Identification and experimental determination of important thermal and hydraulic properties of bedding materials for energy cables

Markus **SCHEDEL**, Christoph **DREFKE**, Ingo **SASS**; TU Darmstadt, Geothermal Science and Technology, Darmstadt Graduate School of Excellence Energy Science and Engineering, (Germany), schedel@geo.tu-darmstadt.de, drefke@geo.tu-darmstadt.de, sass@geo.tu-darmstadt.de

Natalie Simone **JACOBS**, Jan **BRÜGGMANN**; Amprion GmbH, (Germany), NatalieSimone.Jacobs@amprion.net, jan.brueggmann@amprion.net

ABSTRACT

The performance of underground cable systems depends significantly on the thermal properties of the surrounding bedding material and soil. However, the thermal properties of these materials are not constant over time and space but strongly influenced by the respective water content at cable laying depth. The paper illustrates important hydraulic and thermal soil and bedding material properties and methods to determine them experimentally as well as an approach to estimate the relevant boundary conditions with numerical simulations using meteorological data.

KEYWORDS

Thermal cable rating, bedding material properties, boundary conditions.

INTRODUCTION

In order to prevent an accelerated thermal aging or even insulation faults in cable systems due to overheating, the current carrying capacity is usually limited by specific conductor temperatures. As the heat produced by the cables has to be dissipated to the environment, the actual performance of a buried energy cable system is primarily dependent on the thermal properties of the surrounding porous bedding material and soil.

Cable rating calculations based on the IEC standards [1, 2] assume that the bedding material and soil are homogeneous materials with constant material properties or considering in general just two saturation conditions of the material surrounding the cables (wet or dry). However, buried electric cables are at common installation depths from 0.7 to 2.0 m almost exclusively located in unsaturated soil above the groundwater surface. In this area the pore space of porous media like soil is filled with air and water at varying proportions as a result of strongly variable hydraulic potentials by temporal fluctuations of natural environmental and climatic conditions. Since both thermal conductivity and heat capacity of the cable surrounding material vary in dependence of its water content in the range of one order of magnitude, it is crucial to determine the required parameters for cable rating calculations using adequate boundary conditions like saturation or hydraulic potential. In addition to the simplified calculations according to IEC, an exact knowledge of the boundary conditions is also necessary, especially for approaches that use the coupled heat and mass transport in unsaturated porous media for ampacity calculations [3-5].

Although many publications point out the importance of ambient conditions such as temperature or water content, especially in context with the formation and propagation of dryout zones around the cables [7 8], only few approaches for the determination or estimation of these parameters are available. In the late 1980s Koopmanns et al. [9] proposed a thermal rating procedure for cables buried in sand that considers the ambient temperature and the water content at cable level as boundary conditions in addition to the material properties of the soil. They suggested to derive worst-case water contents from the lowest ground water tables as well as to use a water balance model on the basis of meteorological data if it is assumed that evaporation and infiltrating precipitation might influence the moisture content at cable depth.

It seems, however, that this promising approach was not consistently applied in the following years and therefore it is still a major problem nowadays to define adequate boundary conditions for the determination of the required input parameters for the cable rating calculations. Thus, in practice these boundary conditions are usually still defined arbitrarily without considering all influencing factors on the effective thermal properties of the bedding materials.

Therefore, in this contribution important hydraulic and thermal soil and bedding material properties as well as boundary conditions are outlined. Furthermore this paper will give some recommendations for the experimental determination of these properties as well as present the results of a study to estimate the worst-case ambient conditions of the cable surrounding soil. Numerical simulations using coupled heat and mass transfer in unsaturated porous media were carried out using meteorological data from all over Germany of the year 2018 with unusually hot and dry weather as well as exemplary experimentally determined soil parameters.

BEDDING MATERIAL PROPERTIES

Under isothermal conditions, the movement of water in porous media follows hydraulic gradients. In unsaturated materials like soil, the hydraulic potential consists of several specific potentials describing the influence of the various forces acting in the soil on the pore water [10]:

$$h = \psi_z + \psi_m + \psi_g + \psi_o \quad [1]$$

h	Hydraulic potential	in m
ψ_z	Gravitational potential	in m
ψ_m	Matric potential	in m
ψ_g	Gas potential	in m
ψ_o	Osmotic potential	in m

Uniform water flow in variably saturated porous material is usually described using the following equation, also often referred to as Richards equation, or one of its extensions [10]: