11th International Conference on DEVELOPMENT AND APPLICATION SYSTEMS, Suceava, Romania, May 17-19, 2012

Mobile System for Monitoring of Gas Emission on Landfill Sites

Živorad Mihajlović, Vladimir Milosavljević, Nikola Maoduš, Vladimir Rajs, Đorđe Obradović, Miloš Živanov
Faculty of Technical Sciences, University of Novi Sad
str.Trg Dositeja Obradovića nr.6, SER-21000 Novi Sad, Serbia
zivorad@uns.ac.rs, vladimirm@uns.ac.rs, nikolamaodus@uns.ac.rs, rajs.vladimir@gmail.com, djordjeo@uns.ac.rs, zivanov@uns.ac.rs

Abstract — **Gas emissions (gas migrations) that occur due to processes in the landfill site can be harmful to the environment or surroundings. General tendency is to use gas emissions from the landfill as an energy source (natural gas) or burned and converted into harmless compounds. Thus, system for monitoring of gas concentration at landfill site should be installed. In this paper one such system is presented. System is prototype solution for monitoring processes inside of boreholes on a landfill site. Measured concentration of gases in function of well depth can be useful for observation and future exploitation. Integration of microcontroller inside sensing process allows automatic monitoring and support for management of the outer actuators and alarms. The measurement data are collected and displayed in specialized software and stored on a standard LAS (Log ASCII) format.**

Index Terms — **environment protection, gas sensors, landfill gases measurement, microcontroller system, well monitoring.**

I. INTRODUCTION

In the past, landfill sites were rarely engineered and the absence of an environmental monitoring program, meant that the impact of the landfill on the surroundings environment was not assessed. However, over the past decades standards and practices have been steadily improving and many new technologies have been adapted or specifically designed to control and monitor the processes within a landfill [1].

Modern landfills are engineered sites, designed to efficiently contain municipal solid waste while collecting the produced landfill gas. Gas collection systems operate continuously, usually consisting of vertical wells and sometimes horizontal trenches or other zones filled with permeable material within the waste, from which landfill gas is extracted by application of a vacuum. Once the gas is withdrawn, it can be flared, processed into pipeline quality gas or transformed into electricity by combusting in a gas engine/turbine coupled to an electric generator [2].

Methane is common gas product on landfill and it is known that methane has strong greenhouse effect, even stronger than carbon dioxide. Methane has 21 times more potential to trap heat than CO_2, so it is the more potent one of the two [3]. Thus, it is desirable that landfill site has installed system for gas collection, whether the gas is used as fuel, or just burned to decrease influence on environment. Methane (or similar hydrocarbons) mixed with some gases, especially with oxygen, can create explosive mixture. Other landfill gas constituents, such as non-methane organic compounds (NMOCs), can contribute to smog formation while others such as hydrogen sulfide (H_2S) and halides pose health hazards due to their toxicity.

Currently on the market there are several commercial devices that are stationary and generally require labor in the field or GSM modems for measurement. Stationary devices are now largely in the prototype versions, but the results are promising [4]. Problems with stationary devices are theft of equipment, and the necessity of designing low power consumption system. Compared to solutions that measure the concentration inside the boreholes at a fixed depth, this solution gives more information about the processes that occur within the boreholes.

II. FACTORS INFLUENCING LANDFILL GAS EMISSION

Today there are a lot of engineering methods to construct a landfill. The infrastructure is specifically designed to allow extraction of gas and its use as fuel more than flaring. Figure 1 shows the cross section of the landfill. Structure is layered and designed to reduce as much impact on the surrounding of landfill and vice versa. A special attention is made to avoid possible contamination of groundwater. Gas collection system needs to penetrate all the layers where there is a generation of landfill gas.

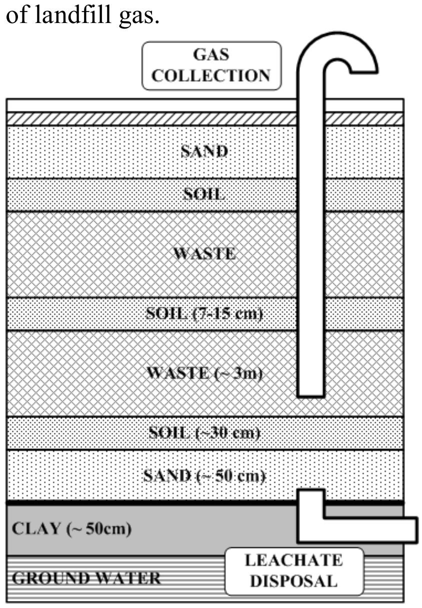

Figure 1. Typical construction of the landfill site with gas collection system

Landfill gas is produced by the decomposition of biodegradable waste in an anaerobic environment.

Regulated landfill sites are constructed with gas management systems using extraction pipes which are laid under the waste cells prior to the commencement of landfill activity. The main constituents of landfill gas and their proportions are captured in Table 1. This value can vary from landfill to landfill, but generally the main components of landfill gas are the greenhouse gases, methane (CH_4) and carbon dioxide (CO_2).

A few decades ago landfill sites were not designed for gas extraction and design process was not perfect as today. In these landfills, it is not possible to predict amount of gas that is produced unlike to modern design that use modern techniques. Today, on modern landfills it is possible to predict the methane generation rate [5].

Efforts have been made to exploit old landfills as a fuel sources as well. There are many factors that influence the emissions on these landfills.

TABLE I. VARIATIONS IN LANDFIL CONCENTRATION [4]

Constituent Gas	Concentration (by volume)	
	Range	Average
Methane (CH4)	35 – 60 %	50 %
Carbon Dioxide (CO2)	35 - 55 %	45 %
Nitrogen (N2)	0 – 20 %	5 %
Oxygen (O2)	0 – 2,5 %	< 1%
Hydrogen Sulfide (H_2S)	1 – 1700 ppm	21 ppm
Halides	NA	132 ppm
Water Vapor (H_2O)	1 – 10 %	NA
Non Methane Organic Compounds (NMOCs)	237 – 14,249 ppm	2700 ppm

A drop in atmospheric pressure can lead to an increase in the amount of gas vented from the landfill. The initial drop in pressure leads to the oxygen in the surface layers of the site being expelled and gases from lower layers of the site diffusing upwards to compensate for the vacancies in the layers.

The soil type where the landfill site is situated is of importance for monitoring gas emissions. Areas near peat or coal soils can have background CH_4 content in the soil [5]. Landfill on clay soil is more isolated from groundwater and depends of precipitation.

The moisture content of the landfill is also a factor. If the surface soils and clay capping are waterlogged, the flow of gas will not be able to reach the surface and this will decrease the amount of emitted landfill gas.

The age of the landfill also results in changes in the rate of landfill emissions. Generation of landfill gas begins 3–12 months after deposition of the waste in the landfill and usually continues for 20–50 years, once the landfill has closed, though some traces of landfill gas production can continue for up to 100 years depending on the rate of degradation and gas production and extraction. The older the landfill, the more the gas emissions will fluctuate. This results from the fact that the older sites did not have gas management and recovery systems put in before filling began. The sites are retrofitted and, therefore, not as effective. Fluxes in CH4 can be more than 10 times greater for an active site without gas recovery compared with a closed site using gas recovery.

All factors indicate that it is necessary to observe the processes within the boreholes for more accurate prediction of gas emission. It is desirable to observe the level of underground water and gas concentration as a function of the depth of borehole. Using this data it is possible to find out the depth at which the process of gas generation is the most intense. In our case the available sensors were used, but the solution can easily be extended with other sensors. Currently designed system measures the concentration of NO2 and CO emissions, ambient temperature and groundwater level.

The following is a description of the hardware.

III. HARDWARE DESIGN

Hardware design consists of two parts: a surface and the probe unit (Fig. 2). Connection is made by 4-wire cable between those units. Collected data are sending to PC trough wireless communication and local application executes further processing.

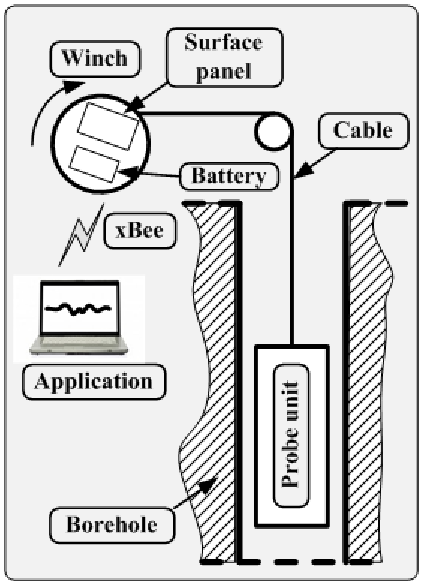

Figure 2. Block diagram of system for landfill gas monitoring inside of borehole

The probe unit consists of gas sensors, temperature sensor and subsystem for groundwater level detection (Fig. 3). First prototype uses sensors for CO (TGS2442 Figaro) and NO_2 (MICS-2710) that were available at the time of designing hardware. Outputs from the gas sensors are connected to the microcontroller's analog inputs. Since the concentration of these gases are small, but still higher than in normal conditions, based on results of measurements it is possible to draw conclusions about the processes within the boreholes. Signals from the gas sensors can be adjusted by potentiometers, either by setting gain in the amplifier circuit or setting load in sensors. In future versions, installation of the digital potentiometer are planned, so that adjustment can be performed in real time over the surface unit. To minimize the consumption, the power of the sensor is supplied via a separate digital switch chip controlled by microcontroller.

The probe unit is equipped with a temperature sensor that is used to compensate gas sensors, and to measure temperature inside the borehole as additional data for internal processes. Maxim DS1820 is the temperature sensor and uses the half-duplex serial 1-wire communication with microcontroller.

Subsystem for the detection of underground water level is twofold, an electromechanical and pure electrical detection of water. Electromechanical method uses a float that activates a set of micro switches connected to the microcontroller. Regardless of the probe position at least one micro switch is activated at the time. Float ensures that the probe does not sink, and thus prevents damage to the electronic part of the probe. Electrical method uses conductivity of groundwater and compares it with reference to the air. Since the conductivity can be variable, electromechanical method is of primary importance in this case.

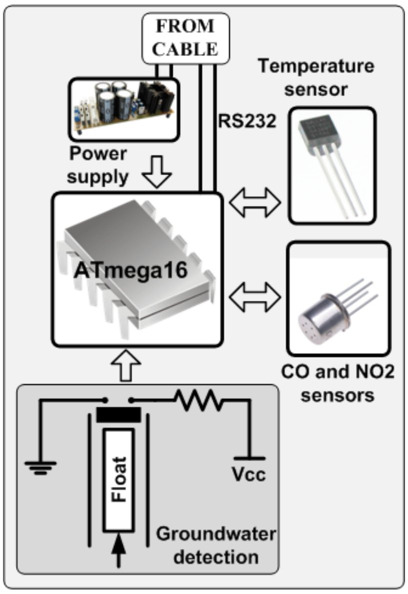

Figure 3. Block diagram of probe unit

In addition, there is a part of the probe that measures the battery voltage. If the battery voltage falls below a critical level, the operator is informed, before failure of voltage regulator circuit.

The main component that controls all peripherals of probe and communicates with the surface unit is the MCU ATmega16. This MCU is low cost, capable to process a lot of peripheral and contain one port for serial communication. In the next section detailed description of the program and communication protocol is given.

The main function of surface unit is collecting data from the probe and sending to application in predefined format. In addition, takes care of depth at which the probe is. Surface unit is controlled by powerful dsPIC30F4013, capable for fast processing a huge amount of data in real time.

Since the installation of commutate brushes is expensive, surface unit is mounted on the winch with cable and rotates together with the lead battery. For measure the depth encoder is usually used, but in this case a single-axis gyroscope (LISY300) is used as available component. Using gyroscope, the rotation of the winch is converted to the depth of the cable and using fact that boreholes are not deep (less than 15m), error is minimal due to the winding. In addition, reed relay is installed to correct errors.

The data collected with the probe are formatted and sent to a PC wirelessly. For wireless transmission xBee modules are used. The application collects data on a PC, displays them in real time and generates standard LAS file for detailed analysis.

IV. SOFTWARE REALISATION

For programming of AVR microcontroller ATmega16 that controls sensor readings inside probe and data sending through cable Codevision IDE is used. CO and NO_2 sensors require very precise timings for proper operation. This is why readout of these two sensors is done through interrupt routine. This ensured that all manufacturer's recommendations are fulfilled so we have correct results and lifetime of sensors. External interrupts are usually used for time critical processes. This is why one external interrupt input is used for readout of water presence sensor. It is important not to submerge probe inside water since this would damage sensors connected to it. Temperature sensor is connected to 1-wire serial interface and its readout is done in main function. Sending of data to microcontroller on the other end of the cable is realized through serial connection. Since cable length is below 25 m, signal TTL level is used for transmission. Cable line voltage level is also monitored so low battery condition can be detected.

All measured data are sent from probe to microcontroller on top in packets. Each packet has unique identifier so loss of packet can be easily detected. Each packet contains information from CO, NO_2 and temperature sensor as well as information about water presence detection and cable line voltage. All data are sent in ASCII format for easy protocol monitoring.

On the top end of the cable Microchip dsPIC30F4013 is used. This microcontroller has two roles. One is to measure probe depth position using two different methods. First method includes integration of gyroscope readout. It gave good measurement resolution with satisfying precision results, but downside is that measurement error is accumulative so for bigger cable length this would represent big problem. This is why second depth measurement system is introduced. Signal from reed relay is measured by using external interrupt inputs. This gave us very reliable depth measurement with resolution of 1 pulse per revolution.

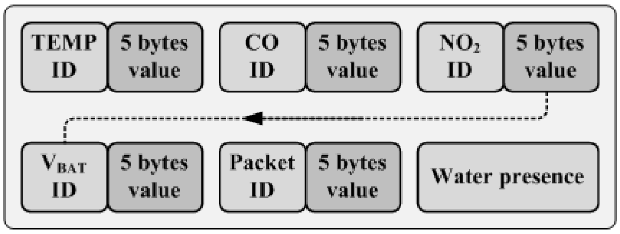

Figure 4. Description of packet sends from probe to surface unit

Second role of dsPIC microcontroller at the top is to act as gateway for incoming data from probe. This is why it was very convenient for us to use model 30F4013 since it has two UART ports to use. One is used as connection with probe and other for connection with specialized software for measured data graphic interpretation and logging called Wellscan. Incoming packets are forwarded to Wellscan with additional information about current depth appended to it.

Signal receiver is a component for simple collection of input data. Signal analyzer is responsible for basic data manipulation, while the processor is responsible for processing at the level of each probe. Probe manager contain settings for every specific probe. Wellscan is developed for deep well borehole monitoring, and it is successfully applied for our needs.

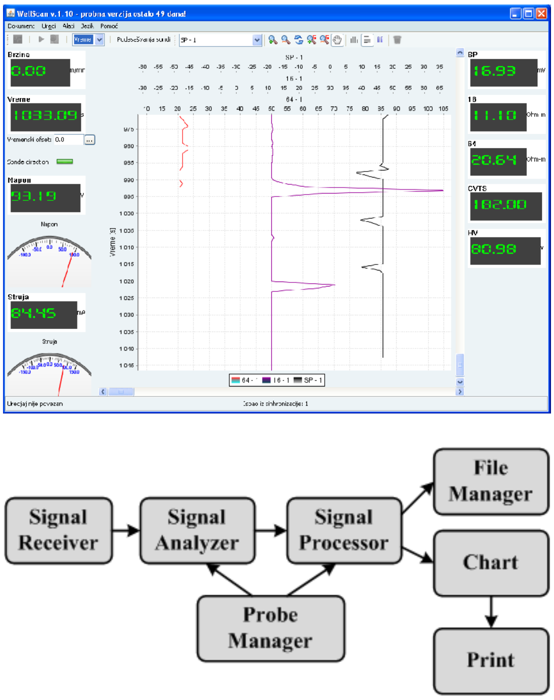

Figure 5. Wellscan software for well logging in standard LAS format with basic architecture

V. EXPERIMENTAL RESULTS

Data analysis showed that there is a difference in the concentration of gases and temperature in the borehole depending on the depth (Fig. 6).

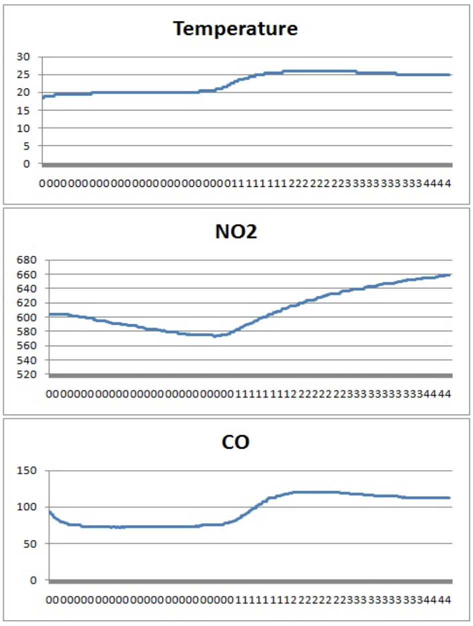

Figure 6. Variations of gas concentration and temperature

Results show dependence of gas concentration and temperature in function of borehole depth. Groundwater was detected between 4 and 5 meters as it was expected at the end of the landfill where boreholes are less deep. In this case, precision of depth measurement is one meter, but changes can be observed clearly. After short time of worm-up needed for gas sensor, probe is slowly lowered into the borehole.

Due to processes inside borehole temperature is greatly increased and the maximum is at a depth of 2 meters. Maximum of concentration of CO is also at 2 meter which is proving that at this depth exists active layer from the point of gas generation. Gas sensor for NO_2 shows variations of concentration but it was later determined that is much slower than the CO sensor.

Prototype device was shown on Figure 6.

Figure 6. Prototype hardware implementation of system for monitoring of landfills

VI. CONCLUSION

Testing in real terrain condition on landfill near city of Novi Sad proves that application of such system is possible.

The disadvantage is that the solution requires the presence of operators who will perform a physical measurement. So the next step in the development of this solution is the automation of measurement process. We also plan the installation of new sensors and is the improvement of methods for calibration.

ACKNOWLEDGMENTS

This paper is part of the project "Development of the methods, sensors and systems for monitoring quality of water, air and soil", III43008. Project has been carried out with the financial support of the Ministry of Science and Education of the Republic of Serbia, to which authors are very grateful.

REFERENCES

[1] "Landfill Manuals – Landfill Monitoring", 2nd edition, 2003, Environmental Protection Agency, Ireland
[2] D. Lepley, L. Tozzi, R. Joseph, "Application and Investigation of the Effect on Emission and Performance Associated with Passive Pre-Chamber Spark Plugs and Integrated Controls on Low Btu-Fueled Natural Gas Engines" Gas Machinery Conference, Nashville, Tennessee, 2011.
[3] K. Sekgoele, S.P. Chowdhury, S. Chowdhury, "Technical and economic assessment of power generation from landfill gas in South Africa", Power and Energy Society General Meeting, pp. 1-8, July 2011, San Diego, USA
[4] B. Kiernan, S. Beirne, C. Fay, D. Diamond, "Monitoring of Gas Emissions at Landfill Sites Using Autonomous Gas Sensors", Environmental Protection Agency, 2010.
[5] C.J. Do, K.J. Tae, "Predicting the Methane Gas Generation Rate at Landfill Sites Using the Methane Gas Generation Rate Constant (k) ", Asian Journal of Atmospheric Environment, Vol. 2-2, pp. 116-124, Dec. 2008