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Autonomous Monitoring System for Measurement of Parameters of Heat Collection Technology at Thermal Active Mining Dumps

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***Abstract*—The paper deals with the problems of development, construction and testing of a special autonomous system for long-term monitoring of environmental signals which are crucial for appropriate functionality of heat collection technology at thermal active mining dumps. Pilot project for heat collection are implemented at old mining dumps in Moravian-Silesian region, particularly at the Hedvika and the EMA mining dumps, as well as at the OZO municipal waste dump. The paper gives a description of autonomous system including definition of its particular modules. It also presents pieces of information gathered during construction, calibration and launching the system under real conditions. Last but not least, it tackles the technology of heat collection that uses the entire system and thus provides very unique data sets for consequent data processing.**

***Index Terms*—Data processing, gas detectors, remote monitoring, temperature measurement, wireless sensor networks.**

I. INTRODUCTION

Underground black coal mining is followed by a number of negative phenomena. One of them is the necessity of exploitation, transport to the surface and storing a huge amount of collateral rock from proximate surroundings of coal seams, mainly carboniferous rock (clay stone, siltstone, and sandstone). Due to their character they are inconvenient for a wider industrial use. Generally they are referred to as “barren rock” or shortly waste and usually stored in proximate surroundings of coal factories, making the wide hills called mullock tips. The amount of coal being stored together with collateral rock depends on technology of separation and processing the product of 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.

In term of thermal process, a very adverse factor is the existence various organic substances being stored into the dumps, including plastics in recent decades. It contains almost the whole trash from coal factories and often municipal waste from surroundings. Even worse is unorganized and often secret store of various waste from close factories, including dangerous chemicals. Documentation of stored material is thus shallow or missing, particularly for old dumps.

Nowadays, with rising importance of improving the quality of living environment, the burning of the dumps represent a significant negative factor and source of pollution of a wide surrounding. Activities of thermal processes lead to a rise of risks with various hazard levels, some of them imminently threatening human lives. The most dangerous risks caused by the burning dumps are as follows:

– Heat generation;
– Release of toxic substances;
– Generation and spread of fine dust;
– Creation of burnt–out space within the dumps;
– Rise of a surface fire.

In order to carry out pilot tests on problematic of usage of thermal processes at old mining dumps two prototypes of heat collection have been created. Both of them are implemented as cylindrical tubes with 5 m length and 30 cm diameter. The first prototype is made of plastic, the second one from steel, see Fig. 1.

(a) (b)

Fig. 1. Installation of heat collectors (a) at the OZO municipal waste dump; (b) at waste rock mining dump Hedvika.

In order to perform research focused on heat collecting from thermally affected mining dumps, mainly for measurements of temperatures and other physical quantities, the telemetry station has been designed and developed. Its

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main purpose is to primarily process the data from temperature sensors and to provide wireless data transfer into dispatching database by means of GPRS technology.

Topics of remote monitoring of thermal processes have been previously discussed in several previously published pieces of work [1]–[5]. The basic concept of the telemetry station has been introduced in [6]. This paper is focused on further development of telemetry unit concept and its usage with respect to its functionality in the field of heat collection.

II. MEASUREMENT AND MONITORING OF THERMAL PROCESSES IN A CLOSE SURROUNDING OF HEAT COLLECTOR

The basic presumption for monitoring, evaluation of thermal activities and heat collection of mining and waste dumps is retrieving the surface and underground temperatures.

Heat collectors are installed underground at 1m depth. Technology of heat collecting is based on principal of heating of inflowing media (most often water) into the collector and its transport to the area where it transmits its thermal energy to the surroundings (room, hall etc.). In some cases the media is simply cooled down in the secondary circuit via a ventilator and passes over the heat in the environment. The basic scheme of the technology of heat collecting is shown in Fig. 2.

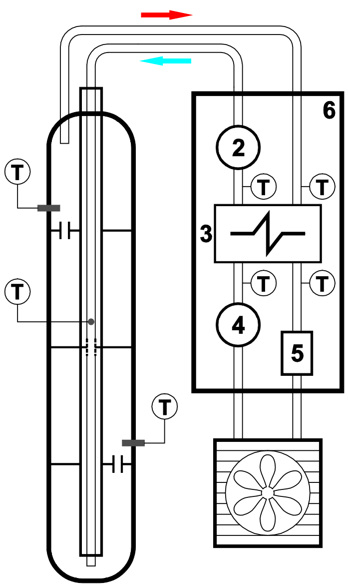

Fig. 2. Simplified technology scheme of heat collecting at the Hedvika mining dump.

The entire technology consists of three heat exchangers. The main cylindrical heat exchanger (1) called “Pershing 200” gathers heat from rock massif. This Pershing is inside divided into four chambers separated by desks. The cooling media, propylene glycol, is flowing through holes located at all desks with Pt100 sensors embedded closely above the holes. Within technology distributing cabinet (6) there is board heat exchanger (3), set of temperature sensors Pt100 and two circulatory pumps. Primary circuit is equipped with the pump referred to as (2), secondary circuit with the one referred to as (4). Secondary circuit also contains heat measurement gauge, referred to as (5). Redundant heat from the secondary circuit is lead away via other heat exchanger equipped with a ventilator. Fig. 3 presents installed heat collector together with arrangement of temperature probes in the surroundings determined for temperature monitoring with respect to collected heat energy.

Fig. 3. Physical installation of the temperature probes at the area.

During heat collecting it is necessary to perform a long-term monitoring of several crucial physical quantities. It is mainly input and output temperature in the primary circuit, temperature in the secondary circuit, pressure in the system and temperature of surrounding waste rock massif in which the heat collector is installed. Temperature measurements are carried out by Pt 100 sensors located at input and output of the collector, then at the input and output of secondary circuit and inside the surrounding mass. Sensors in the mass are installed in cross-cylindrical concept in predefined distances from collector’s center, see Fig. 4, located at depths of 2.5 and 3.5 meters.

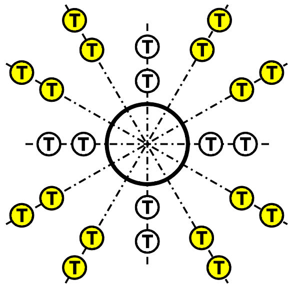

Fig. 4. Location of the temperature probes in the collector surroundings.

Signals from all used sensors in this technology (temperatures, pressure, flow etc.) are monitored by use of a commercial telemetry station, signals related to this unit are marked in white color in Fig. 4. The used commercial station M4016 of the company Fiedler-Mager is characterized by large-sized and well-worked out for long-term use in fieldwork without necessity of external power supply. Given commercial stations are long-term used without any problems in a range of application over all the Czech Republic. There is only one disadvantage – the fact that they are enable to measure concentration of dangerous gases (CO, CH4, CO2). The next disadvantage is its versatility for monitoring of water management and in connection with it its high price.

Our telemetric unit tries to eliminate this given imperfection which focuses on monitoring the quality our environment (temperature and humidity of the air, dustiness, concentration of the gases). The advantage of our developed unit is its modularity and low price.

Other temperatures in Fig. 4, indicated by yellow color, will be processed by currently developed telemetry unit. These sensors are in a bigger distance from the collector and about 10 cm underground. Both systems provide GPRS data transfer to the dispatching station where the data is stored in the database. Consequently it is accessible through on-line visualization in the form of dynamic web page.

III. TELEMETRY UNIT

The currently developed concept of the telemetry unit is represented by Fig. 5. It is a functional prototype that allows measurement temperature from up to 16 points by means of Pt100 sensors.

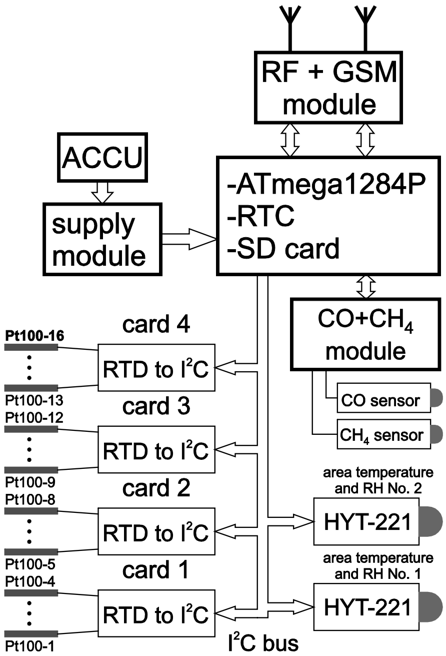

Fig. 5. Block scheme of telemetry unit.

Moreover, it is capable of measuring temperature and humidity of surrounding air and additionally carbon oxide (CO) and methane (CH_4) concentrations. Basic concept of measurement of toxic gases has been described in [2].

Prototype of telemetry unit is composed of total 8 circuit boards. The basic board is equipped with ATmega1284P microcontroller containing two USART ports. The first USART port serves for communication with GSM module Quectel M10, the second one for communication with RF module running within ISM frequency 433 MHz. The basic board also contains RTC circuit and SD card slot. I2C bus connects two board circuits with AD converters and other circuits for 4-wire temperature measurement via resistance temperature sensors Pt100. Monitoring of temperature and humidity of the air is provided by use of new intelligent sensors HYT-221. These sensors dispose of high precision (±0.2 °C for temperature, ±1.8 % for relative humidity). They also dispose of temperature compensation and measured values are filtered and transferred into I^2C protocol by use of embedded microcontroller. Addresses of these sensors can be customized and thus it makes it possible to connect up to 119 other sensors. Concentrations of the gases are so far measured with the module described in [2].

The next advantage of our telemetric unit is wireless setting its systems parameters, such as sample time, name of stored file, etc. This requirement was included into our concept due to worse operational access into box with telemetric unit. This box is mostly dug in the ground. Wireless setting is provided in ISM band on 433 MHz.

IV. TEMPERATURE MEASUREMENT

As it was mentioned above, 4-wire connection is used for temperature measurement. Current source is developed in feedback connection, holding the level of constant current source at 1 mA. This current is set by a precise voltage reference 3.3 V and precise resistor 3300 Ω. The design of current source was inspired by [7].

Voltage difference of voltage loop is measured by instrument amplifier INA2126, needed value of the gain K = 10 is provided by a precise resistor. AD converter is implemented by use of circuit ADS1115 that allows switching its own internal reference and thus to increase accuracy of the circuit at lower values of input voltage. It is 16bit AD converter with the voltage scale divided between -4.096 V and 4.096 V. For positive voltage it can be used 2^{15} quantization levels. Usage of precise current source and precise instrument amplifier leads to the relation (1)

$$U_{ADC}(T) = R(T) \cdot I \cdot K, \tag{1}$$

where $R(T)$ is predefined according [8]:

$$R(T) = R_0\left[1 + AT + BT^2 + C(T - 100\ °\mathrm{C})T^3\right], T < 0\ °\mathrm{C}, \tag{2}$$

$$R(T) = R_0\left(1 + AT + BT^2\right), T \geq 0\ °\mathrm{C}, \tag{3}$$

here $A = 3.9083 \cdot 10^{-3}\ °\mathrm{C}^{-1}$, $B = -5.7750 \cdot 10^{-7}\ °\mathrm{C}^{-2}$, $C = -4.1830 \cdot 10^{-12}\ °\mathrm{C}^{-4}$, $R_0 = 100\,\Omega$.

Table I defines approximation polynomials for calibration of resistance sensors, given by relation (4)

$$T_{\mathrm{fit}} = a \cdot ADC^2 + b \cdot ADC + c, \tag{4}$$

where ADC represents the value measured by AD converter.

TABLE I. CALIBRATION COEFFICIENTS.

T in °C	U_{ADC} in V	ADC [-]	Coeff. in °C
$\langle -50;0)$	$\langle 0.803;1.000)$	$\langle 0;2^{15}-1)$	Eq. (4)
$\langle 0;260)$	$\langle 1.000;1.977)$	$\langle 2^{15};2^{16}-1 \rangle$	Eq. (5)
$\langle 260;850)$	$\langle 1.977;3.903)$	$\langle 2^{16};2^{17}-1 \rangle$	Eq. (6)

$$a = 1.0020 \cdot 10^{-8}, b = 7.3562 \cdot 10^{-3}, c = -245.66, \tag{5}$$

$$a = 1.0622 \cdot 10^{-8}, b = 7.3007 \cdot 10^{-3}, c = -244.46, \tag{6}$$

$$a = 1.6139 \cdot 10^{-8}, b = 6.5060 \cdot 10^{-3}, c = -215.60. \tag{7}$$

Application allows switching among three ranges of AD converter: 0 V to 1.024 V (temperatures up to 0 °C), 0 V to 2.048 V (temperatures between 0 °C and 260 °C) and 0 V to 4.096 V (temperatures above 260 °C). To be able to use the entire scale of AD converter for measurement of low voltage levels, automatic range selection is being performed by the system according the last measured temperature. Resulting value measured by AD converter is then adjusted with respect to currently selected range. This modification helped to increase the range of AD converter into the interval from 0 to 131072. The lowest range provides quantization step 1 bit, the second interval 2 bits and the third one 4 bits.

Figure 6 shows comparison of absolute and relative error while using above mentioned approximation. These errors have been evaluated according to relations (8) and (9):

$$\Delta T = T_{\text{fit}} - T_{\text{real}} \quad [°\text{C}], \tag{8}$$

$$\delta T = \frac{\Delta T}{T_{\text{real}}} \cdot 100 \quad [\%], \tag{9}$$

where T_{real} represents real temperature value.

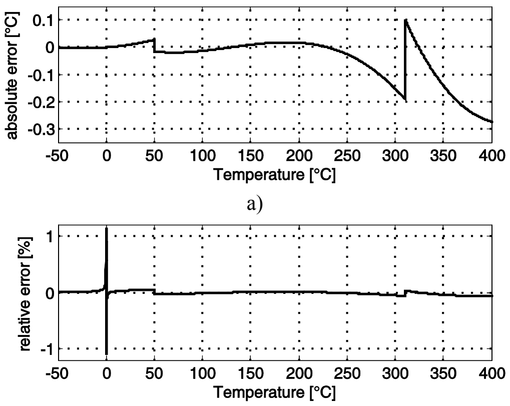

Fig. 6. Approximation of temperature dependence of Pt100 sensor.

Approximation coefficients introduced in (3) to (5) are used in the program for temperature measurement. Figure 7 represents photo of telemetry unit prototype.

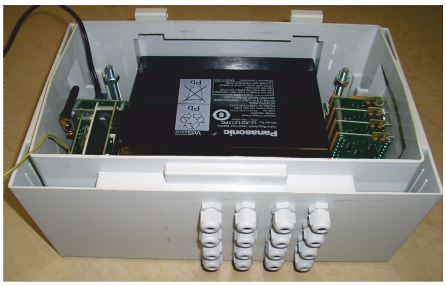

Fig. 7. Prototype of telemetry unit.

All of the circuit boards are fixed to a chassis located in the assembly cabinet providing IP66 protection, cable grommets dispose of IP68 protection. The entire telemetry unit is currently powered by lead maintenance-free accumulator with 17 Ah capacity. It is continuously recharged by an external charger taking the power from collecting heat technology.

All measured values are saved in given time interval to SD card (units up to ten minutes). Subsequently in given time interval (units of hours) the saved files in format CSV are sent through GSM modem to controlling server with the service FTP. Files with data are imported to MySQL database and subsequently displayed through dynamic websites [9]. Further are these data processed through MATLAB where the statistic figures are evaluated and simple spread prediction is carried out. The article [10] describes the application for afterwards processing data with description of MATLAB with MySQL.

The next advantage of our designed complex measuring system is archiving of all measured data in database and the access to it is enabled from anywhere and anytime. The subsequently processing does not have to be using SW MATLAB, how was mentioned but there can be created easy graphs or statistic processing e.g. using SW MS Excel etc.

V. CONCLUSIONS

The deployed technology of heat collecting is used for research reasons regarding modeling and prediction of endogenous fires in rock massif at the Hedvika mining dump. Measured temperatures, pressures and flows are essential parts of experiment as they are used for mathematical model. By the end of February 2013, due to extension of number of the parameters for mathematical model, it is planned to launch the telemetry system that will communicate with other existing telemetry systems. Currently there is no problem with electric energy consumption as the permanent power sources are always present at the installation areas. Future work on the telemetry unit will be focused on decrease of energy demands so as the system could be able to be used for solely battery operation. Apart from this, the part of the system that takes care of measurement of toxic gases concentrations will be replaced for autonomous converter unit providing communication between combined sensor TGS3870 and I^2C bus.

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