



# Modeling of thermal mass transfer in porous media with applications to the organic phase transition in landfills

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## Abstract

In order to describe the thermomechanical behavior of landfills, a constitutive model based on the macromechanical Theory of Porous Media (TPM) for a saturated thermoelastic porous body has been developed. The body under investigation consists of an organic and inorganic solid phase and a gas phase. All interaction relations between the constituents such as mass transfers, interaction forces and energy supplies are taken into consideration. Based on a consistent thermomechanical treatment the governing equations are obtained as a set of equations which consists of the balance equations of momentum and mass for each individual constituent, the balance equation of energy for the mixture and the physical constrained conditions. In this set of macroscopic equations, several parameters are contained. They are interrelated by constitutive relationships in order to complete the system of equations. This procedure renders the set of equations solvable. Thus, we obtain a mathematical concept to describe the motion of the solid phase, the pressure of the gas phase, the temperature of the mixture and the biodegradation of organic material into a gas mixture of methane and carbon dioxide produced by bacterial decomposition during stable methane fermentation (biogas).

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## 1. Introduction

The European Union is at the forefront of international efforts to combat mitigate climate change, one of the greatest environmental and economic threats facing the planet. The Earth's average surface temperature rose by around 0.6°C during the 20th century. It seems to be evidence that most of

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the global warming over the last 50 years is attributable to human activities which cause emissions of carbon dioxide ( $\text{CO}_2$ ), methane ( $\text{CH}_4$ ) and other greenhouse effect gases. Landfilling belongs to an important global source of greenhouse gases.

The EU strives for all industrialized countries to take urgent action to reduce or limit their future greenhouse gas emissions (Council Directive 99/31/EC, Article 1, 26 April 1999), see [1]. According to the estimations by Intergovernmental Panel on Climate Change [2], the global average surface temperatures is expected to rise. This temperature increase could trigger serious consequences for humanity and other life forms alike, including a rise in sea levels and severity of extreme weather events, see [3,4].

The conversion processes in landfill body are an important global source of methane and carbon dioxide. Landfilling is worldwide the most widespread waste disposal practice. After solid wastes are deposited in a landfill, physical, chemical and biological processes modify the waste, whereby carbon dioxide ( $\text{CO}_2$ ) and methane ( $\text{CH}_4$ ) will be produced. Both substances cause the greenhouse effect in the atmosphere, however, one molecule of methane has a 21-fold specific greenhouse potential compared to one molecule of carbon dioxide, see Houghton et al. [5]. Lack of understanding and experience with respect to the long-term behavior of such systems is remarkable. In this case, the time scale belongs to hundreds of years. Therefore, development of a numerical model describing the effect of solid phase composition (consisting of organic and inorganic materials) and the pore structure of the landfill body

on the conversion phenomena and multi-component gas transport is of great importance.

The biological and chemical effects in a landfill have a strong interrelation between each other which leads to a highly coupled set of differential equations to be solved. This has been done within the framework of a standard Galerkin procedure whereby the resolving weak formulations are inserted into the finite element program FEAP. Thus, we are able to express the usefulness of the proposed theory by dint of a numerical simulation.

However, first of all a consistent model has to be developed. This has been done based on the well established Theory of Porous Media for which basic relations will be summarized in the following section.

## 2. Theory of Porous Media

The Theory of Porous Media is the mixture theory restricted by the concept of volume fractions. Hereby, we consider a continuum which consists of several constituents. As aforementioned, the investigated porous body consists of  $\varphi^S$  (solid),  $\varphi^O$  (organic),  $\varphi^L$  (liquid) and  $\varphi^G$  (gas), see Fig. 1. In the volume fraction concept it is assumed that the porous solid always models a control space and that the pores are statistically and homogeneously distributed. A porous medium occupying the control space of the porous solid  $B_S$ , with the boundary  $\partial B_S$ , consists of constituents  $\varphi^\alpha$ , ( $\alpha = S, O, L, G$ ) with real volumes  $v^\alpha$ , where the index  $\alpha$  denotes  $\kappa$  individual constituents. The boundary  $\partial B_S$  is a material surface for the solid

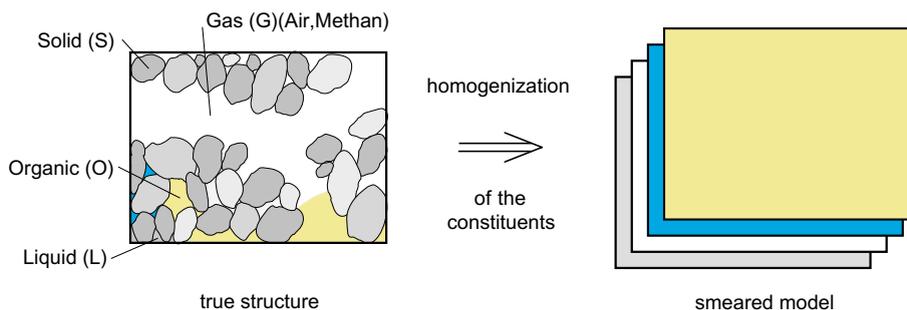


Fig. 1. Homogenization.

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