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Intelligent Monitoring System for Biogas Detection Based on the Internet of Things: Mohammedia, Morocco City Landfill Case

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Abstract: Mechanization is a depollution activity, because it provides an energetic and ecological response to the problem of organic waste treatment. Through burning, biogas from mechanization reduces gas pollution from fermentation by a factor of 20. This study aims to better understand the influence of the seasons on the emitted biogas in the landfill of the city Mohammedia. The composition of the biogas that naturally emanates from the landfill has been continuously analyzed by our intelligent system, from different wells drilled in recent and old waste repositories. During the rainy season, the average production of methane, carbon dioxide, and oxygen and nitrogen are currently 56%, 32%, and 1%, respectively, compared to 51%, 31%, and 0.8%, respectively, for old waste. Hazards levels, potential fire, and explosion risks associated with biogas are lower than those of natural gases in most cases. For this reason a system is proposed to measure and monitor the biogas production of the landfill site remotely. Measurement results carried out at various sites of the landfill in the city of Mohammedia by the system show that the biogas contents present dangers and sanitary risks which are of another order.

Key words: Internet of Things (IoTs); biogas; monitoring; composition; detection; landfill

1 Introduction

During the 20th century, humans faced two new significant challenges relating to energy consumption and environment (global warming, exhaustion of resources, ...). In 1976, the first climate conference was organized by the World Meteorological Organization (WMO) in Geneva, and climate change was recognized for the first time as a major global problem[1]. Although energy has always been a vital issue for humanity, energy consumption and production are some of the main contributors to global warming. These issues should not simply encourage us to exploit energy resources more efficiently, but also should favour the development of new ways of energy production through renewable energies[2].

Recently, an unavoidable energy crisis is signified due to the constantly rising demographics and increasing consumption of limited resources in societies. In response, it is imperative and urgent to adopt new energy sources that are efficient and harmless to the environment[3]. Renewable energies have the advantage of being available in unlimited quantities[4]. Their exploitation is a means of meeting energy needs while preserving the environment. These forms of energy

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generate little or no waste or emissions[5]. One of the main forms of renewable energy is energy from biomass, which includes biogas. Biogas comes from the fermentation of animal or plant organic matter in the absence of oxygen, and is composed for the most part of methane (CH_4) and carbon dioxide (CO_2)[6].

All organic waste, when it decomposes, it produces huge quantities of CH_4 and CO_2. These gases contribute to the increase of the greenhouse effect. Methanisation, i.e., the fermentation of organic matter (decomposition of plant or animal matter) or household waste in the absence of oxygen, produces a gas called biogas. Biogas is an explosive gas, because it is mainly composed of methane, which is toxic due to the presence of hydrogen sulfide (H_2S) and corrosive. The fermentation process brings bacteria and suspended particles that can cause discomfort to humans[7]. Biogas is a mixture of CH_4 (generally between 50% and 70%), CO_2, H_2S in small proportion, as well as water vapour in variable concentrations. Biogas can be produced naturally in the atmosphere, especially in swamps and in landfills. It is also artificially synthesized in digesters, especially for the treatment of wastewater and sewage sludge. It can also be found in the food industry[8].

Currently, there are gas analysis techniques available to accurately determine the composition of a gas environment, such as gas chromatography and mass spectrometry[9, 10]. However, these instruments are unsuitable in some cases because of their cost, size, and difficulty of use. Chemical sensors, on the other hand, do not have these disadvantages and are a good alternative to previous analysis systems. Among the chemical sensors, these metal oxide sensors are most interesting because of their easy use. These sensors were first developed in the sixties by Taguchi[11]. In our days, we need high-performance biogas detection systems that have been growing steadily for several years in various fields, from analytical chemistry to the detection of gas leaks in domestic appliances. The objective of our work is to build an intelligent landfill environment monitoring system for detecting biogas elements and also for analyzing the composition of the biogas.

The rest of this paper is organized as follows. In Section 2, we describe the area of study as we give some basically information. Section 3 is reserved for materials and used methods. The obtained results are detailed and discussed in Section 4. Finally the paper is concluded in Section 5.

2 Description of the Study Area and Measurement Sites

Since February 2012, the new storage center located along Road P3313, at Chaba El Hamra Rural Municipality of Beni Yakhlef zone, Mohammedia, Morocco, has been receiving household and similar wastes from different activities. The controlled landfill of Mohammedia-Benslimane is based on the rational storage of solid wastes in order to avoid any harmful risks of human health and the environment. It is located on a site where the lithology is relativity impermeable and is designed to take care of five large traps[12]. These traps consist of drainage and collection networks, which enable the recovery and treatment of the formed leachate in the landfill, while respecting the set values for water withdrawals and consumption.

The landfill gas composition (natural emanation) was measured from wells drilled at the landfill sites. The technique used was passive extraction[13]. The measurements were made considering two different sites. An initial measurement campaign was carried out for old waste and others for new waste. The choice of the system installation points is based on the wind direction and inclusivity of all the points that surround the landfill, which for this study, requires three sites. Three catchment wells (Site 3) were drilled in the old deposits (Site 1) and the second campaign (Site 2) involved the same wells as with the first campaign (see Fig. 1). The sites were equipped with 102-mm-diameter PVC pipes, screened at the base over a 6-m length. The wellheads were sealed with betonies, and each well was fitted with a control valve. A collection network was installed which connects each well to a central point (measuring apparatus and pumping equipment). This is the part of the conventional arrangements used to determine the in-situ composition of biogas in landfills[14–16]. It has already been presented by Ref. [17] for the extraction

Fig. 1 Study site localisation.

and valorization of biogas in the landfill of Akreuch (Morocco).

3 Material and Method

3.1 Biogas composition measurement

An Automated Extraction Monitoring System (AEMS) biogas analyzer was utilized which continuously measures the contents (expressed in percentage by volume), this specifically includes CH_4, CO_2, oxygen (O_2), nitrogen (N_2), and other gases, that make up the gas emanating from each well. Equipped with two infrared detectors, the biogas analyzer can provide the proportions of constituent gases based on cellular galvanic principles. The absolute detection limit of the instrument is 0.1% for the volumes of CH_4, CO_2, and O_2. The uncertainties associated with the measurement of CH_4, CO_2, and O_2 are 3%, 3%, and 1%, respectively, for volumes greater than 5%. While for volumes below 5%, the uncertainties are 0.3%, 0.3%, and 1%, respectively.

The samples were taken in Tedlar bags and glass ampoules. Combustion was carried out at 1200℃ under conditions of oxygen; the absorption of gases in hydrogen peroxide solution was followed by an ion exchange chromatographic determination of the sulfate, chloride, and fluoride ions formed. H_2 and N_2 were analyzed by molecular sieve chromatography with a Thermal Conductivity Detector (TCD). While CH_4 and CO_2 were analyzed by porous polymer chromatography with TCD as well. On the other hand, C_2 to C_5 compounds were analyzed by porous polymer chromatography with a Flame Ionization Detector (FID), while carbon monoxide (CO) was analyzed by the non-dispersive infrared technique. Lastly, H_2O was determined by the Karl-Fisher technique from a known volume of gas.

3.2 Proposed system

The basic idea of the system is to monitor the biogas generated from the landfill and update the database remotely. The next set of actions would be to interface all the sensors needed to measure CH_4, CO_2, O_2, and N_2. The test device used in this study is an intelligent system for measuring and monitoring landfill biogas via the Arduino Uno card. Figure 2 shows the overall architecture of the proposed system.

The Internet of Things (IoTs) module is placed with each biogas burner near the biogas plant, which measures the biogas utilization and sends a Shot Messaging Service (SMS) with authentication code to the Android application, which acts as an SMS gateway via a Globle System for Mobile (GSM) module or via Bluetooth on the computer. After validating the authentication code, the Android application pushes the statistics into the web database, only when the internet is available. An interactive dashboard on the application reflects the change of data in the database for each user and the dashboard is also able to generate a player. The IoTs module also makes it easy to control remote installations, where the administrator can lock the module when the user does not pay the bill, the administrator can also unlock the IoTs module. Both locking and unlocking of the IoTs module are done by sending SMS messages to the GSM module application.

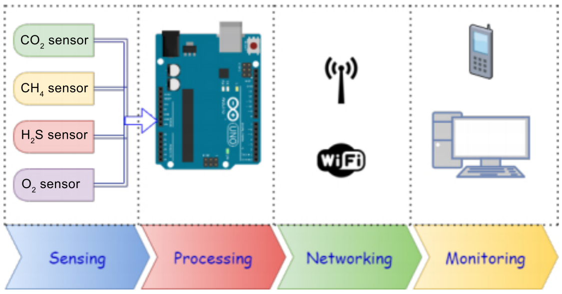

Fig. 2 Architecture of the proposed system.

Arduino Uno R3 Card: The Arduino system is an electronic board-based microcontroller and minimum components to realize more or less advanced functions at low cost. It has a USB interface for programming with an open-source platform, which is based on a simple microcontroller board and software, that is a true integrated development environment to write, compile, and transfer (Fig. 3). The Arduino board can be directly powered by a Direct Curent (DC) jack connector which

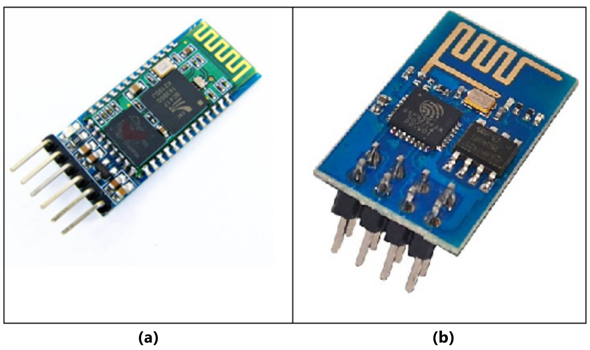

Fig. 3 (a) Bluetooth module HC-05 and (b) ESP8266 pin details.

is connected to a voltage regulator built into the board. The power supply via this connector must be between 5 V and 12 V[18].

Wi-Fi module and Bluetooth module: In this application, the ESP8266 Wi-Fi module is used (Fig. 3), which integrates a Transmission Control Protocol/Internet Protocol (TCP/IP) convention stack on a chip. When associated with a Wi-Fi organization, an IP address is obtained which is available in its neighboring system. The module has 2 General Purpose Input/Output (GPIO) sticks near the Universal Asynchronous Reception and Transmission (UART) pins. It also has a built-in Serial Peripheral Interface (SPI) convention which uses the two UART pins as information lines and the two GPIO sticks as control lines and clock signal. A 1 MB memory is available on one chip and it feeds the card with all controllers and Phase Locked Loops (PLLs). The processor-on-chip is a 32-piece processor[19].

Sensors: The system consists of various sensors, such as temperature sensor, humidity sensor, and CO_2 sensor (MQ-7), as shown in Fig. 4. These sensors will separately measure air parameters, including temperature, CO_2 levels, and relative humidity of key natural factors. This sensor system gives the single voltage that corresponds to a specific climatic factor. The microcontroller will then transform this simple voltage into computerized information[20]. The transfer is used to perform Alternating Current/Direct Current (AC/DC) gadget exchange activities. In the proposed framework, the transfer is used to control the cooling fan. When the ambient temperature exceeds the breakpoint, the cooling fan is switched on by transfer[21].

Based on an ME2-O2 gas sensor, this module from Seeed Studio is capable of precisely measuring the oxygen concentration in ambient air. This organic reaction sensor generates a very weak current when air flows through it. The module integrates a conversion/amplification stage to retrieve the data through an analog input of an Arduino module, for example, or any microcontroller with this type of input[22].

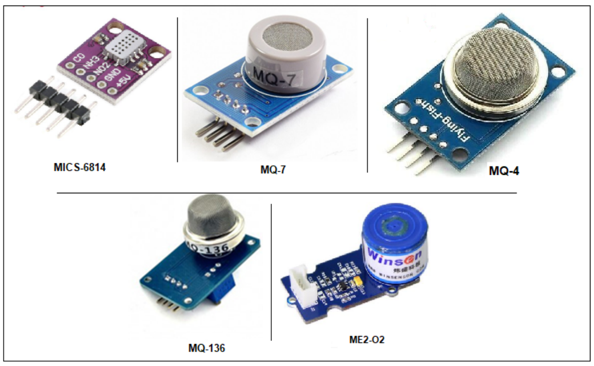

Fig. 4 Sensors used in the system.

The MICS-6814 gas sensor module, detecting for Nitrogen Dioxide (NO_2) and CO, is used for Arduino. The chip structure of this silicon gas sensor consists of a micromechanical precision diaphragm and a heating resistor integrated with the sensing layer at the top. Three separate gas sensors are integrated which detect automotive exhaust, as well as industrial and agricultural waste gases in harsh environments[23].

The MQ-4 methane gas sensor is a semiconductor gas sensor that detects the presence of CH_4. The sensor's simple analog voltage interface requires only a single analog input pin from the microcontroller[24]. The gas sensor's detection concentration range of 200×10^{-6} to $10\,000\times10^{-6}$ is suitable for gas leak detection. For example, the sensor can detect if someone has left a gas stove on. The sensor can operate at temperatures ranging from –10℃ to 50℃ and consume less than 150 mA at 5 V.

MQ136 gas sensors are used in air quality monitoring equipment and are suitable for the detection and measurement of H_2S. It is widely used in H_2S domestic gas alarm, H_2S industrial gas leak alarm, and H_2S portable gas detector. It has good sensitivity to H_2S gas in a wide range, and has advantages, such as long service life, low cost, and simple drive circuit[25].

4 Experimental Result and Discussion

Biogas is a mixture of combustible CH_4 and CO_2, and is produced by the anaerobic fermentation of organic matter contained in wastes. The relative proportions of these gases depend on the nature of the fermented substrate and the fermentation conditions. Biogas can be produced spontaneously under natural conditions (swamps, household waste dumps, etc.) or in specific installations called digesters. Digestion is a technique of depollution and conditioning of liquid or solid wastes.

4.1 Classical method analysis results

In the landfills in the city of Mohammedia, CH_4 concentrations represent between 54% and 58% of the volume of biogas produced. While in mechanization plants, CH_4 concentration is 55.6% of the volume of biogas produced. Other combustible gases (hydrocarbons, hydrogen sulfide, etc.) do not significantly increase the concentration of flammable gases in the biogas. The concentrations of inert gases (e.g., N_2) and toxic gases (e.g., H_2S) vary according to the waste composition. The release of large quantities of inert gases into the atmosphere leads to air dilution, which consequently decreases oxygen concentration. If this decrease is significant (oxygen content of around 1%), there is a risk of asphyxiation. Remember that the regulatory minimum oxygen content in a workplace is 19%. The risks of intoxication mainly concern (excluding particles) H_2S, CO, CO_2, and Volatile Organic Compounds (VOCs). Site measurements show that VOCs only present a risk at concentrations generally found in undiluted biogas except on special cases. CO_2 concentration is observed to be 31% with the highest contents (close to 32%) mainly related to the case of landfills. The H_2S value of the landfill is 600×10^{-6} and its production can vary greatly at the measuring point. The emission of H_2S can be extremely high in chemical products and thus great vigilance and regular monitoring of the biogas composition from chemical industry wastes using appropriate measurements are required. Other pollutants may include VOCs and heavy metals as well. Even in the form of trace elements, the presence of hydrocarbon halides and organometallic compounds (harmful siloxanes) can cause long-term corrosion due to the production of halogenated acids and silica (abrasion of engine metal surfaces, fouling of spark plugs, valve malfunction, etc.).

The composition of biogas is generally CH_4 (almost 55.6%), CO_2 (about 32%), hydrogen sulfide S equitates to H_2S biogas raw (it is 1000×10^{-6}), clean biogas less than 100×10^{-6} H_2O, ammonia NH_3 less than 100×10^{-6}, N_2 less than 2%, hydrogen H_2 less than 1%, CO less than 33%, O_2 between 5% and 12%, air less than 2%, volatile O_2 organic compounds VOCs in low concentrations less than 1% v/v, and water saturation H_2O between 2% and 7%. In the absence of oxygen, biogas is produced by the fermentation of animal or vegetable organic matter. Its composition varies according to the nature of the incoming substrates and the operating conditions. Figure 5 gives an example of the indicative composition of agricultural biogas. CH_4 is a greenhouse gas whose Global Warming Potential (GWP) over a century is twice as high as that of CO_2. It is therefore particularly important to limit its release into the atmosphere as much as possible.

4.2 Results of the analysis of intelligent system

The averages of the various measurements (expressed as %) done by season, by well, and for each deposit type are summarized in Table 1. The proportions of

Major components of biogas	Value
CH_4 (%)	55.6
CO_2 (%)	32
N_2 (%)	1
O_2 (%)	1
H_2S (10^{-6})	600

Fig. 5 Characterization of Mohammedia landfill biogas.

Table 1 Variation in the composition of biogas in the sites.

Site	Major components of biogas				
	CH_4 (%)	CO_2 (%)	N_2 (%)	O_2 (%)	H_2S (10^{-6})
Site 1	52.0	30.0	0.6	0.7	590
Site 2	33.0	32.0	1.0	0.8	600
Site 3	56.0	32.5	1.2	0.9	602

CH_4 and CO_2 are predominant, with higher rates of CH_4 emanation observed. For both seasons, the average CH_4 production rate is 52% in older deposits (Site 1) and 55.5% in newer deposits (Site 3) with a 3.5% difference, while the CO_2 production rate is 30% and 32.5%, respectively, with a 2.5% difference. On the other hand, in old deposition (Site 2), the average percentage of CH_4 in wet season is approximately the same as in the dry season, which is 53.3%, while concentrations of CO_2, O_2, and N_2 in the dry season are relatively higher than those in the wet season. However, in recent deposition (Site 3), the rate of different types of biogas in both seasons is practically negligible. In addition, CH_4 and CO_2 represent on average more than the total biogas released in older deposits and 56% deposits for both seasons. Oxygen and dinitrogen have an average emissivity.

CH_4 and CO_2 concentrations are lower than those found in previous reports, which is explained by a very low N_2 content (1.1% instead of 20% (see Table 1)). The H_2S content is very low and close to the average for engineered landfill sites.

For the former deposits of the landfill of the city of Mohammedia, the measured concentrations of the main compounds (CO_2 and CH_4) correspond exactly to the values in other journals (Site 1). As can be seen, the sulfur product content is extremely variable from one site to another as previous reported. The contents of CH_4, CO_2, and H_2S in this paper are in line with the predictions and characteristics presented from previous studies.

The homogeneity of the biogas distribution between different seasons was tested with the Fisher test. The Fisher test, or F-test, is a statistical hypothesis test that evaluates the equality of two variances (or means) by relating the two variances (or means) and verifying that the ratio does not exceed a certain theoretical value. If the result of F-test is greater than the theoretical value, the assumption that the two variances are equal is rejected.

The measurement of natural biogas released from the three sites (large dry season and large wet season) is shown in Table 1) gives high proportions of CH_4 and CO_2. These two gases account for 56% (average of the measurements) and 30% (average), respectively, of the total emanation in ancient deposits; i.e., less for both gases. In recent deposits, the emanation of these two gases represents higher values. These overall emanation rates (94.5% in old deposits and 73% in recent deposits) are higher than the estimated 64% for landfills by the European Union[26]. Also, the CH_4 emanation rate is much higher than that of the Technical Landfill Centre (TLC) of Crgy-les-Meaux (France), which is 50%[27]. This landfill is distinct from the other European landfills by its age (open since 1970) and by the total absence of an isolation perimeter, which makes the nuisances and risks unbearable, as in the case of the Akoudo landfill[28].

5 Conclusion

The biogas from the landfill consists mainly of CH_4 (52% and 56%, corresponding respectively to the total emanation of the old and recent deposits (average of the two seasons)) and CO_2 (30% and 3%, corresponding respectively to the average of the two seasons of the old and recent deposits). The production rate of CH_4, relative to CO_2, is high in doubling, reflecting the anoxicity of the landfill and its high capacity to produce CH_4. This capacity appears to be kept latent by the continued presence of leachate at the level of recent deposits. At the level of old deposits, this latency phenomenon is observed during the rainy season and has the advantage of constituting an inhibiting source of greenhouse gas production. However, whatever the season and the type of waste, the rate of CH_4 and CO_2 production is higher than 50% and 20%, respectively, i.e., more than 30% for both biogases, despite the latency phenomenon observed. These various observations imply that the Mohammedia landfill site is a major source of greenhouse biogas production. The application of the proposed system makes it possible to permanently monitor biogas emissions at the level of recent and old deposits. However, insignificant CO_2 and N_2 ratios are observed at the level of old deposits. Consequently, it is found that the natural biogas emanation is independent of the type of season in recent deposits. On the other hand, in old deposits, rainwater contents of more than 80% in the waste mass appear to have an inhibitory effect on the rate of methane production.

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