server in selected intervals where they are processed, visualized and archived. Data are sent at defined times by GPRS technology. Fig. 5 shows the visualization of the measured CO concentration in mA on the website.

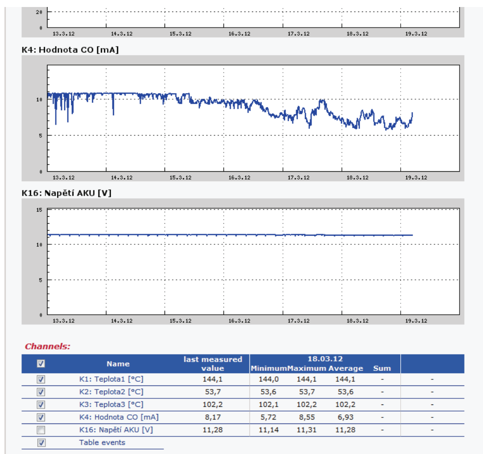

Fig. 5. Measured concentration of CO in mA

Data are archived at the dispatching station in a MySQL database, which together with PHP represents the basis of an own information system about the monitoring based on a dynamic website. The website contains basic information about the monitored locality, including photographs and diagrams of the locations of the individual measuring probes. Furthermore, there is an option to display dynamic graphs and historic trends of selected quantities in the particular probe, including the display of the current values.

Response to alarm status

The website mentioned above displays the current values, historic trends, graphs for particular quantities at a selected time and so on. If the limit value of any quantity is reached (according to the selected levels as mentioned above), authorized persons must be immediately notified. The method of notification is divided into the following categories:

- Visual information on the website, by a change in the color of the information window for the measured quantity to red with a flashing effect and an acoustic alarm signal.
- Sending a warning information email to specified persons, including exact designation of the measuring location and information about the measured value of the particular quantity.
- Sending a warning SMS to specified persons, including exact designation of the measuring location and information about the measured value of the particular quantity.

Conclusions

The contribution provides a description of a unique measuring system that monitors the temperature and hazardous gas concentrations within old mining dumps affected by thermal processes in the long term. The development of the system started several years ago and the individual prototypes have been tested and installed in the Hedvika and Ema mining dumps. The greatest problem that has to be considered in the design and construction of the measuring system is the extreme natural conditions at the place of its installation, which namely include high temperature (approximately 150°C). With regard to the complicated calibration of the gas sensor for temperatures exceeding 60°C, the system will be soon adjusted for the use of a different type of sensor (electrochemical sensor [7]). With regard to the necessity of feeding the entire system by batteries (unavailability of 230V), the following development will focus on the minimization of consumption of all components (replacement of sensors with a combined CO + CH_4 gas sensor).

Acknowledgements

The work and the contribution were supported by the project of the Grant Agency of Czech Republic – TAČR TA01020282 “Enhancement of quality of environment with respect to occurrence of endogenous fires in mine dumps and industrial waste dumps, including its modeling and spread prediction”.

References

1. **Fort A., et al.** CO sensing with SnO2–based thick film sensors: Surface state model for conductance responses during thermal–modulation // Sensors and Actuators B–Chemical. – Elsevier Science SA, 2006. – No. 1–2(116). – P. 43–48. DOI: 10.1016/j.snb.2005.11.070.
2. **Hájovský R., Ožana S.** Long term temperature monitoring and thermal processes prediction within mining dumps // Proceedings IDAACS. – Prague, 2011. – P. 522–526. DOI: 10.1109/IDAACS.2011.6072821.
3. **Litwhiler D., Lombardi B.** Testing of carbon monoxide and carbon dioxide sensors with simple apparatus in an engineering education laboratory // Proceedings ASEE. – Austin, 2009. – P. 3–16.
4. **Meijer G.** Smart Sensor Systems. – Wiley, 2008. – 404 p. DOI: 10.1002/9780470866931.
5. **Signal Processing and Calibration Techniques for CO Detectors using TGS2442. –** FIGARO Japan. Online: http://www.figarosensor.com/products/signal.pdf.
6. **Technical Information for Methane Gas Sensors.** – FIGARO Japan. Online: http://www.figarosensor.com/products/2611Dtl.pdf.
7. **Technical Information for Carbon Monoxide Sensors.** FIGARO Japan. Online: http://www.figarosensor.com/products/5042Dtl.pdf.

Received 2012 03 19
Accepted after revision 2012 01 14

R. Hajovsky, M. Pies. Complex Measuring System for Longtime Monitoring and Visualization of Temperature and Toxic Gases Concentration // Electronics and Electrical Engineering. – Kaunas: Technologija, 2012. – No. 6(122). – P. 129–132.

The contribution describes a developed measuring system intended for long-term monitoring of temperatures and hazardous gas concentrations within old mining dumps affected by thermal processes. It includes a short introduction describing the creation of thermal processes, including related hazards and impact on the environment. Furthermore, the contribution provides a detailed analysis of sensors for measuring CO and CH_4 gas concentrations. It provides the advantages and disadvantages of the individual sensors, including the experience with their use. The conclusion contains a description of the complex measuring chain, including the data transfer technology and visualization at the dispatching station. Ill. 5, bibl. 7 (in English; abstracts in English and Lithuanian).

R. Hajovsky, M. Pies. Ilgalaikio temperatūros ir toksinių dujų koncentracijos monitoringo ir vizualizacijos matavimo sistema // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2012. – Nr. 6(122). – P. 129–132.

Aprašoma sukurta matavimo sistema, skirta ilgalaikiam temperatūros ir pavojingų dujų koncentracijos monitoringui senuose kasybos sąvartynuose, paveiktuose terminių procesų. Pateikta detali jutiklių, skirtų CO ir CH_4 dujų koncentracijai matuoti, analizė. Pateikiami atskirų jutiklių privalumai ir trūkumai bei jų naudojimo patirtis. Aprašyta matavimo grandinė, įskaitant duomenų perdavimo technologiją ir vizualizavimą išsiuntimo stotyje. Il. 5, bibl. 7 (anglų kalba; santraukos anglų ir lietuvių k.).