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Characterization of thermal properties of municipal solid waste landfills

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ABSTRACT

Municipal waste landfills represent not only a source of landfill gases, but a source of thermal energy as well. The heat in landfills is generated by physical, chemical and microbiological processes. The goal of our study was to characterize the thermal properties of municipal solid waste (MSW) samples of the given landfill. A new apparatus was designed and constructed to measure heat flow. A systematic test series of 17 discrete measurements was carried out with municipal waste samples of 1.0–1.7 m^3. The thermal conductivity, heat diffusivity and specific heat capacity of the samples were determined.

Analysing the results of the sampling and our experiments it was realized that the theoretical fundaments should be clarified. Two theories were developed for the serial and for the parallel heat flow in three phase disperse systems. The serial and parallel models resulted in different theoretical estimations. The measured thermal conductivity and heat diffusivity were better characterized by the parallel heat flow estimations. The results show that heat can flow parallel in solid, liquid and gas phases. Characterization of thermal properties serves to establish the fundament of heat extraction from municipal waste landfills.

1. Introduction

“Service for the future” is the motto of .A.S.A. International. The Hungarian branch of .A.S.A. International is highly motivated in its research and development pursuits aimed at protecting our environment. Its employees produced the first RDFs (refuse derived fuel) in Hungary, they have a landfill gas utilization system and they are working on R&D projects having to do with soil amelioration by innovative waste utilization technologies and also on landfill decomposition heat utilization.

In Hungary landfilling plays a significant role in MSW handling processes. In spite of the fact that disposal of municipal wastes by landfilling has become the final and least preferable solution according to the hierarchy of waste management, 4.6 million tons of municipal solid waste is still landfilled yearly. Not to mention the many existing waste landfills, this can be treated as raw material for the future. Although up-to-date technologies exist to produce energy from landfill gases, the efficient utilization of the large amount of heat produced in waste by decomposition processes is still problematic. A large amount of heat is stored by the material mass of a landfill. .A.S.A. Hungary Ltd. realized this problem and started to study this field. The “DEPOHO – KMR 12-1-2012-0128” research and development project is working to establish the fundaments and develop solutions related to heat exchanging, extracting and utilization technologies.

The characterization of thermal properties is essential in estimating the heat extraction potential, planning the technology and controlling the decomposition processes inside a landfill. It is essential to avoid undercooling, because appropriate temperature is important for the biological decomposition processes and for methane production. Landfill gas utilization (electricity production), followed by heat extraction, has the highest priority. An additional advantage in using heat exchangers within landfills is that their operation along with the landfill processes may be controlled. According to Coccia et al. (2013) not only processes going on inside the landfills can be controlled but the expected life service of the landfill liner system can also be influenced. If high temperatures are forming in the bottom of a landfill, great demands are made on the elements of the landfill liner system (HDPE geomembrane) resulting in the dehydration of the geosynthetic clay liners (GCLs). These harmful effects can be decreased by heat removal from the base of landfills. According to Viebke et al. (1994), exposed to a maximum temperature of 20 °C, the service life of a typical HDPE geomembrane is expected to be approximately 600 years. The service life of HDPE geomembrane decreases to less than 50 years if exposed to temperatures around 50 °C. This paper reports on the development of a new measuring device and evaluation protocol

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to determine the thermal (thermal conductivity, specific heat and heat diffusivity) and physical (bulk density and volumetric fractions of the three phases) properties of municipal waste landfills.

2. Current state of knowledge

2.1. Area description

The .A.S.A. Hungary Ltd. operated landfill is located in Gyál – Hungary, where 100,000–150,000 tons of mixed municipal solid waste is landfilled every year. Up till now five landfill sections have been put into operation. Samples were only taken from the II–III–IV landfill sections. Table 1 shows the geometric characteristics and the period of deposition time of the five different landfill sections (see Fig. 1).

The landfill under study represents an up-to-date facility. The applied landfilling technology includes landfilled waste compaction with compactors and periodical inert material covering. There is an installed advanced leachate collection system with drainage and isolated leachate ponds. Leachate is sprayed back into the waste body regularly without pre-treatment. There is an installed state of the art active type of landfill gas extraction (vacuum is applied) and utilization system as well. The installed electricity production power is higher than 2 MW.

2.2. Thermal properties of disperse materials

The heat flow in materials, especially in disperse multi-phase systems is a really complicated phenomenon. In our study the heat conductance through a three phase disperse system (landfilled municipal waste) is studied. The internal energy of a continuous phase material is determined by the molecular kinetic energy of the microscopic building "blocks" of the material. The molecules in the higher temperature zone with higher kinetic energy exchange vibration energy with their neighbors resulting in heat flow from the higher temperature zone into the lower temperature zone. Heat goes through a phase interface similarly with oscillating energy exchange between the molecules of the phases. Thermal conductivity describes the magnitude of ability of the conducting heat of a given material (λ, unit: W/m K). Thermal conductivity is the quantity of heat transmitted due to the unit temperature gradient in unit time under steady conditions, in a direction normal to a surface of unit area (Perry and Green, 1997). This definition explains why the thermal conductivity of a vacuum is zero. In a vacuum there are no vibrating molecules, which are capable to transmit heat. The other two thermal parameters of continuous one phase materials are the specific heat capacity C_m and the thermal diffusivity κ. The specific heat capacity (C_m, unit: J/g K) describes the ability of a given mass of a substance to store internal energy while undergoing a given temperature change, but without undergoing a phase transition (Lide, 2009). The thermal diffusivity (κ, unit: m^2/s) is the thermal conductivity divided by density and specific heat capacity at constant pressure (Gladwell and Hetnarski, 2009).

Table 1
Geometric characteristic and period of deposition time of different landfill sections.

Identification number of landfill sections	Geometric size (m^3)	Period of deposition time
I	377,596	1999–2003
II	426,322	2003–2006
III	593,059	2006–2009
IV	400,000	2009–2012
V	423,900	2012–2014

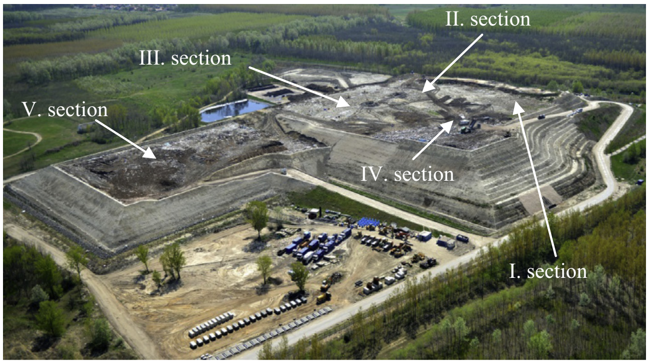

Fig. 1. The municipal waste landfill in Gyál.

The inherent thermal properties of continuous phases have been described, but the situation is much more complex for unsaturated porous media. The macroscopic conduction of heat is microscopically a complicated multiphase process with strong convective components. Thermal behavior of materials is strongly affected by phase shifting; the effective thermal properties of phase shifting have to be taken into account. The latent heat in the vapor phase and the sensible heat in the liquid phase play significant roles as well. A rather interesting phenomenon is the following. If particles are packed together, and rough wetting covers the surface of them, a curved water–gas interfacial surface develops around the pores. Consequently, because in this case the interfacial energy cannot be neglected, the evaporation temperature will change (Roth, 2012). Later we will see that the macroscopic results measured by the developed test equipment are really affected by these mentioned phenomena, but theoretical consideration is not given here. Instead, only the inherent thermal properties of disperse materials are investigated. In the following let's examine the resultant (inherent) thermal conductivity of solid–gas two phase's disperse systems. A very simplified approach to describe this situation is the model when virtually all the particles form a continuous solid body instead of their real dispersity state (Figs. 7 and 8). There might be two virtual setups regarding the direction of the heat flow. If heat goes serially through the phases, then the gas phase determines the heat flow. The resultant serial conductivity will be low, representing the lower limit. If heat goes parallel through the phases, one part of it can easily go through the solid phase and the other part finds itself faced with the low conductivity gas phase. The resultant parallel thermal conductivity is the upper limit. (Equations for serial and parallel three phase inherent thermal conductivities are presented in Section 5.1). The resultant thermal conductivity of a real solid–gas disperse system falls in between the limits, and it depends on many parameters, namely the particle size-, shape-, and density distributions and, basically the concentration. The first to introduce a model was probably Maxwell (1873) who offered one for dilute two phase systems, when there is no particle–particle contact in the system. Later, many others developed different models (Zehner and Schluder, 1970; Cheng and Hsu, 1999) for different dispersity states and materials (Kandula, 2011).

2.3. Thermal properties of soils

In the previous section the thermal complexity of unsaturated porous media was demonstrated. In the case of municipal wastes the situation is more complicated, because in the solid phase, the waste itself is very heterogeneous and contains many organic and many inorganic components as well. There are only a few works (Gori and Corasaniti, 2013; Altimi et al., 2014) dealing with this topic in the literature, and no comprehensive study exists. Soils also represent a three phase unsaturated and heterogeneous

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