[Review]

Application of the Arrhenius Equation in Geotechnical Engineering

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The reliable measurement of geotechnical properties in cold regions should account for their fluctuations with temperature. The objective of this paper is to introduce a chemical model based on the Arrhenius equation that can predict the properties of materials as their temperature changes. The model can monitor phases and reaction rates as they change with temperature. It has been already applied in the fields of geology, construction, chemistry, materials engineering, and food science. The application of the Arrhenius equation requires a reliable estimate of the activation energy. Therefore, this study also demonstrates several methods for evaluating activation energy in different contexts through summaries and reviews of previous research related to the Arrhenius equation. This paper may be of wide use in obtaining temperature-dependent parameters in geotechnical engineering.

Key words: activation energy, arrhenius equation, geotechnical engineering, phase change, temperature

Introduction

The establishment of a reliable rail link between Europe and Asia has effected notable economic stimulation through improved transportation. The northerly latitudes, including those of the Korean Peninsula (33°-43° N), can show continuously low temperatures even in daytime. At low temperature, soil becomes dense because there is more pore water in the soil, and the soil is also less porous. Andersland and Ladanyi (1994) describe frozen soil as a class of soil, and various researchers have sought to characterize frozen soil. Isaksen et al. (2001) suggested the importance of an active layer after measuring temperature depth profiles through soil. Harris et al. (2003), Humlum et al. (2003), and Rachlewicz and Szczucimski (2008) tried to distinguish frozen layers by measuring long-term temperature data. Invasive methods are limited in that they must penetrate the stiff soil, and non-invasive geophysical methods have been used to examine frozen soil. Gibas et al. (2005) proposed an electrical resistivity survey to detect layers from measured resistivity profiles. Westermann et al. (2010) used Ground Penetration Radar to estimate subsurface properties. However, the practical use of these techniques has mostly been limited to conditions above 0°C, and measuring frozen soil in winter remains difficult. Experimental and numerical studies should be performed under winter conditions to determine reliable design parameters.

The Arctic and Antarctic are representative areas consisting of frozen soil that can have similar strength to rock. In such cold regions, penetration tests of strength and other properties are hampered by the difficult conditions. How-

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ever, it is possible to predict the design parameters of cold materials using data measured under non-freezing conditions. Predictions can be made owing to the relationship between the products and reactants of phase changes due to temperature. The Arrhenius equation is the appropriate model for predicting parameters according to phase changes, and it can be used to estimate the properties of materials as temperature and energy change (Amasaki et al., 2000; Galwey and Brown, 2002).

This paper introduces the Arrhenius equation and its use to estimate parameters as temperature varies. The application of the Arrhenius equation in various fields is also examined. Among the equation’s input values, the activation energy denotes the energy required to effect a change of phase. The accurate estimation of activation energy is important. Therefore, the method of determining the activation energy is also addressed. Finally, the possibility of using the technique in geotechnical engineering is explored.

**Arrhenius equation**

The Arrhenius equation, suggested by Svante Arrhenius in 1889, is based on the van’t Hoff equation, and it was initially applied to the temperature-dependence of reaction rates. Even though the apparently simple equation is based on the empirical relationship between temperature change and reaction rate, it provides remarkably accurate predictions.

Reacting molecules need to collide with a certain energy in order to react, and their velocity is proportional to the energy of collision. Therefore, temperature, through its effect on molecular velocities, greatly affects the reaction rate. Other factors that influence the rate of a reaction include the type of reaction, the effect of any catalysis, and the reactants’ concentrations. Among these factors, this paper focuses on the effects of temperature with regard to phase changes.

Morrison and Boyd (1978) suggested that the reaction rate (R) is the product of the collision frequency (C), an energy factor (E), and an orientation factor (O), as shown in equation (1). The energy factor relates to the energy of a collision being sufficient to perform the reaction, and the orientation factor is related to the probability of collision,

\[
R = C \cdot E \cdot O \quad (1)
\]

as follows:

\[
K = A \cdot e^{-\frac{E_{act}}{RT}} \quad (2)
\]

where \(k\) is the final reactant, \(A\) is constant, \(E_{act}\) is the activation energy (kJ mol\(^{-1}\)), \(T\) is absolute temperature (K), and \(R\) is the gas constant (8.314 J K\(^{-1}\) mol\(^{-1}\)).

**Application of the Arrhenius equation**

The Arrhenius equation shows that the reaction rate (as