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Prototype heat exchange and monitoring system at a municipal solid waste landfill in China

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ABSTRACT

A prototype heat exchange and monitoring system was installed and operated in a newly filled municipal solid waste (MSW) landfill, located in Wuxi City, China. In this study, a test was conducted using the system to investigate the influence of heat exchange on waste temperature over three heat exchange stages. During the period of sharp increase of waste temperature, the first stage test was performed, whereas during the period of gradual increase of waste temperature, the second and third stages were performed. The results showed that (1) the waste temperature increased during the first two months after the commencement of temperature observations. This increase in temperature partially counteracted the effect of the heat exchange system on waste temperature during the first stage test. (2) During the subsequent 360 days, the waste temperature increased gradually. The influence of the heat exchange system was relatively more effective during the second and third stages than during the first stage. (3) During the test, the waste temperatures showed similar changes throughout the saturated portion of the waste, which was below the leachate level. (4) At ten days after the third heat exchange stage, the waste temperature increased gradually to the previous elevated temperature. The results of the test demonstrate that waste temperatures are mainly affected by thermal conduction in the waste mass and thermal convection in the leachate. Moreover, preliminary suggestions are provided for the installation of heat exchange pipes in landfills.

1. Introduction

The heat generated in the biodegradation of municipal solid waste (MSW) has a considerable influence on biochemical reaction processes in waste and the geosynthetic material processes within the liner system and pipe networks of the landfill, and contributes to the rise in temperature in MSW landfills (Dach and Jager, 1995; Houi et al., 1997; Yoshida et al., 1997; Rowe, 1998; Koerner, 2001; Yeşiller and Hanson, 2003; Yeşiller et al., 2005; Hanson et al., 2010; Bouazza et al., 2011; Jafari et al., 2014; Megalla et al., 2016). Faitli et al. (2015a) were the first to report that heat generation in landfills could be used as a new thermal energy resource. Heat exchange as well as conventional gas exchange from MSW landfills represent viable sources for energy production (Coccia et al., 2013; Grillo, 2014). According to the statistical yearbook published on October 13, 2017, by the National Statistical Bureau of the People's Republic of China, the total weight of MSW generation in China in 2016 was 203.620 million tons, of which 118.664 million tons was disposed into sanitary landfills. If the heat energy in landfills can be utilized, it will lead to the conservation of other energy sources and also decrease the volume of greenhouse gases emitted into the environment. Additionally, the optimum range of temperature for mesophyll biochemical decomposition is 30–41 °C (Hartz et al., 1982; Barlaz et al., 1987; Cecchi et al., 1993); however, in landfills, the waste temperature is often higher than this optimum range (Hanson et al., 2010; Jafari et al., 2014). The MSW temperature can be controlled within the optimum range by regulating the waste temperature, which will increase the degree of organic degradation and decrease the time required to achieve a steady state of biodegradation. Yeşiller et al. (2016) systematically reported that the changes in waste temperature can result in the creation of a new type of bioreactor landfill. Moreover, the high temperatures in landfills weaken the properties and service life of geosynthetic materials in the liner system (Rowe et al., 2010; Jafari et al., 2014; Hanson et al., 2015). According to the prototype

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heat exchange test of an MSW landfill, the working state can be optimized by regulating the waste temperature in landfills; therefore, preliminary empirical data can be obtained from field tests for practical engineering applications. In this study, the prototype heat exchange monitoring system was conducted to (1) measure the variations of waste temperature in a newly-placed MSW layer; (2) identify the characteristics of the increase in waste temperature for the newly placed MSW layer; (3) monitor and investigate the variations of waste temperature during the test in three heat exchange stages; and (4) present suggestions for the design of temperature regulation in landfills.

2. Description of the installation of the prototype heat exchange and monitoring system

The heat exchange and monitoring test was conducted in a relatively new layer of landfill in Wuxi City, China, which is approximately 100 km northwest of Shanghai. A cross section through the Wuxi landfill reveals that it is basically composed of two parts. The bottom approximately 30 m section is composed of old waste, and the upper about 8.4 m section is composed of a thick layer of newly deposited waste that was placed on December 19, 2015. In the newly filled MSW layer, a 25 m long, 15 m wide and 8.4 m deep area was demarcated for the prototype heat exchange test. In Wuxi City the average air temperature is about 18 °C and the precipitation is 2001 mm/year. Fig. 1(a) shows a schematic drawing of the prototype heat exchange system.

High density polyethylene (HDPE) pipe with an outer diameter (OD) of 160 mm and a length of 20 m was used as the protection pipe (PE-1) for the copper and polyethylene of raised temperature resistance pipes (PE-RT pipes) that conveyed the circulating water in the prototype heat exchange system, to maintain the high quality of the circulating water. As shown in Fig. 1(a) and (b), the horizontal part of the PE-1 pipe was filled with water to allow heat to be transferred easily. Fig. 1(b) shows a cross-sectional view of the water circulation system consisting of copper pipes, PE-RT pipes and the PE-1 pipe. Two copper pipes (OD: 20 mm) and two PE-RT pipes (OD: 20 mm) were placed in the PE-1 pipe as water loop pipes. During the heat exchange test, water was pumped through the copper and PE-RT pipes, and flow gauges were connected to the copper and PE-RT pipes. A pump with a nominal flow rate of 1.11 kg/s was submerged in the water tower with a capacity of 10 m^3 and connected to the copper pipes and the PE-RT pipes. The flow rates of the circulating water during the three stages were 0.35–0.39 kg/s, 0.35–0.38 kg/s and 0.36–0.38 kg/s, respectively. Arrays of temperature sensors (range: −30 °C to 70 °C; accuracy: ±0.1 °C) were placed at specific intervals on the protection pipe (PE-2) as shown in section I and section II of Fig. 1(a) and Groups A-D in Fig. 2(a). The temperature sensor cables were passed through the PE-2 pipes to the surface of the landfill for the monitoring and recording of waste temperature. A total of 35 temperature sensors were used in the test, with three temperature sensors placed in the water tower and at points L and R (Fig. 1) of the PE-1 pipe, Group A (9 sensors) and Group C (9 sensors) placed in the

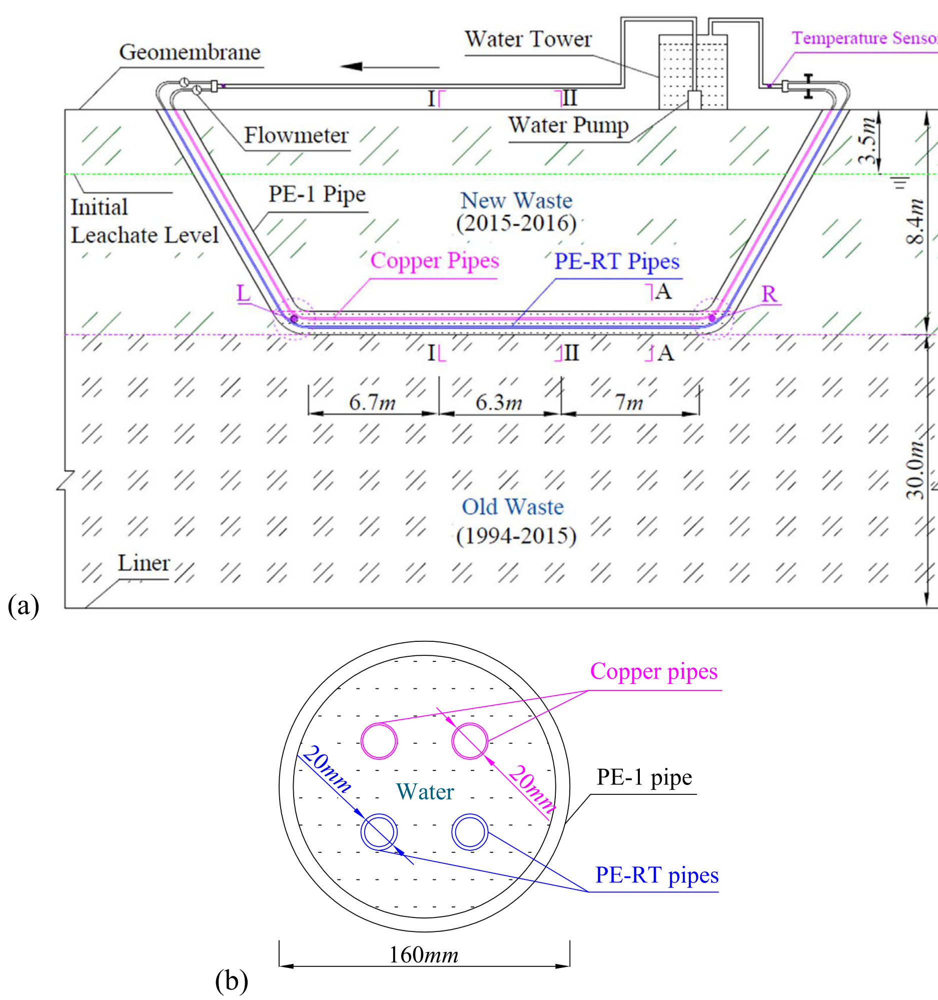

Fig. 1. Prototype heat exchange system: (a) schematic drawing of prototype heat exchange system; (b) schematic cross-section (Section A) of the water circulation pipes.