USE OF ALTERNATIVE COVER MATERIALS TO CONTROL SURFACE EMISSIONS (H$_2$S AND VOCS) AT AN ENGINEERED LANDFILL

Yann Le Bihan [1,*], David Loranger-King [2], Nicolas Turgeon [1], Nadine Pouliot [3], Nicolas Moreau [4], Daniel Deschênes [4] and Guy Rivard [5]

[1] CRIQ, EIE, 333 Franquet street, Quebec G1P 4C7, Canada
[2] Mrc de Bellechasse, Saint-Lazare-de-Bellechasse, Quebec, Canada
[3] Ville de Québec - Service des projets industriels et de la valorisation, Quebec, Canada
[4] EnGlobe Corp - Centres régionaux de traitement de sols et de la biomasse, Quebec, Canada
[5] AIM Éco-Centre, Saint-Augustin-de-Desmaures, Quebec, Canada

ABSTRACT

Between 2010 and 2015, the Bellechasse Regional County Municipality (Bellechasse RCM) was affected by particularly noxious odors issuing from its Municipal Solid Waste Landfill (Bellechasse RCM MSWL) in Armagh, Canada. A study carried out in 2015-2016 by Centre de recherche industrielle du Québec (CRIQ) confirmed that it was still possible for hydrogen sulfide (H$_2$S) emissions to cause odor issues in and around the site. The experimental project carried out by CRIQ in cooperation with Bellechasse RCM, Englobe, Quebec City and the Regroupement des récupérateurs et des recycleurs de matériaux de construction et de démolition du Québec (represented by AIM Éco-centre) made it possible to test three (3) different industrial residue as an alternative cover materials on site and study how they controlled H$_2$S emissions, volatile organic compounds (VOCs) and odors at the Bellechasse RCM's landfill. The site was monitored from November 2016 to September 2017 to confirm the effectiveness of alternative biofiltration cover materials (soil + compost), domestic waste incineration bottom ash and 0 to 2.5-inch concrete residues and to compare the results with the sand cover currently used as the cover material. Effectiveness was determined by measuring the Area Source Emission Rate (ASER) with a 3 m x 3 m static flux chamber developed for the project. Methane measurements were concomitantly taken to confirm that the biogas could escape through the cover materials. The monitoring results made it possible to demonstrate that domestic waste incineration bottom ash as well as 0-2.5 in. concrete received the highest load of H$_2$S and showed an H$_2$S capture performance of greater than 83%. For volatile organic compounds, materials such as 0-2.5 in. concrete and the alternative biofiltration cover materials were most effective for capture (greater than 73%) for the highest loads. The lowest content of CH$_4$ after covering was measured for the alternative cover materials. The site where the incineration bottom ash was used managed to decrease odors by ±200 odor units. Overall, we have demonstrated in this project, the capacity of different alternative cover materials under real condition for the control of gas emissions from landfill.

1. INTRODUCTION

The control of hydrogen sulfide (H$_2$S), a toxic, foul-smelling gas (rotten egg odor), remains a significant environmental challenge for several industrial and municipal sectors including landfills. The primary sources of sulfur compounds in landfills that generate H$_2$S include gypsum residues (CaSO$_4$), the sulfur contained in organic matter (food and paper), and biosolids (sludge from waste water treatment plants). The residues from gypsum panels, frequently used in the construction of interior walls because of their high degree of fire resistance, undoubtedly constitute one of the most significant sources of sulfur compounds, particularly in construction, renovation, and demolition (CRD) landfills. The production of H$_2$S from buried gypsum residues has been studied by a number of researchers, including Xu et al. (2010) and Fairweather and Balaz (1998).

The main technologies currently available for the treatment of H$_2$S rely on the principles of absorption (chemical scrubbing), adsorption (activated charcoal), or biological

processes (sulfo-oxidant microorganisms). Although the effectiveness of these so-called "conventional" technologies have largely been demonstrated in an industrial context for several years (Davis, 2000), their primary disadvantage is related to operating costs (chemical products, adsorbents, packing, etc.), which can be significant, or even prohibitive, depending on the load to be treated. This is what is currently driving a number of R&D teams to identify and test different treatment approaches based on industrial ecology; in other words, the identification of innovative and sustainable outlets for the use and valorization of industrial residues (Sarperi et al., 2014, Starr et al., 2012).

For that matter, scientific studies indicate that some materials considered as residues are quite capable of removing H_2S and other foul-smelling gaseous contaminants. For example, incineration ash has been used in several studies, and the results indicate that these materials have a significant affinity for certain sulfur compounds and for CO_2 (Mostbauer et al., 2012; Tirnoveanu, 2004; CRIQ, 2016).

The use of off-specification compost has also been widely documented with regard to the biological treatment of hydrogen sulfide using biofilters (Yang and Allen, 1994; Syed et al., 2006). A study by Xu et al. (2010) identifies several types of material as alternative cover materials, and the results they obtained indicate that the H_2S capture performance is significantly better with materials such as compost, fine concrete residues and soil amended with lime. Plaza et al. (2007) also used a mix of hydrated lime and sandy soil, as well as concrete residues, as covering in laboratory tests. The best performance for H_2S removal was obtained with concrete chips (< 2.5 cm) and sandy soil containing hydrated lime (5% w/w).

When considering the option of using alternative cover materials to replace the sand currently in use as daily cover, the Bellechasse Regional County Municipality (Bellechasse RCM), which was grappling with an H_2S odor problem at its engineered landfill, decided to launch an on-site, proof-of-concept project at its landfill to test three (3) different cover materials.

The originality of the project lies in the use of a large static flow chamber for monitoring H_2S emissions from a landfill over a period of one year. The use of a static flow chamber was performed by Capena et al 2013, Cabral et al 2010 for CH_4 emission or COV emission. To our knowledge, there are little information regarding the use of a static flow chamber for H_2S emissions.

To measure gas emissions, a large static flux chamber was used as gas emissions can not be accurately assessed with a small chambers (Geck et al 2016a, 2016b). The typical small chamber is significantly smaller than 1 m2. Thus, chamber measurements are prone to missing emissions if emissive areas are larger than the base area of these chambers. In addition, it has been reported that emission level are underestimate while using a small chamber especially when the advective component of the flux is dominant (Pilhatie et al 2013). Other studies have shown that static flux chamber also underestimated gas emission and to avoid this underestimation, gas flux chamber should be equipped with at least one fan and a vent tube to increase mixing and reduce pressure propagation (Juszczak et al 2009).

The project goals described in this article therefore aim to present the main results concerning the control of H_2S emissions, volatile organic compounds (VOCs), and odors obtained from three (3) different alternative cover materials and to compare their performance with the current cover material (sand). The project took place at Bellechasse RCM landfill in Armagh (Québec, Canada) during the period between November 2016 and September 2017.

2. MATERIALS AND METHODS

2.1 Description of the landfill site

The Bellechasse RCM Municipal solid waste landfill MSWL covers a surface area of 15 hectares, representing an operating lifetime of about 40 years and a total capacity of 1,444,200 m^3. All of the MSWL's cells have a double layer of protective membrane, with treatment of leachate and biogas as required by current regulations. According to the current agreement, 33 municipalities are served by the current site. Remedial work aiming to control landfill gases emitted by the closed cells, which had been permanently covered, was carried out in summer 2012. Thus, four (4) passive waste biogas burners were installed and put into operation in August of the same year.

2.2 Description of the static flux chamber (SFC)

A 3 m x 3 m static flux chamber (SFC) was developed in order to carry out monitoring in the field. The SFC, which covers a wide surface, has the advantage of measuring emission rates more quickly. The development of the static flux chamber was inspired by the work of Geck et al. (2015). These authors used a 5 m x 5 m flux chamber to measure CH_4 emissions at a landfill. In our case, and for easier handling, a reduced-size 3 m x 3 m chamber was considered to be transportable by two (2) people. The chamber was assembled using a molded aluminum structure whose top was covered with Coroplast polypropylene plastic, and the sides with Flexfoil-type insulating material. These materials are known to have low VOC emissions. Five-meter-long (5 m) Teflon pipes placed at four (4) locations in the chamber enable collection of the gases. Two (2) battery-powered fans (1.5-1.6 m/sec@30 cm) provided air circulation in the chamber. The chamber is shown in Figure 1.

The validation stage for the static flux chamber (SFC) was carried out using an H_2S standard reference gas in concentrations of 1.98, 8.5, and 100 pm with a flow rate of 0.1 to 10 L/min. The Area Source Emission Rate (ASER) measured for H_2S is calculated according to the following equation:

$$Measured\ ASER = \frac{V}{A} \times \frac{dC}{dT} \tag{1}$$

Where:
dC/dT = The variation in gas concentration as a function of time in the SFC ($\mu g/m^3$.h or $\mu l/m^3$.h). This variation must have an increasing slope with a significant coefficient of determination in order for the ASER to be calculated.
V=Volume of the chamber=3.0294 m^3;

FIGURE 1: Appearance of the static flux chamber (3 m x 3 m).

A=Surface area of the chamber=9.18 m^2;
Factor V/A=0.33 m.

ASER measured using the chamber during validation or in the field was calculated using the approach described by Eun et al. (2007) and Green et al. (2010). The measurements of gas concentrations were collected immediately after the SFC was closed (time = 0) and every 30 seconds thereafter for 10 to 20 minutes. The gas flow (H$_2$S or VOC) was determined by plotting the gas concentration (C) in relation to elapsed time (t). The slope of the adjusted straight line (dC/dT) was determined by a regression, and a non-zero flow was only noted if there was a significant coefficient of determination (T test) with a 95% confidence interval (p < 0.05). If no significant correlation was observed, a flow of zero was recorded. ASER measured in the field is calculated according to Equation 1.

During the validation stage, it was possible to compare the measured ASER and the theoretical ASER calculated based on the flow rate and concentration of the standard reference gas. This approach was proposed by Green et al., 2010. The linear slope measured for dC/dT was considered to be valid if the coefficient of determination was significant at a threshold of 0.05 (T-test). Otherwise (with a decreasing or no significant slope), the emissions rate was considered to be zero.

During a series of experimental measurements in the field, the general operations of the components were verified. This verification aimed to ensure:

- the flowrate of the fans, with validation using a Kestrel 1000 anemometer from 0.3 to 40 m/sec on the morning of any monitoring day,
- the operation of the fans (visual verification of blade rotation) between each measurement;
- the absence of condensation in the sampling pipes (visual verification);
- the seal between the edges of the chamber and the ground, primarily on the windy side.

2.3 Description of cover materials used

The four (4) cover materials were supplied by the project's collaborators. The City of Québec supplied the Municipal Solid Waste Incinerator Bottom Ash (IBA); Englobe provided a mix of soil + compost called the alternative biofiltration cover material (ABCM); 3RMCDQ (represented by AIM Eco-centre) provided the chipped concrete residues (0-2.5 inches); and finally, the current cover material (control), the sand, was supplied by the Bellechasse RCM.

The first step before field test has consisted in characterizing the three (3) alternative covering materials with regard to hydraulic conductivity and grain size. All alternative cover materials were sampled from containers at eight (8) different locations. Four subsamples were collected at ten (10) cm depth and four (4) others at 30 cm depth. To be used as a daily recovering materials, the materials must meet the criteria described in paragraph 42 of the "Règlement sur l'enfouissement et l'incinération de matières résiduelles" (Gouvernement du Québec 2016). The requirements of this regulation are based on the minimum hydraulic conductivity of 1 x 10^{-4} cm / s and the material must have less than 20% by weight of particles with a diameter equal to or less than 0,08 mm.

Other complementary test on all materials have been done including acid leaching tests as described by SPLP, EPA 1312 to simulate acid rain were carried out (CEAQ2012). The concentration of heavy metals, phenolic compounds and VOCs have been measured on the leachate (result not shown).

A volume of approximately 10 m³ of each material was transported to the site to carry out the tests over a 5 m x 5 m area. No top soil was added because the effectiveness of the recovering materials alone have been measured.

As shown at Figure 2, the surfaces were cleaned of the plant layer and leveled. Subsequently, baseline emission rates were measured using the 3m x 3m static flow chamber for each of the test area. Table 1 present the characterization of the cover materials.

2.4 Analysis of gases and odors

The gas emission rates were measured using the specific devices shown in Table 2.

On each day of analysis, field blanks were produced for the H_2S, VOC, and CH_4 measurements on the access path near the test site.

2.4.1 Measurement of H_2S

Hydrogen sulfide (H_2S) was measured using two (2) methods. The first, a one-off approach, was carried out during the localization of the emissions zones. This method provides a qualitative approach to determine whether H_2S has been emitted locally in order to position the test banks.

For the measurement of the initial surface emission rate and for regular monitoring, the 3 m x 3 m static flux chamber (SFC) was used to analyze the concentration of H_2S every 30 seconds using a JEROME® brand portable hydrogen sulfide (H_2S) analyzer, model 631-X. This frequency corresponds to the device's maximum rate of analysis. The device can measure from 0.003 ppm to 50 ppm. The verification of the standard reference was carried out in October and November 2016 and March and July 2017 using

TABLE 1: Description of cover materials.

Material	Installed thickness (m)	Volume of material covering 1 m² (m³)	Dry mass density (kg/m³)	Dry mass of material covering 1 m² (kg)
Incinerator bottom ash (IBA)	0,1	0,1	1 469	147
0-2.5 cm concrete residues	0,1	0,1	1 480	148
Alternative biofiltration cover material (ABCM)	0,15	0,15	1 675	251
Control sand	0,2	0,2	1 634	327

FIGURE 2: Photos showing the cleaning of the surface (top left photo), the measurement of initial ASER (top right photo), and the final appearance after the installation of the cover materials.

TABLE 2: Gas measurement devices used in this project.

Gas	Measurement device	Detection limit	Pumping capacity (ml/min)
H_2S	Jerome 631 X #77830604	0,003 ppmv	150
VOC_{total}	PBRae 3000	1 ppbv	500
CH_4	20L Tedlar sampling bag single-point-in-time lab analysis Gasmet DX4015 FTIR	1 ppmv	4 000
Odor	30L Nalophan sampling bag in triplicate with external dynamic olfactometry analysis (EN 13725:2003).	Lab blank <13 odor units	4 000

three standard reference gases containing a representative concentration range of the contaminant, namely hydrogen sulfide (H_2S).

2.4.2 Measurement of VOCs

VOCs were sampled in a similar fashion to the H_2S measurement. For determining the initial surface emission rate and for regular monitoring, the 3 m x 3 m SFC was used to measure and analyze the VOC concentration every 30 seconds using a Model 3000 ppbRAE type portable device. This device's detection limit ranges from 1 ppb to 10,000 ppm. Before measuring VOCs, the chamber was ventilated in order to eliminate gases accumulated inside during the previous measurements. This ventilation was carried out by lifting the chamber up and down five (5) times in order to expel the gaseous mix accumulated in the enclosure.

2.4.3 Measurement of methane

Methane was measured using a one-off approach between the measurement of the H_2S and the VOCs under the SFC. This measurement was intended to detect biogas emissions through the layers of tested materials. Since methane is a gas that does not dissolve in water, it can indicate the presence of real biogas emissions through the cover materials. The use of a sealed cover material could, for example, prevent the biogas from diffusing through the material, which would give a zero result for gas analysis (H_2S and VOCs). In this case, the significant presence of methane indicates real biogas emissions through the filling material.

The sample was taken on site using a vacuum chamber (Lung) and Flexfoil PLUS® bags (20 liters). The gas was collected using a GilAir Plus type pump adjusted to a flow rate of 4L/min.

Subsequently, the samples were analyzed in the laboratory within 24 hours. The concentration of CH_4 was evaluated using a Gasmet DX 4015 FTIR gas analyzer. This device's detection limit is 1 ppm. The device was calibrated every six (6) months, in the months of November and May. A laboratory blank was also measured, as was a field blank.

2.4.4 Measurement of odors

For the olfactometric analyses (odors), gas samples were collected in triplicate using a lung-type extraction system under vacuum and 30-liter NalophanTM bags under the SFC. The samples were then sent to an external olfactory evaluation lab (Consumaj Experts Conseils), where they were analyzed using a dynamic olfactometer in compliance with the NF EN 13725:2003 standard within 24 hours. During transport and storage, the samples were

maintained at ambient temperature (~ 20°C) and were not exposed to light. The results are given in odor units per meter cubed of air (O.U./Nm³). The analysis of odors was carried out at the beginning of the project during the initial measurements, before covering by the test materials, and at the end of monitoring.

3. RESULTS AND DISCUSSION

3.1 Validation of the static flux chamber (SFC)

The 3 m x 3 m SFC developed by CRIQ was validated using field tests. Different concentrations of standard reference H_2S gas were used, at 1.98, 8.5, and 100 ppm with flow rates varying from 0.1 to 10L/min. These conditions made it possible to generate theoretical ASERs varying from 1.93 to 2055 µg of H_2S/m^2/h covering the range of measurements collected during an earlier study in the field

To calculate the theoretical ASERs of H_2S during the validation of the SFC using standard reference gases, the following equation was used:

$$Calculated\ ASER =$$

$$= \frac{Injected\ gas\ flow\ rate\ (m^3/h) \times Concentration\ H_2S\ (ug/m^3)}{A} \quad (2)$$

Where:
A = surface of the SFC, namely 9.18 m².

An example of the measurement of H_2S ASER in the 3m x 3m chamber is presented in Figure 3. It represents a validation test carried out with an H_2S standard reference gas at 105 ppm injected at a flow rate of 0.1L/min. The ASER value measured here is calculated using Equation 1.

Using the data presented in Figure 3 and the measure of the slope, the measured ASER was calculated using Equation 1 and compared with the theoretical ASER calculated based on the gas flow rate and the concentration of standard reference gas injected into the static flux chamber.

For the laboratory tests, the relationship between the theoretical ASER values and the measured ASER values is presented in Figure 4. In this figure, all of the theoretical ASER values calculated based on concentrations of standard reference gas and specific flow rates (Equation 2) have been plotted as a function of the ASER value measured in the chamber, according to Equation 1.

The correlation between the two parameters is significant. Thus, from the ASER measured using the SFC and the correlation obtained in Figure 4, a corrected ASER can be calculated using a correction factor (Eq. 3).

$$Corrected\ ASER = 1.263\ x\ ASER\ (measured\ eq.1) + 13.59 \quad (3)$$

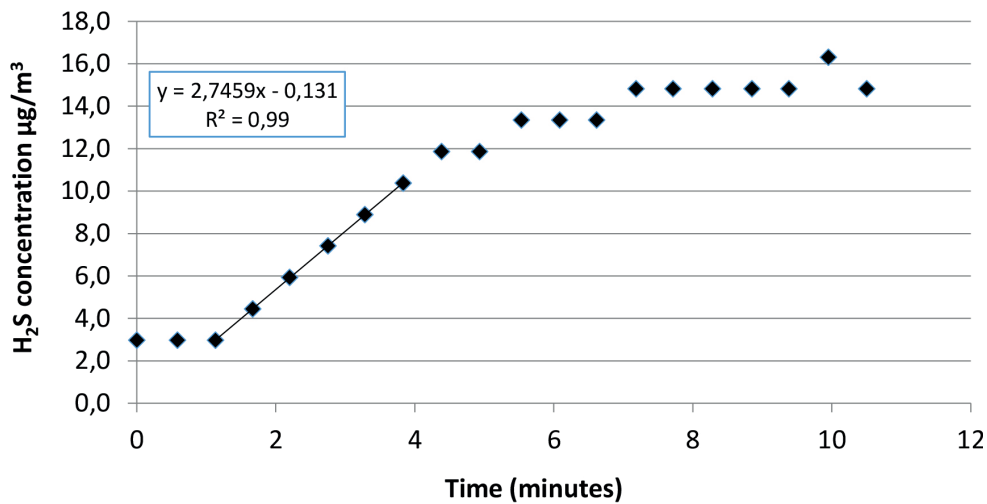During field tests of H_2S emissions, Equation 3 was

FIGURE 3: Validation tests of the SFC using an H_2S standard reference gas at 105 ppm and a flow rate of 0.1L/min.
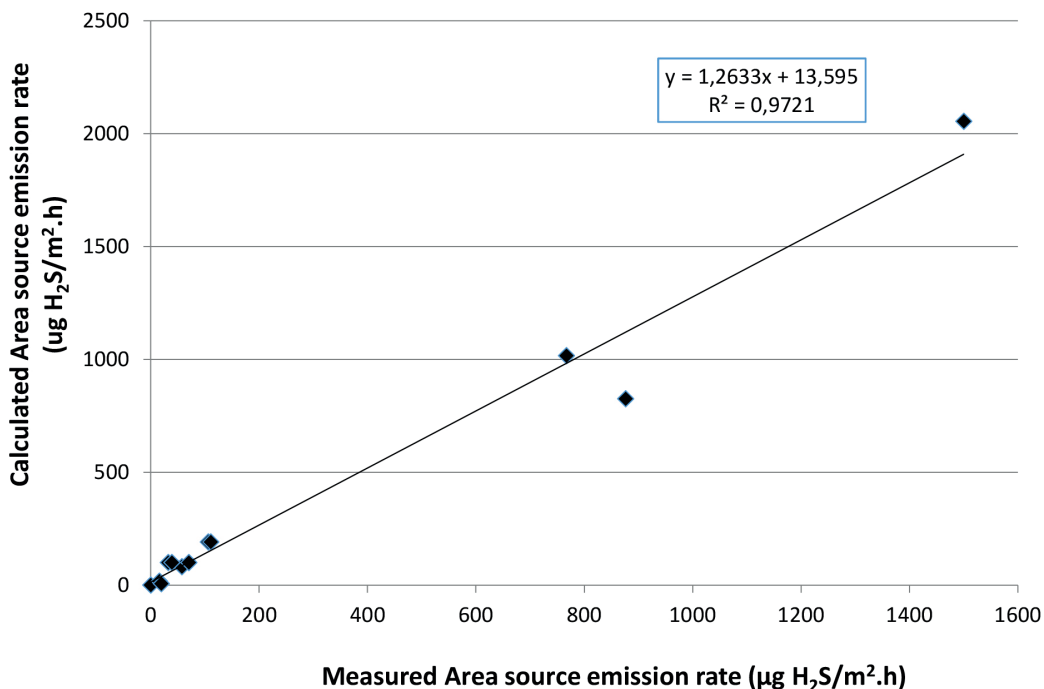

FIGURE 4: Relationship between calculated ASER (standard reference gas with controlled flow rate - Equation (2) and ASER measured using the 3m x 3m chamber - Equation (1)).

used to calculate corrected ASER. Because of time constraints, the correlation presented in Figure 3 was not carried out with VOCs. Given this, the measured ASER values for VOCs were calculated directly from Equation 1 without any correction.

3.2 Monitoring of gaseous emissions from different cover materials

The removal effectiveness performance during field tests are presented in Figures 5 and 6. These figures make it possible to compare the different materials used for capturing H_2S and VOCs during the study period. Since the initial ASER, and therefore the load applied to the cover mate-

rials, differs from site to site, this graphical approach makes it possible to compare performance between sites. The dotted line presents a material able to capture 100% of the applied load. The more effective a material, the more the points approach the dotted line, indicating 100% efficiency.

The gas load applied was defined as follows:

$$Gaseous\ load\ applied_t =$$

$$= \frac{(Initial\ ASER\ x\ 24h\ x\ number\ of\ days\ of\ monitoring)}{1,000\ x\ mass\ of\ the\ dry\ material\ per\ 1\ m^2} \quad (4)$$

Where:

The gas load applied (mg H_2S/kg material or ml VOC/kg dry material);
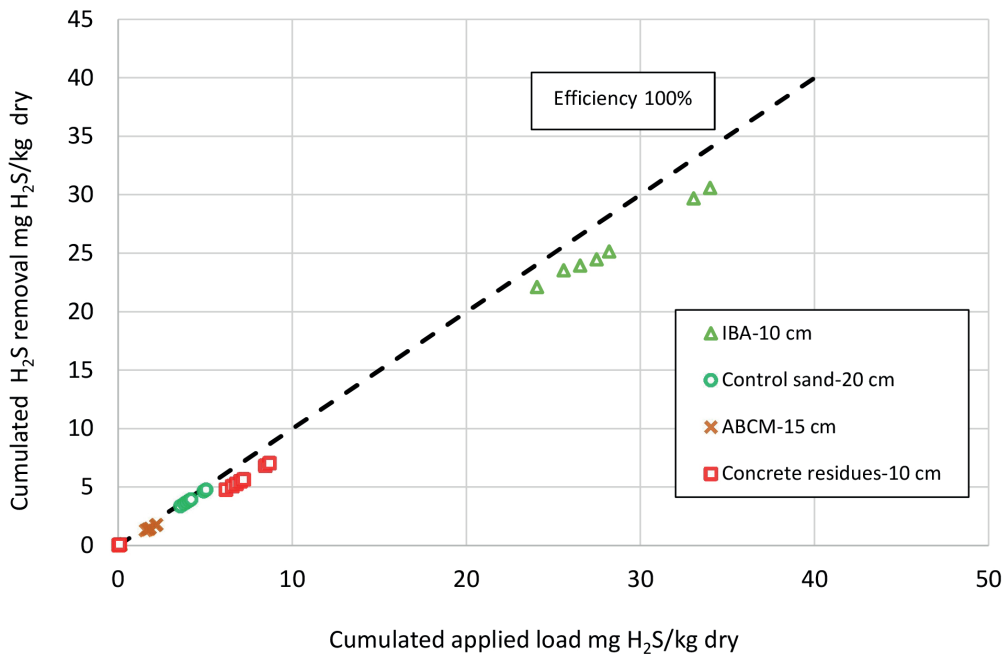
Initial ASER (μg H_2S/m^2.h);

FIGURE 5: Relationship between the applied load of H_2S (eq. 4) and the cumulative captured load (eq. 6) during field tests for different cover materials.
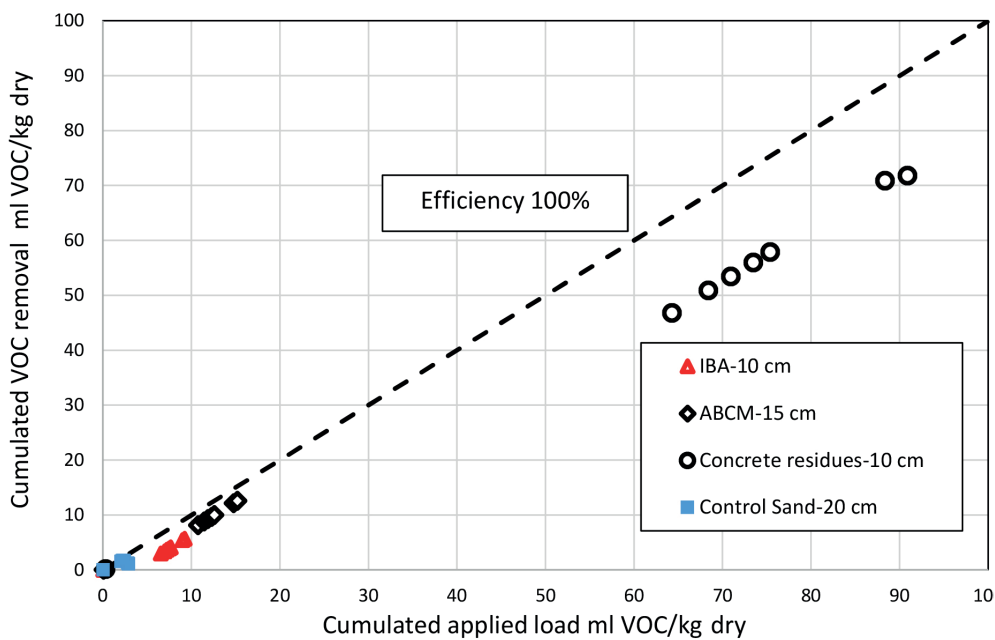

FIGURE 6: Relationship between the applied load of VOC (eq. 4) and the cumulative captured load (eq. 6) during field tests for different cover materials.

1,000 = conversion factor for µg to mg.

The factor used to evaluate the performance of the cover materials is referred to as "cumulative load removed by the material." This value corresponds to the difference between the initial ASER, which is constantly generated under the material, and the ASER emitted or measured during monitoring. In sum, the material receives emissions of gaseous pollutants such as H_2S and VOCs constantly, and some passes through to be released constantly (emitted

ASER). The fraction of ASER emitted was measured in the field eight (8) times during a 286-day monitoring period. From these ASERs, the loads were calculated by taking the difference between the initial load and the emitted load (Equation 5); it is therefore possible to estimate the quantity of pollutants retained by the material at a time T.

$Gaseous\ load\ emitted =$

$$= \frac{(\int_0^t ASER\ emitted \times 24h)}{1,000 \times mass\ of\ the\ dry\ material\ per\ 1\ m^2} \quad (5)$$

Where:
gaseous load emitted (mg H_2S/kg material or ml VOC/kg dry material);
Emitted ASER (µg H_2S/m².h). The ASERs emitted at a time T are estimated by linear extrapolation between two (2) measured ASERs;
1,000 = conversion factor for µg to mg.

Thus, the performance of the material expressed in the form of the cumulative captured load is written according to Equation 6 as follows:

$$Cumulative\ removed\ load = Applied\ gaseous\ load_t\ (eq.4) + - Gaseous\ load\ emitted_t\ (eq.5) \qquad (6)$$

According to the results presented in Figure 5, the bench test using the IBA as well as the 0-2.5 in. concrete received the highest load of H_2S and showed the best H_2S removal performance, greater than 83%. The Sand control material as well as the 15 cm ABCM also showed good capture performance, but for lower loads of H_2S. Taking these lower loads into account, it is difficult to draw a conclusion about their effectiveness for higher loads. For VOCs (Figure 6), the materials such as Concrete and ABCM showed better capture effectiveness (> 73%) for higher loads.

The different materials tested here have already been subjected to a variety of scientific studies, which demonstrated their capacity for removing H_2S and other foul-smelling gaseous contaminants. For example, MSWI bottom ash, because it is alkaline, was used in several studies, and the results indicate that this material would have a strong affinity for certain sulfur compounds and for CO_2 (Mostbauer et al., 2012; Tirnoveanu, 2004; Turgeon et al., 2017).

The use of compost has also been widely studied with regard to the biological treatment of hydrogen sulfide using biofilters (Yang and Allen, 1994; Syed et al., 2006). The study by Xu et al. (2010) evaluated several types of materials as alternative covers including sandy soil, compost, fine concrete residues (79.6% < 2 mm), and mixes of lime with sandy soil with different proportions by weight. The results they obtained indicate that H_2S capture performance is significantly better with materials such as compost, fine concrete residues and soil amended with lime. Plaza et al. (2007) also used a mix of hydrated lime and sandy soil, as well as concrete residues, as covering in laboratory tests. In this study, the best performance for H_2S removal was obtained with concrete chips (< 2.5 cm) and sandy soil containing hydrated lime (5% w/w). In this case, alkaline materials such as incineration bottom ash and concrete residues seem more effective for the abatement of H_2S. That said, for ABCM, the low applied loads did not allow us to draw a conclusion about the material's purifying capacity.

For VOCs, treatment usually involves microbial activity, and the use of composts or other organic materials is widely documented in the scientific literature (Chou et Cheng 1997, Liu et al 2009).

The results of one-off measurements of CH_4 are presented in Table 3. These measurements were taken once the analyses of H_2S were complete and made it possible to detect the presence of biogas diffusing through the cover materials. CH_4 is poorly water soluble and adsorbable, and

its biodegradation using methanotrophic bacteria can be relatively quick, but requires specific environmental conditions (CRIQ, 2015). Aerobic conditions, warm temperatures, and nitrogen and phosphate-based nutrients are all conditions that can be found in the ABCM mix.

The olfactometric results are presented in Table 4. The odor units indicate the number of times that the sample had to be diluted before 50% of the judging panel could perceive the odor. The hedonic quality of the odor was not evaluated in the expression of odor units. A high number indicates a gas that requires a high degree of dilution before being perceived by 50% of the judging panel, regardless of whether the odor was pleasant or foul. The gas collected from the platform covered with IBA was odorous with an average of 360 OU/Nm³. An abatement of around 200 OU/Nm³ is nevertheless observed with this material, since at first the collected gas registered 564 OU/Nm³. Since the odor of IBA resembles that of fresh concrete, it is normal to perceive this odor being released by the material at the end of the project. As has already mentioned, the elevated OU/Nm³ value does not represent the quality of the odor, but rather its intensity.

In the case of ABCM, the odor levels of the collected gas at the beginning and end of the project were relatively low (32 and 28 OU/Nm³). For the control sand, the gas collected at the end of the project was more odorous than at the beginning (26 and 81 OU/Nm³).

4. CONCLUSIONS

This experimental project took place from autumn 2016 to the end of summer 2017. Tests to monitor the performance of different cover materials were carried out at the BELLECHASSE RCM Engineered landfill in Armagh (Québec, Canada). The field tests aimed to confirm the effectiveness of alternative biofiltration cover materials (ABCM), MSW incineration bottom ash (IBA), and 0-2.5

TABLE 3: One-off measurement of CH_4 in the static flux chamber.

Material	One-off measurement of CH_4 concentration (ppmv)	
	Before covering	After covering
20 cm control sand	455	366
10 cm IBA	132	71
10 cm concrete (0-2.5 inches)	61	66
15 cm ABCM	51	22
Field blank	ND	6

TABLE 4: Olfactometric monitoring of emissions in the static flux chamber.

Material	Measurement of Odor units (U.O/Nm³ of air) Average ± standard deviation (n=3 obs)	
	Before covering	After covering
20 cm control sand	26 ± 4	81 ± 3
10 cm IBA	564 ± 45	360 ± 60
10 cm concrete (0-2.5)	246 ± 28	ND
15 cm ABCM	32 ± 2	28 ± 5

inch concrete residues and to compare the results with the sand currently used as the cover material. The effectiveness of these materials specifically evaluated their ability to reduce emissions of H_2S and VOCs. Effectiveness was determined by measuring the Area source emission rate (ASER) with a 3 m x 3 m measuring chamber developed for this project. Methane measurements were concomitantly taken to confirm that the biogas could escape through the cover materials. Olfactometric analysis were also carried out at the beginning and end of the project to evaluate the abatement of odors by all cover materials.

The results of the characterization made it possible to verify that the bench test with IBA and the 0-2.5 in. concrete received the largest load of H_2S and showed H_2S capture performance of greater than 83%. For VOCs, the materials such as 0-2.5 in. concrete and ABCM showed the best capture effectiveness, greater than 73%, for the highest loads. Lower loads of CH_4 after covering were measured on the bench test using the alternative biofiltration cover materials. For odor monitoring, the bench test using the IBA succeeded in decreasing odors by ±200 OU/Nm^3.

Overall, we have demonstrated in this project, the capacity of different alternative cover materials under real condition for the control of gas emissions from landfill. However, field tests always involve the unexpected and can generate results affected by climate and environmental conditions that are more thoroughly controlled in laboratory tests.

ACKNOWLEDGEMENTS

REFERENCES

Cabral, A. R., Capanema, M. A., Gebert, J., Moreira, J. F., & Jugnia, L. B. (2010). Quantifying microbial methane oxidation efficiencies in two experimental landfill biocovers using stable isotopes. Water, Air, & Soil Pollution, 209(1-4), 157-172

Capanema, M. A., Ndanga, E., Lakhouit, A., & Cabral, A. R. (2013). Methane oxidation efficiencies of a 6-year-old experimental landfill biocover. In Proceedings Sardinia 203, Fourteenth International Waste Management and Landfill Symposium S. Margherita di Pula, Cagliari, Italy; 30 September-4 October 2013.

CEAQ (2012) Centre d'expertise en analyse environnementale du Québec (2012). Protocole de lixiviation pour les espèces inorganiques, MA. 100 – Lix.com.1.1, Rév. 1, Ministère du Développement durable, de l'Environnement, de la Faune et des Parcs du Québec, 2012, 17 p.

Chou, M. S., & Cheng, W. H. 1997. Screening of biofiltering material for VOC treatment. Journal of the Air & Waste Management Association, 47(6), 674-681.

CRIQ 2015. Développement d'un inoculum méthanotrophe. Dossier CRIQ no PE46357, Rapport final, 28 pages

CRIQ 2016. Étude du mâchefer de l'incinérateur de la Ville de Québec envers l'élimination du sulfure d'hydrogène (H_2S). Dossier CRIQ no PE50122, rapport final, 27 pages.

Davis, W. T., 2000. Air Pollution Engineering Manual. 2nd Ed., AWMA, Wiley Interscience.

Eun, S., Reinhart, D. R., Cooper, C. D., Townsend, T. G., & Faour, A. 2007. Hydrogen sulfide flux measurements from construction and demolition debris (C&D) landfills. Waste Management, 27(2), 220-227.

Fairweather, R. J., Barlaz, M. A. 1998. Hydrogen sulfide production during decomposition of landfill inputs, Journal of Environmental Engineering ASCE, 124, 353–361.

Geck, C., Scharff, H., Pfeiffer & J. Gebert 2015. Validation of a Simple Model to Predict Efficiencies of methane Oxidation systems. Proceedings Sardinia 2015. Fifteenth International Waste Management and Landfill Symposium S. Margherita di Pula, Cagliari, Italy; 5 – 9 October 2015.

Geck, C., Röwer, I. U., Kleinschmidt, V., Scharff, H., & Gebert, J. (2016a). Design, validation and implementation of a novel accumulation chamber system for the quantification of CH_4 and CO2 emissions from landfills. Technical Report

Geck, C., Scharff, H., Pfeiffer, E. M., & Gebert, J. (2016b). Validation of a simple model to predict the performance of methane oxidation systems, using field data from a large scale biocover test field. Waste management, 56, 280-289.

Gouvernement du Québec (2012). Règlement sur l'enfouissement et l'incinération de matières résiduelles. Québec, Canada.[En ligne] http://www2. Publications du quebec. gouv. qc. ca/dynamicSearch/telecharge. php.

Green, R. B., Hater, G. R., Thoma, E. D., DeWees, J., Rella, C. W., Crosson, E. R., & Swan, N. 2010. Methane emissions measured at two California landfills by OTM-10 and an acetylene tracer method. In Proceedings of the Global Waste Management Symposium 2010 (pp. 3-6).

Juszczak, R., Pihlatie, M., Christiansen, J. R., Giebels, M., Schreiber, P., Aaltonen, H., ... & Urbaniak, M. (2009, April). Effect of headspace mixing in static chambers and sampling protocol on calculated CH_4 fluxes from soils. In EGU General Assembly Conference Abstracts (Vol. 11, p. 9715).

Mostbauer, P., Olivieri, T., Lombardi, L., & Paradisi, A. 2012. Pilot-scale upgrading of landfill gas and sequestration of CO2 by MSWI bottom ash. In Ash 2012 Conference, January (pp. 25-27).

NF EN 13725 Standard, B. 2003. Air quality−Determination of odour concentration by dynamic olfactometry. BS EN, 13725, 2003.

Pihlatie Mari K., Jesper Riis Christiansen, Hermanni Aaltonen, Janne F.J. Korhonen, Annika Nordbo, Terhi Rasilo, Giuseppe Benanti, Michael Giebels, Mohamed Helmy, Jatta Sheehy, Stephanie Jones, Radoslaw Juszczak, Roland Klefoth, Raquel Lobo-do-Vale, Ana Paula Rosa, Peter Schreiber, Dominique Serca¸ Sara Vicca, Benjamin Wolf, Jukka Pumpanen, (2013). Comparison of static chambers to measure CH_4 emissions from soils. Agricultural and forest meteorology, 171, 124-136.

Plaza, C., Xu, Q., Townsend, T., Bitton, G., & Booth, M. 2007. Evaluation of alternative landfill cover soils for attenuating hydrogen sulfide from construction and demolition (C&D) debris landfills. Journal of Environmental Management, 84(3), 314-322.

Liu, Q., Li, M., Chen, R., Li, Z., Qian, G., An, T., Fu, J & Sheng, G. 2009. Biofiltration treatment of odors from municipal solid waste treatment plants. Waste Management, 29(7), 2051-2058.

Sarperi, L., Surbrenat, A., Kerihuel, A., & Chazarenc, F. 2014. The use of an industrial by-product as a sorbent to remove CO2 and H_2S from biogas. Journal of Environmental Chemical Engineering, 2(2), 1207-1213.

Starr, K., Gabarrell, X. & Villalba G., 2012. Life cycle assessment of biogas upgrading technologies, Waste Management, Elsevier, 32, pp. 991-999.

Syed, M., Soreanu, G., Falletta, P. & Béland, M. 2006. Removal of hydrogen sulfide from gas streams using biological processes-A review. Canadian Biosystems Engineering, 48, 2.

Tirnoveanu, D. R. 2004. Étude des propriétés épuratoires des mâchefers d'incinération d'ordures ménagères et de leur mise en œuvre (Doctoral dissertation, Université de Limoges).

Turgeon, N., Le Bihan, Y., Savard, S., D'Aoust, M., Fournier, M., & Sénéchal, D. 2017. Utilisation de mâchefer d'incinération de déchets solides municipaux pour l'élimination du sulfure d'hydrogène: Un exemple d'écologie industrielle. Vecteur Environnement, 50(4), 40-47.

Xu, Q., Townsend, T., & Reinhart, D. 2010. Attenuation of hydrogen sulfide at construction and demolition debris landfills using alternative cover materials. Waste Management, 30(4), 660-666.

Yang, Y. & Allen, E. R. 1994. Biofiltration control of hydrogen sulfide 1. Design and operational parameters. Air & Waste, 44(7), 863-868.