HYDRAULIC CONDUCTIVITY OF NON PREHYDRATED GEOSYNTHETIC CLAY LINERS TO ACIDS

Y. Liu[1], A. Bouazza[1], and W. P. Gates[1]
[1]Deparment of Civil Engineering, Monash University, Australia; Tel: +61-03 99058901; Fax: +61-03 99058974
Email: yang.liu@monash.edu,malek.bouazza@monash.edu, will.gates@monash.edu

ABSTRACT

Geosynthetic clay liners (GCLs) are widely used in landfill and other engineering projects as waterproof materials due to their low hydraulic conductivity when in contact with water.However, GCLs are now often expected to contain mining liquids with low pH, and an assessment of GCL performance to acidic liquids is required. The hydraulic conductivity of a commercial Australian geosynthetic clay liner has been evaluated under various effective pressures and concentrations of sulfuric acid solutions. In our study, we modified the traditional flexible wall testing equipment by installing pH and EC sensors in the influent and effluent lines to determine automatically the in/out-flow pH/EC values and therefore assess chemical equilibrium in real time. All the values are compared with the values obtained with water as permeant. The results show that the hydraulic conductivity values increased significantly with the increasing concentrations of acid solutions, the elevated effective stress improved the hydraulic performance of GCLs. All the chemical compatibility tests were conducted on non-prehydrated GCLs.

Keywords: Geosynthetic clay liners, hydraulic conductivity, acid conditions

INTRODUCTION

Geosynthetic clay liners (GCLs) are industry manufactured hydraulic barriers which generally consist of a layer of bentonite(powdered or granular, sodium or calcium)encased between two geotextiles or attached to a geomembrane and combined together by stitching, needle punching and/or gluing with an adhesive(Estornell and Daniel 1992).Since the 1990s, GCLs have been widely used as hydraulic barriers in landfill liners/covers, surface impoundments and waste containment projects (Rowe 2007, Bouazza 2002) due primarily to their low hydraulic conductivity to water ($k<10^{-10}$m/s). For GCLs without an attached film or coating, the low hydraulic conductivitymainly comes from the bentonite component which swells when in contact with water. Typically, sodium bentonite is applied because of its better swelling properties.

GCLs are considered to be equivalent to other hydraulic barriers such as compacted clay liners (CCLs) mainly based on the low hydraulic conductivity to water(Koerner and Daniel 1995). However, in most cases, GCLs are expected to contain non-standard liquids other than water, which may alter the hydraulic conductivity.Therefore, a compatibility test, which uses the non-standard liquids as permeant solutions,should be performed on GCLs specimens to assess the technical equivalency to other barriers.

Numerousstudieshave already been conducted to evaluate the hydraulic performance of GCLs with non-standard liquids. Greater hydraulic conductivity values were found when permeationwithchemical solutions(Ruhl and Daniel 1997, Shackelford et al. 2000, Simpson 2000) and acid mine drainage (AMD) (Kashir and Yanful 2001, Shackelford et al. 2000, Shackelford et al. 2010), but potential pore filling resulted in decreased hydraulic conductivity of a GCL when permeation with alkaline solutions (Bouazza 2002, Gates and Bouazza 2010, Gates and Hines 2010, Benson et al. 2010).However, few studies focused on the extreme pH conditions (i.e. pH<3/pH>10). In mining industry applications, GCLs have a high probability to be in contact with acidic solutions, e.g., in heap leach containment systems (Hornsey et al. 2010)or the acidic leachate resulting from oxidation of impounded tailings(Shackelford et al. 2010). Acid attack may result in increased porosity of bentonite and decreased swelling thus causing increased hydraulic conductivity of the whole GCL(Fall et al. 2009, Gates et al., 2009).Consequently, the main purpose of this paper was to evaluate the compatibility of geosynthetic clay liners under acidic conditions. The result of this study may provide helpful reference to the use of GCLs under acidic conditions.

MATERIALSAND METHODS

Geosynthetic Clay Liners

All hydraulic conductivity tests in this study were conducted on a commercial Australian GCL.The GCL is made from polypropylene geotextiles (woven on one side and non-woven on the other side) and sodium bentonite powder.Fiber-reinforcement by needle-punching across the entire surface of the product and thermally locked to ensure a high shear strength, resulted in an initial unconfined thickness between 5 and 7 mm.For the bentonite component, an undisclosed polymer was added to improve the hydraulic performance. All the technical data of the GCL areshown in Table 1.

Table 1 Technical data for GCL provided by the manufacturer or measured at Monash or by the CSIRO Mineralogical Services.

GCL	
Mass per unit area (g/m^2)*	4380
Geotextile Configuration (Carrier-Cover)*	Woven- Non-woven
Hydraulic conductivity (m/s)[#] (ASTM D5084)	1.5×10^{-11}
Bentonite	
Montmorillonite Content (in bulk)	79
(in <0.2 micron fraction) (%)	100
Cation Exchange Capacity (CEC) (cmol/kg)	78[&] 100[^] 109[$]
Swell index (mL/2g)[#]	23
Fluid Loss (mL)[#]	14
%Exchangeable sodium	63[&&]

Note: [&] CEC measured by ammonium displacement on bulk sample.[^]CEC estimated by Methylene blue adsorption on bulk sample;[$] CEC measured by Ba saturation of < 0.2 micron fraction;[&&] measured by ammonium displacement and analysis of Na by ICP AES. * provided by the manufacture; [#] tested in Monash lab.

Acidic Permeant Solutions

Three different concentrations (0.015M, 0.125M and 0.5M) of sulfuric acid solution were used in this study to mimic mild, medium and strong acidic conditions. Such acid concentrations can be expected in most heap-leach leachates. The pH, electrical conductivity (EC) and ionic strength of these acid solutions are shown in Table 2.Electrical conductivity (EC) and pH values were measured with Con6+ conductivity meter and pH5+ meter from EUTECH Instruments Pty. Ltd.

Hydraulic Conductivity Tests

The hydraulic conductivity tests were conducted generally according to ASTM D 6766-"Standard Test Method for Evaluation of Hydraulic Properties of Geosynthetic Clay Liners Permeant with Potential Incompatible Liquids".

The GCL specimens were cut from a large GCL sheet using a sharp knife. A circular cutting ring with an inner diameter of 76mm and water was sprinkled onboth inside and outside edges of the cutting ring to prevent the loss of bentonite. Then the initial mass and thickness of the specimens were measured.

Table 2 Properties of acidicpermeant solutions.

Concentration (M)	pH (Target/ Measured)	EC (mS/cm)	Ionic strength (M)
0.015	1.5/1.48	7.47	0.045
0.125	0.6/0.66	66.9	0.375
0.5	0/0.25*	197.6	1.5

Note: *real value accuracy limitedby measuring range of the pH meter.

The modified hydraulic conductivity test equipment is shown in Fig. 1. Three flow pumps were used to provide the inflow, outflow and cell pressures. Two interface chambers were installed in both inflow and outflow lines between the flow pumps and the cell to prevent potential damage to the pumps. The interface chamber is designed for permeability testing using aggressive chemical solutions e.g. acid in this study. This prevents the acidic solutions from entering the pumps and also isolates the chemical to the sample with a three-way ball valve.An impermeable membrane was also used to isolate the acid and water within the chamber. Two pH and EC sensors were inserted in-line between the interface chambers and the GCL sample to measure the pH/EC values of the influent and effluent. The pH and EC data were collected periodically. A thickness gage measured deformation of the specimen during the test.

Before connecting the equipment, the lower part of the interface chamber in the inflow line was entirely filled with sulfuric acid solution, and the lower part of the chamber in the outflow line was completely emptied. The upper parts of both interface chambers were filled with water.

The prepared GCL specimen was then placed into the permeameter. One sheet of filter paper was placed between the top and bottom porous stones and the specimen to prevent intrusion of the material into the porous stones. Flexible membrane was used to encase the specimen against the leakage and rubber O-rings were also used to provide adequate seal at the base and cap.

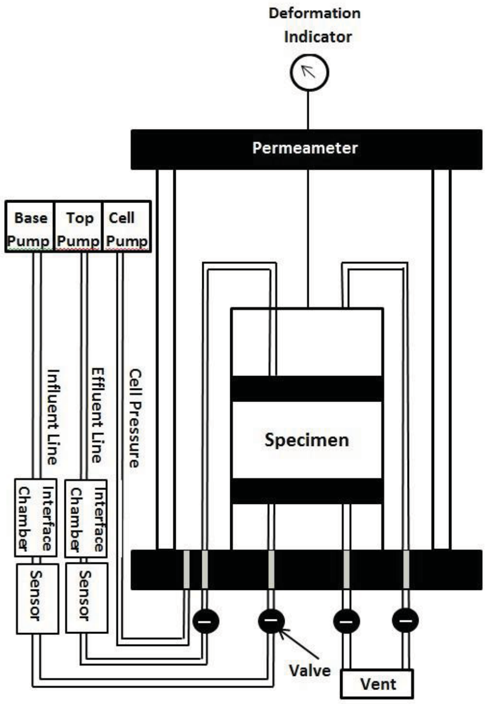

Fig. 1 Hydraulic conductivity equipment diagram.

After assembling, the specimen was directly exposedto sulfuric acid solution for 48 hours to mimic the worst-case scenario in the field. The cell pressure and that of influent and effluent lineswere increased to 105 kPa, 70 kPa and 70kPa respectively to flush the sulfuric acid solution through the drainage lines until allvisible air bubbles were removed.Then the pressure of cell was increased to 550 kPa and to 515 kPa on both sides of the specimen and maintained for 48 hours to achieve a degree of saturation before permeation.

The permeation was established by increasing the inflow pressure to 530 kPa to produce upward flow through the specimen.The termination criteria for the hydraulic conductivity test were as per the ASTM standard.

Hydraulic conductivity tests were conducted with three concentrations (0.015M, 0.125M and 0.5 M) of sulfuric acid solutions at two effective stresses levels (35kPa and 200kPa). The first series (35 kPa)was performed according to the ASTM standard to provide the conformance for the application and the second series (200 kPa)was aimed to evaluate the impact of increased effective stress on the hydraulic conductivityof non-prehydrated GCL as many occur in heap-leach pads.

RESULTS

Laboratory measured data of hydraulic conductivity results at 35 kPaeffective stress are shown in Figs.3, 4 and 5.The results indicate that all three sulfuric acid solutions have adverse influence on the hydraulic performance of GCLs compared to water as permeant (k_w=1.5×10^{-11}m/s), and higher concentration led to higher hydraulic conductivity therefore worse performance (Fig. 3a,4a,5a). The ratio of the hydraulic conductivity values based on permeation with water k_w to the value permeant with H_2SO_4 were$k_w/k_{0.5}$ ~48, $k_w/k_{0.125}$~16 and $k_w/k_{0.015}$ ~5. (Fig. 2).

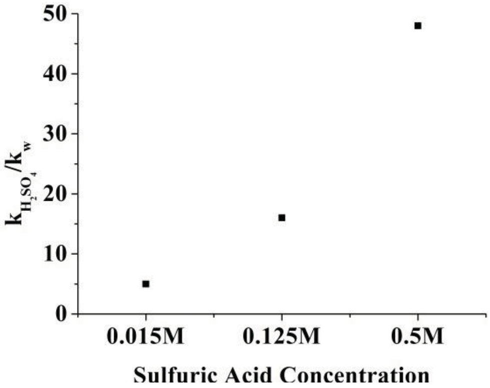

Fig. 2 Ratio of hydraulic conductivity permeant with H_2SO_4 to that permeant with water.

For elevated effective stress tests (200 kPa), the strongest acid solution at 0.5 M was first selected to conduct the test; the value $k_w/k_{0.5}$ at 200 kPa was ~5, which was essentially the same as 0.015 M at 35 kPa.

It can therefore be expected that the ratio of k_w/k would be lower than 5 for 0.125 M and 0.015 M H_2SO_4at 200 kPa.As expected, higher effective stress resulted in the decreased hydraulic conductivity and improved the hydraulic performance of GCLs.

As shown in Figs. 3b, 4b and 5b, the tests were terminated when the volumetric flow ratio Q_{out}/Q_{in}fell between 0.75 and 1.25.For all the tests, more than 20 pore volumes of flow (PVF) passed through the specimens before steady state. Greater acid concentration required fewer days to reach the steady state. 34 days, ~22 PVF for 0.5 MH_2SO_4, while 43days, ~21 PVF and 61days, 25PVF for 0.125 M and 0.015 M H_2SO_4, respectively.

For the test at 200 kPa effective stress, 63 days and 25 PVF were required to reach steady state at highest acid concentration (0.5 M). The test permeant with 0.125M H2SO4 at 200 kPa is currently in progress (10 days, < 2 PVF) and is expected to reach equilibrium in about 3 months.Data of pH and EC are also shown in Figures 3c/d,4c/d and 5c/d. In all cases, the values of pH_{out}/pH_{in} were greater than 1, but then decreased towards 1 as the tests progressed, while the ratio of EC_{out}/EC_{in} were initially lower than 1, and then gradually increased to 1 with increasing PVF.

The trends of pH_{out}/pH_{in} and EC_{out}/EC_{in} indicate the relationship of initial pH and EC values of GCLs and the pH and EC values of H_2SO_4 solutions.Bentonite from the GCL was mixedwith deionized water at a ratio of1:5 (50g: 250g).Leachate of the paste was collected by using apressurized (690kPa) cell and equilibrated for two weeks. The initial pH and EC values of bentonite from the GCL were 9.7 and 0.2 mS/cm, and the pH_{acid} were lower than $pH_{specimen}$, EC acid were greater than $EC_{specimen}$, even after 48 hours exposure. All the trends were in agreement with the study by Shackelford et al (1999).

DISCUSSIONS

The low hydraulic conductivity of geosynthetic clay liners is primarily attributed to the swelling bentonite component. As mentioned by Mitchell (1993),swelling is influenced by the ionic strength of the liquids. With the ingress of H_2SO_4solutions, the swelling was greatly decreased due to the greater ionic strength of the acid than water (Table 2).

As shown in Figs. 3, 4 and 5, the hydraulic conductivity decreased initiallywithinseveralPVFs, and then generally increased gradually to a stable level. Initially, the GCL specimens were still under hydratedeven when having been exposed to permeant acids for 48 hours before permeation, and the swelling bentonite component resulted in smaller k values.

However, when the specimens were acid saturated, the hydraulic conductivityincreased since H^+ and ionic strength dominated the system rather than hydration. Acid attack by these H_2SO_4 concentrations may result in partialdissolution of smectite (Liu et al 2012), and the release of multivalent cations (Fe^{3+}, Al^{3+}, and Mg^{2+}) could have resulted in a reduction in clay swelling. Accordingly, little constriction of the pore space existed, andcorresponding hydraulic conductivity values were greater. Higher acid concentrations (ionic strength) caused a greater negative impact on the swelling and hydraulic performance of GCL.

At high effective stress (200 kPa), the specimen was compressed compared to the lower effective stress indicating fewer pore space and resulting lower hydraulic conductivity. In addition, the time required to reachequilibrium was longer.

CONCLUSIONS

The measured data of hydraulic conductivity from laboratory tests suggestsulfuric acid solutions exert adverse impact on the hydraulic performance of non-prehydrated geosynthetic clay liners. The lowest acid concentration (0.015M) increased the saturated hydraulic conductivity by 5 times over that of water ($k/k_w=5$), and this increased, respectively, to 16 and 48 times with 0.125 and 0.5M acid. Higher acid concentration lead to limited swelling due either to ionic strength or acid attack (or both) and resulting greater k. Correspondingly, the test time required to reachequilibrium was shorter for the higher acid concentrations.

The elevated effective stress caused the closure of pore space and therefore restricted flow through the GCL specimens and the resulting lower hydraulic conductivity. The measured k based on the permeation with 0.5 M H_2SO_4 at 200 kPa effective stress was around 5 times to the k permeant with water ($k/k_w=\sim5$) similar to the value of 0.015 M at 35 kPa effective stress, while the time required (63days) to reach the equilibrium for the same acid concentration (0.5 M) at high effective stress (200 kPa) nearly doubles the time (34 days) at low effective stress (35 kPa).

The test results indicate the degradation in hydraulic performance of non-prehydrated GCLs when permeated with acidic solutions.Further tests are still needed to completely assess the compatibility/incompatibility of GCLs under acidic conditions.

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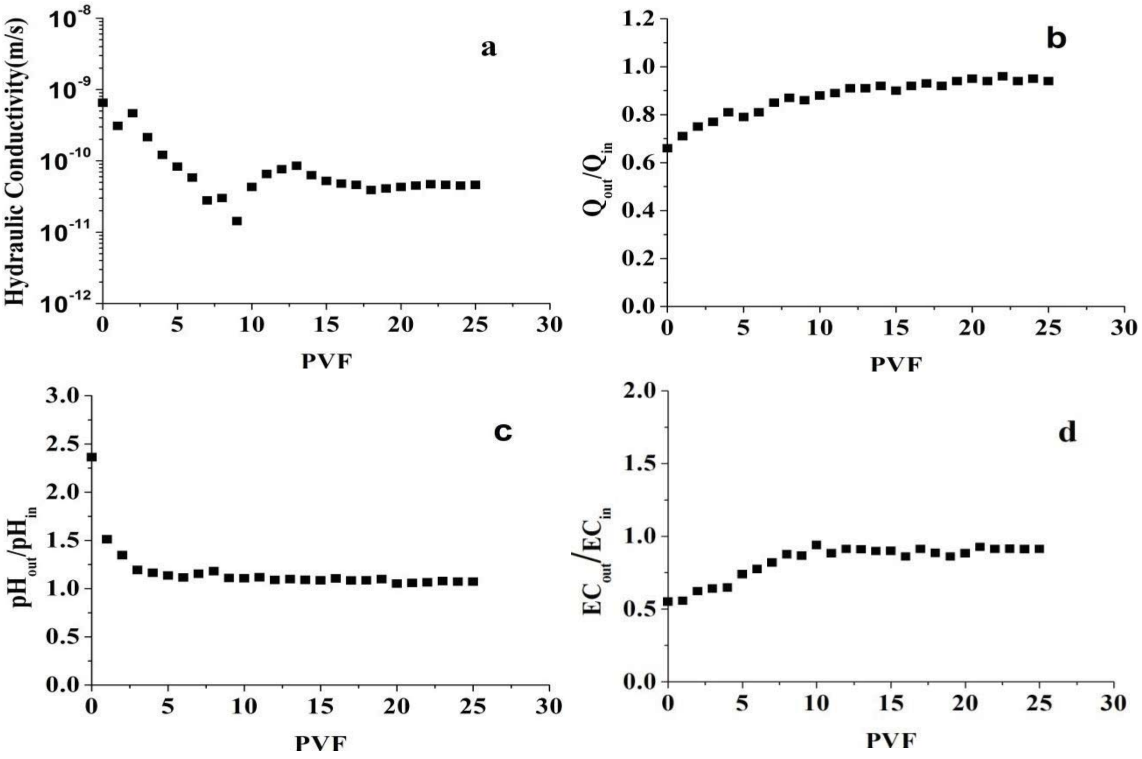

Fig. 3 Results of hydraulic conductivity test permeant with 0. 015M H_2SO_4at 35kPa effective stress.

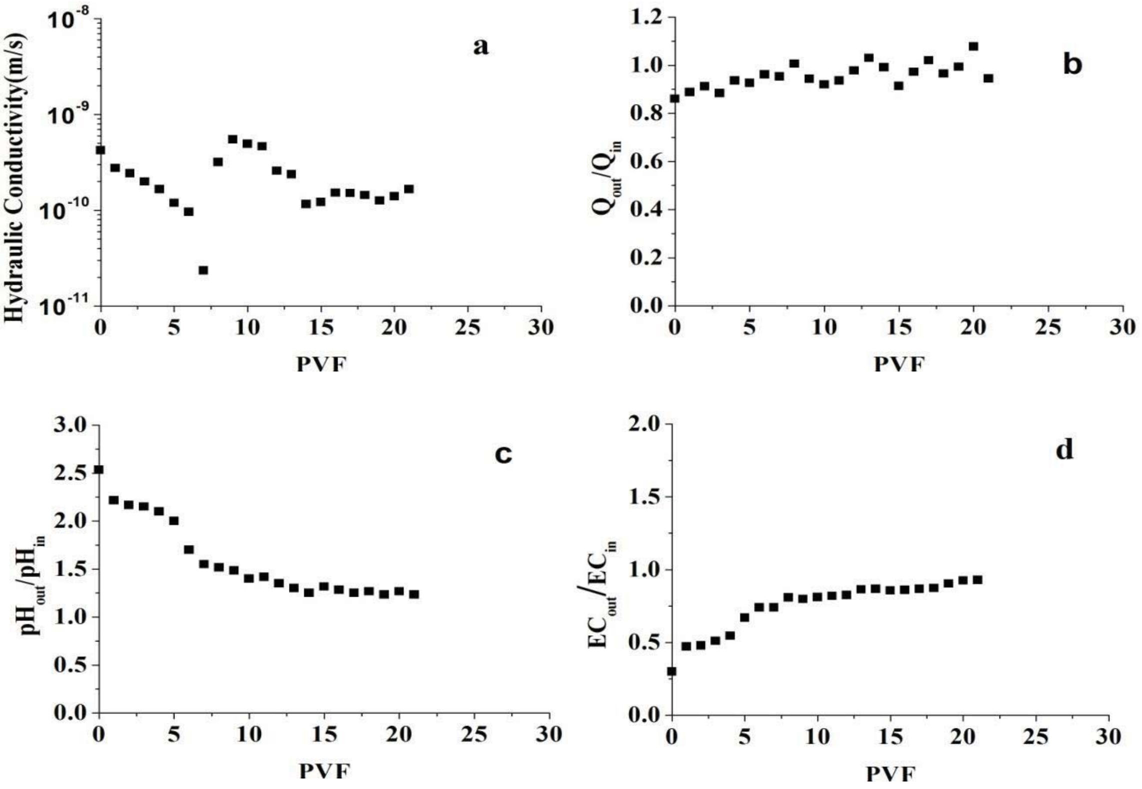

Fig. 4 Results of hydraulic conductivity test permeant with 0. 125M H_2SO_4at 35 kPa effective stress.

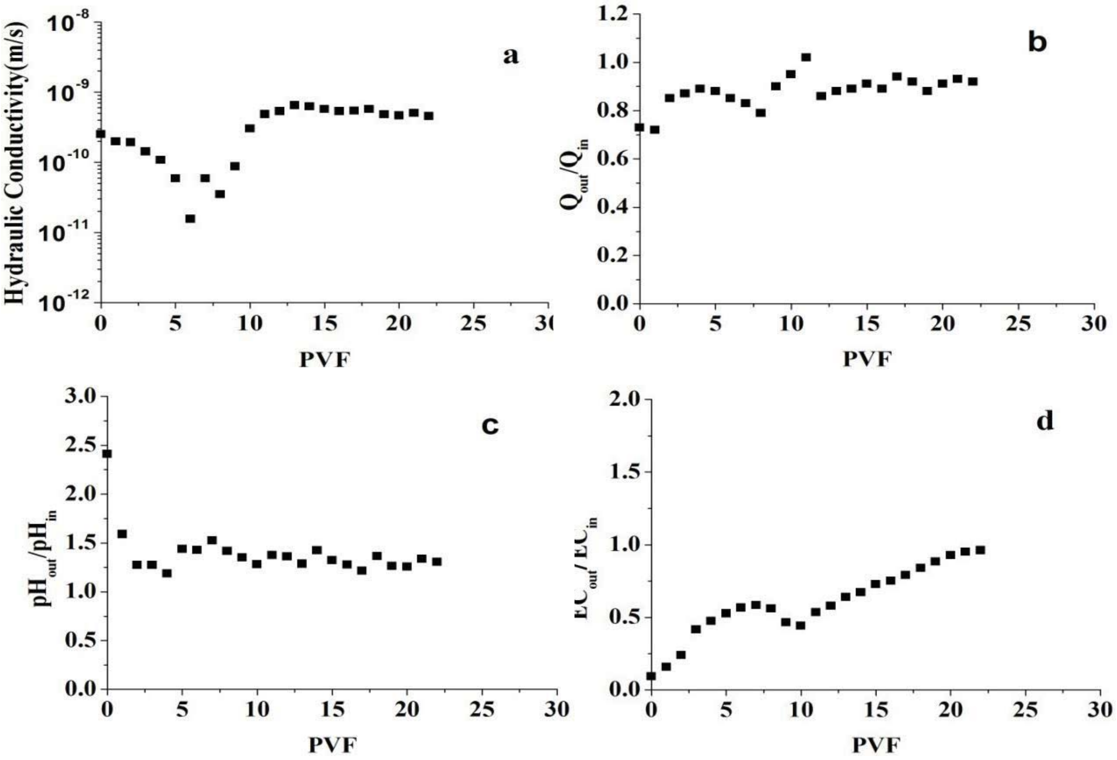

Fig. 5 Results of hydraulic conductivity test permeant with 0. 5M H_2SO_4at 35 kPa effective stress.

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