Experimental Study on Utilization of Waste Cement Kiln Dust-Sand Soil Mix for Landfill Liner

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Abstract: In this paper, an extensive laboratory program has been carried out to investigate the effectiveness of using waste cement kiln dust (CKD) and sandy soil mix as a liner for municipal landfills. Recently, the environmental concerns related to Portland cement production in terms of global warming (emission of CO2) and disposal of CKD are becoming increasingly substantial. Researchers are always working not only on finding new alternatives for landfill liners, which prevent (or reduce up to acceptable levels) the aqueous contaminants, but also the low-cost solution is one of the important goals. Therefore, the main objective of this research work is to introduce a landfill liner material that satisfy the standards as well as represents an economic and friendly-environmental solution for disposal of waste CKD which causes a critical environmental problem for some of developing countries.

Four different mixes of sand and waste CKD, which have the following percentage by weight (including: 10%, 20%, 30%, and 40%), were prepared and tested in the laboratory. The results indicated that the mix which has CKD content of 40% by weight, succeeded in achieving extremely low hydraulic conductivity ($k=6.5*10^{-10}$ cm/sec) although the mix was subjected to the effect of synthetic leachate as permeating fluid (i.e., under sever operation conditions). Thus, waste CKD and sand mix is a cheap, yet effective, alternative for municipal landfill liners compared to other conventional waste liner materials like cement and lime.

Keywords: *Cement Kiln Dust (CKD); Municipal Landfills; Coefficient of Hydraulic Conductivity; Recycling; Sand.*

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I. INTRODUCTION

Portland cement production is one of the most energy-consuming industry as well as it emits large quantities of carbon dioxide, thus it has negative impact on environment by making the earth warmer (Abeln et al. 1993, Abdel-Rahman Abeln et al. 2021). Moreover, the major environmental concern experienced by the global is the disposal of waste cement kiln dust (CKD) that is generated during the cement production process. Abeln et al. (1993) reported that "CKD is particulate matter that is collected from cement kiln exhaust gases and consists of entrained particles of clinker, unreacted and partially calcined raw materials, and fuel ash enriched with alkali sulfates, halides and other volatiles". Besides, CKD has chemical composition similar to that of the conventional Portland cement. The major constituents are compounds of lime, iron, silica, and alumina.

Significant quantities of CKD are generated every year all over the world. The production rate of CKD is estimated to be 15–20 % of manufactured cement which can be estimated approximately by more than 2.8 billion tons annually (Alharthi et al. 2021, Al-Harthy et al. 2023, Ashley 2023). Considering the estimated global cement production of 4.1 billion tons in the year 2020, a huge quantity of the CKD needs to be handled (Ashley 2023). For example, in United States about 15 million tons of CKD are produced annually in 38]. Additionally, USEPA (1998) estimated that 52% was disposed of in landfills, 43% in piles and less than 1% in ponds. Furthermore, Alharthi et al. (2021) reported that 80% of disposable CKD requires to be landfilled that would cause environmental and strained landfill space issues. This furthers the need for environmentally sound alternatives for CKD's disposal. Consequently, its storage poses a problem and is considered a source of potential contamination.

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Despite of improvements in kiln operations and efforts that have gone into reuse applications, considerable amounts of CKD continue to require disposal through stockpiling or land filling (Sreekrishnavilasam 2006).

The main problems associated with waste CKD are by summarized as following: (1) CKD usually produced in very huge quantities; and (2) particles of the CKD are normally very fine particles which act as a difficulty in utilization of CKD. Modern dust-collecting equipment is designed to capture virtually all CKD and much of this material can today returned to the kiln. However, for various reasons a significant portion (30%-50%) must be removed as industrial waste (Kessler 1993, USEPA 1993, USEPA 1998). Consequently, in United States for example, more than 4 million of CKD are considered as unsuitable for recycling in the cement manufacturing process and require disposal annually (Todres et al. 1992).

In this regard, researchers are usually working not only on discovering new alternatives for landfill liners that can achieve environmental standards but also the low-cost solution is one of the important goals. Therefore, using waste CKD as constructive material for landfill lining has double benefits:

- Introducing a low-cost material for landfill lining, especially that the cost of cement dust material is nothing in regard of its transportation and disposal expenses.
- Protect the environment through recycling this health hazard waste material which is essentially produced during cement manufacturing process.

In the last decades, several studies have been explored new applications for waste CKD. Sreekrishnavilasam et al. (2007) performed a preliminary study on CKD components and their physical and chemical characteristics and found that the high-water absorption capacity and limited cementing properties of landfilled CKD makes it as an ideal cover material for sanitary landfills. Furthermore, previous studies conducted by (e.g., Bhatty 1995, Santagata and Bobet 2002, Miller, and Azad 2000, Peethamparan et al. 2006, Tatsuhara et al. 2012) have shown that treating soil with CKD can improve a number of its geotechnical properties, and that some CKDs may be effective soil stabilizers, waste treatment, asphalt pavement and other applications. Recently, Awad et al. (2023) studied the utilization of basalt dust and limestone dust as substitutes for sand in concrete mix designs, demonstrating enhancements in physical and mechanical properties such as: compressive strength, strain-strain behavior, and tensile strength. Figure 1 shows the typical methods for encapsulation of waste materials in landfill sites. There are mainly three techniques, namely: geomembranes, compaction, and recently the attenuation layer method has attracted attention (e.g., (Abdel-Rahman Abeln et al. 2021, Mo 2020, Tabelin 2018, Tang, 2014). The later method is cost-effective as it requires low investment to execute and offers better mechanical stability and constructability with sufficient compaction, unlike the layered system using geo membranes.

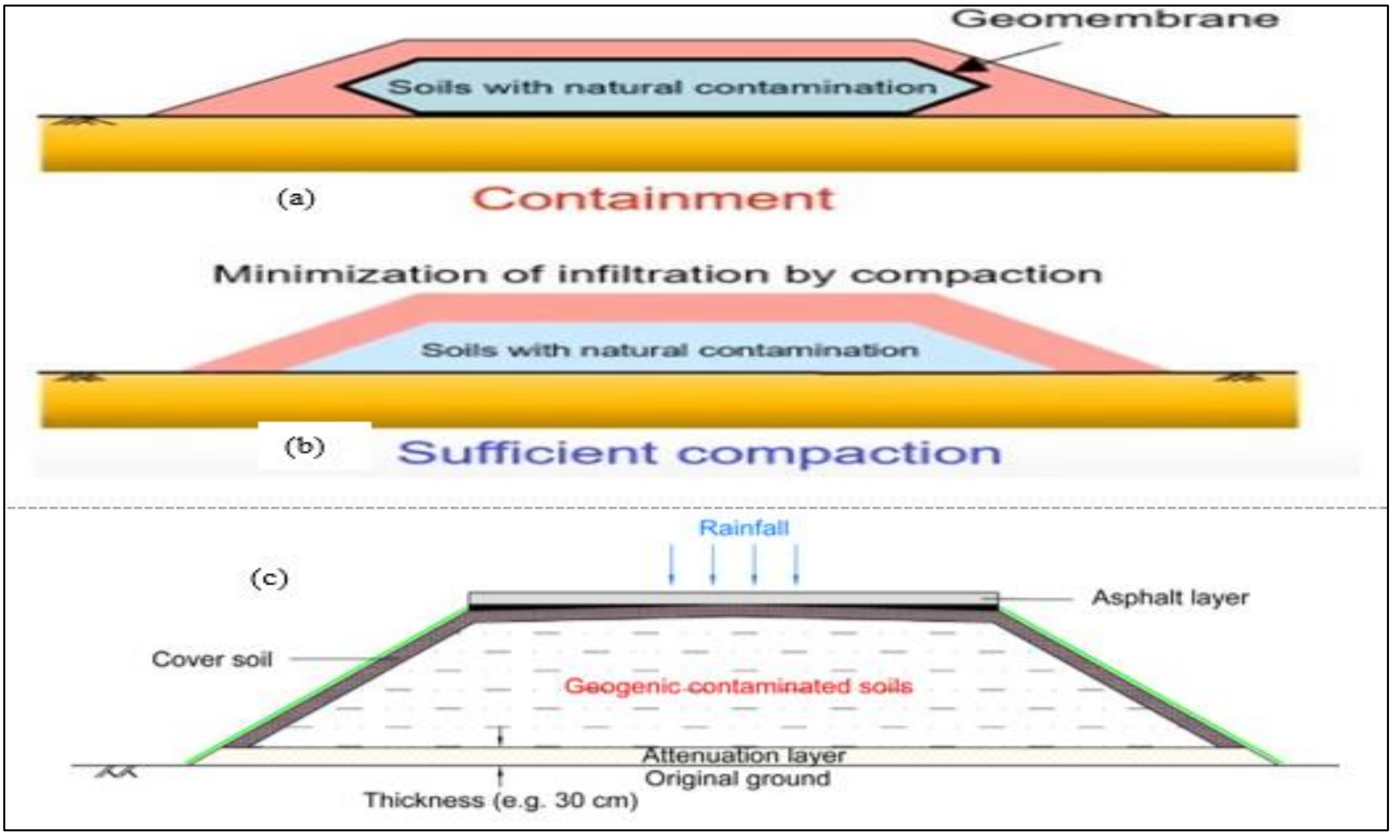

Fig 1: Schematic of Different Conventional Design Methods: (a) Geomembranes; (b) Compaction; and (c) Attenuation Layer (after Tang et al. 2014).

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Kedzi (1979) mentioned that "the selected liner for municipal landfills must achieve consistent performance and be compatible with the expected leachate for the design life of the facility to eliminate the expected infiltration. Several environmental agencies require that the liner has permeability not less than 8.64x10^{-5} m/day (1×10^{-7} cm/sec) to restrict the migration of contaminants".

When cement mixed with fine grained soil, a strong bond is created between the soil minerals and forms a matrix which reduces soil plasticity, soil water retention, hydraulic conductivity, and increases the soil shear strength. Thus, the use of cement as an amendment had the optimum combination of volumetric shrinkage reduction, and hydraulic conductivity reduction (Gathuka 2021).

II. OBJECTIVES AND METHODOLOGY OF THE PRESENT WORK

The main objective of this research is to introduce landfill liner materials that meet the standard requirements and achieve the regulations of Environmental Protection Agency (EPA) considering the economical factor. Therefore, this work studies the effectiveness of recycling of one of industrial waste materials, which basically results from cement industry (i.e., Cement kiln dust - CKD), as a landfill liner from geotechnical and environmental engineering point of view. The recycling of such waste material leads to significant benefits: (1) providing low-cost mix through using material of low-cost except for transportation, and (2) eliminating of CKD waste material which is currently causing an environmental problem in some developing countries. Accordingly, this research introduces a comprehensive experimental program in order to investigate the potential of using waste cement kiln dust (CKD) and sandy soil mix as a liner for municipal landfills to function as an excellent barrier performance against contamination. Figure 2 depicts the stepwise procedures for the methodology of the work adopted in this research.

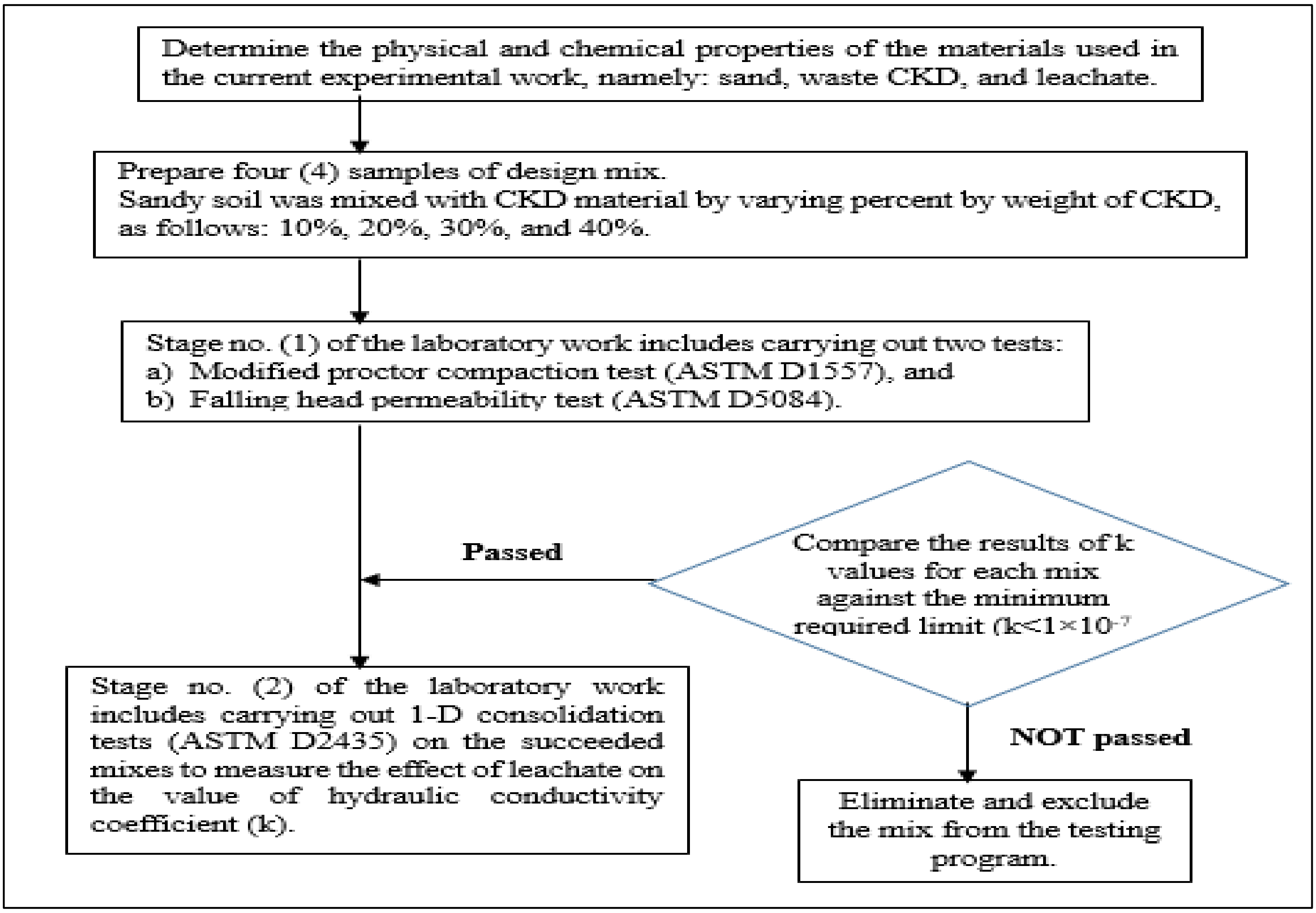

Fig 2: Staged Procedures for the Methodology of the work Adopted in this Research

III. PHYSICAL AND CHEMICAL PROPERTIES OF THE USED MATERIALS

This section introduces the physical and chemical properties of materials that was used in the present experimental study.

A. Sand

The used sandy soil in this testing program was passing through sieve no. 4 (4.75mm) to ensure a uniform testing condition. As shown in Fig Figure 3, plot of particle size distribution curve which indicates that the fines content (i.e., silt and clay particles smaller than 0.075mm - passing sieve no. 200) was almost equal zero. Uniformity (U) and curvature (C) coefficients were equal to 2.52 and 1.34, respectively, hence, according to the USCS the sand was classified as poorly graded sand (SP).

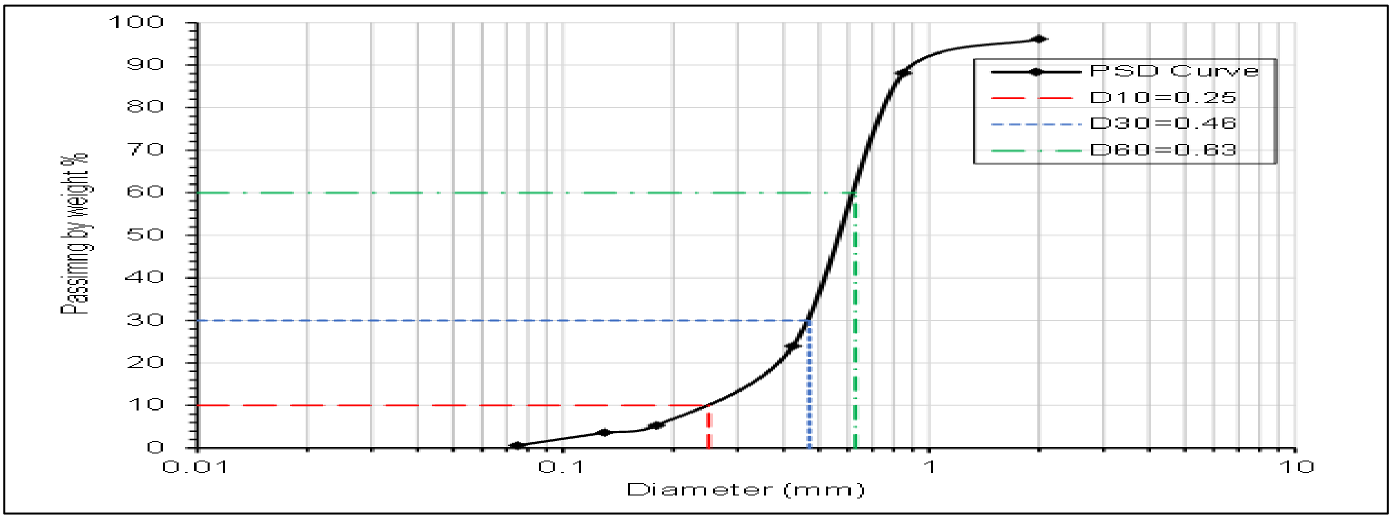

Fig. 3 Particle Size Distribution curve for the used Sand Material

B. Cement Kiln Dust (CKD)

The CKD used in this experimental study was provided by the Helwan Cement Co., which is located in south of Cairo, Egypt. Several samples of waste CKD from the stock pile material were collected and transported to the laboratory. Figure 4 shows the processes of Portland cement production, and it can be seen that CKD is collected from kiln exhaust gases. The quantity of dust generated is dependent upon various factors: the type and size of the processing equipment, especially the chain system; the kiln air velocities; the type of fuel used; the chemical and physical parameters associated with the raw materials; and the size to which the raw materials are ground. Mineralogical examination of the dust indicates four groups of minerals, as described below (Corish and Coleman 1995):

- Raw minerals; e.g., carbonates, quartz, argillaceous material, etc.
- Partly to fully clinkerized minerals, e.g., decomposed raw minerals, clinker minerals, intermediate phases, etc.
- Free lime.
- Periclase.

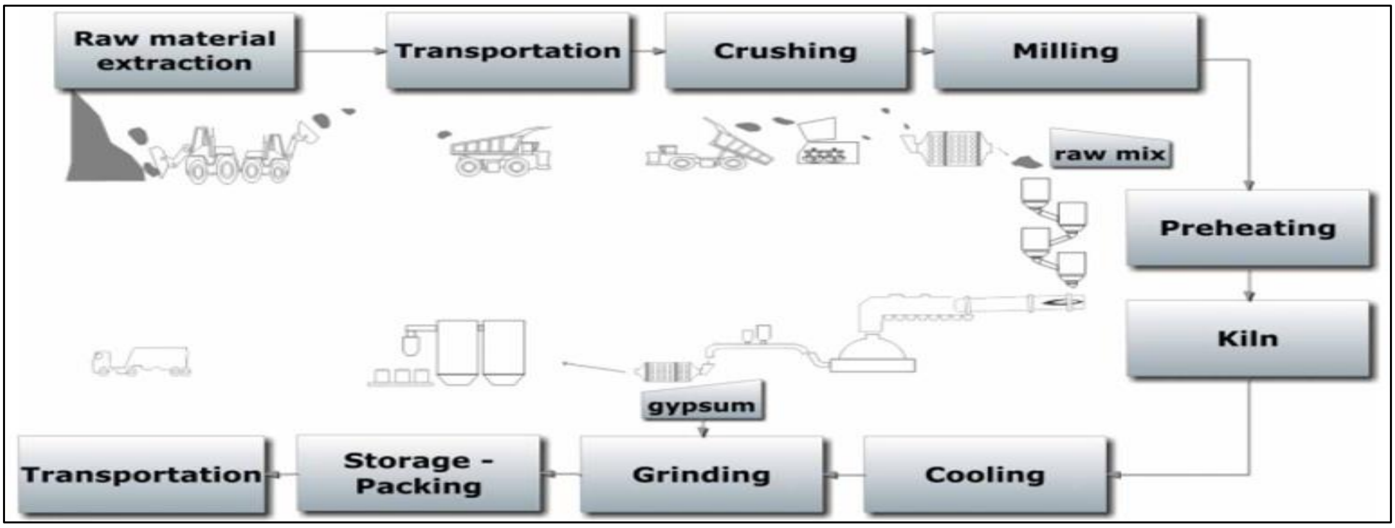

Fig 4: Overall Cement Manufacturing Process (after Maslehuddin 2008a).

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Tables (1) and (2) represent the chemical composition and physical properties of CKD used in the present study along with the corresponding values given in the previous studies by other researchers. It is obvious that this is substantial variation in percentage of calcium oxide (CaO), percentages of silica (SiO_2), and aluminum oxides (Al_2O_3). The pH of CKD water mixtures is generally around 12. It contains significant alkalis, and is considered to be caustic. Trace constituents in CKD including certain trace metals such as cadmium, lead, selenium, and radionuclides are generally found in concentrations less than 0.05% by weight (Chrysostomou et al. 2017).

Table 1: Chemical Composition of CKD used in the Present Study Compared to the Values Introduced in Earlier Studies by other Researchers

Reference	**Present study**	**Maslehuddin et al. 2008a**	**Sreekrishnavilasam et al. 2006**	**El-Aleem et al. 2005**	**Al-Harthy et al. 2003**	**Udoeyo and Hyee 2002**	**Baghdadi and Rahman 1990**
Silica (SiO_2)	17.56	17.1	15.05	13.37	15.80	2.16	13.94
Aluminum oxide (Al_2O_3)	1.37	4.24	6.75	3.36	3.60	1.09	4.74
Iron oxide (Fe_2O_3)	0.83	2.89	2.23	2.29	2.80	0.54	2.36
Magnesium oxide (MgO)	0.85	1.14	1.64	1.90	1.90	0.68	2.15
Calcium oxide (CaO)	34.68	49.3	43.99	42.99	63.80	52.72	45.9
Sodium oxide (Na_2O)	0.86	3.84	0.69	3.32	0.30	NA	1.03
Potassium oxide (K_2O)	3.16	2.18	4.00	3.32	3.00	0.11	1.71
Coloride (Cl)	5.56	NA	NA	NA	NA	NA	NA
Sulphur oxide (SO_3)	3.88	3.56	6.02	5.10	1.7	0.05	13.94
Loss on ignition (L.O.I)	29.63	15.8	21.57	15.96	NA	42.39	26
Note: Oxide values expressed in % by mass of cement							

Table 2: Typical Physical Properties of CKD used in the Present Study Compared to the Values Given in Earlier Studies by other Researchers

Property	**Present study**	**Baghdadi and Rahman 1990**	**Aggarwal et al 2023**	**Collins and Emery 1983**
Gradation (75% passing)	NA	NA	NA	0.030mm (#450 sieve)
Maximum particle size	NA	NA	NA	0.300mm (#450 sieve)
Specific surface (cm2/g)	7250	3303	6070	4600-14000
Specific gravity	2.7	2.75	2.57	2.6-2.8

C. Leachate Material

The leachate compensation material was prepared in the laboratory as per as the following manual: "Geotechnics of Landfill Design and Remedial Works Technical Recommendations GLR (1993)". The chemical composition (i.e., ingredients) of the prepared leachate was as following:

- 5% inorganic acid (hydrochloric, nitric and sulfuric acids, each 33 vol%), pH 1;
- 5% organic acid (acetic and propionic acid, each 50 vol%), pH 2.2;
- metal salt leachate (nickel chloride, copper chloride, chromium chloride, zinc chloride, each 1g/l), pH 2.9; and
- synthetic leachate (0.15ml sodium acetate, 0.15ml acetic acid, 0.05ml glycine, 0.007ml salicylic acid), pH ~4.5.

IV. TESTING PROGRAM

Testing program was mainly conducted on the prepared samples of CKD-sand soil mixes to determine the optimum percentages of the mix components that satisfy the required permeability values recommended by regulations and standards of municipal landfill. Thus, four selected percentages of CKD materials were mixed with sandy soil in the testing program, including: 10%, 20%, 30%, and 40% of weight. Furthermore, the compositions of each mixture (i.e., quantities of sand soil and waste CKD material) used the investigated mixes are given in Table (3).

Table 3: Weights of Sand Soil and Waste CKD Material used in the Studied Mixes

Mix ID	**1**	**2**	**3**	**4**
CKD content in the mix (%)	10	20	30	40
Sand weight (Kg)	2.03	1.790	1.560	1.318
Waste CKD weight (Kg)	0.230	0.450	0.670	0.878

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➢ *Laboratory Work was Divided into two Main Stages, Namely:*

- *Stage (1):*

The aims of this stage are: (1) identify the influence of compaction moisture content on the hydraulic conductivity of compacted mix; and (2) measure the hydraulic conductivity which can vary depending on the compaction moisture content of the tested mix. The tremendous variation in hydraulic conductivity is attributed to the differences in the microstructure of the compacted CKD-sand mixes with varying compaction moisture content.

✓ Modified proctor compaction test (ASTM D1557), using a mechanically operated steel rammer of 2 inches (51 mm) diameter and weight of 10Ib (4.5 kg), with an arrangement to control the height of drop to a free-fall of 15 inch (45.7 cm) above the elevation of the compacted samples that used in the compaction.

✓ Falling head permeability test for mixes prepared at the optimum water content (ASTM D5084).

- *Stage (2):*

One-dimensional consolidation test (ASTM D2435). In this stage, investigation of the effect of the leachate on (k) values for the successful mixes, which passed the first stage, was performed. Odometer cell was implemented as inundation medium for the tested samples and was loaded under applied vertical stresses up to 1600 kPa.

V. RESULTS AND ANALYSIS

As mentioned earlier, the purpose of this first stage of laboratory program was to determine the required percentage of cement dust that achieve a coefficient of permeability less than 1×10^{-7} cm/sec. Thus, the first step was the determination of the dry density-water content relationship for different tested mixes. For permeability tests, the mixes were prepared using the results of the compaction test (i.e., maximum dry unit weight, γ_{dmax}, and optimum moisture content, $w_{o.m.c}$).

A. Compaction Parameters of CKD-Sandy Soil Mixes

Compaction characteristics for the four prepared mixes were determined as per ASTM D1557. Table (4) gives the values of maximum dry unit weight (γ_{dmax}) and the corresponding values of optimum moisture content ($w_{o.m.c}$) for the tested mixes.

Figure 5 depicts the results of modified Proctor tests (i.e., compaction curves) on the four different dust-sandy soil mixes. Furthermore, Figure 6 shows the variation of $w_{o.m.c}$ and γ_{dmax} values with relative to the CKD content for the tested mixes. It can be noticed that $w_{o.m.c}$ values increased by increasing the content of CKD. On the other hand, the values of γ_{dmax} decreased slightly by increasing the content of CKD. It was obvious that the $w_{o.m.c}$ values were affected much higher than the γ_{dmax} whereas the $wo_{.m.c}$ increased about 135% due the increase of CKD content from 10% to 40%. This behavior can be attributed to fineness of the CKD material, the addition of CKD resulted to a substantial shift in the compaction curve (i.e., higher $w_{o.m.c}$ and lower γ_{dmax} with increasing CKD content). Subsequently, these compaction characteristics have been observed because of the void filling by the kiln dust. For more than 30% of CKD, there was an overdose of the dust and lubricating effect, reducing the maximum dry unit weight.

Table 4: Compaction Test Results for the Different Four Mixes

Mix ID	**1**	**2**	**3**	**4**
Waste CKD material content (%)	10	20	30	40
γ_{dmax} (kN/m^3)	20.72	20.59	20.50	20.18
$w_{o.m.c}$ (%)	6.00	6.84	8.85	14.11

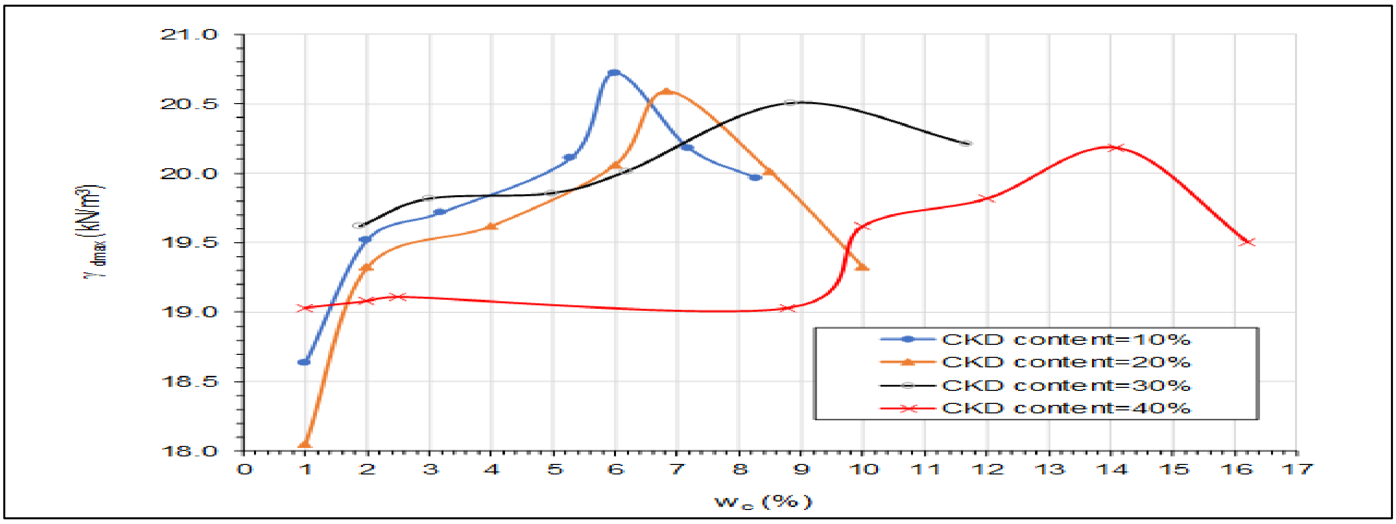

Fig 5: Compaction Curves for the Prepared Samples of Various CKD Content

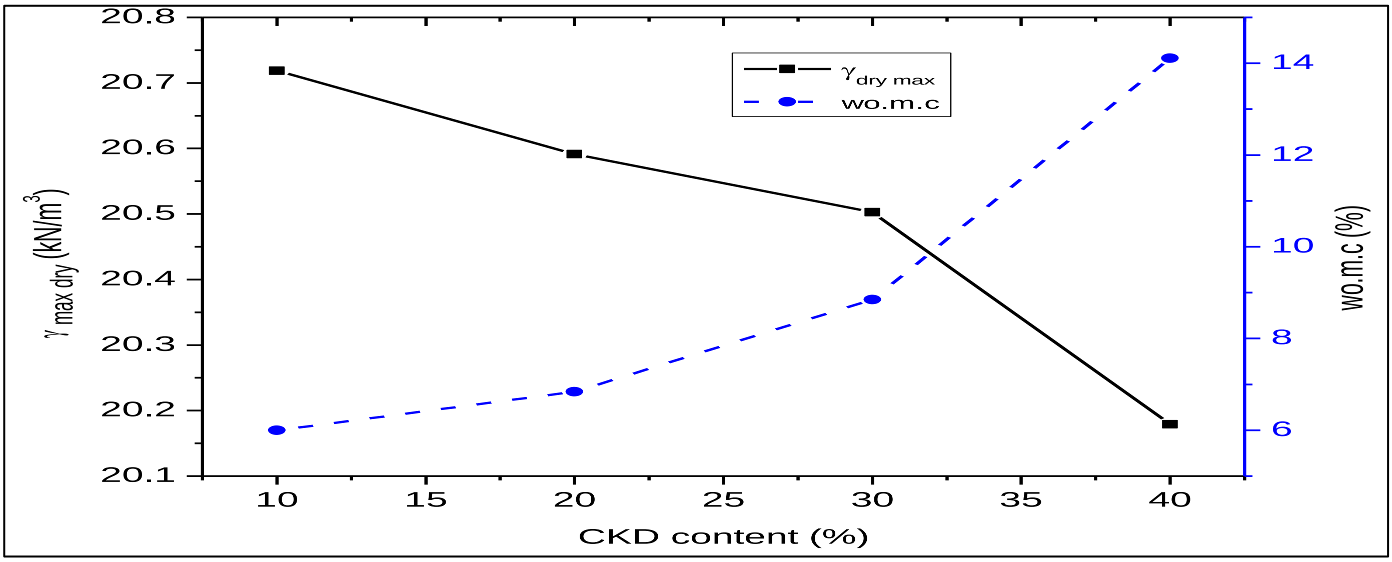

Fig 6: Measured Compaction Parameters with Variation of CKD Content

B. Results of Permeability Tests

Typically, hydraulic conductivity coefficient (k) of lining material plays a significant role for designing of landfills in municipal sites. Therefore, the main objective for this this part is to find out the suitable mix that achieved the maximum acceptable limit value of hydraulic conductivity coefficient (i.e., $k \leq 1\times10^{-7}$ cm/sec). Figure 7 illustrates the setup of the permeability test apparatus which carried out according to ASTM D5084.

The samples were placed and tested in the compaction mold to measure the coefficient of permeability for the different mixes. The sample preparation was as follows:

- Measure the dimensions of the metal cylinder of the compaction mold (A*L), then calculate its volume (v).
- Obtain the value of (γ_{dmax}) from the compaction curve of the tested mix and the corresponding ($w_{o.m.c}$).
- From the values of (γ_{dmax}), ($w_{o.m.c}$), and (v) the weight of the sample that achieves the required density can be determined.
- Compact the weighted mix inside the compaction mold till it reaches the required volume for each mix.

Four mixes of different CKD content (10, 20, 30, 40%) mixed with sandy soil were carried out. Each mix was investigated at the point of optimum moisture content and the corresponding maximum dry unit weight obtained previously from the compaction curves. Additionally, falling head permeability tests were carried out under hydraulic gradient ($i= \Delta h/\Delta L$, the difference in the hydraulic head over a distance along the flow path) ranges from 6 to 10 in order to simulate the low hydraulic gradient in the actual landfill sites.

During samples preparation for permeability test, it was observed that full saturation period for the samples increased drastically with relative to increase in CKD content in the mix, and saturation time ranged between 10 to more than 250 days to complete full saturation. The steady state condition was reached when three successive measured readings of water head have quite subtle differences.

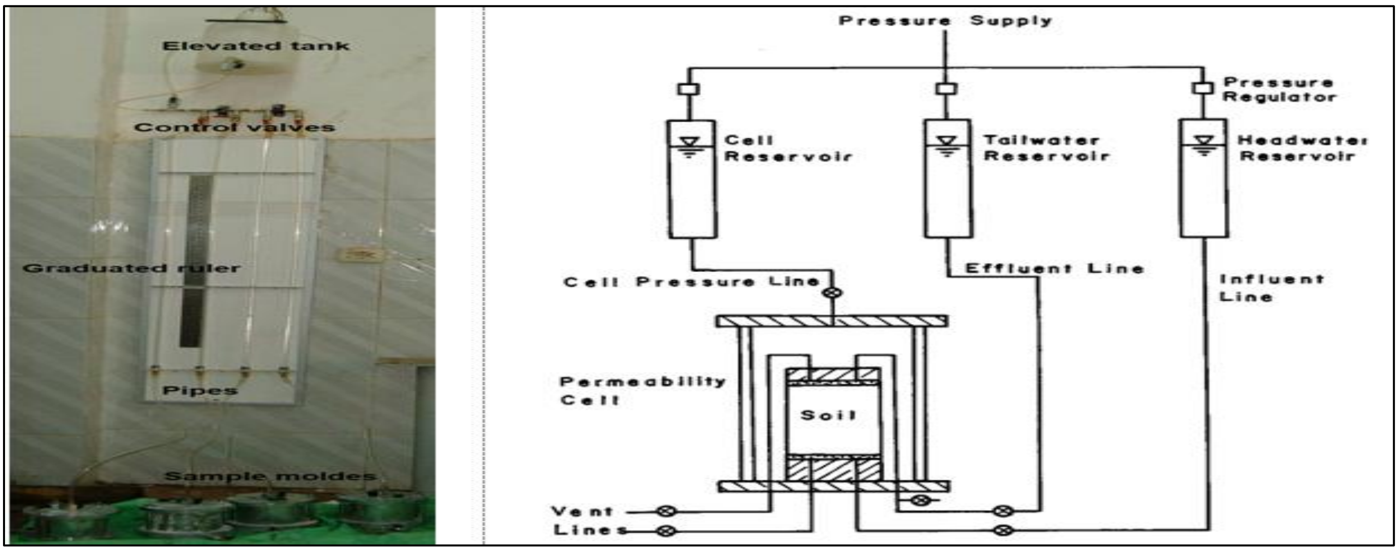

Fig 7: Setup of Permeability Test Apparatus (after ASTM D5084)

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The rate of flow of the water through the sample at any time (t) can be given by the following equation:

$$q = k\frac{h}{L}A = -a\frac{dh}{dt} \quad (1)$$

Rearrangement of Eq. (1) and integration with limits of time from 0 to t and with limits of head difference from h_1 to h_2 gives the following equation:

$$k = 2.3\frac{aL}{At}log_{10}\frac{h_1}{h_2} \quad (2)$$

Where: q is flow rate; a is cross-sectional area of the standpipe; A is cross-sectional area of the soil sample; L is length of the sample; t is elapsed time; h_1 is initial head difference at time t=0; and h_2 final head difference at time t= t_2.

Table (5) summarizes the measured values of (k), elapsed time for full saturation, and CKD content for the mixes. Figure 8 shows the variation of k values with elapsed time represented in log-log scale. It was clear that for mix no.1 (CKD content= 10%), the elapsed time for reaching to the steady state condition was very short period of time (9 days). compared to the other mixes, as shown later. Mix no. 1 has failed to reach the target value of k value as the final measured hydraulic conductivity coefficient was equal to 1.32×10^{-4} cm/sec. For mix no.2 (CKD content= 20%), the elapsed time for reaching to the steady state achieved after 69 days. It was observed that this sample began to take longer periods of time to reach the steady state. This mix succeeded in reaching the target value of k as the final measured coefficient of hydraulic conductivity was equal to 5.81×10^{-8} cm/sec. For mix no.3 (CKD content= 30%), the elapsed time for reaching to the steady state was to achieved after 105 days. This mix succeeded in reaching the target value of k where the final hydraulic conductivity value= 1.53×10^{-9} cm/sec. For mix no.4 (CKD content= 40%), the elapsed time for reaching to the steady state was 250 days. This mix succeeded in reaching the target value of k where the final measured hydraulic conductivity coefficient value was equal to 5.47×10^{-10} cm/sec.

Figure 9 illustrates the effect of variability of CKD content on the final measured hydraulic conductivity coefficient. The effect of CKD content on (k) value can be noticed to be highly significant especially for mixes contain low content of CKD (i.e., ≤20%); the variation from 10% to 20% decreased the permeability coefficient about 3.5 orders of magnitudes. The difference in k value was about 1.5 order of magnitudes between the samples contain CKD= 20% and 30% then become 0.7 order of magnitude between the mix contains 40% and 30%.

Table 5: Measured Coefficient of Hydraulic Conductivity Versus CKD Content

CKD (%)	**Required time to reach 1×10^{-7} (days)**	**Elapsed time for saturation (days)**	**Measured final, k (cm/sec)**
10 (Mix no.1)	Not achieved	9	1.32×10^{-4}
20 (Mix no. 2)	35	69	5.81×10^{-8}
30 (Mix no. 3)	42	105	1.53×10^{-9}
40 (Mix no. 4)	14	More than 250	5.47×10^{-10}

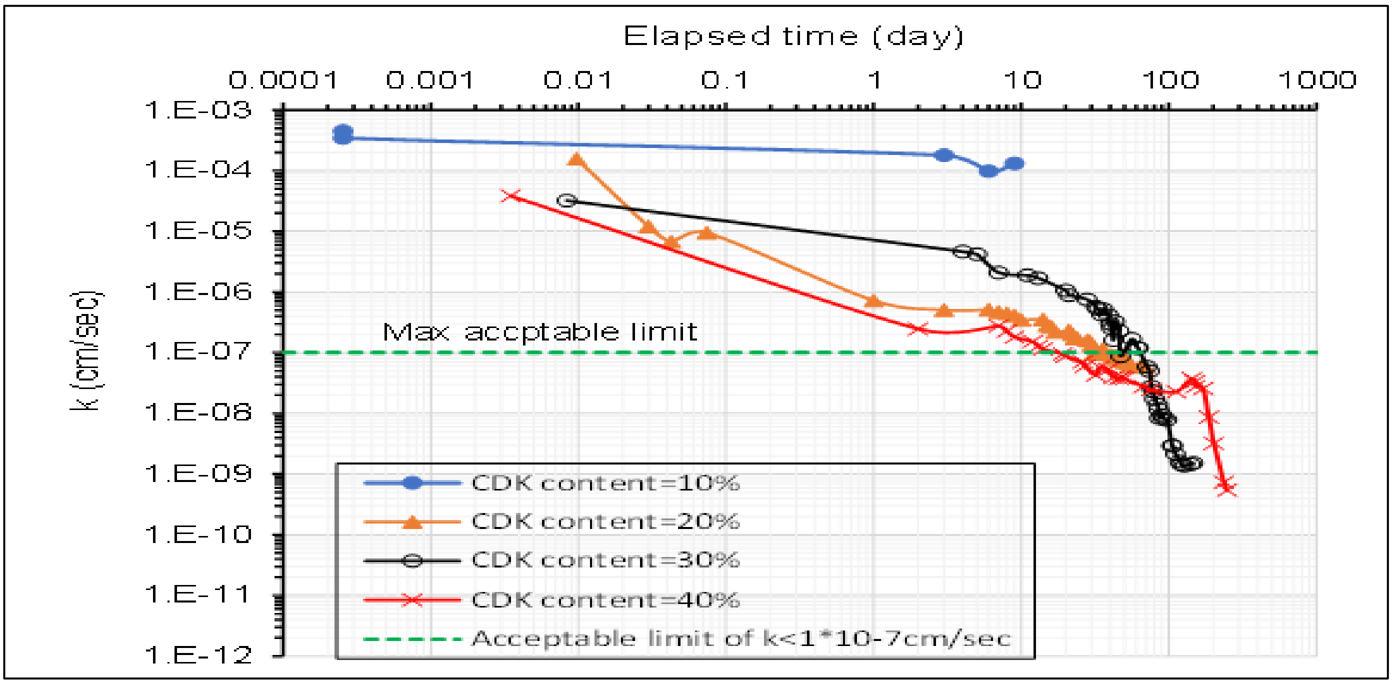

Fig 8: Variation of Hydraulic Conductivity Versus Elapsed Time

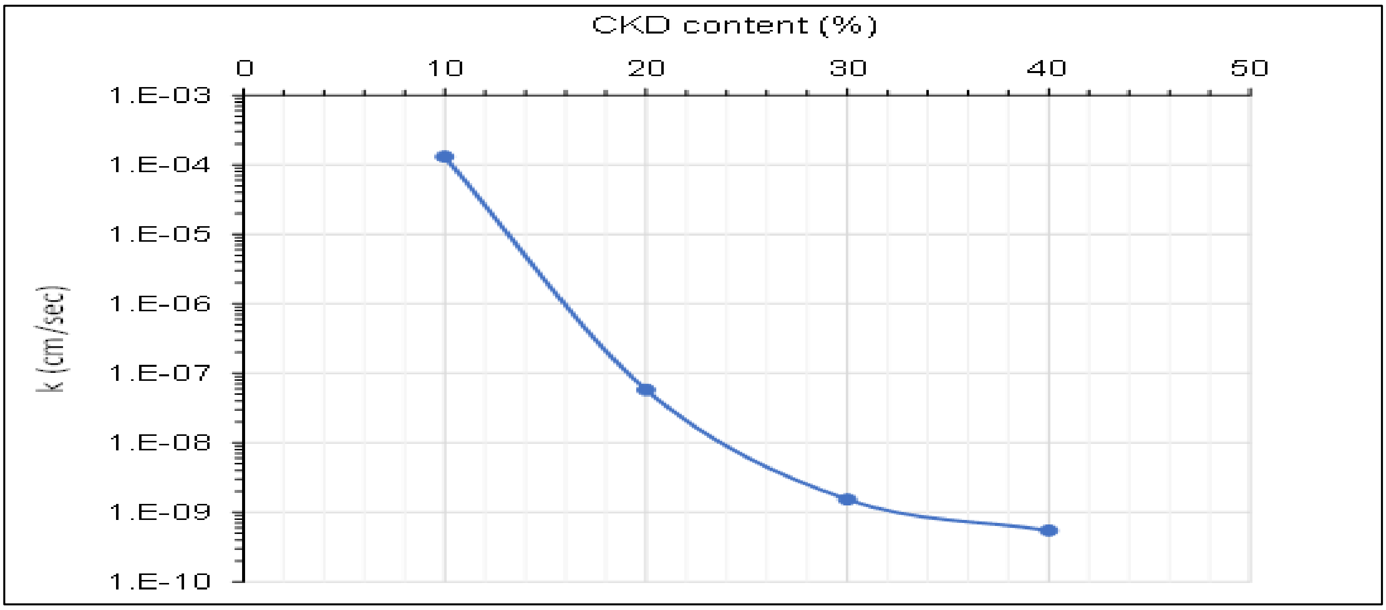

Fig 9: Variation of Hydraulic Conductivity Coefficient with CKD Content.

C. Effect of Leachate on Permeability of the Tested Samples

In the second stage of the testing program, one-dimensional consolidation tests (as per ASTM D2435) were carried out on the succeeded mixes to measure the effect of leachate on the hydraulic conductivity coefficient (k). The aim of exposing the mix to the leachate was to simulate the actual severe site conditions at municipal landfill site.

Practically, however, it was difficult to determine the hydraulic conductivity coefficient (k) using the available falling head test apparatus, as the leachate would react with the plastic materials and with the metal molds and molds which in turn would result in false values of (k). Accordingly, the permeability was measured indirectly through the one-dimensional consolidation test via using the odometer cell as inundation medium for the tested samples. The sample preparation was carried out as follows:

- Measure the dimensions of the metal ring of the consolidation ring then calculate its volume.
- Obtain the point of (γ_{dmax}) from the compaction curve of the tested mix.
- From the (γ_{dmax}), ($w_{o.m.c}$) and the measured volume of the metal ring (v) the weight of the sample that achieves the required density can be determined.

Compact the weighted mix inside the metal ring till it reaches the required volume. Initially, consolidation test was performed by using potable water as permeating fluid, then the test was repeated using leachate to determine the effect of leachate on permeability properties. Table (6) summarizes the results of one-dimensional consolidation tests under applied vertical stresses up to 1600 kPa for samples of CKD-sandy soil mix (40% content) submerged in potable water and leachate.

From the theorem of soil compressibility (i.e., consolidation), the following equation can be used for estimating (k) value corresponding to each vertical loading cycle:

$$k = C_v m_v \gamma_w \tag{3}$$

$$m_v = \frac{a_v}{1 + e_o} \tag{4}$$

$$a_v = \frac{\Delta e}{\Delta p} \tag{5}$$

Where: k is coefficient of hydraulic conductivity; C_v is coefficient of consolidation; m_v is coefficient of volume compressibility; a_v is coefficient of compressibility; e_o is initial void ratio; Δe is change in void ratio; and Δp change in vertical stresses.

Figure 10 depicts the curves of 1-D consolidation tests (e-log p) for CKD-sandy soil mixes of CKD content equal 40% which were conducted under the effect of two different environmental conditions (i.e., water and leachate as permeating fluid). It is obvious that the variation in the value of the void ratio (e) is small (about 6% variations under different environmental conditions) which reflects the low plasticity of this type of mix. Furthermore, Figure 11 shows the relationships between vertical stress (p) versus coefficient of permeability (k) for the mix of CKD=40% submerged in water and leachate as permeating fluid. It be seen that the two mixes succeeded in satisfying the permeability condition at all loading values. Moreover, the coefficients of hydraulic conductivity (k) calculated from consolidation tests under leachate effect were ranged between 1×10^{-8} and 6.5×10^{-10} cm/sec. However, the corresponding values for the same test conducted under portable were ranged between 1.8×10^{-8} and 5.4×10^{-10} cm/sec. This indicates that effect of leachate on the permeability of the mixes, which has CKD content of 40%, is negligible (the largest difference was about 0.5 orders of magnitude at applied vertical stress of 400 kPa).

Table 6: Results One-Dimensional Consolidation Tests for CKD-Sandy Soil Mix no. 4 (CKD Content of 40%)

Vertical Stress, p (kPa)	Submerged in Potable Water			Submerged in Leachate		
	e	C_v (cm^2/day)	k (cm/sec)	e	C_v (cm^2/day)	k (cm/sec)
25	0.39	N/A	N/A	0.38	N/A	N/A
50	0.39	970.86	1.8E-08	0.38	634.07	1.0E-08
100	0.39	275.96	8.2E-09	0.38	111.36	3.0E-09
200	0.38	384.20	6.1E-09	0.38	313.84	4.7E-09
400	0.38	136.10	1.6E-09	0.37	623.24	6.2E-09
800	0.38	157.22	1.1E-09	0.37	154.14	1.2E-09
1600	0.37	61.34	5.4E-10	0.36	106.91	6.5E-10

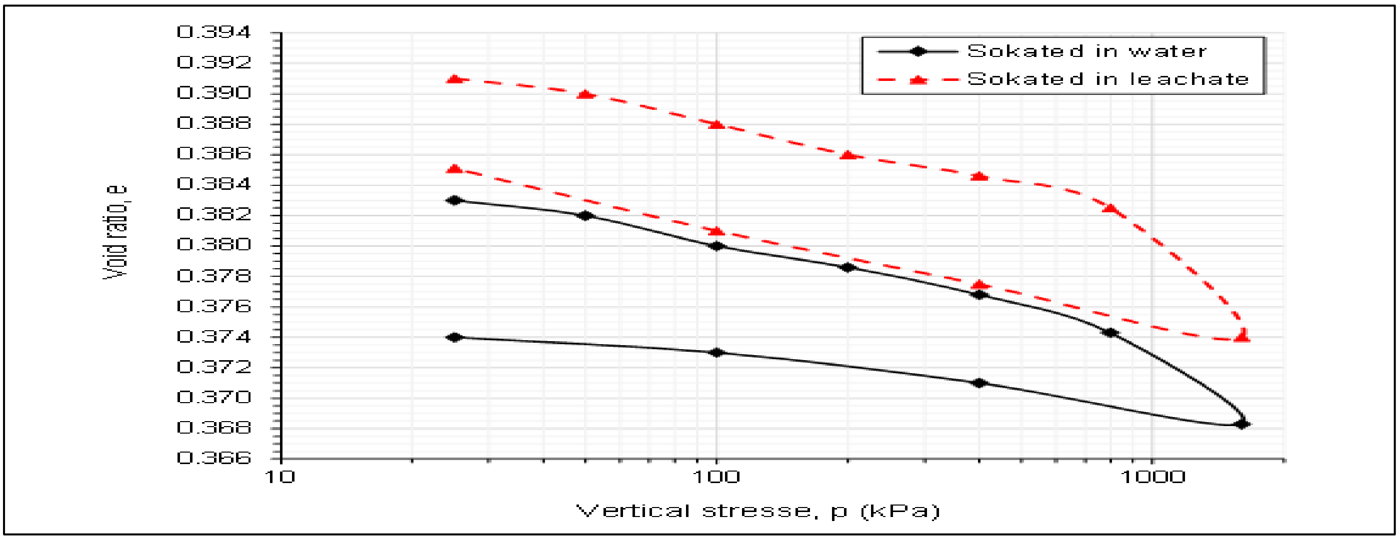

Fig 10: Consolidation Curves for Mix no. 4 (CKD=40%) under the Effect of Different Environmental Conditions (Water and Leachate as Permeating Fluid)

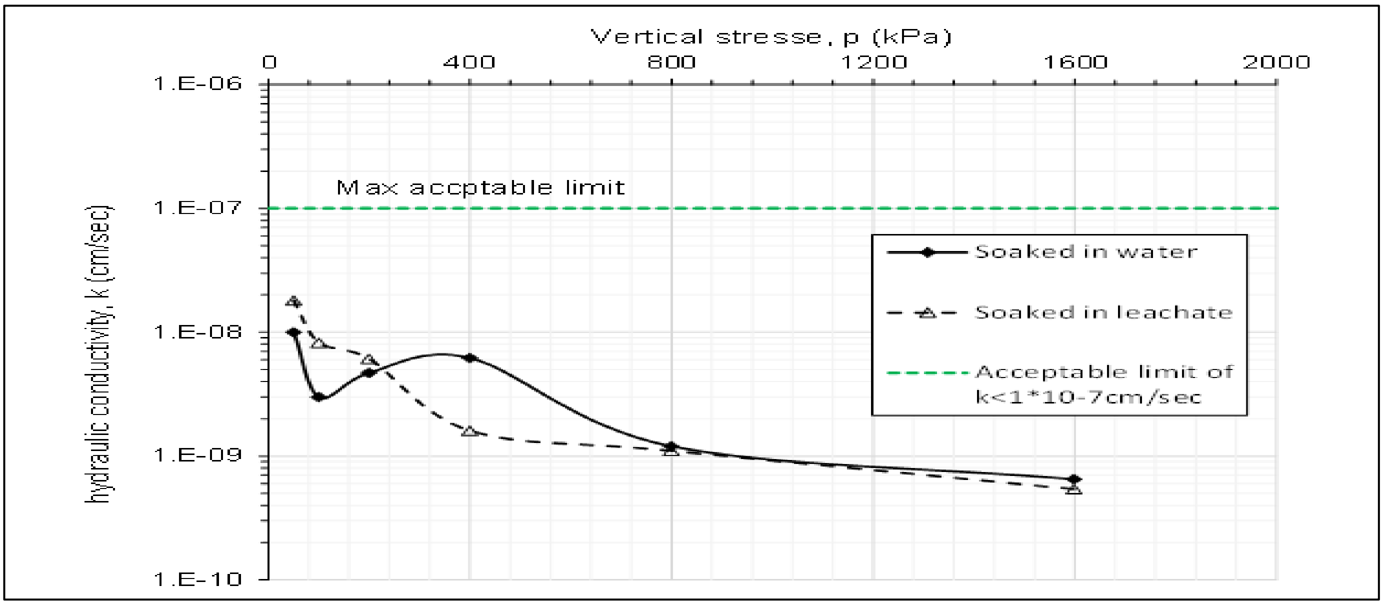

Fig 11: Vertical Stress (p) Versus Coefficient of Permeability (k) for Mix no. 4 (CKD=40%) Submerged in Two Different Environmental Conditions

VI. SUMMARY AND CONCLUSIONS

Growing quantities of waste CKD (a fine powdery material, gray to tan in color), as by-product of Portland cement production, pose problems regarding their environmentally safe disposal, and rising space requirement for municipal landfill locations. Therefore, waste CKD recycling for sustainable development was investigated in this paper by utilizing such waste material after mixing with sandy soil as lining for construction of municipal landfill. Based on the experimental results discussed above, the following findings are withdrawn:

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- For the tested mixes, the content of waste CKD had significant impact on the values of $w_{o.m.c}$ rather than on the γ_{dmax}. Optimum moisture content increased about 135% due to an increase in CKD content of 40%. This behavior can be attributed to fineness of the material, the addition of CKD resulted to a substantial shift in the compaction curve (i.e., higher $w_{o.m.c}$ and lower γ_{dmax} with increasing CKD content).
- The mix that had waste CKD content of 40%, succeeded in achieving the required value of hydraulic conductivity coefficient (k) by the standards even though the mix was subjected to leachate during testing. In terms of permeability, influence of the leachate on the tested mix was too small (about 0.1 orders of magnitude compared to water as permeating fluid) so that the effect can be considered as negligible under aggressive site conditions.
- Utilization of waste CKD-sandy soil mix as liner material for installing municipal landfills is a good solution and important alternative, as it hinders the leachate infiltration into the original ground and underground water as well as provides a safe disposal method for waste CKD.
- The optimum recommended percentage of waste CKD was varied between 30% and 40% by the mix weight. This range of waste CKD content can be implemented in construction of landfill liner due to environmental and economical aims. As a result, the CKD-sandy soil mix can serve as a cost-effective and efficient alternative to traditional landfill liner materials.

DECLARATIONS

- Conflict of Interest: the author declares that he has no conflict of interest.

REFERENCES

[1]. Abeln, D.L., Hastings, R.J., Scxhreiber, R.J. and Yonley, C. (1993), "Detailed illustration of contingent management practices for cement kiln dust", Research and Development Bulletin, SP115T, Portland Cement Association, Skokie, IL.

[2]. Abdel-Rahman, A.H., Awad-Allah. M.F. and Mamdouh, K. (2021), "Utilization of low-quality bentonite in landfill liners", Lowland Technology International, 23 (1), 9-16. https://doi.org/https://doi.org/10.0001/ialt_lti.v23i1.792.

[3]. Aggarwal, J., Goyal, S. and Kumar, M. (2023), "Sustainable utilization of industrial by-products spent foundry sand and cement kiln dust in controlled low strength materials (CLSM)", Construction and Building Materials, 404, Article 133315. https://doi.org/10.1016/j.conbuildmat.2023.133315.

[4]. Alharthi, Y.M., Elamary, A.S. and Abo-El-wafa, W. (2021), "Performance of plain concrete and cement blocks with cement partially replaced by cement kiln dust", Materials (Basel) 14 (19) 5647. https://doi.org/10.3390/ma14195647.

[5]. Al-Harthy, A.S., Taha, R. and Al-Maamary, F. (2003), "Effect of cement kiln dust (CKD) on mortar and concrete mixtures", Construction and Building Materials, 17 (5), 353–360. https://doi.org/10.1016/S0950-0618(02)00120-4.

[6]. Ashley, K.H. (2021), "Minerals information – cement from united states geological survey", U.S. Geology Survey Miner, Mineral Commodity Summaries, 200 p. https://doi.org/10.3133/mcs2021. ISBN 978-1-4113.

[7]. ASTM, D1557 (2006) "Standard test methods for laboratory compaction characteristics of soil using modified effort".

[8]. ASTM D5084 (2006) "Standard test methods for measurement of hydraulic conductivity of saturated porous materials using a flexible wall permeameter".

[9]. ASTM D2435 (2006) "One-Dimensional consolidation properties of soils".

[10]. Awad, M., Shaqadan, A., Al-Adwan, J. and Maraqa, F. (2023), "Recycling of basalt and limestone cutting dust in concrete", Civil Engineering Journal 9 (5) 1173–1186. http://dx.doi.org/10.28991/CEJ-2023-09-05-010.Bhatty JI (1995) Alternative uses of cement kiln dust. In: Research and development bulletin, RP327. Skokie (IL): Portland Cement Association.

[11]. Baghdadi, Z.A. and Rahman, M.A. (1990), "Utilization of kiln dust in clay stabilization", Journal of King Abdulaziz University: Engineering and Science, 2, 153–163.

[12]. Bhatty, J.I. (1995), "Alternative uses of cement kiln dust. In: Research and development bulletin", RP327. Skokie (IL): Portland Cement Association.

[13]. Chindaprasirt, P. and Chalee, W. (2014), "Effect of sodium hydroxide concentration on chloride penetration and steel corrosion of fly ash-based geopolymer concrete under marine site". Constr. Build. Mater, 63, 303-310. https://doi.org/10.1016/J.CONBUILDMAT.2014.04.010.

[14]. Chrysostomou, C., Kylili, A., Nicolaides, D et al. (2017), "Life cycle assessment of concrete manufacturing in small isolated states: the case of Cyprus", International Journal of Sustainable Energy, 36, 825–839. https://doi.org/10.1080/14786451.2015.1100197.

[15]. Collins, R.J. and Emery, J.J. (1983), "Kiln dust–fly ash systems for highways bases and sub-bases", Federal Highway Administration, Report No. FHWA/RD-82/167, Washington DC.

[16]. Corish, A. and Coleman, T. (1995), "Cement kiln dust" Concrete, 29 (5), 40–42.

[17]. Dyer, T. D., Halliday, J. E., and Dhir, R. K. (1999). "An investigation of the hydration chemistry of ternary blends containing cement kiln dust", Journal of Materials Science, 34(20). 4975-4983. https://doi.org/10.1023/A:1004715806829.

[18]. El-Aleem, S.A., Abd-El-Aziz, M.A., Heikal, M. and El-Didamony, H. (2005), "Effect of cement kiln dust substitution on chemical and physical properties and compressive strength of Portland and slag cements", Arab J Sci Eng, 30, 263–273.

[19]. Environmental Assessment of Existing Industries in Bhutan, NEC 1999.

[20]. Gathuka, L., Kato, T., Takai, A., Flores, G., Inui, T. and Katsumi, T. (2021), "Effect of acidity on attenuation performance of sandy soil amended with granular calcium-magnesium composite", Soils and Foundations 61, 1099–1111. https://doi.org/10.1016/j.sandf.2021.05.007.

[21]. German Geotechnical Society for the International Society of Soil Mechanics and Foundation Engineering Geotechniqus of Landfill Design and Remedial Works Technical Recommendations -GLR, Ernst, Berlin. (1993).

[22]. Kedzi, S. (1979), Stabilized earth roads development in geotechnical engineering. Elsevier Scientific, New York.

[23]. Kessler, G.R. (1995), "Cement kiln dust (CKD) methods for reduction and control", IEEE Transaction on Industry Applications, 31 (2), 407–412. https://doi.org/10.1109/28.370292.

[24]. Maslehuddin, M., Al-Amoudib, O., Shameema M., Rehmana, M. and Ibrahim, M. (2008a), "Usage of cement kiln dust in cement products – research review and preliminary investigations", Construction and Building Materials, 22, 2369–75. https://doi.org/10.1016/j.conbuildmat.2007.09.005.

[25]. Miller, G. and Azad, S. (2000), "Influence of soil type on stabilization with cement kiln dust", Construction and Building Materials, 14 (2), 89–97. https://doi.org/10.1016/S0950-0618(00)00007-6.

[26]. Mo, J., Flores, G., Inui, T. and Katsumi, T. (2020), "Hydraulic and sorption performances of soil amended with calcium-magnesium composite powder against natural arsenic contamination", Soils and Foundations 60 (5), 1084–1096. https://doi.org/10.1016/j.sandf.2020.05.007.

[27]. Oss, H.G., "Minerals information – cement". Retrieved January 2010, from United States Geological Survey; 2010. http://minerals.usgs.gov/minerals/pubs/commodity/cement/.

[28]. Peethamparan, G.A Olek, J. and Helfrich, K. (2006), "Evaluation of the engineering properties of cement kiln dust (CKD) modified kaolinite clay", Proceedings of the 21st International Conference on Solid Waste Technology and Management, March 26–29, Widener University, Philadelphia, PA, pp. 997–1006.

[29]. Santagata, M. and Bobet, A. (2002), "The use of cement kiln dust (CKD) for subgrade stabilization/modification", SPR No. 2575, Purdue University, West Lafayette, Indiana, USA.

[30]. Seo, M., Lee, S., Lee, C. and Cho, S. (2019), "Recycling of cement kiln dust as a raw material for cement", Environments - MDPI, 6(10), 113. https://doi.org/10.3390/environments6100113.

[31]. Sreekrishnavilasam, A., King, and Santagata, M. (2006), "Characterization of fresh and landfilled cement kiln dust for reuse in construction applications", Journal of engineering geology, 85, 165-173. https://doi.org/10.1016/j.enggeo.2005.09.036.

[32]. Sreekrishnavilasam, A., Rahardja, S., Kmetz, R., Santagata, M. and Santagata, M. (2007), "Soil treatment using fresh and landfilled cement kiln dust", Construction and Building Materials 21(2), 318-327. https://dOI: 10.1016/j.conbuildmat.2005.08.015

[33]. Sun, Z., Cui, H., An, H., Tao, D., Xu, Y., Zhai, J and Li ,Q. (2013), Synthesis and thermal behavior of geopolymer-type material from waste ceramic", Construction and Building Materials, 49, 281-287. https://doi.org/10.1016/J.CONBUILDMAT.2013.08.063.

[34]. Tabelin, C., Igarashi, T., Villacorte-Tabelin, M., Park, I., Opiso, E., Ito, M. and Hiroyoshi, N. (2018), "Arsenic, selenium, boron, lead, cadmium, copper, and zinc in naturally contaminated rocks: A review of their sources, modes of enrichment, mechanisms of release, and mitigation strategies", Science of The Total Environment, 645, 1522–1553. https://doi.org/10.1016/j.scitotenv.2018.07.103.

[35]. Tang, Q., Katsumi, T., Inui, T. and Li, Z. (2014), "Membrane behavior of bentonite-amended compacted clay", Soils and Foundations, 54, 329–344. http://dx.doi.org/10.1016/j.sandf.2014.04.019.

[36]. Tatsuhara, T., Arima, T., Igarashi, T. and Tabelin, C. (2012) "Combined neutralization–adsorption system for the disposal of hydrothermally altered excavated rock producing acidic leachate with hazardous elements", Engineering Geology, 139–140,76–84. https://doi.org/10.1016/j.enggeo.2012.04.006.

[37]. Todres, H., Mishulovich, J. and Ahmed, J. (1992), "Cement kiln dust management: Permeability", Research and Development Bulletin RD103T, Portland Cement Assoc., p7. Skokie, Illinois.

[38]. Udoeyo, F. and Hyee, A. (2002), "Strength of cement kiln dust concrete", ASCE Journal of Materials in Civil Engineering, 14 (96), 524–526. https://doi.org/10.1061/(ASCE)0899-1561.

[39]. U.S. Department of Transportation (USDOT) Federal Highway Administration: Turner Fairbanks Highway Research Center, User guidelines for waste and by-product materials in pavement construction: FHWA-RD-97-148 (1998).

[40]. US Environmental Protection Agency (USEPA). Report to Congress on Cement Kiln Dust. Office of Solid Wastes. U.S. Environmental Protection Agency. (1993).

[41]. US Environmental Protection Agency (USEPA). Technical Background Document on Ground Water Controls at CKD Landfills. Office of Solid Waste U.S. Environmental Protection Agency. (1998).