



25th ABCM International Congress of Mechanical Engineering
October 20-25, 2019, Uberlândia, MG, Brazil

COBEM2019-1429

ASSESSMENT OF METHANE EMISSION USING INFRARED THERMOGRAPHY - A CASE STUDY IN THE JOCKEY CLUB CONTROLLED LANDFILL

Ana Rafaela Sobrinho de Miranda

Marcela Cardoso Rodrigues

Hugo Mesquita

Luciano Soares da Cunha

Antonio Cesar Pinho Brasil Junior

University of Brasilia, Darcy Ribeiro University Campus, Mechanical Engineering Department, Technology Faculty - Environmental and Energy Laboratory - 70910-900, Brasilia – DF

anarafaclamiranda@gmail.com

marcelacrodrigues@gmail.com

hugomsq@hotmail.com

soares.cunha.l@gmail.com

brasiljr@unb.com

Abstract: Landfills are considered the third largest source of methane emissions in the world, it is a risk to the environment being flammable and a polluting gas. Focusing on atmospheric emissions of methane (CH_4) from landfills, this study directs efforts to verify CH_4 screening methods. Considering as a case study the Jockey Club Controlled Landfill (ACJ), once known as the largest landfill in Latin America. The goal is to prove a relationship between the surface thermographic indicators and methane emission. Two methods of analysis were applied: surface temperature measurement with Thermal Infrared (TIR) and determination of CH_4 emissions with a portable gas monitor (GEM-5000). Results provided both important information on the amount of main methane emission points emitted from the ACJ and the correlation between the thermal anomalies with methane emission points in landfills. The study proves a relation between surface temperature and methane emission, allowing a new control tool for methane emissions, environmental remediation and energy use in a landfill area.

Keywords: methane surface emissions, infrared thermography, landfill gas, waste disposal

1. INTRODUCTION

Solid waste disposal areas (landfills) produce large amounts of polluting gases to the environment, being responsible for 11 % of global emissions (Sanches, et al., 2016). This emission, known as biogas or landfill gas, is a gaseous mixture typically composed of 50 to 60 vol% of methane (CH_4), 10 to 50 vol% of carbon dioxide (CO_2) and 1 to 5 vol% of other gases (hydrogen H_2 , sulfuric gas H_2S , oxygen O_2 and nitrogen N_2) (Costa, 2006); (Alves, 2000).

Landfills are characterized as the third major source of methane emissions in the world (Sánchez and Narros, 2016). Biogas is a component produced from the anaerobic decomposition, which transforms organic matter into methane and carbon dioxide in a process called methanogenesis (Lewis *et al.*, 2003a).

Methane emissions from landfills are heterogeneous in nature and arise from localized critical points (Röwer *et al.*, 2011), which generate concerns and direct researches towards the control and containment of the contaminant areas. Not only methane is an important greenhouse gas with a global warming potential 25 times greater than carbon dioxide, once the concentration of methane and oxygen in the air reaches a certain level within a range, the gas becomes flammable and can cause large explosions. The minimum value is called the lower flammability limit and the maximum upper flammability limit. Out of this limit, the air does not present explosive characteristics (Gharagheizi, 2008). In addition, even if the composition of the air is not at flammable levels, the inhalation of methane gas at certain levels of concentration and time of exposure is harmful to human health and may cause dizziness, shortness of breath and fainting (Themelis and Ulloa, 2007).

Biogas has a high calorific power, and facing these problems, energy recovery appears as an alternative solution to the appropriate use of methane generated in landfills. Thus, methane gas monitoring is relevant due to its high calorific power, explosive potential and polluting potential, creating a situation that involves energy recovery and environmental

remediation, evidencing the synergies between the two paths.

A National Solid Waste Policy (Brazilian Law 9.605/2012) was created in 2012, it established deadlines for closure and recovery of Brazilian dumps, replacing them with landfills, where there is a better control of working conditions and management of waste disposal, allowing the prevention of methane emissions. There will be an increase in extraction of biogas from the landfill areas, as those areas will have better conditions than previously to receive the municipal solid waste, improving anaerobic digestion of organic matter and directing this gas to energy generation.

Methane generation occurs through an exothermic process called methanogenesis, which results in the emission of landfill gas (LFG) in temperatures up to 60 °C (Fjelsted *et al.*, 2019). As the biogas migrates to the surface, the soil through which it flows reaches a higher temperature than the surrounding environment, thus the presence of the gas can be detected by thermal anomalies on the surface of landfills and dumps. To this end, international initiatives have made use of Thermal Infrared (TIR) as a technique for detection of methane on the surface, and can cite the surveys of Fjelsted *et al.* (2019) and Tanda *et al.* (2016). Some limitations of this technique are observed, where it is stated that the results may be slightly influenced by the incidence of sunlight, wind and ambient temperature (Fjelsted *et al.*, 2019).

The current literature review about the utilization of infrared thermography to detect landfill gases can be summarized by some scientific productions, such as Fjelsted *et al.* (2019), which organized studies that tested the thermography as a screening tool for emission hotspots of LFG with varied results. Some studies have reported limited relationships between LFG emissions and surface temperatures ((Battaglini *et al.*, 2013), (Desideri *et al.*, 2007), (Battaglini *et al.*, 2013), (Lewis *et al.*, 2003a)).

Given this context, the present study aims to verify the relation between the surface thermographic indicators and the indicative of the presence of methane. Directing efforts to the methods and techniques of screening of CH₄, this study used as a case study the Jockey Club Controlled Landfill (ACJ), located in the Federal District, which was known as the largest waste deposit area in Latin America, the landfill had its activities closed in 2018. Two methodological procedures were used in order to contribute to the detection of methane leakage on the surface of the ACJ. The contribution of this study is the validation of a gas leakage detection methodology, which will point out important environmental indicators, directing possible ways of environmental remediation and energy recovery of degraded areas.

2. METHODOLOGY

The methodology in this paper consists in the application of two different techniques that will lead to a comparative analysis on the concentration of methane and the thermal anomalies of the surface of specific points along the ACJ. For gas concentration measurements a GEM-5000 gas analyzer was used, and to detect temperature anomalies by infrared thermography a FLIR A325sc was used.

The occurrence of fissures is an indication of either a contraction of layers of clay material, due to soil moisture variations, which occur periodically under the influence of local climatic conditions, or due to the organic degradation of the organic material, which results in shift of the buried waste. Through these fissures there is a significant increase in gas emissions that can be observed through the cover layer (Oliveira, 2005). During the lifespan of the cover layer, the existence of these fissure significantly increases the permeability of the surface to rainwater and fugitive emissions of biogas, culminating in cycles of greater (dry periods) and minor (rainy periods) fugitive emissions (Oliveira, 2005).

An area with frequent fissures occurrence within the ACJ was established for data collection and divided into ten points for comparison purposes. In order to avoid external interferences in the results, such as temperature increase by solar incidence, the data collection was performed between 5h and 7h. Three data collection campaign were performed at 10 points on the side of the slope that contained the cracks, using the two methodologies described.

2.1 Jockey Club Controlled Landfill - Case Study

The ACJ, which was once one of the largest dumps in Latin America, has 175 hectares. The waste deposition in the site was carried out directly on the soil and then compacted with another layer of upturned soil. The soil did not receive a type of waterproofing or drain system, not meeting any environmental protection requirements. Therefore, the produced sludge penetrated freely through the soil and the biogas production was not measured or collected (Cavalcanti, 2013). In 2015 the ACJ was transformed into a controlled landfill, when efforts were directed to soil protection and landfill gas collection. The biogas is extracted and burned into burners that were constructed along the landfill. The landfill is located between the Plano Piloto and Taguatinga and is bordered by the Cabeceira do Valo stream (affluent of Paranoá Lake) and Brasilia's National Park, and nearby there is an area of farms with production of vegetables and raising small animals. Figure 1(a) gives an overview of the area in question.

The data collection in this study was executed during three campaigns, the side of a specific slope of the ACJ was selected in order to concentrate 10 points of data collection. Figure 1 (b) shows the area considered in this study.

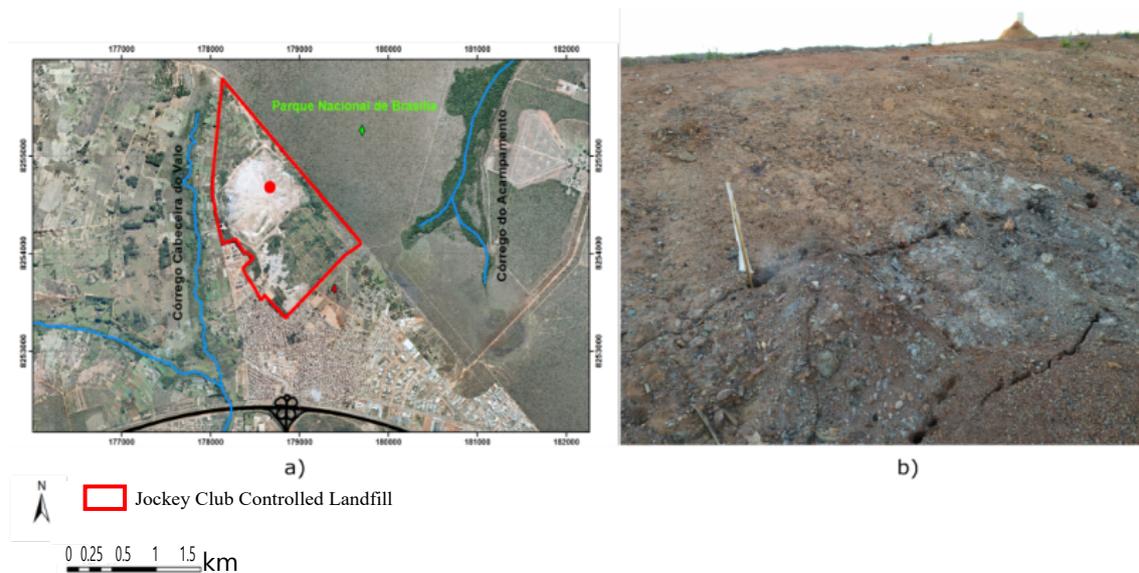


Figure 1. a) ACJ Location. Source: Adapted from Cavalcanti (2013). b) Case study area. Source: Authors.

2.2 Infrared Thermography

Infrared Thermography is a non-invasive technique that measures the temperature distribution of a surface through a thermal camera. It is an imaging technique that receives and processes mid to long wave infrared radiation and converts it into a temperature profile from objects, in this scenario, the landfill's covering soil. The use of this technique could increase efficiency in landfill gas collection as it can identify problems along the gas collector system (Tanda *et al.*, 2016).

Biogas is produced from an anaerobic digestion process of organic matter, it is an exothermic reaction. Upon migration to the surface, a temperature increase of the soil through which it flows is expected to occur (Fjelsted *et al.*, 2019). The thermal energy produced by the anaerobic digestion of the waste can raise the temperature of the soil up to 55 °C.

Measuring the soil surface temperature of dumps or landfills could allow the detection of biogas leaks or points suitable for extraction. The current study used a FLIR A325sc infrared thermography camera, designed to provide accurate thermal images on a spectral range of 7.5-13.0 μM and temperatures from -20 °C to 120 °C. Lewis *et al.* (2003b) indicates a measurement error of infrared thermography at 2 °C.

2.3 Gases Concentration Measurements with portable monitor gases GEM-5000

After the identification of high temperature points along the area, these points are verified with a portable gas analyzer to characterize the fugitive gas emissions composition of the landfill. Those critical points of temperature could be indications of a high methane concentration gas that is escaping the biogas extractor system, which causes damages to the environment and represents a loss of efficiency in the energy generation system of the landfill area, if there is one. Even with efficient covers, few landfills are estimated to recover more than 60% of the available gas.

With the portable gas analyzer, the CH₄ and CO₂ levels are checked following the same route as that followed with the camera. A GEM-5000 portable gas monitor was used in this study to measure methane, carbon dioxide and oxygen concentrations. This method allows a correlation between methane gas concentration emission with the point of thermal anomalies obtained by infrared thermography. This technique allows the intersection of methane gas concentration points with points of thermal anomalies of infrared thermography.

The identification of CH₄ and CO₂ is done by a dual wavelength infrared cell with reference channel, which shows the results in percentage (0-100 %). The identification of O₂ is done with an internal electrochemical cell (0-25 %). The sensor can't measure samples containing more than 25 % of O₂ of the total gas volume, this is due to technical limitations of the electrochemical sensor used to measure the gas. It is expected that a certain minimum level of methane flux is necessary before a temperature difference can be detected by the infrared camera (Fjelsted *et al.*, 2019).

Solar radiation will give an uneven surface heating and can affect the biogas emissions. The temperature contrast between soil and ambient should be maximized to result in better images from the infrared camera. Thus, all data was collected before sunrise, as to avoid solar radiation and have better contrast between soil and air temperature. A comparison between soil temperature and methane concentration will be studied to measure the relation of methane emission and temperature anomalies along the landfill.

3. RESULTS AND DISCUSSION

A correlation between fugitive emissions from the ACJ and the temperature given by thermography was obtained for the ten points considered in this study. Emissions were measured at the slope surface. Methane concentrations ranged from 1 % to 38 % and the temperatures measured by infrared thermography images ranged between 10 ° to 55 °C.

From the entire ACJ side slope of the measurement campaigns, a fissure and other specific points were considered for the measurements. Three points in the fissure (points 1, 5 and 6), and the other three above, involving a portion of the soil visibly smooth (points 2, 3 and 4), shown in Figure 2, formed an initial set of data collect. The left part of Figure 2, is an image of the fissure with an indication of six points where the CH₄ and CO₂ surface concentrations were collected. The right side is the thermographic image of the same location, where the temperature range ranges from 0 °C to 55 °C.

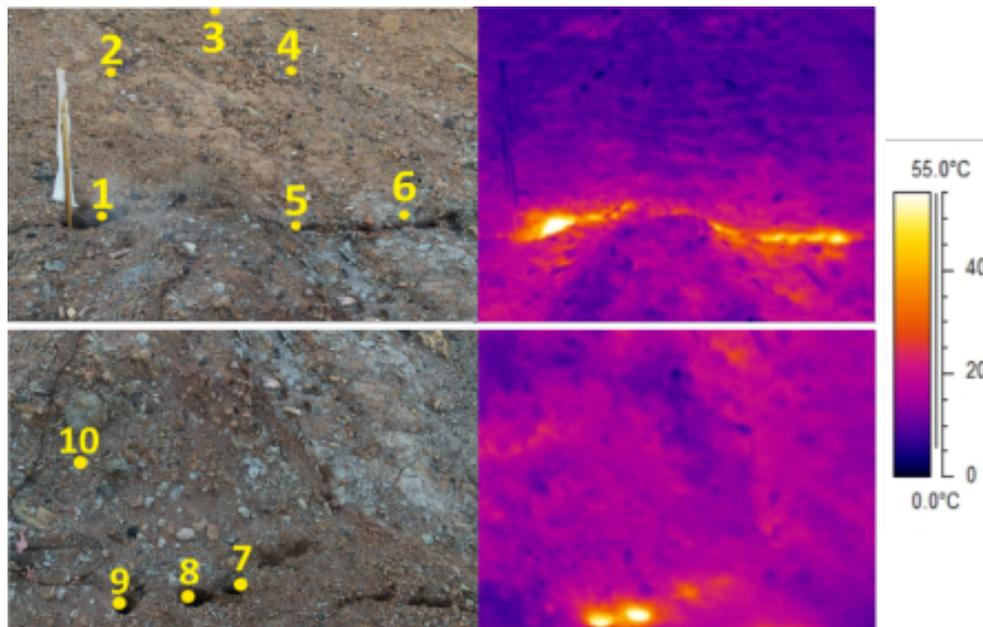


Figure 2. Points location and termographic image (°C). Source: Authors.

Throughout the smooth surface, a lower temperature is noted, and a temperature difference is easily identifiable on the image. In the thermographic image, the fissure is highlighted by the temperature difference and indicates a temperature around 40 °C to 55 °C.

Likewise, Figure 2 shows measurement points 7, 8, 9 and 10 below the fissure indicated. Points 7, 8 and 9 are located in holes of the soil, being potentially points of high gas emissions. Point 10 was located between the fissure and the other openings, on a smooth surface. From both thermographic images, it can be observed that the indication of thermal anomalies is related with the openings of the ground (fissure and holes), indicating the relevance of the infrared thermography technique regarding the identification of anomalies on the surface of landfills or dumps.

Graph 3 shows the correlation between the concentration of CH₄, in percentage, on the Y axis, and the surface temperature given by the thermography in °C on the X axis. A trend line is plotted among the ten points where the measurements occurred indicates an increasing convergence behavior between the two parameters.

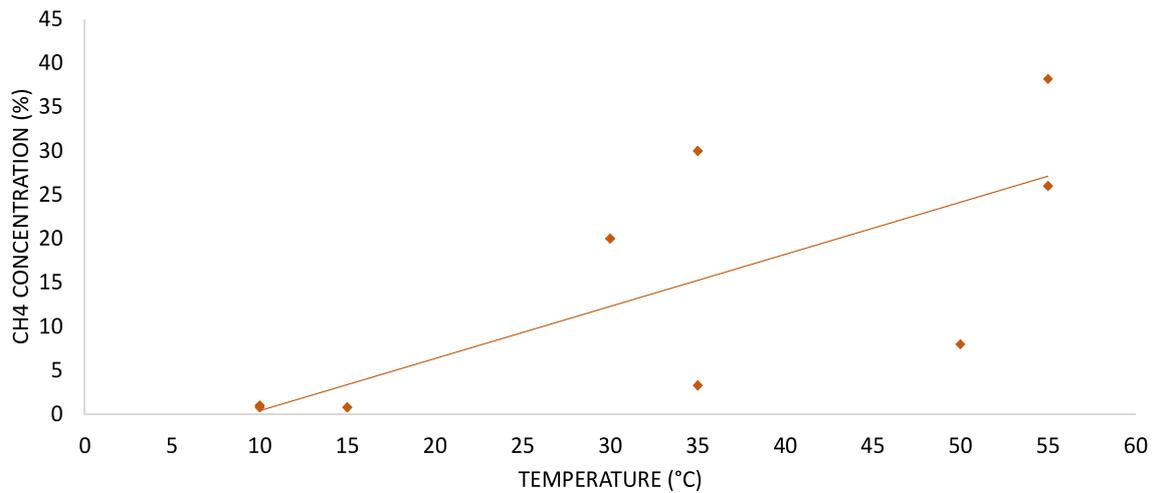


Figure 3. CH₄ concentration (%) versus Temperature (°C). Source: Authors.

Data was also plotted on a graph which shows the ten measurements points and correlates the variations of CH₄ and surface temperature, showing the trend lines for both variables (graph 4) .

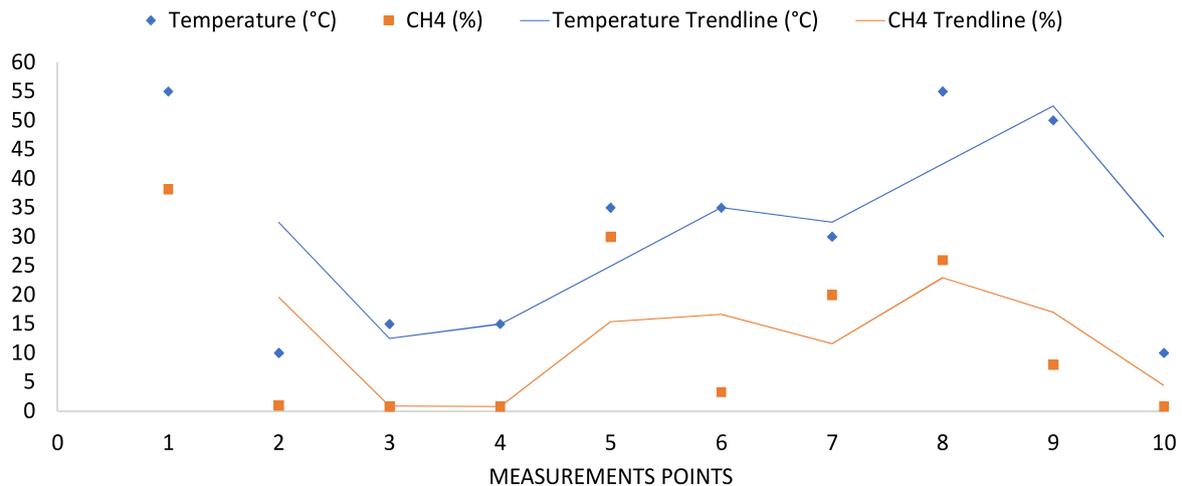


Figure 4. CH₄ concentration (%) versus Temperature (°C) with trendline. Source: Authors.

At two points, there is a divergence between the concentration and temperature measurements. At point 6, methane concentration is 3 % and disagrees with the high temperature measured at the surface, 35 °C. Similarly, at point 9, a 8 % CH₄ concentration was measured, while a temperature of 50 °C was indicated by surface thermography.

According to Fjelsted *et al.* (2019), infrared thermography has some limitations to the identification of gas emissions due to the influence of parameters on the measurements, and it is not possible to directly correlate the thermal anomalies with the presence of landfill gas (LFG) or methane. Local and environmental conditions, such as sunlight, wind and ambient temperatures, are factors that can interfere with thermography when used in gas detection. According to Fjelsted *et al.* (2019) and Lewis *et al.* (2003b), both the decomposition of organic residues, whose reaction caused by microbacteria releases heat, and the oxidation of methane can cause temperature differences on the surface surrounding the flow. Oliveira (2005) shows that soil properties and disposition can affect the measurements, soil age, layer thickness, quality of compaction and cover layer material can all affect the methane flow through the landfill.

Concentration measurements of carbon dioxide, the second main component of biogas, were also made and correlated with CH₄ concentrations and temperature, in order to verify the viability of the proposed methodology. Graph 5 shows the trend lines between the concentration of the two gases in relation to the temperature variation, where surface emissions from 0.3 % to 37 % of CO₂ were detected. The coherence between the concentrations of the two gases and the variations in surface temperature is understood as another important indicator of this methodology.

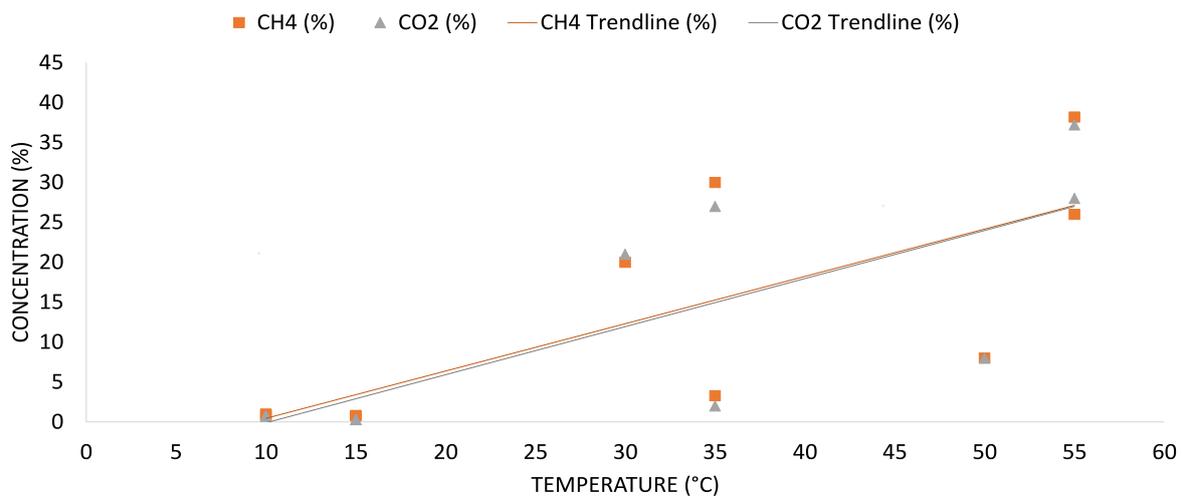


Figure 5. CH₄ and CO₂ concentration (%) versus Temperature (°C). Source: Authors.

The overlap of concentration levels in the thermographic image is shown in Figure 6, where a convergence between the highest temperature points and the highest methane concentrations was observed. It is important to note that the same correlation these results indicate can be verified in Fjelsted *et al.* (2019), although the scale of temperatures in Brazilian landfill soil is much higher than in Denmark.

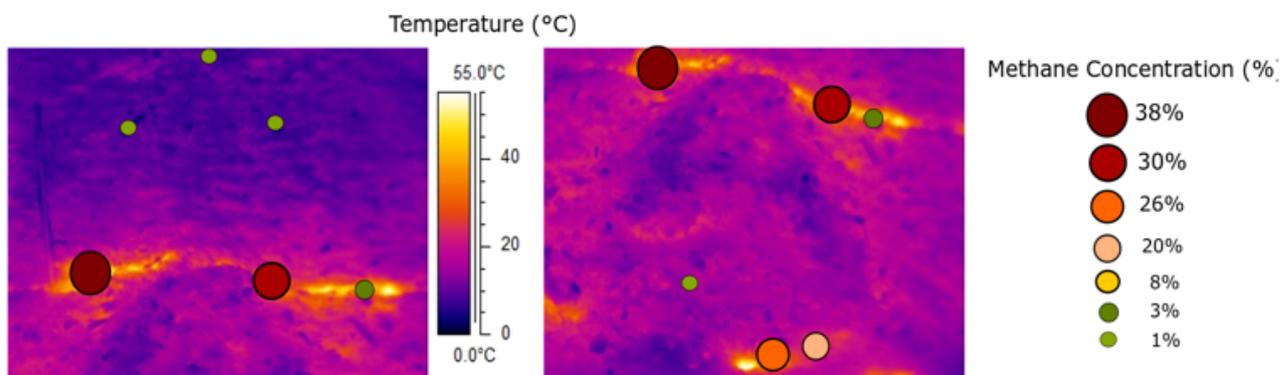


Figure 6. Thermographic image of ACJ (°C), with methane concentration in interest points (%). Source: Authors.

The thermographic images, complemented by the CH₄ and CO₂ concentration data allows not only the identification of high gas emission points, but also pointed a necessity to install a burner at the critical case study point (point 1). Currently, the ACJ is inactive, receiving only construction waste. The analyzed area in this study does not receive any type of organic waste anymore but a minimum control of the local conditions is necessary, to reducing the environmental impacts generated by the landfill gas emissions.

4. CONCLUSION

The ACJ situation as an old dump that, after being built without the required geotechnical structure for solid waste deposition, receives a ground cover, is common in Brazil. This causes the waste decomposition and the generation of landfill gas to occur without control, causing damage to the environment and human health. Testing of new reliable low-cost tools is necessary to optimize maintenance and capture of landfill gas for both environmental and energy recovery.

The literature indicates the use of thermography screening methods in landfills gas leaks detection as a tool that still needs complementation, which was verified during data collection. It is also necessary to use tools capable of observing the entire surface of the landfill to provide a clear picture of the situation.

The ACJ still receives waste from the construction sector, this results in an uneven soil layer that can prevent methane emissions to the surface. In this scenario, it is possible to explain the difference between the low methane concentration and the high surface temperature at points 6 and 9, where the degradation reaction of the residues disposed there may have been the main cause of the surface heating.

Emissions were measured at the slope surface. Methane concentrations ranged from 1 % to 38 % and the temperatures

measured by infrared thermography images ranged between 10 °C to 55 °C. Considering that there was no interference of solar incidence in the results of the ten analyzed points, eight points showed there was convergence between the temperature rise and high CH₄ and CO₂ concentrations, which shows a correlation between fugitive emissions from the ACJ and the temperature given by thermography.

This study shows that infrared thermography is a promising methodology for gas leaks identification in landfills with efficiency, speed and at low cost, suitable for Brazil's situations of landfills with little gas collection infrastructure and low investment capacity.

5. REFERENCES

- Alves, J.W.S., 2000. *Diagnóstico técnico institucional da recuperação e uso energético do biogás gerado pela digestão anaeróbia de resíduos*. Ph.D. thesis, Universidade de São Paulo.
- Battaglini, R., Raco, B. and Scozzari, A., 2013. "Effective monitoring of landfills: Flux measurements and thermography enhance efficiency and reduce environmental impact". *Journal of Geophysics and Engineering*, Vol. 10, No. 6. ISSN 17422132. doi:10.1088/1742-2132/10/6/064002.
- Cavalcanti, M.M., 2013. "Aplicação De Métodos Geométricos no delimitamento da pluma de contaminação nos limites do aterro controlado do Jockey Clube de Brasília". p. 128.
- Costa, D.F.d., 2006. "Geração de energia elétrica a partir do biogás do tratamento de esgoto". Technical report, Universidade de São Paulo.
- Desideri, U., Leonardi, D. and Proietti, S., 2007. "APPLICATION OF INFRARED THERMOGRAPHY TO STUDY BEHAVIOUR OF BIOGAS CAPTION WELLS". Technical report.
- Fjelsted, L., Christensen, A.G., Larsen, J.E., Kjeldsen, P. and Scheutz, C., 2019. "Assessment of a landfill methane emission screening method using an unmanned aerial vehicle mounted thermal infrared camera – A field study". *Waste Management*, Vol. 87, pp. 893–904. ISSN 18792456. doi:10.1016/j.wasman.2018.05.031. URL <https://doi.org/10.1016/j.wasman.2018.05.031>.
- Gharagheizi, F., 2008. "Quantitative structure-property relationship for prediction of the lower flammability limit of pure compounds". *Energy and Fuels*, Vol. 22, No. 5, pp. 3037–3039. ISSN 08870624. doi:10.1021/ef800375b.
- Lewis, A.W., Yuen, S.T. and Smith, A.J., 2003a. "Detection of gas leakage from landfills using infrared thermography - Applicability and limitations". doi:10.1177/0734242X0302100506.
- Lewis, A.W., Yuen, S.T. and Smith, A.J., 2003b. "Detection of gas leakage from landfills using infrared thermography - Applicability and limitations". *Waste Management and Research*, Vol. 21, No. 5, pp. 436–447. ISSN 0734242X. doi:10.1177/0734242X0302100506.
- Oliveira, L.R.G.d., 2005. "Estudo das emissões de biogás em camadas de coberturas de aterro de resíduos sólidos urbanos".
- Röwer, I.U., Geck, C., Gebert, J. and Pfeiffer, E.M., 2011. "Spatial variability of soil gas concentration and methane oxidation capacity in landfill covers". *Waste Management*, Vol. 31, No. 5, pp. 926–934. ISSN 0956053X. doi:10.1016/j.wasman.2010.09.013.
- Sánchez, C. and Narros, A., 2016. "Determination of methane and carbon dioxide surface emissions in a Spanish landfill". In *12th International Conference and Exhibition On Emissions Monitoring*.
- Tanda, G., Migliazzi, M., Chiarabini, V., Cinquentti, P., Lewis, A.W., Yuen, S.T., Smith, A.J., Fjelsted, L., Christensen, A.G., Larsen, J.E., Kjeldsen, P. and Scheutz, C., 2016. "Assessment of a landfill methane emission screening method using an unmanned aerial vehicle mounted thermal infrared camera – A field study". *Waste Management*, Vol. 87, No. 5, pp. 436–447. ISSN 0734242X. doi:10.1088/1742-6596/755/1/011001. URL <https://doi.org/10.1016/j.wasman.2018.05.031>.
- Themelis, N.J. and Ulloa, P.A., 2007. "Methane generation in landfills". *Renewable Energy*, Vol. 32, No. 7, pp. 1243–1257. ISSN 09601481. doi:10.1016/j.renene.2006.04.020.

6. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.