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Leachate removal rate and the effect of leachate on the hydraulic conductivity of natural (undisturbed) clay

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Hydraulic conductivity (HC) is perhaps the most important unique parameter determined in the laboratory for predicting mobility of leachates through clay liners. Typically, HC must be < or = $1x10^{-9}$ m/s for soil liners and covers used to contain hazardous waste, industrial waste, and municipal solid waste (MSW). Soil samples used in this study were obtained from the Kemerburgaz landfill in Istanbul. The study presents change in clay HC brought about by the chemical reactions between clay and a permeant. Any change induced by such a reaction in the microstructure (microfabric) of the clay was studied by scanning electron microscope. In order to determine the removal capability of the natural clay, COD, SS, VSS, Total P, TKN, Cu, Mn, Fe are also measured in the influent and effluent of the lab-scale reactor.

Keywords: Hydraulic conductivity, Leachate, Natural clay, Permeability, Removal efficiency

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Introduction

Leachate is a kind of waste liquid consisting of waste contaminants. Natural clays are widely used to line landfills and waste impoundments, to cap new waste disposal units, and to close old waste disposal sites. Solid waste landfills constitute a potential major threat to groundwater quality[1,2]. Water present in waste, rainwater infiltration during and/or after the landfilling process and groundwater penetration can result in the generation of leachate. During decomposition, landfill gases, CO_2, CH_4, H_2S are also produced[3,4]. In order to prevent ecological environments from being polluted, modern engineered landfills are designed based on two basic principles: Containment and Attenuation. Generally, bottom liner and cover liner systems are successfully employed to isolate the landfilled waste, minimize the production of leachate and cut off the leakage of leachate. Properly designed landfills can greatly decrease the leakage of leachate, but can not absolutely prevent it, especially when uncertainties such as those involved in civil engineering design, landfill operation, and the occurrence of geological hazards nearby the landfill site are considered[5].

Kemerburgaz landfill of Istanbul is densely industrialized and over populated. Leachate of Kemerburgaz landfill may originate from hazardous household wastes (paints, solvents, oils, cleaning compounds, pesticides) and small - scale industrial wastes. Also, the origin of these pollutants is thought to be hazardous waste illegally dumped degradation compounds[6]. Hence, this landfill can contaminate groundwater, if leaks in the insulation system occur. The state of the art of landfilling includes the use of geomembrane (high density polyethylene), and geotextile liners over clay layers. However, volatile organic compounds (VOCs) were found to permeate geomembranes in a matter of days[7].and clay liners without much retardation[8]. Also, geomembrane do little to inhibit the transport of VOCs, because VOCs diffuse readily through geomembrane polymers[6,7,9-11]. Furthermore, temperature rising during organic matter biotransformation can deteriorate isolation system of landfill[6,12,13]. Therefore, the effectiveness of modern landfill liner systems to attenuate the migration of such contaminants into surrounding soil and ground water is of concern.

This study evaluates effects of leachate on hydraulic conductivity (HC) of natural clays, thereby evaluating effectiveness of these clays as liners in preventing groundwater contamination. To determine removal capability of the natural clay, chemical

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oxygen demand (COD), suspended solid (SS), volatile suspended solid (VSS), total phosphorus (P), total kjedhal nitrogen (TKN), copper (Cu), manganese (Mn) and ferrous (Fe) are also measured in influent and effluent of the lab-scale reactor.

Materials and Methods

The methods and procedures fall into three categories: (1) Physico-chemical characterization of the clay soil; (2) Permeameter tests and microstructure of the clay; and (3) Effluent analysis.

Permeability and Hydraulic Conductivity

HC defines the capacity of a porous medium to conduct a particular fluid, and is a function of both the medium and the fluid. Permeability, also known as the intrinsic or absolute permeability, expresses the capacity of flow in terms of the properties of the porous medium only[14]. The intrinsic permeability (K, in cm^2) and the coefficient of HC (k, in cm/s) are related by the following equation:

$$k = K\,\upsilon/\rho$$

where υ = absolute viscosity of permeant (in poise, g/cm-s); ρ = mass density of the permeant (g/cm^3), and g = acceleration of gravity (cm/s^3). Typically, HC must be less than or equal to $1x10^{-9}$ m/s for soil liners and covers used to contain hazardous waste, industrial waste, and MSW.

Study Areas and Soil Samples

MSW of the Istanbul (European side) are disposed to Kemerburgaz. Approx 6000 tons/day of MSW are being disposed to this landfill and 1000-1500 m^3 leachate/day is being produced. MSW are disposed at a part of 20 ha (average waste height: 40 m) of 125 ha landfill area in the last 5 years and the landfill site is projected for 25 years usage[6]. The soil used in this study exhibited the existence of kaolinite, illite and shapeless particles of quartz (naturally occurring clay of landfill). Soil samples were obtained from Kemerburgaz landfill clay (HC as k=1 $x10^{-9}$ m/s, density 1950 kg/m^3), in Istanbul. The permeability was measured using the constant head permeameter[15].

Experiments

Soil was permeated with distilled water and leachate. To determine the removal efficiency of natural clay, COD, SS, VSS, total P, TKN, Cu, Mn and Fe are measured in the influent and effluent. All analysis was made according to Standard Methods[16]. The other tests on the uncontaminated and the contaminated clay have been performed using scanning electron microscope photography.

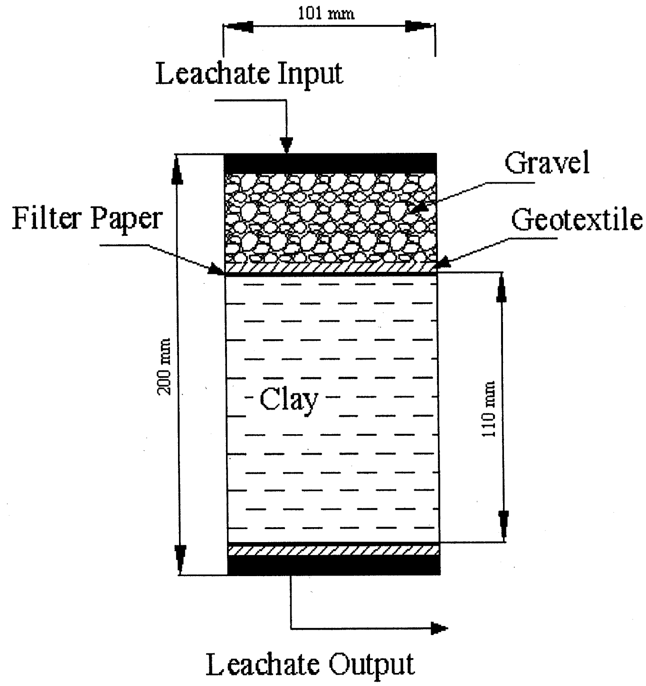

Fig. 1—Experimental setup

Samples were taken by driving a specific sampler from the soil and transferred to the laboratory and then pressed into the permeability reactor. In order to prevent the swell (expansion) of the clay in the apparatus, pieces of gravel were placed upon it. Meanwhile a perforated plexiglass filters have been placed on and under the soil sample together with the filter papers. The mold reactor tests were performed by flowing the liquid downward through the 100 mm diam natural specimens (Fig. 1). Height of the natural clay was 110 mm. Clay was saturated under 0.3 bar pressure. Permeability tests were performed with water. After 3-4 weeks, water was replaced by leachate.

Results and Discussion

Physico-Chemical Properties of the Clay

Soil samples, bluish-gray to brownish-gray, contained kaolinite, illite and ill-sorted quartz. X-ray diffraction analysis showed illite (mica) in decreasing abundance, and kaolinite and ill-sorted quartz in increasing abundance. Only kaolinite is considered true clay mineral. Soil samples contained: moisture, 15-40; plastic limit, 20-40; and liquid limit, 40-80%;

Table 1—Hydraulic conductivity (permeability) value

I Reactor		II Reactor	
Clean water permeability $\times 10^{-10}$ m/s	Leachate permeability $\times 10^{-10}$ m/s	Clean water permeability $\times 10^{-10}$ m/s	Leachate permeability $\times 10^{-10}$ m/s
9.848	10.8	10.4	11
9.939	11	9.104	10.2
8.225	8.99	8.631	9.64
9.380	11.8	8.503	11
8.123	11.1	9.899	11.7
10.90	12.7	9.932	9.7
9.631	12.2	7.974	8.82
8.459	9.36	8.459	10.8
Average, 9313	Average, 10994	Average, 9113	Average, 10358
SD, 910	SD, 1212	SD, 812	SD, 877

SD; Standard deviation

unit weight of soil solid, 2.62-2.72; and dry unit weight, 1.50-1.70 g/cm^3.

Hydraulic Conductivity (Permeability) Measurements

Two constant head permeameters made of plexiglass materials (Fig. 1) were prepared and filled with natural clay. Using distilled water as a permeant, permeabilities (*k*) were determined in 3-4 weeks to ensure proper column behavior. HC (permeability), *k*, was found to be: water, 9.848x10^{-10}; and leachate, 10.8x10^{-10} m/s (Table 1). These results show that leachates can cause a little bit increase in the permeability. This increase may have an effect on HC of the clay. A weak trend is observed of increasing or decreasing permeabilities. The results of the duplicate permeameters are quite similar.

The structure of clay used in this study is hexagonal (Fig. 2). After permeating leachate through the clay, the structure of clay was changed to needle-like crystal structure; and this disturbance was caused by the leachate. If the clay is permeated with chemicals separately, different chemical-structure of the contaminated clay was determined.

Effluent Analysis

To determine removal capacity of the natural clay, COD, SS, VSS, total P, TKN, Cu, Mn and Fe have been measured in the influent and effluent of the reactor. Influent concentration of leachate was measured as 22000 mg/l [Fig. 3 (a)]. After 21 days, permanent (water) was replaced by the leachate. And effluent of COD concentration has been measured as 5750 mg/l. It is believed that replacing the water causes the sharp decrease in the effluent concentration by leachate (leachate was diluted by water). In the

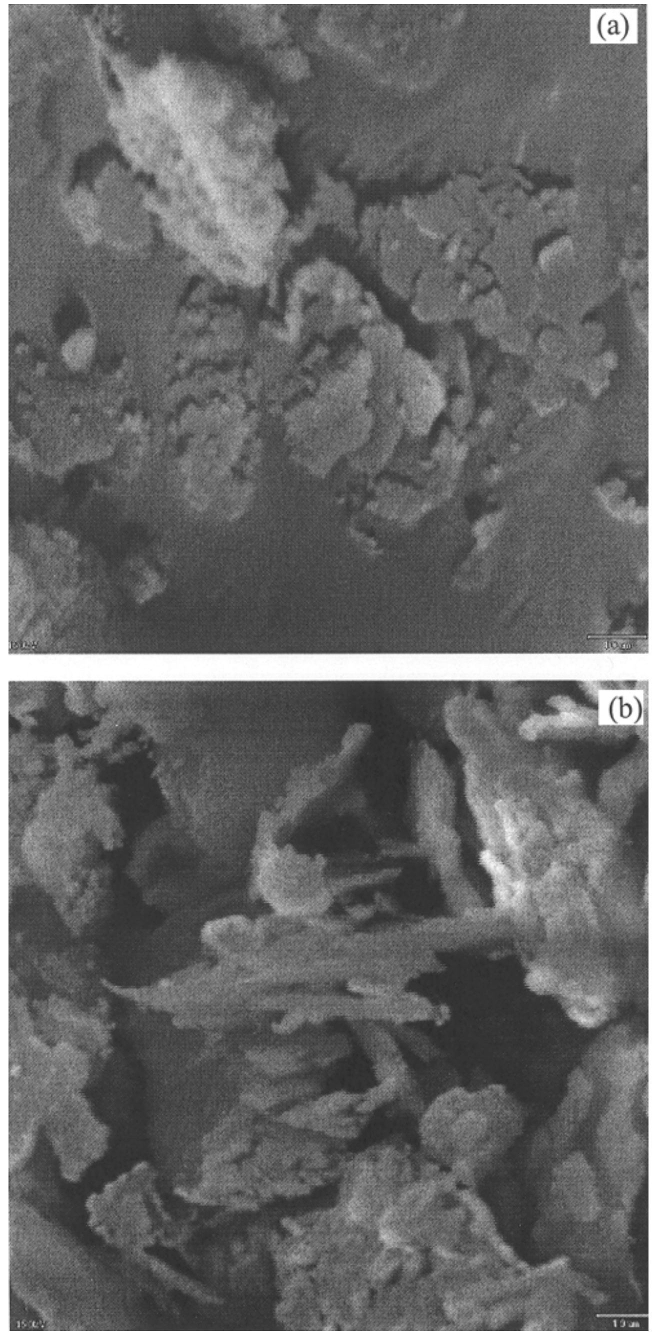

Fig. 2— (a) The photograph of the original clay under the scanning electron microscope (magnification 10000), (b) The photograph of the clay contaminated with the leachate (magnification 10000)

30th day of the experiment, leachate penetration took place in the natural clay and water was completely removed from the system. In the 60th day, COD effluent concentration was measured as 15789 mg/l. In the 84th day of the experiment, an increase was observed in the effluent concentration of the leachate as 20000 mg/l, caused by changes in clay

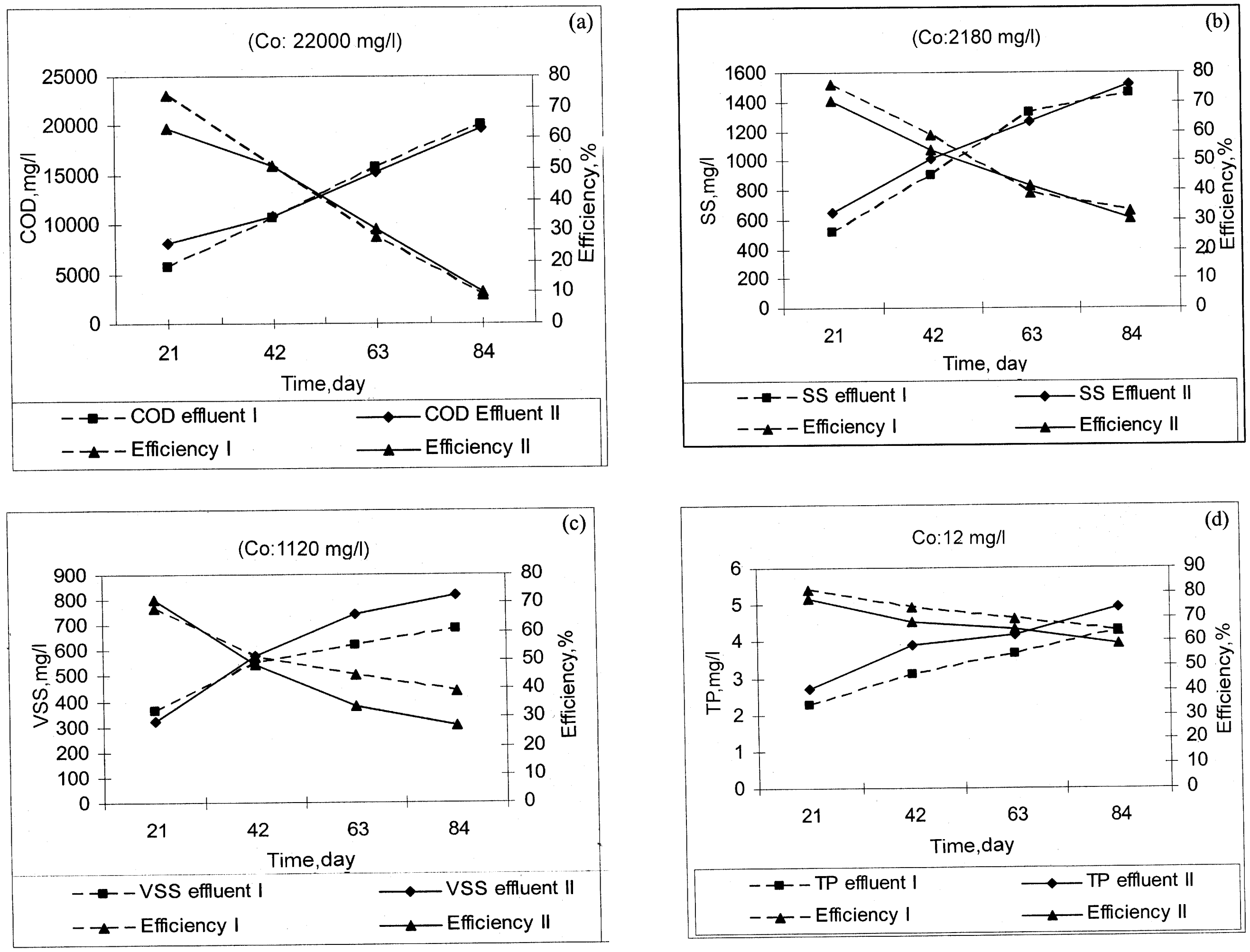

Fig. 3—Concentrations of a) COD, b) SS, c) VSS and d) TP

permeability. That was due to the permanent chemical reactions in the clay. It is believed that the structural change in the clay has been produced by this reaction between the permanent and the clay.

The changes of the effluent concentration of VSS, SS, total P, and TKN are similar with COD effluent concentrations (Figs 3 & 4). Fe–Mn removal efficiency increases with time (Fig. 4). $Fe(OH)_3$ and MnO_2 precipitations on the clay particles increase oxidation rate because of autocatalytic effect. This causes that the Fe-Mn removal efficiency of clay is higher than the other parameters.

Conclusions

X-ray diffraction analysis showed existence of kaolinite, illite and shapeless particles of quartz in the clay. HC (permeability) of the clay (Table 1) was slightly larger for water (9.848×10^{-10} m/s) than that of leachate (10.8×10^{-10} m/s). Thus, leachates can cause in the permeability a little bit increase, which may have an effect on HC of the clay. The structure of the clay used in this study was hexagonal. After permeating leachate through the clay, the structure of the clay was changed to needle like crystal structure caused by the chemical content of the leachate. One of the criteria for ending the tests was to monitor the influent and effluent concentrations of the permeant liquid. Average removal percentage was: COD, 74; VSS, 76; SS, 71; TKN, 85; and total P, 81%. Removal percentage for metals is quite high and efficiencies are as follows: Fe, 99; Mn, 99; and Cu, 72%.

To prevent the possible contamination of ground water and the environment by the leachate produced from impounded wastes, the sides and bottom of the impoundment must be lined. An effort should be made to evaluate permeability of clay liners in

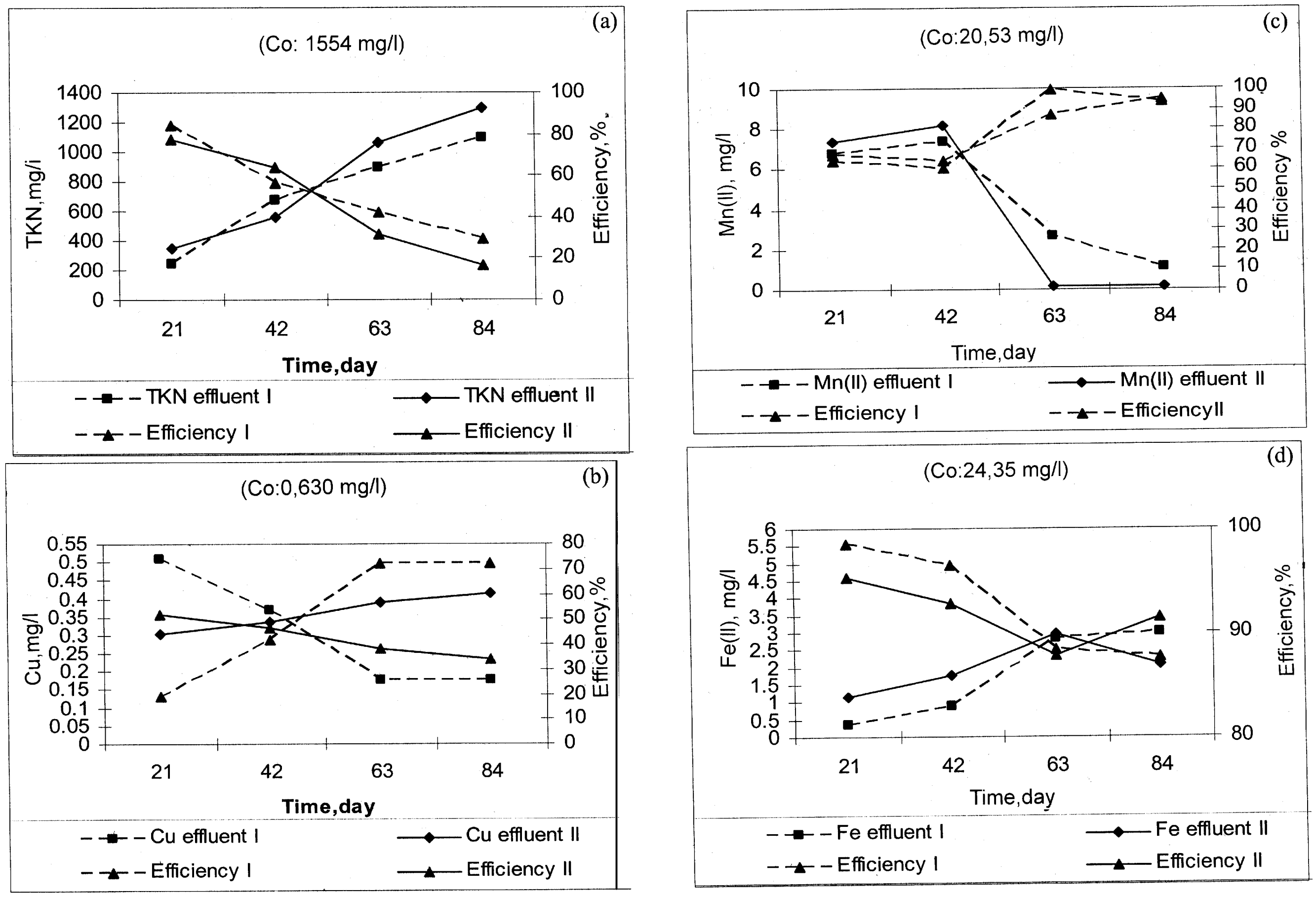

Fig. 4—Concentrations of a) TKN, b) Cu, c) Mn (II) and d) Fe (II)

landfills and surface impoundments where leachates have been disposed. Due to large number of these facilities, priority should be given to evaluating the clay liners of disposal sites in close proximity to potable groundwater resources.

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