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Column percolation test for contaminated soils: Key factors for standardization

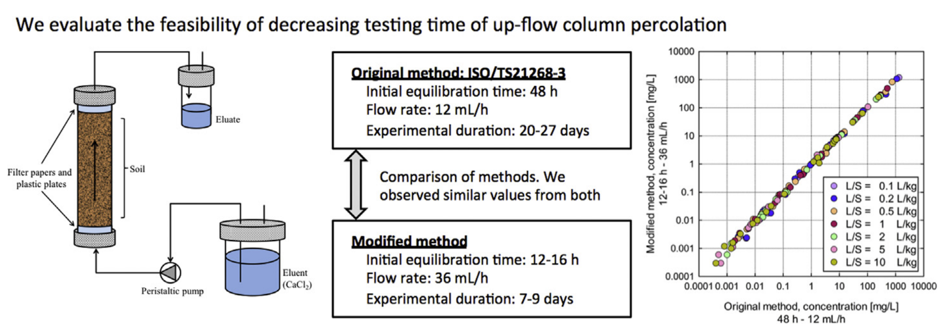
Angelica Naka[a], Tetsuo Yasutaka[b,*], Hirofumi Sakanakura[a], Ute Kalbe[c], Yasutaka Watanabe[d], Seiji Inoba[d], Miyuki Takeo[e], Toru Inui[e], Takeshi Katsumi[e], Takuro Fujikawa[f], Kenichi Sato[f], Kazuo Higashino[g], Masayuki Someya[g]

[a] National Institute for Environmental Studies, 16-2 Onogawa, Tsukuba, Ibaraki 305-8506, Japan
[b] National Institute of Advanced Industrial Science and Technology, 1-1-1 Higashi, Tsukuba, Ibaraki 305-8567, Japan
[c] Federal Institute for Materials Research and Testing, Unter den Eichen 87, 12205 Berlin, Germany
[d] Central Research Institute of Electric Power Industry, 1646 Abiko, Abiko-shi, Chiba 270-1194, Japan
[e] Kyoto University, Yoshida-honmachi, Sakyo, Kyoto 606-8501, Japan
[f] Fukuoka University, 8-19-1 Nanakuma, Jonan, Fukuoka 814-0180, Japan
[g] Tokyo Metropolitan Research Institute for Environmental Protection, 1-7-5 Shinsuna, Koto, Tokyo 136-0075, Japan

HIGHLIGHTS

- Ways to reduce the duration of column percolation tests specified in ISO/TS 21268-3 were proposed.
- Four equilibrium periods and two flow rates on four different soils were tested.
- The time to perform column percolation tests can be shortened from 20 to 30 days to 7–9 days.
- The recommended initial equilibrium period is 12–16 h, shorten from 48 h.
- The recommended flow rate is 36 mL/h which is three times that specified in ISO/TS 21268-3.

GRAPHICAL ABSTRACT



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ABSTRACT

Column percolation tests may be suitable for prediction of chemical leaching from soil and soil materials. However, compared with batch leaching tests, they are time-consuming. It is therefore important to investigate ways to shorten the tests without affecting the quality of results. In this study, we evaluate the feasibility of decreasing testing time by increasing flow rate and decreasing equilibration time compared to the conditions specified in ISO/TS 21268-3, with equilibration periods of 48 h and flow rate of 12 mL/h. We tested three equilibration periods (0, 12–16, and 48 h) and two flow rates (12 and 36 mL/h) on four different soils and compared the inorganic constituent releases. For soils A and D, we observed similar values for all conditions except for the 0 h–36 mL/h case. For soil B, we observed no appreciable differences between the tested conditions, while for soil C there were no consistent trends probably due to the difference in ongoing oxidation reactions between soil samples. These results suggest that column percolation tests can be shortened from 20 to 30 days to 7–9 days by decreasing the equilibration time to 12–16 h and increasing the flow rate to 36 mL/h for inorganic substances.

* Corresponding author.
E-mail address: t.yasutaka@aist.go.jp (T. Yasutaka).

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1. Introduction

Soil contamination can result from a number of different activities and events, including industrial, construction, and mining activities; natural disasters, such as tsunamis; and accidents, including nuclear plant accidents that may lead to radioactive contamination of soil. Contaminated soil materials pose major environmental and human health risks. As such, strategies for the remediation or disposal of soils should be carefully planned and managed.

Evaluation of the leaching behavior of contaminated soil is very important for an accurate assessment of the risk of contaminated soils transferring pollutants into seepage water, groundwater, or surface water. Several leaching methods have been developed and implemented into environmental regulations in many countries. These include batch tests [1–6], column tests [7–10], lysimeter tests [11–15], and sequential leaching tests [16–19]. These methods aim to determine the concentrations of chemicals expected in water that has come in contact with contaminated soil or other solid materials for a certain period of time [20].

Batch tests have been extensively used worldwide for compliance testing because their low costs, simple design, and low test duration (usually 24 h) make them convenient for routine testing. However, the disadvantage is that the information produced from the batch test is limited as it only provides a single result at one liquid-to-solid (L/S) ratio, which does not reflect real world conditions. Moreover, with certain type of soils, batch tests require additional effort for centrifugation, minimizing carry over, filtration and separation of suspended solid and water, managing formation of emulsions, etc. This may lead to a higher work load than expected and varying results depending on the experimental conditions before chemical analysis.

Column tests, on the other hand, resemble field conditions more closely and are suitable to assess the long-term release of chemical constituents from soil into water bodies. The column test's advantage over a batch test is that it allows for the observation of high initial concentrations of percolates at low L/S ratios (equilibrium concentrations) and the time-dependent release of chemicals, which is required for the prediction of leaching behavior under field conditions. However, column tests are more costly and time consuming, and more labor intensive compared with batch tests.

Internationally, several standards for column tests are available. In Table 1, we present the scope, apparatus, solid material, particle size, packing method, leachant, equilibration period after saturation, flow rate, and number of collected eluate fractions indicated by the technical specifications or standards of the following agencies: ISO/TS (2007), CEN (2004), NEN (2004), DIN (2009), USEPA (2013), Nordest (1995), ASTM (2001), and OECD (2004) [7–10,21–24]. The ISO-TC190 SC7 WG6, responsible for the development of leaching tests for soil and soil-like materials, has discussed upgrading the ISO/TS 21268-3 to a fully validated standard; Japanese experts are now undertaking that task. As presented in Table 1, column tests specified by ISO/TS 21268-3 require the collection of seven fractions in total, ranging from L/S ratios = 0.1 to 10 L/kg. At higher L/S ratios, the test takes 20–30 days, which is a long period of time, especially if applied to routine evaluations. Thus, there is an interest in shortening the experimental period. To achieve this, at least three possibilities can be considered: (a) increasing the flow rate; (b) decreasing the equilibration period after saturation; and (c) decreasing the height and the diameter of the column.

Focusing on the dimensions of the column, Kalbe et al. [25] and Lopez Meza et al. [26] conducted experiments using columns of different diameters and heights. For flow rates related to fixed contact times ranging from 2.5 to 36 h, they observed no appreciable differences in the leaching behavior of selected inorganic parameters from bottom ash and demolition waste. Contaminated soil was not considered in that study. ISO/TS 21268-3 [7] states that the equilibration period after soil saturation should be at least 2 days (48 h) to allow equilibration of the system. The addition of this equilibration period to the time required to conduct the experiments further lengthens the total time investment required. There is one robustness validation study available [27] on the effect of flow rate, material grain size, and equilibration period within column tests following prCEN/TS 16637-3 [28] using granular construction products partly derived from waste (the initial draft of this standard, named with the working title TS-3, was very similar to ISO/TS 21268-3). The outcome of the study indicated that the equilibrium adjustment period after saturation can be reduced, and that the flow rate can be increased; both of these adjustments have now been implemented into the procedure [28].

Our objectives are (a) to evaluate the effect of equilibration period and flow rate on the release of hazardous substances, (b) to study the effect of equilibration period after saturation on the leaching of inorganic constituents (decreasing to 0, 12 or 16 h), and (c) to judge whether it is possible to shorten the column percolation experiment time by increasing the flow rate to 36 mL/h from 12 mL/h. If these changes are effective, we will propose that they be included in the upgrade of ISO/TS 21268-3 to a full ISO standard.

2. Materials and methods

2.1. Materials

We used four types of soils with different characteristics to perform the experiments; they are hereafter referred to as soils A, B, C, and D. Table 2 shows the physical and chemical characteristics of the four soils. Soils A and B were anthropogenically-contaminated soils, soil C was excavated from a depth of about 5–10 m and contained natural heavy metals and soil D was a naturally-contaminated soil. We measured the maximum particle size and moisture content by JIS A 1203 (2009) [29], the loss of ignition by JIS A 1226 (2009) [30], the particle density by JIS 1202 (2009) [31] and the particle size distribution by JIS A 1204 (2009) [32]. Detailed methods of these physical and chemical analysis are shown in Table S.1. Total heavy metal contents were determined after melting the soil by microwave digestion, aqua regia or steam distillation (Ministry of Environment, 2012) [33], We sieved the four soils using a 2-mm opening mesh. We prepared about 10 kg of each soil and used the coning and quartering method to sub-divide the soil into smaller samples.

2.2. Methods

We carried out up-flow column percolation tests following the procedure described in ISO/TS 21268-3 [7]. The procedure of this technical specification and our experimental conditions are shown in Table 3. This technical specification requires at least 2 days (48 h) of equilibration period after saturation and a 12 mL/h flow rate (or a 15 ± 2 cm/day linear velocity) for a column with a diameter of 5 cm. In this study, we tested three additional equilibration times, 0, 12 and 16 h, as well as an extra flow rate of 36 mL/h. Six different laboratories, located in different prefectures in Japan, conducted column experiments according to the conditions specified in Tables S.3–S6. Chemical analyses of all collected eluates from all column percolation experiments were conducted only in one laboratory.

Table 4 shows the number of experiments for every condition and the sample dry mass packed into each column. We packed the specimen into the columns with moisture content equivalent to field conditions (the specimen was not dried). We used approximately the same amount of soil in each test for every soil type. To prevent soil material loss and to facilitate uniform distribu-