# A THERMO-HYDRO-MECHANICAL FINITE ELEMENT MODEL OF FREEZING IN POROUS MEDIA—THERMO-MECHANICALLY CONSISTENT FORMULATION AND APPLICATION TO GROUND SOURCE HEAT PUMPS

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## ABSTRACT

Freezing phenomena in porous media have drawn great attention in geotechnics, construction engineering and geothermal applications [1]. Solid-liquid phase transitions in porous media are accompanied by volume changes and coupled to heat and mass transfer. Namely, the latent heat of phase change can retard temperature changes around the phase transition temperature and groundwater flow patterns are altered by freezing and thawing processes. Therefore, the THM coupled behaviour of the water-ice-solid mixture plays an important role for predicting frost resistance and propagation.

A macroscopic THM freezing model is derived based on the Theory of Porous Media (TPM). The entropy inequality is utilized to derive the thermodynamically consistent constitutive laws to supplement the balance equations. In this study, we focus on an equilibrium approach for ice formation. The specific relations characterizing the freezing process can be formulated to account for typical features observed during phase change in porous media such as latent heat of fusion, alteration of porosity and different natural configurations of ice and solid phases. To accommodate for large volume dilatations induced by ice formation, both infinitesimal and finite strain approaches are considered. The model facilitates physical insight into THM aspects such as micro-cryo-suction and the pore space blockage. While the THM model itself can describe phase change in porous media in a general way, the coupling to specific technical systems like a numerical model of borehole heat exchangers makes it suitable for practical use in the design of, e.g. shallow geothermal applications.

## REFERENCES

[1] Tianyuan Zheng, Haibing Shao, Sophie Schelenz, Thomas Vienken, Zhonghe Pang, Olaf Kolditz and Thomas Nagel "Efficiency and economic analysis of utilizing latent heat from groundwater freezing in the context of borehole heat exchanger coupled ground source heat pump systems", Applied Thermal Engineering, 105 (2016), 314-326.