Prediction of Injection Radius for Soil Improvement Processes with Biogrout (MICP)

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ABSTRACT

Microbial induced calcium carbonate precipitation (MICP) is an innovative method in soil improvement, primarily applied to sandy soils. This technique is classified as a sustainable (green) method of soil improvement due to its environmental compatibility and has garnered significant attention from researchers in recent years. However, the novelty of this field means that most research has been conducted at the laboratory scale, highlighting the need for realistic physical models.

This research investigates the soil injection process for different fluids. Firstly, the injection of water into the soil is simulated using the finite volume method, and the results are validated against those obtained from simulations performed in Seep/w software. This comparison confirms the accuracy of the finite volume method in predicting water movement around the injection pipe. Next, the injection of bio-grout and its movement within the soil matrix is simulated using the finite volume method, with these results compared to a physical model constructed under laboratory conditions. The modification of the Richards equation to estimate permeability in the radial direction around the injection point results in a simulation that closely approximates the actual injection of bio-grout into the soil. The rate of advance of the saturation front for bio-grout is slower than that for water, and the positional difference in the injection radius between these two fluids becomes more pronounced over time.

KEYWORDS

Richard's equation, injection radius, saturation front, bio- grout, finite volume method

1.Introduction

Microbially Induced Calcium Carbonate Precipitation (MICP) is an innovative technique that uses bacteria to induce calcium carbonate precipitation, effectively enhancing the mechanical properties of loose sandy soils[1]. This method has shown promising results in improving soil stability and shear strength, particularly in marine environments[2]. However, the durability of MICP-treated sands under conditions such as wet-dry cycling and seawater exposure poses challenges, with jute fiber reinforcement proposed as a possible solution[3]. Additionally, studies have explored MICP's effectiveness in mitigating wind erosion and addressing heavy metal contamination[1, 2]. The reduction in soil permeability through MICP is influenced by factors including solution concentration and sand structure[4]. Overall, MICP presents extensive applications in environmental remediation and soil improvement, making further research essential in this emerging[5].

1. Methodology

2-1 Materials

In this study, Firoozkooh 161 sand, a uniform silica-fractured sand, was used. physical properties are summarized in Table 1[3, 6, 7].

Table 1. specifications of the sand 161 firoozkooh

D_{10} (mm)	0.136	C_c	0.969
D_{30} (mm)	0.202	C_u	2.261
D_{60} (mm)	0.308	e_{max}	0.910
G_s	2.65	e_{min}	0.612

2-2 Bacteria and Cement Solution

Pasteuric sporosarcina bacteria were selected due to their high urea activity, Gram-positive nature, and ability to thrive at pH levels above 8.5 and in high calcium concentrations [6, 8, 9]. Primary cultivation was performed in solid nutrient broth supplemented with 2% urea. The subsequent liquid culture medium was prepared under aerobic conditions with a pH of 9 using sodium hydroxide for adjustment. The liquid culture was incubated at 25±2 degrees Celsius and stirred at 180 rpm for 24 hours. Optical density measurements, taken at a wavelength of 600 nm to assess bacterial growth, indicated an optimal value of 0.84[10]. Bio-grout was prepared by combining the culture medium and cement solution in equal volumetric ratios, as detailed in Table 2.

Table 2: Composition of culture medium and injection solutions

Solution	Substance	amount
Culture medium	Yeast Extract	20 gr/liter
	NH4Cl	10 gr/liter
	NiCl2	10 micro.mol/liter
Cementation solution	CaCl2	1 mol/liter
	Urea	1 mol/liter

2. Discussion and Results

Immediately after the completion of the injection process, the permeability coefficient was measured under bio-grout and the normalized results of the permeability of 161 firoozkooh sand for bio-grout are plotted in Figure 1.

Figure 2 shows that the radius penetration of liquids for water and biogrout over time. Water displays a higher saturation front volume and saturation rate than biogrout, and this difference increases significantly as time passes after injection.

Figure 3 displays the radial penetration versus time plot for both the physical laboratory model and the developed finite volume method for biogrout. The results indicate that the finite volume method closely resembles those of the physical laboratory model in estimating radial penetration for biogrout.

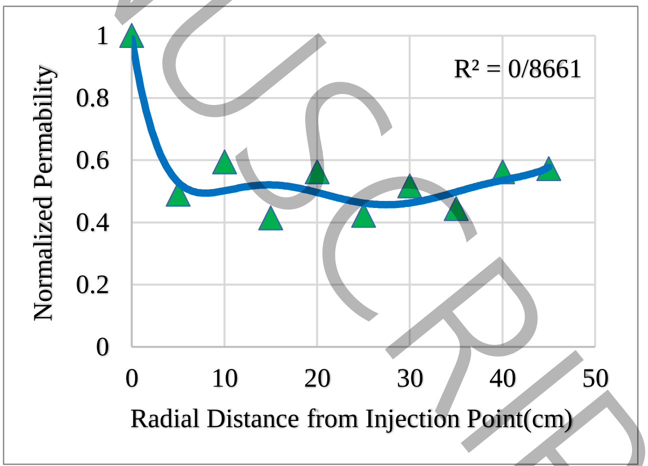

Figure 1. normalized permeability in radial line

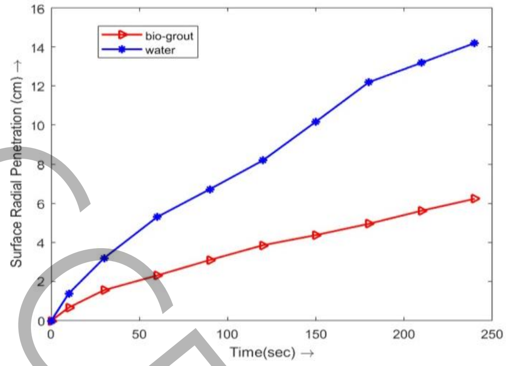

Figure 2. Surface radial penetration in soil for two different fluid (bio-grout and water)

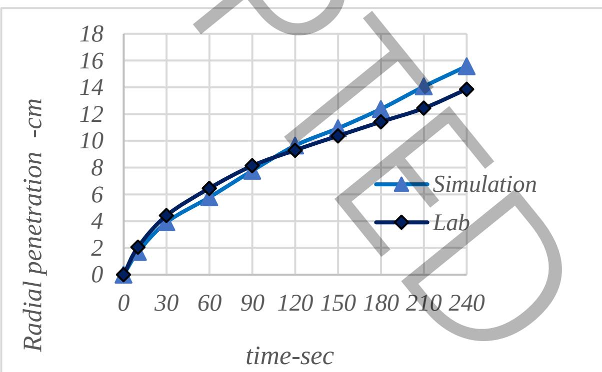

Figure 3. Time History of radial permeability of bio-grout around the injection pipe

3. Conclusions

The study attempted to investigate the penetration radius in the process of injecting bio-grout in soil environment using the Finite volume method.

The laboratory results of the physical model developed for the injection of bio-grout were also compared with the results of the simulation of the finite volume method developed based on the modification of the radial permeability diffusion coefficient. The main results are as follows:

• For non-Newtonian fluids such as bio-grout that react with soil, the use of Richard's theory alone is not used to solve the equation of fluid movement in soil.

• In order to develop the Richard equation to solve the differential equation of the finite volume method, it is necessary to measure the values of calcium carbonate and permeability along the radius and the effect of these is considered as a correction coefficient in the Richard equation.

• The predicted values for the penetration radius at any time of the beginning of the injection, if the fluid is of water type, it is greater than if the fluid is of bio-grout type.

• A comparison of the results of the laboratory penetration radius measurement with the results of the finite volume method simulation shows a small difference, which indicates the accuracy of the method used.

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