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Exploring the Impact of Ice Formation on Soil Temperature for Ground Source Heat Pumps

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Soil temperature is a key parameter defining the coefficient of performance (CoP) for shallow burial ground source heat pumps (GSHP). Whilst many studies incorporate the effects of temperature attenuation due to conduction and temperature reduction due to evaporation, few studies incorporate the effects of latent heat of fusion associated with ice formation/thawing. This latter effect will be more important in areas experiencing continental climates, where GSHP is considered to be particularly attractive.

Our project concerns developing an appropriate numerical modelling framework to explore the impact of ice formation/melting on GSHP-CoP. As a simple first step, we developed a heat conduction model accounting for moisture freezing and thawing combined with evaporation. The water is assumed immobile within a rigid solid porous matrix. Water within the soil matrix exists as either ice or liquid. Gains and losses of heat due to ice formation/thawing, respectively, occur throughout the model domain. Loss of heat due to evaporation occurs only at the soil surface, with water being instantaneously replaced such that the total mass of water in the system remains constant. The water (both ice and liquid) and soil are assumed to be in local thermal equilibrium. The resulting partial differential equation (PDE) uses specific internal energy as the primary dependent variable. Numerical solution is achieved using the method of lines.

An important factor that appears during the phase transition is the melting point temperature depression. Researchers mainly use a modified version of the Clapeyron equation known as the *generalised Clapeyron equation*, which estimates the equilibrium relationship between the temperature and pressure in freezing soils. Modifications to the original Clapeyron equation have been considered necessary because of potential misunderstandings about how matric potential (the capillary suction associated with soil pores) affects the melting temperature of ice.

To explore these ideas further, we studied the process of freezing of compressible water in a rigid tank of constant volume. The classical Clapeyron equation was coupled with the specific water volume functions to obtain two coupled ordinary differential equations (ODEs). These equations were then extended to consider freezing of water in a porous medium using constant rock properties and a uniaxial strain assumption. By solving the ODEs we were able to plot freezing point temperature as a function of liquid water volume fraction for different rock compressibilities.

Our preliminary simulations demonstrate important aspects concerning the effect of ice on soil temperature. The presence of ice leads to significant delays in changes in temperature around the melting point. Furthermore, heat conduction within the ice is faster due to its higher thermal diffusivity as compared to liquid water. There is also a significant difference between how the liquid water volume fraction depends on freezing temperature for the rigid tank model with and without uniaxial strain condition. It is expected that such effects will have a significant impact on GSHP-CoP. Future work will involve incorporating a more accurate representation of liquid and vapour movement within the soil as well as the effect of salt on the melting point depression.

Participation

In-Person

References

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