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The Effect of Leachate on the Compacted and Consolidated Clay Soils

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ABSTRACT

Solid waste landfills constitute a potential major threat to groundwater quality. Water present in the waste, rainwater infiltration during and/or after the landfilling process and groundwater penetration can result in the generation of leachate. Leachate is a kind of waste liquid consisting of waste contaminants. Clay soils are natural matters to minimize the permeability of natural soil liners in landfill areas. Some contaminants in the leachate can alter compacted clay soils and cause increasing or decreasing permeability.
This study investigates effects of leachate on the permeability of the compacted and consolidated clay soils, thereby evaluating the effectiveness of these clay soils as liners in preventing groundwater contamination. To determine removal capability of compacted and consolidated clay soils, some metal ions (Fe(II), Mn(II)) are also measured in influent and effluent of the lab-scale reactor.
According to results of this study, Fe(II) and Mn(II) removal efficiency increases with time. $Fe(OH)_3$ and MnO_2 precipitations on the clay soil particles increase oxidation rate depending on the autocatalytic effect. Also, in the beginning, some decrease has been observed in the compacted and consolidated clay soils permeability associated with the contamination. However, as time goes by, these results show that leachates may cause an increase in the permeability.

Keywords: Clay soil, leachate, metal ions, permeability.

INTRODUCTION

The landfill is an economical method which has been preferred more than 30- 40 years for the waste disposal of domestic and industrial wastes of developed and developing countries. Regular disposal of these wastes produced every day has a major importance. Every year 450-500 million tonnes solid wastes are produced due to the population of the world and 70% of these wastes are embedded in a solid waste landfill. It is estimated that 70 thousand tonnes wastes are formed in Turkey. 14000 tonnes of wastes are collected in Istanbul (9000 tonnes from European part and 5000 tonnes from the Anatolian part are carried to landfills and eliminated.

Planning and design of solid waste storage area have been developed using a quite complex technology (Shashikumar, 1992; Sertdemir, 2010). One of the most important aims of the solid waste storage area design is to minimize the risks in terms of environmental and human health. Properly constructed landfill should prevent the pollution of underground and surface waters and remove the environmental and social apprehensions. There are some factors need to be considered for the design of the landfill. The most important one is the bottom layer of the landfill and this layer having between 1m and 2 m thickness is a clay layer which is laid with geomembrane. Some researchers indicated that organic chemicals harm compacted clay and the quality of being impermeable of the material. Thus this issue should be considered attentively during the planning of the plant (Shashikumar, 1992).

Leachate occurs from MSW during the landfill process cause of several effects, such as precipitation, rainfall, surface runoff, biological degradation in the waste, etc. (Bou-Zeid et al. 2004; Xue et al.2013). Landfill leachate possesses a dark color and a strong smell, which contains high organic and inorganic contaminants. Leachate has some pollutants in aqueous solution. They are classified as four groups: dissolved organic matter (volatile fatty acid and more refractory organic matter such as humic substances), macro inorganic compounds (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, NH_4^{+}, Fe^{2+}, Mn^{2+}, HCO_3), heavy metals (Cd^{2+}, Cr^{3+}, Cu^{2+}, Pb^{2+}, Ni^{2+}, Zn^{2+}), and xenobiotic organic compounds originating from chemical and domestic residue present at low concentrations (aromatic hydrocarbons, phenols, pesticides, etc.) (Christensen et al. 1991) and microorganisms that indicate, predominantly total and thermotolerant coliform (Moravia et al. 2013; Yao, 2017).

Clays are natural matters to minimize the hydraulic conductivity of natural soil liners in landfill areas. Intrinsically, aplenty clay soils and re-compacted clay liners can represent a key component of landfills (Hamdi et al. 2013).

In this study, the change in clay soil permeability and the removal efficiency of Fe(II) and Mn(II) ions in the leachate in clay soil. For this purpose, leachate sample obtained from Şile – Kömürcüoda landfill in Anatolian Part, is filtered in disturbed clay soil which is subjected to compaction using the standard methods and consolidated reactors, so the permeability of the sample was found as experimentally. The change of Fe(II) and Mn(II) ions in influent and effluent of the reactor were investigated for determination of treatment capacity of clay soil.

MATERIALS AND METHODS

Experimental Setup

In this study permeability with constant head experiment method was used (Janardanan et al. 1989). 6 reactors were used and height of the clay in the reactors was 11 cm. Reactors were equipped with geotextile and porous material. In 3 reactors upper of the clay was compressed with pebble stones and in other 3 reactors piston system was used. Reactors compressed with pebble stones contain clay soil compressed with standard compaction, other 3 reactors contain both compressed with standard compaction soil and consolidated soil. Firstly, reactors were saturated by tap water with 0.3 bar pressure and then fed with leachate Fe(II) and Mn(II) parameters were analyzed in the leachates taken from the effluent of the reactors. Figure and the photo of the experimental setup were shown in Figure 1.

(a) **(b)**

Figure 1. Schematism (a) and photo (b) of the experimental setup.

Permeability Calculation Method

Water comes from the reservoir with constant water level is collected in the tank passing through the soil and the filter. After obtaining a stable stream, water amount collected in the tank is determined at a certain time. "k" is calculated using Darcy's law.

Water load on the sample.

$$H = H_1 - H_2$$

Cross-sectional area of the sample

$$A = \pi * D^2 / 4$$

Permeability coefficient

$$K_t = Q * L / (H * A * t)$$

Analysis Methods

Compaction Experiment

Compaction experiment was performed according to ASTM D 698 methods.

Consolidation Experiment

Measurement watch having 0.01 mm sensitive was installed on the piston system to find compression amount and speed. Then weight amounts were assigned as 19 kg, 38 kg and 76 kg for 0.25 kg/cm^2, 0.5 kg/cm^2 and 1 kg/cm^2 pressure levels, respectively. Consolidation experiment pages were prepared for each reactor and hanging weight, total weight, applied pressure, date, hour were saved. The changes in measurement hours were recorded in pages 4 min, 8 min, 15 min, 30 min, 1 h, 2 h ve 4 h after hanging the weights. This process was repeated during the loading and removing the weights. Then consolidation was completed following the results and graphs of time-compression.

Waste Analysis

For determination of treatment capacity of clay soil, Fe(II) and Mn(II) analysis in effluent of the reactor were performed according to the standard methods (Greenberg, 2005).

RESULTS AND DISCUSSION

Propertıes of Leachate And Clay Soil Used in The Study

Properties of Leachate

Results of Fe(II) and Mn(II) analysis in the leachate from Şile-Kömürcüoda landfill were given in Table 1.

Table 1. Fe(II) and Mn concentrations of leachate (Cansız, 2011).

Date	Fe(II) (mg/L)	Mn(II) (mg/L)
	65.3	1.33

Properties of clayey soil

Silty clay was used in this study. The colour of the clay varies from yellowish gray to brownish gray. Clay samples of Şile Kömürcüoda Landfill consist of clay (Gürpınar Formation) and sand (Çukurçeşme Formation) from bottom to the top.

Table 2. Properties of clay used in Kömürcüoda Landfill (Sertdemir, 2010; Baştürk et al. 2013).

Chemical Analysis (%)		Mineral Content (%)		Sieve Analysis (%)	
SiO_2	51-54	Kaolinite	68-71	63 µm	100
Al_2O_3	27-29			40 µm	99
Fe_2O_3	2.5-2.7	Free Quartz	6-9	20 µm	98
TiO_2	1.1-1.2			6 µm	91
CaO	0.1-0.2			2 µm	69
MgO	0.7-0.8	Illit	15-18	1 µm	47
Na_2O	0.0-0.1				
K_3O	2.7-2.9	Others	2-5		
SO_3	----				

Leaking loss 8.5 – 9% water absorption 0.2 – 0.4%

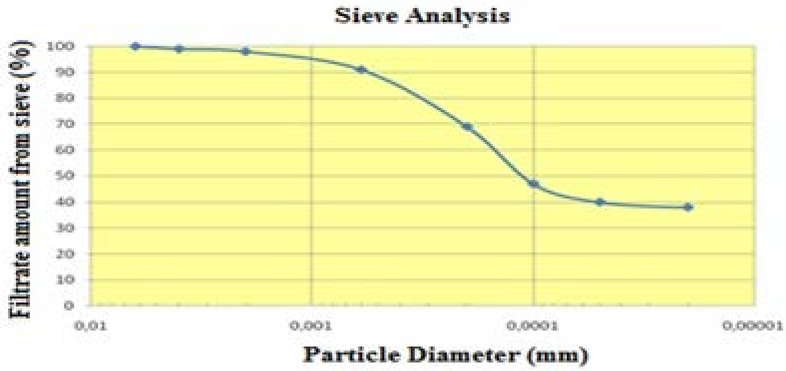


Figure 2. Sieve analysis.

Clay sample of Şile-Kömürcüoda Landfill consists of 68-71% kaolinite, 6-9% free quartz, 15-18% illite, 2-5% other minerals. The permeability of the clay, leaking loss and water absorption capacity were determined as $k=1x10^{-8}$ cm/h, 8.5 – 9% and 0.2 – 0.4%, respectively.

Results of Compaction, Permeability and Consolidation Tests

Compaction Test Results

The change of compaction experiment results was determined for the soil used for filling due to water content of pacing degree obtained with a compaction energy. There are two kinds of Proctor tests. These are Standard Proctor Test and Modified Proctor Test. The connection between the water content of the soil and compressed dry density was determined and results were shown in Table 3 and Fig. 3.

Table 3. Compaction experiment results**.**

Sample coming from	Kömürcüoda
Volume of pot	1000 cm^3
Diameter	10.47 cm
Height	11.56 cm
Number of layers	3
Weight of rammer	2.5
Downfall height	30.5
Number of Strikes	25 strike for each layer

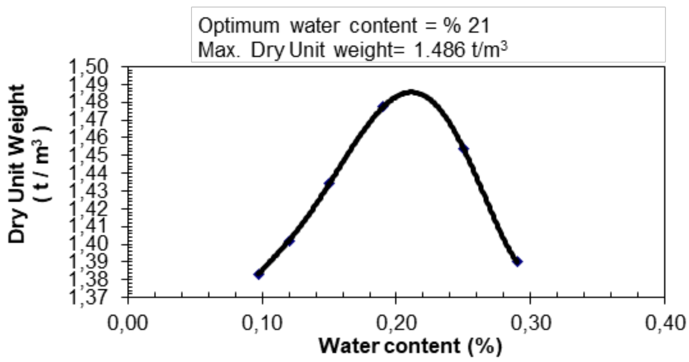


Figure 3. Compaction test results.

Results of Permeability and Consolidation Tests

Results of permeability tests performed using various energy applications on compressed clay sample are given in Figure 4. Permeability tests were done on clay samples compressed with standard compaction. Samples were prepared as 3% more and 3% less than optimum water content. Permeability measurements were performed on prepared 3 samples and permeabilities were determined to pass of the leachates. Same processes were repeated other samples consolidated with standard compaction. Strain and deformation curves of consolidated samples are shown in Figure 4. Permeability values obtained after these processes are given in Figure 5.

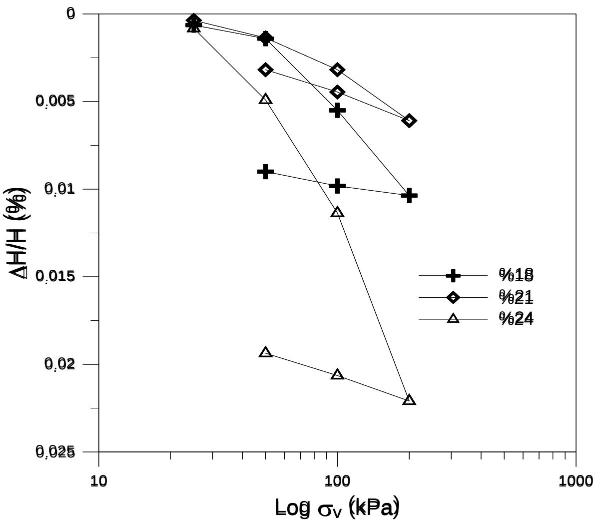


Figure 4. Odometer strain – deformation curve.

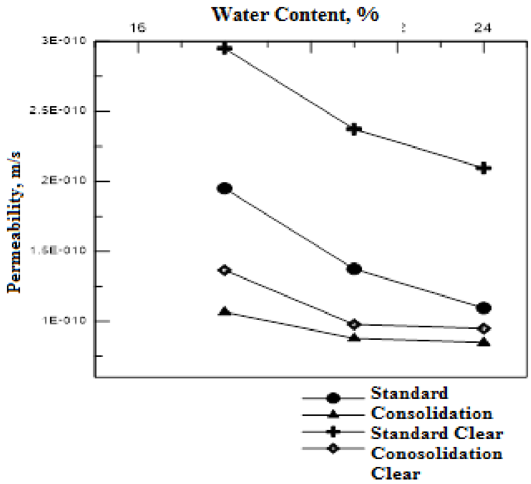


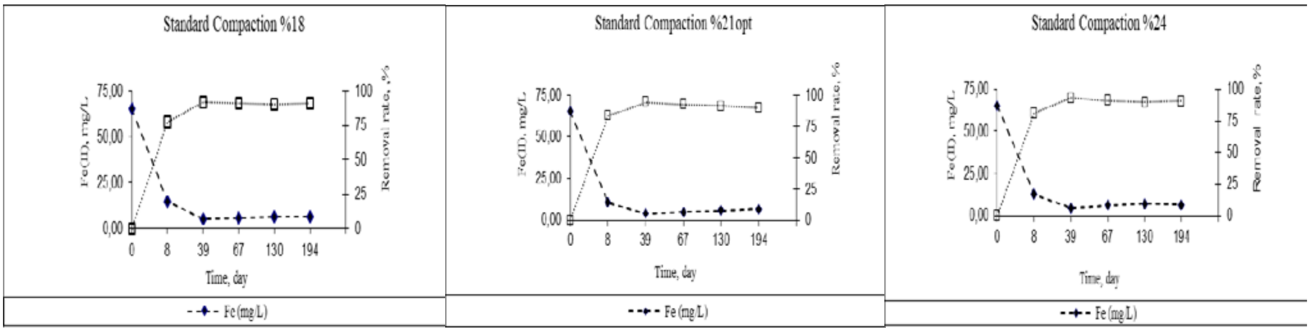
Figure 5. Permeability test results of samples compressed standard compaction and samples applied consolidation with standard compaction.

As can be seen from the figure, changes in permeability of clay sample were observed due to pollution and consolidation application. It has been also observed that suspended materials and microorganisms in the leachate cause a decrease in permeability due to the filling of the gaps in clay soil particules. Besides, water passes quickly in the samples compressed with standard compaction and passes hardly in the samples compressed with standard compaction under consolidation load. Permeabilities of samples compressed with standard compaction and compressed with standard compaction and consolidation are 10^{-10} m/s and 10^{-11} m/s, respectively. The reason of this case is considered as gaps in the samples under loads decrease and cause a difficulty for the passing of the water.

Treatment Experiment Results of Leachate in Clay Soil

In this study removal efficiencies were investigated for Fe(II), Mn(II) in Şile-Kömürcüoda Landfill leachate using destroyed clay soil compressed with standard compaction and standard compaction and consolidation. Found data are given below.

Iron Analysis Results

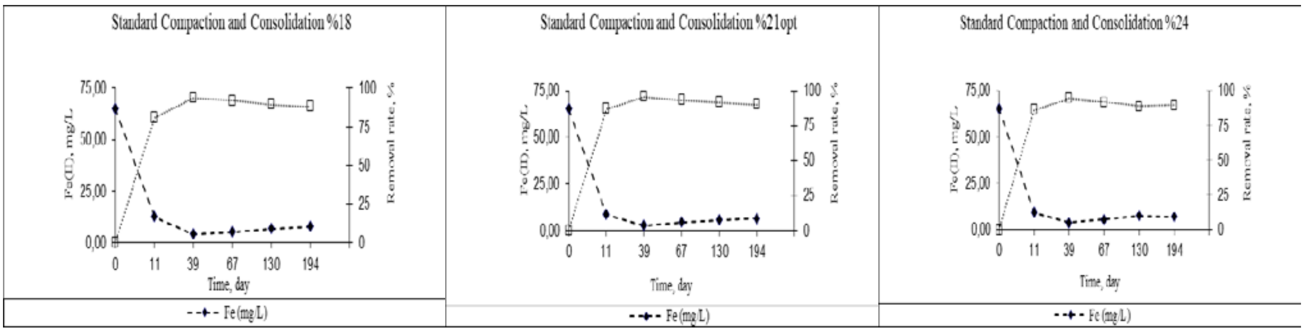


(a) **(b)** **(c)**

Figure 6. Change and removal efficiency of Fe(II) (a) Standard compaction, water content %18(opt.-3), (b) Standard compaction, water content %21(opt.), (c) Standard compaction, water content %24(opt.+3).

The input value of Fe(II) in leachate was found as 65.30 mg/L and first passing of leachate from clay soil took 8 days. As can be seen from the figures, a decrease was observed in Fe(II) value of the effluent leachate from the reactor, so an increase was observed in efficiency. At 39. day, in the reactor containing the sample compressed using standard compaction methods with 21% humidity (optimum), effluent Fe(II) value and removal efficiency were found as 3.84 mg/L and 94%, respectively.

At 39. Day, in the samples having the optimum water contents %21, %18 and %24, Fe(II) effluent values and removal efficiencies were found as 3.84 mg/L, 5.41 mg/L, 4.42 mg/L and %94, %92, %93, respectively (Figure 6). The removal efficiency of the sample compressed with standard method was found as 93 % and removal was monitored during 194 days. However as seen from the figures, it has been observed that removal efficiency increased until 39. day and then it started to decrease. This change can be explained as adsorption until 39. day and desorption afterwords. The removal efficiency of Fe(II) was found to be quite high.



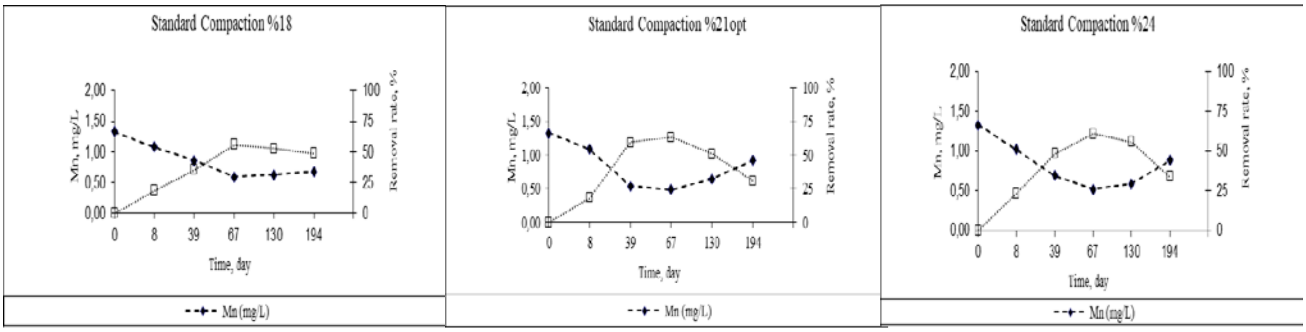
(a) **(b)** **(c)**

Figure 7. Change and removal efficiency of Mn(II) (a) Standard compaction and consolidation, water content %18(opt.-3), (b) Standard compaction and consolidation, water content %21(opt.), (c) Standard compaction and consolidation, water content %24(opt.+3).

The input value of Fe(II) in leachate was found as 65.30 mg/L. The first passing of leachate from compaction and consolidated clay soil took 11 days. On day 11, in the reactor containing compressed and consolidated sample having 21% humidity (optimum), it was found that Fe(II) effluent value was 8.4 mg/L and removal efficiency was 87%; on day 39 it was found that Fe(II) effluent value was 2.79 mg/L and removal efficiency was 96%. On day 11, in the reactor containing compressed with standard method sample having 18% humidity (optimum), it was found that Fe(II) effluent value was 12.5 mg/L and removal efficiency was %80.8; on day 39 it was found that Fe(II) effluent value was 4.19 mg/L and removal efficiency was 93.5%. On day 11, in the reactor containing compressed with standard method sample having 24% humidity (optimum), it was found that Fe(II) effluent value was 9.1 mg/L and removal efficiency was %86; on day 39 it was found that Fe(II) effluent value was 3.83 mg/L and removal efficiency was 94% (Figure 7). Optimum removal efficiency was found high at optimum humidity.

It has been found that removal efficiencies of Fe(II) were 94% for the samples compressed with standard compaction and consolidation and 93% for the samples compressed with standard compaction at 21% humidity (opt).

Manganese Analysis Results

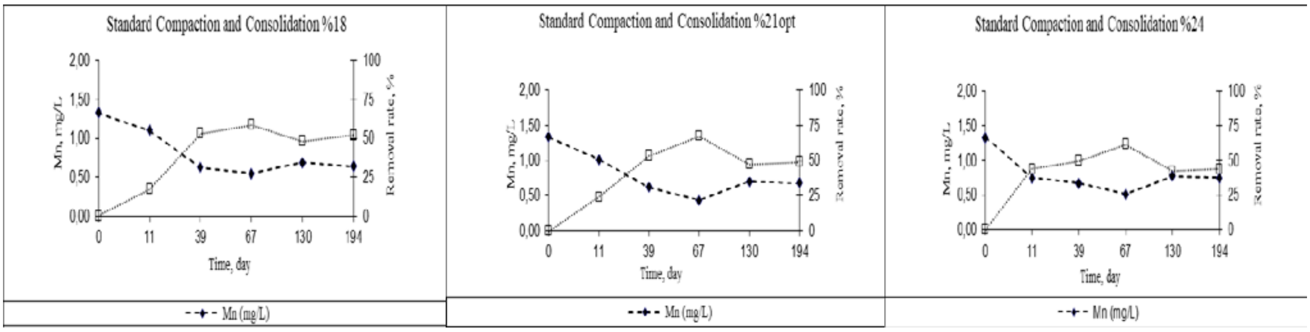


(a) **(b)** **(c)**

Figure 8. Change and removal efficiency of Mn(II) (a) Standard compaction, water content %18(opt.-3), (b) Standard compaction, water content %21(opt.), (c) Standard compaction, water content %24(opt.+3).

Passing of the leachate having 1.33 mg/L Mn(II) input value took 8 days from standard clay soil. As can be seen from the figures, a decrease in Mn(II) of the leachate coming out from the reactor was come true at 8. Day. Mn(II) effluent value decreased to 1.09 mg/L in the reactor containing compressed sample having 21% humidity with standard compaction method. In this reactor removal efficiency of Mn(II) was found to be 18%.

On day 67, in the samples having 21%, 18% and 24% water content, Mn(II) effluent value were found as 0.49 mg/L, 0.59 mg/L, 0.52 mg/L and removal efficiencies were found as 63%, 56%, 61%, respectively. (Figure 8). As seen from the figures, it was observed that average removal efficiency of the samples compressed with standard method was 60% and generally Mn(II) removal efficiency increased until the day 67 then it decreased on other days. This change indicates that desorption has started between the days 67 and 130. At the end of the 194 days monitoring adsorption study, Mn(II) removal efficiency was high in the samples compressed with standard compaction method.



(a) **(b)** **(c)**

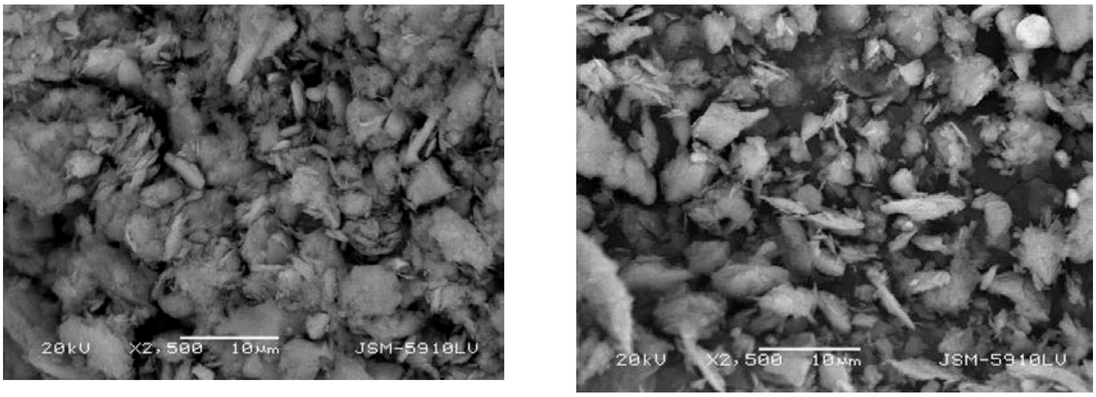
Figure 9. Change and removal efficiency of Mn(II) (a) Standard compaction and consolidation, water content %18(opt.-3), (b)Standard compaction and consolidation, water content %21(opt.), (c) Standard compaction and consolidation, water content %24(opt.+3).

On day 11, Initial Mn(II) value was measured as 1.33 mg/L and first passing of the leachate from standard and consolidated clay soil took 11 days. On day 11, decreases were observed in Mn(II) values in effluent leachate from the reactor. In the reactor containing compressed sample with standard method and consolidation having 21% humidity (optimum), it was found that Mn(II) effluent value was 1.01 mg/L and removal efficiency was 24%; on day 39 it was found that Mn(II) effluent value was 0.62 mg/L and removal efficiency was 53%. On day 11, in the reactor containing compressed sample with standard method and consolidation having 18% humidity (optimum), it was found that Mn(II) effluent value was 1.10 mg/L and removal efficiency was 17%; on day 39 it was found that Mn(II) effluent value was 0.63 mg/L and removal efficiency was 53%. On day 11, in the reactor containing compressed sample with standard method and consolidation having 24% humidity (optimum), it was found that Mn(II) effluent value was 0.75 mg/L and removal efficiency was 44%; on day 39 it was found that Mn(II) effluent value was 0.67 mg/L and removal efficiency was 50%. Similarly, on day 67, removal efficiencies were found as 67% at 21% (optimum) humidity, 59% at 18% humidity and 62% at 24% humidity (Figure 9). As seen from the results, at optimum humidity removal efficiency was found higher than other results.

Removal efficiencies of Mn(II) were found as 67% of consolidated soils compressed with standard compaction method and 63% as of soils compressed with standard compaction method at 21% (opt) humidity.

SEM Analysis Results

Displays of 2500 times enlarged images of clean and contaminated soils taken from Şile-Kömürcüoda Landfill using scanning electron microscopy (SEM) were given in Figure 10.



(a) **(b)**

Figure 10. SEM images of (a) Clean Soil, (b) Contaminated Soil.

Images of clean soil were shown in Figure 10 (a) and contaminated soil in Figure 10 (b). As can be seen from the images, structure of clay particules is amorphous (shapeless). It can be obviously seen from the images that leachate is accumulated between clay balls and surfaces (black parts in balls) in contaminated samples.

Various mechanisms affect the soil permeability as well as removal of pollution in leachate during the passing od leachate in clay soil. These effects are mechanical filtration, sedimentation, adsorption, chemical reaction and biological activities.

Mechanically, filtration is the process by which some pollutants are trapped by the filter material during the polluted water passing through the filter bed. The solids being as suspension form are kept here because their dimensions are larger than the bed material pores. However, contaction of the particles with each other during the filtration large balls are formed, so contamination of pollutants to the effluent water is prevented. Sedimentated materials during the filtration reduce the pore volume and water speed increases due to the narrowing of the section where the water passes. Adsorption is one of the most important process for disposal of colloids and small suspended particules from the water. Adsorption forces are effective for short distances such as 0.01 – 1 µm. However, thickness of the layer covering clay particules is wider than the distance. When this case is considered, adsorption does not affect fastening the particles. However, this situation is different. Particles in water are brought closer clay grains with the transport mechanisms assisting adsorbtion. So, particles are held due to the decrease in the distance. Transport mechanisms are classified as intersection, inertia, gravity, diffusion and hydrodynamic effects. During the filtration, some reactions are occurred. So, dissolved pollutants are separated and turned into less hazardous materials or turned into undissolvable materials and removed from water by sedimentation and adsorption.

CONCLUSIONS

In this study including investigations of clay soil permeabilities and treatment capacities of Fe(II) and Mn(II), yellowish brown-gray silty clay provided from Şile Kömürcüoda Landfill Area was used. For the results of permeability tests with the leachate, permeability changes were observed separately of the samples compressed with standard compaction and consolidation with standard compaction. It was found that permeability of clay soil was low.

The removal efficiency of Fe(II) was 95% of the samples compressed with standard compaction and consolidation at 21% (opt) humidity and removal efficiency of Fe(II) was 94% of the samples compressed with standard compaction at 21% (opt) humidity.

The removal efficiency of Mn(II) was 67% of the samples compressed with standard compaction and consolidation at 21% (opt) humidity and removal efficiency of Mn(II) was 63% of the samples compressed with standard compaction at 21% (opt) humidity.

When the test results of Fe (II) and Mn (II) parameters are examined in general removal efficiencies of the samples compressed with standard compaction and consolidation are higher than removal efficiencies of the samples compressed with standard compaction methods.

In this study removal efficiencies of Fe(II) and Mn(II) were provided after filtering the leachate in clay soil and it was observed that clay is a natural treatment mechanism.

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