

Long-Term Temperature Monitoring of a Municipal Solid Waste Landfill

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Abstract

This study was conducted to investigate heat generation in a landfill on a field scale, including the variation of temperatures. Data were collected at Štěpánovice landfill in southwestern Czech Republic. Temperatures were determined over a monitoring period of 21 months. Mean annual value of the difference between outdoor temperature and temperature at a depth of 100 cm in the landfill body in 2012 amounted to 5.4°C, and for the reporting period of 2013 it equaled 5.2°C. No significant differences among measured temperatures were recorded at particular depths (50 cm, 75 cm, and 100 cm). Mean temperature at the surface of the landfill within the whole reporting period was 3.2°C higher than ambient temperature (in the reporting period). This is explained due to the decomposition activity within the landfill site leading to the emission of warm gases. The results provide new information for the estimation of the selection of plant species suitable for reclamation, which have higher chances to tolerate the unfavorable conditions they would be exposed to a technically reclaimed landfill body.

Keywords: municipal solid waste, landfill, heat generation, temperature

Introduction

The establishment of sustainable landfills is a key strategy in modern waste management concepts. Since conventional municipal solid waste (MSW) landfills are regarded as a potential source of significant organic and inorganic emissions over long time periods [1-3], measures have to be taken to sustainably mitigate both the current and (potential) long-term emissions of the waste materials in terms of landfill gas and leachate [1].

Landfills may release environmentally harmful emissions over hundreds of years [4, 5]. Waste in landfills converts to organic and inorganic compounds in the gaseous/liquid states by undergoing various chemical and biological transformations, leading to the formation of

landfill gas (LFG) and landfill leachate. These processes are generally divided into four phases. In hydrolysis, particulate material is converted to soluble compounds that are degraded to simpler acids, alcohols, and CO₂ (acidogenesis). Then degradation continues to acetate and hydrogen formation (acetogenesis), and finally methane and CO₂ formation (methanogenesis). The landfill temperature, moisture content/additive water amount, water characteristics (i.e., precipitation rainfall or other water entering landfills), available oxygen, and waste characteristics are among the many factors contributing to gas and leachate generation at landfill sites and subsequently determine the characteristics of LFG and landfill leachate [4, 6]. Furthermore, the different forms of degradation are not definitive, since dynamic variations in the environmental conditions result in changes in their distribution and rates within the landfill [4, 7, 8].

The management of landfill emissions, for both the long term and after closure, is an important and resource-inten-

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sive task. Landfills are usually operated for decades. The potential environmental risks should be understood completely in order to achieve the sustainability of landfill operational strategies. Among other factors, the landfill temperature plays a key role in determining the long-term potential of landfill emission. The actual landfill temperature may vary widely within one landfill [4].

The landfill temperature is affected by the size and height of the landfill, climatic conditions, and landfilling operations, which determine the circumstances in which microbial decomposition occurs. Understanding the impact of temperature on landfill emissions (especially landfill leachate), is significant for the improvement of long-term landfill management strategies in order to minimize landfill emissions, accelerate waste stabilization, and shorten the landfill aftercare period [4].

While various studies have been conducted on the generation and distribution of leachate and gas in landfills [9-14], limited information has been reported related to thermal analysis of MSW, including heat generation, ground surface temperature conditions overlying wastes, and thermal properties. In general, comprehensive long-term thermal trends are not available for landfills, nor have effects of operational or climatic conditions on heat generation in landfills been investigated.

Heat generation and temperature distributions in MSW landfills have not been commonly investigated. This study provided analysis of thermal aspects of MSW landfill using field measurements.

The objective of this study was to investigate temperature of landfill. This investigation aims to understand how environmental conditions affect the vegetation characteristics of a landfill. This knowledge may be useful in the selection of appropriate vegetation species that are adaptable to landfill environmental conditions and help improve the control of LFG emissions from a closed landfill.

Experimental

Our study was conducted at an MSW landfill in southwestern of Czech Republic. Waste has been placed at the site since 1996, originally in controlled trenches with liner systems and leachate and gas collection and removal systems [3, 15-17]. The landfill is divided into three cells. This landfill has an authorized volume of about 569,000 m³. Its waste generation and composition is presented in other publications [3, 17].

All three landfill cells are equipped with a landfill leachate collection system. Landfill cells are re-circulated with landfill leachate to accelerate stabilization. After closing cell A, the landfill was covered with soil to a depth of 130 cm, and planted over with grasses and trees. An environmental recovery and technological restoration program was constructed, and the site was reconstructed from 2008 to 2009.

Climatic and operational conditions for the landfill site investigated in this study are presented in Table 1. The Štěpánovice landfill is located near Klatovy city (Pilsen region, Czech Republic).

Table 1. Climatic and operational conditions.

Parameter	
Average air T (°C)	7.1
Mean surface temperature (°C)	9.3
Annual normal precipitation (mm)	582
Mean annual earth temperature (°C)	7.4
Landfill body capacity (10 ³ ·m ³)	569
Average waste intake (10 ³ kg·year ⁻¹)	18,914
Primary Daily Cover	Soil

Testing Program

The testing program included an extensive field investigation of temperatures at MSW landfill with varying climatic conditions.

Analyses

Spatial and temporal variations of temperatures at the sites were investigated, effects of climatic and operational conditions were analyzed, and rates of temperature change also were determined.

Our aim was to measure and determine temperature differences at various depths of the landfill body (10 cm, 50 cm, 75 cm, and 100 cm) and outdoor temperatures in the period from January 2012 to September 2013. Temperature measurement in °C at different depths of the landfill body was carried out on a daily basis for a determined period of time, using a mercury thermometer manufactured by SKLO UNION Kavalier glassworks (range of the thermometer is from -20°C to +40°C) and digital contact thermometer PFEUFFER (Fig. 1). Temperature was measured by outdoor sensor for temperature measurement HOBO (range from -20°C to +70°C, with an accuracy of ±0.7°C, resolution ±0.4°C), which was placed in the area of the MSW Štěpánovice landfill scale.

Results and Discussion

Following the measurements, the results were processed and the course of daily temperatures was evaluated. Average monthly temperatures, the differences between mean monthly outdoor temperature and the temperature at a depth of 100 cm in the landfill body were examined, as well as the average annual outdoor Fig. 4 illustrating the difference between outdoor temperature and the temperature at 100 cm depth in the landfill body.

Fig. 2 shows the course of daily temperatures in the landfill body at stated depths and the course of outdoor temperature for the period January-December 2012. Daily outdoor temperatures for the period January-December 2012 show greater temperature fluctuations than daily tempera-



Fig. 1. Measurement location.

tures in the landfill body at depths of 50 cm, 75 cm, and 100 cm. The most significant oscillations of daily temperature occur at the outdoor temperatures (from -20°C on 6 February 2012 to 22°C on 22 August 2012) and at the temperatures in the landfill body at a depth of 10 cm (temperatures ranged from -7°C on 13 February 2012 to 20.6°C on 22 June 2012). As seen from Fig. 2, daily temperature in the landfill body at depths of 50 cm, 75 cm, and 100 cm showed almost identical development for all three depths. No significant differences among measured temperatures were recorded in particular depths (50 cm, 75 cm, and 100 cm).

Fig. 3 illustrates the development of average monthly values of measured outdoor temperatures and temperatures at stated depths of the landfill body for the period January-December 2012. The lowest mean values were monitored at monthly temperatures measured in February 2012 (outdoor 6.2°C , at 10 cm depth -2.5°C , at 50 cm depth 1.6°C , at 75 cm depth 2.0°C , and at 100 cm depth 1.7°C). From March 2012 average temperatures were gradually increasing; the highest mean values were recorded from July to August (outdoor 14.7°C in July, at 10 cm depth 17.7°C in July, at 50 cm depth 20.0°C in August, at 75 cm depth

19.8°C in August, and at 100 cm depth 19.2°C in August). From August to December 2012 a decline in average monthly temperatures at all observed depths as well as in the outdoor temperature was recorded.

Higher mean monthly temperatures for all of 2012 were measured in the landfill body at depths of 50 cm, 75 cm, and 100 cm. Average outdoor temperature for 2012 amounted to 5.7°C , at 10 cm depth it was 8.7°C , at 50 cm depth 11.4°C , at 75 cm depth 11.3°C , and at 100 cm depth 11.0°C .

Based on mean monthly temperature in 2012, the differences between outdoor temperatures and the temperatures at 100 cm depth of the landfill body in particular months were calculated. In addition, average annual value of the difference between outdoor temperature and the temperature at 100 cm depth of the landfill body was determined. The obtained results were recorded in graph (Fig. 4).

The highest mean monthly temperature in 2012 was monitored in September (8.2°C) and the lowest in March (2.4°C). Average annual value of the difference between outdoor temperature and the temperature at 100 cm depth of the landfill body in 2012 amounted to 5.4°C .

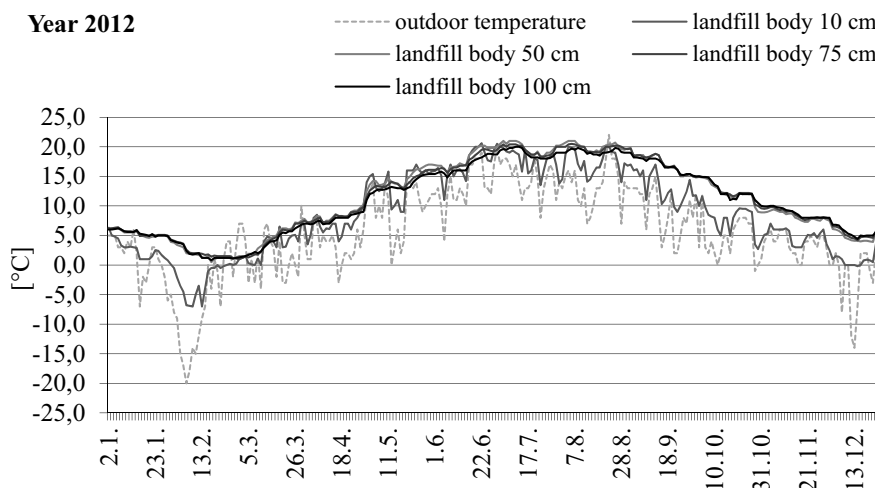


Fig. 2. The course of mean daily temperatures in the period January-December 2012.

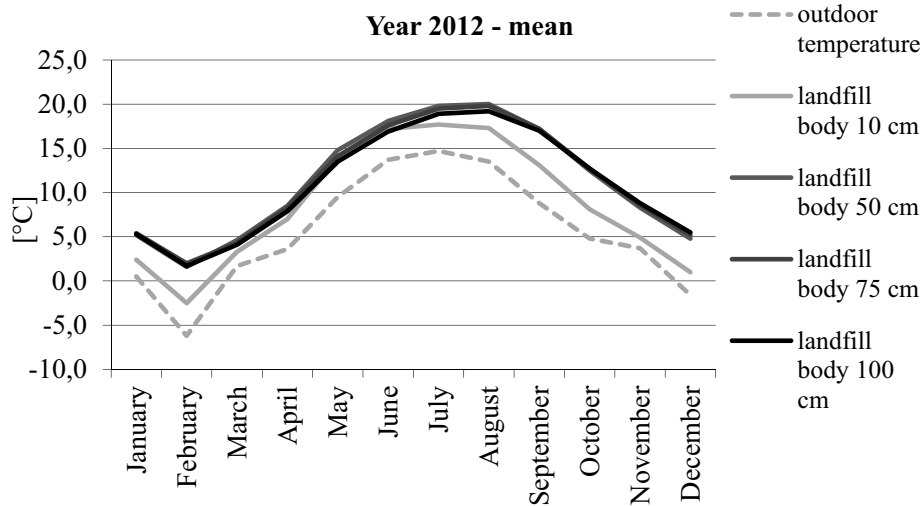


Fig. 3. The course of mean monthly temperatures in the period January-December 2012.

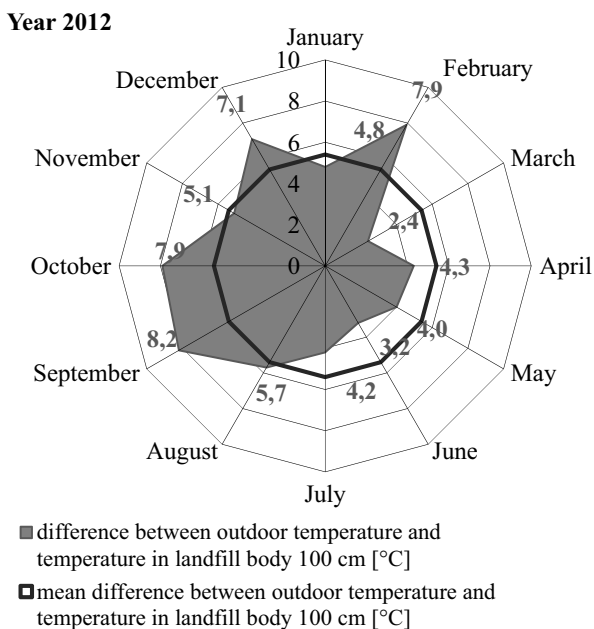


Fig. 4. Differences among outdoor temperatures and temperatures at a depth of 100 cm in the landfill body in 2012.

Fig. 5 shows the course of daily temperatures in the landfill body at specified depths and the course of outdoor temperatures for the period January-September 2013. Daily outdoor temperatures in the period January-September 2013 show greater temperature fluctuations than daily temperatures in the landfill body at depths of 50 cm, 75, and 100 cm. The highest daily temperature fluctuations in the monitored period concern outdoor temperatures from -8°C on 11 February 2013 to 21.4°C on 22 June 2013 and temperatures at 10 cm depth of the landfill body (temperatures ranged from -0.8°C on 18 January 2013 to 24.5°C on 21 June 2013). As shown in Fig. 5, daily temperatures in the landfill body at depths of 50 cm, 75 cm, and 100 cm showed almost identical development for all three depths. No significant differences among measured temperatures were recorded in particular depths (50 cm, 75 cm, and 100 cm).

Fig. 6 shows the development of mean monthly values of measured outdoor temperatures and temperatures at determined depths of the landfill body for the period January-September 2013. The lowest average values were recorded at monthly temperatures measured in February

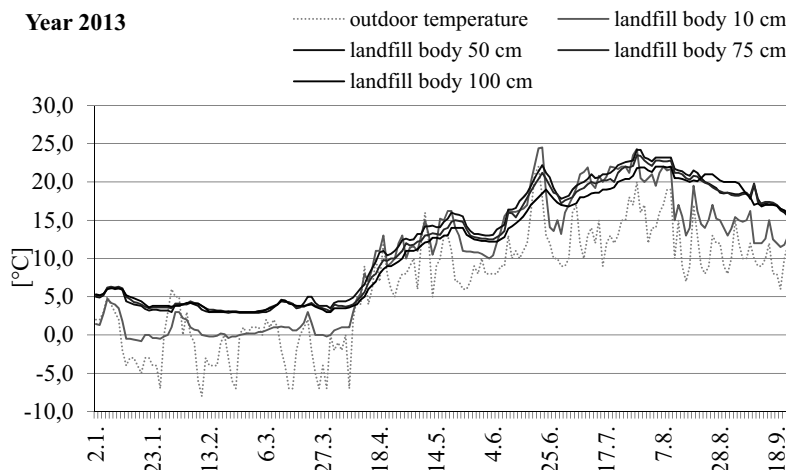


Fig. 5. The course of daily temperatures in the period January-September 2013.

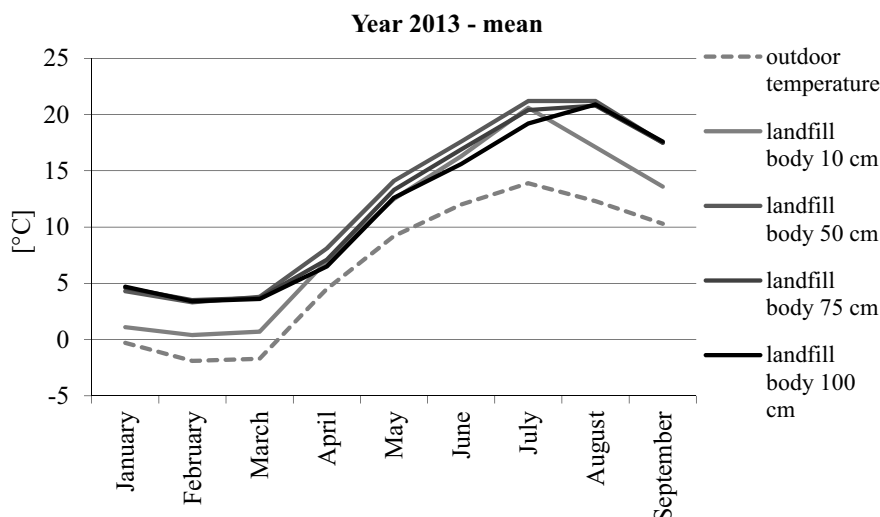


Fig. 6. The course of mean monthly temperatures in the period January-September 2013.

2013 (outdoor -1.9°C, at 10 cm depth 0.4°C, at 50 cm depth 3.3°C, at 75 cm depth 3.5°C, and at 100 cm depth 3.4°C). From March 2013 average monthly temperatures were gradually increasing; the highest average values were recorded in the period July-August (outdoor 13.9°C in July, at 10 cm depth 20.6°C in July and at 50 cm depth 21.2°C in August, at 75 cm depth 20.8°C in August, at 100 cm depth 20.9°C in August). In the period from August to September 2013 a decline in average monthly temperatures at all observed depths as well as in the outdoor temperature was recorded.

Higher average monthly temperatures for the period 2013 were measured in the landfill body at depths of 50 cm, 75 cm, and 100 cm. The average outdoor temperature during the reporting period of 2013 was 6.5°C, at 10 cm depth 9.9°C, at 50 cm depth 12.3°C, at 75 cm depth 12.0°C, and 100 cm depth 11.5°C.

Based on mean monthly temperature figures in the period January-September 2012 the differences between outdoor temperatures and temperatures at 100 cm depth of the landfill body in particular months were calculated. In addition, average annual value of the difference between outdoor temperature and temperature at 100 cm depth of the landfill body was determined. The obtained results were recorded in graph (Fig. 7).

The highest mean monthly value of the difference between outdoor temperature and the temperature at 100 cm depth in 2013 was determined for August (8.6°C) and the lowest for April (2.0°C). Average annual value of the difference between outdoor temperature and the temperature at 100 cm depth of the landfill body in 2013 amounted to 5.2°C.

Conclusions

This study was conducted to extensively investigate heat generation in landfill on a field scale, including the variation of temperatures. Data were collected at Štěpánovice landfill located in Czech Republic. Temperatures were determined over 21 months. The conclusions provided below are drawn based on long-term monitoring of temperatures within various depths of a municipal solid waste landfill:

- Mean annual value of the difference between outdoor temperature and temperature at a depth of 100 cm in the landfill body in 2012 amounted to 5.4°C, and for the reporting period of 2013 it was 5.2°C.
- No significant differences among measured temperatures were recorded at particular depths (50 cm, 75 cm and 100 cm).
- Mean temperature at the surface of the landfill within the whole reporting period was 3.2°C higher than ambient temperature (in the reporting period). This is explained due to the decomposition activity within the landfill site leading to the emission of warm gases from the site.

Year 2013

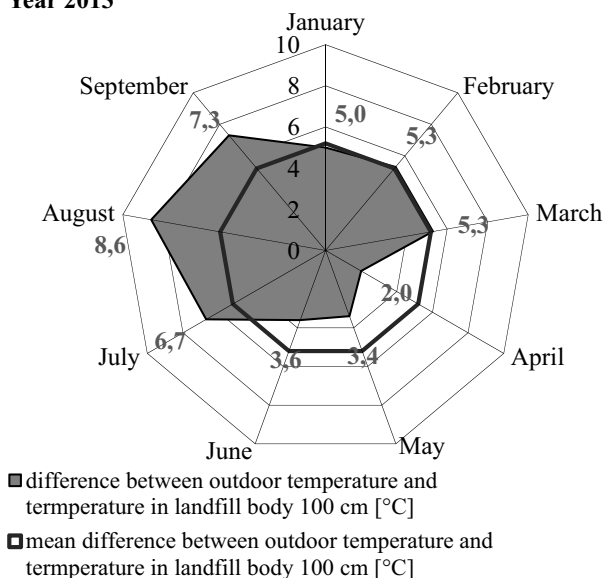


Fig. 7. Differences among outdoor temperatures and temperatures at 100 cm depth of the landfill body in 2013.

- Temperature may be a significant factor affecting plant establishment and growth.
- The results provide new information for the estimation of the selection of plant species suitable for reclamation, which have higher chances to tolerate the unfavourable conditions they would be exposed to at a technically reclaimed landfill body.

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