Leachate composition of lead and cadmium ions from solidified mortar mixed with Nanosilica

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Abstract. Soils contaminated with Cd and Pb ions are a great problem that affects human health and the environment. Intending to decrease the environmental risk. Solidification/ stabilization (S/S) is one of the commonly used and economic remediation technologies to treat contamination by heavy metals in soils compared with other remediation technology. To understand the leaching mechanism from the (S/S) process, the EPA Semi-dynamic Tank Leaching method 1315 and unconfined compressive strength test was carried out to test the effectiveness and performance of the solidification process of contaminated sands with Pb and Cd ions by using ordinary Portland Cement locally produced and nanomaterial. Tow mix designs were performed on the contaminated sands at three different pollution concentrations and three ratios of synthesized Nanosilica from rice husk as additive replacement of cement. The Nanosilica as-prepared has amorphas form, average diameter equal to 52.83 nm and surface area around 618 m²/g. This paper discusses the effects of Nanosilica on leaching contamination from solidifying samples and compressive strength. The leaching rate of lead and cadmium ions from the test specimens demonstrated the effectiveness of nanoparticles in reducing the release of contaminant. Diffusion studies from the S/S matrixes indicated low and very low mobility of lead and cadmium ions respectively. For all test specimens, the mean leachability index was found to be higher than 9.

Keywords: Solidification/ Stabilization; Cd and Pb ions; nanosilica; leaching test

1. Introduction
The inappropriate management of heavy metals and mixed wastes poses a serious threat to the health of humans and other living organisms and their environment. Even though the above waste is handled or disposed of in an abortive manner, earnest harm is probable, including threats to human health. Therefore, for adequate description, designation, classification and characterization, the fundamentals of the management of heavy metal waste are essential to provide limits to the problem [1]. Where heavy metals are not biodegradable, they are toxic, mutagenic and carcinogenic in many cases, (HM) accumulates in water, soils, sediments and ecosystems override their appropriate amounts, they represent a major environmental hazard (Hassan, 2010). Lead (pb) and Cadmium (Cd) are commercial types of heavy metals that naturally present in the environment, it is not degradable in nature and will thus, once released to the environment, stay in circulation, where its toxic at very low exposure levels and has acute and chronic effects on health and environment. The realistic goal is to reduce risks by treating and disposing of hazardous waste by converting pollutants into less hazardous or non-hazardous solids [2].

Typically, it’s a process that involves the mixing of waste with binders to reduce the volume of contaminant leachability using physical and chemical characteristics to convert contaminated soils, solid wastes, sludge, and mixed wastes to environmentally acceptable form and then goes to landfill or others possibly channels [3]. Where a binder system employing several reagents is being applied, the most commonly used binding agents in this technology include Ordinary Portland cement (OPC), cement-fly ash, cement-kiln Dust, cement-activated carbon, gypsum, lime [4] were used to treat soils contaminated.
Cementitious material is popular widely because of its advantages of availability, low cost, and simple operation. In addition, the high strength, low permeability and relatively high durability of hydraulic cement make it a good binder for this waste management technique [5].

In addition to Portland cement, pozzolanic materials have been used in some studies where led to the strength of the cement mixed is increased, its density is increased, voids are decreased, the propensity for alkali-silica reaction (reaction with glass) is decreased, or even virtually eliminated. Materials such, silica fume, ground granulated blast furnace slag, fly ash and ground glass are classified as pozzolan materials [6]. Nanotechnology is the science that studies phenomena and manipulation of materials at atomic, molecular, and macromolecular scales, where properties of materials differ significantly from those at a larger scale. Nanomaterials have important applications in health, medical treatments, civil, fabrication, information, techniques, environments, and energy sources [7]. Silica in nanoscale has proved to be a very effective additive to polymers by improving durability, compressive strength, and flexibility also increases the hardening process, increases its density. Additionally, the high strength, low permeability and relatively high durability of hydraulic cement make it a strong binder for this waste management technique because of the benefits of availability, low cost and basic activity. Reduces its porosity, and improves the binding among cement paste and aggregates or the strength of the interfacial transition zone [8].

The present study was focused on the environmental properties of the solidification/stabilization process of contaminant soil with lead and cadmium ions by using the binder consist of Portland cement and Nanosilica as additive. Making an assessment for this treatment for the disposal or waste by Semi-dynamic Leaching Tank procedure and compressive strength, also focused on the effectiveness of add Nanosilica to the solidification mixture.

2. Materials and Methods

2.1. Materials

Heavy metal ions (lead and cadmium) were prepared to simulate contamination in soil. The synthetic procedure was done by using the molecular weight standard preparations procedure [9]. Samples of sand used in construction and locally available were taken from a pit near the sandy area at Al-Akhdar in the Karbala Governorate. Sieve analysis of the sand sample is given in Table (1) that following ASTM C136 / C136M–19 standard method (ASTM, 2006). Iraqi Ordinary Portland cement was used in this study manufactured by MASS group holding company- cement plant Bazyan, Sulaymaniyah. The cement Type I - CEM I 42.5 R, the company certified IQS 9001:2015, Distill water with pH =7.3 and EC= 12 µs/cm, for mixing and curing all mortar specimens. Nanosilica (NS), prepared from rice husk, has an amorphous structure and average particle diameter equal to 52.83 nm with a dimension range of 30-75 nm and surface area 618 m2/g.

| Table 1: Gradation of Sieve analysis and sand Properties |
|----------------------------------------------------------|
| Sieve Size (mm)                                         | Accumulative passing % | 100 | 97.2 | 91.1 | 75.39 | 50.79 | 21.31 | 0.02 |
| Sand Density (kg/m3) | Specific gravity | Sulfite SO3% | pH | Absorption % |
| 1530 | 2.67 | 0.06 | 8.1 | 0.90 |

2.2. Experimental Procedure

- Preparation of artificially contaminated soil: samples of sand were washed with distal water and dry at 90°C to remove salts and impurities. After washing the sand samples, they sprayed with heavy metal ion (lead, cadmium) solutions prepared in advance to achieve three concentrations of metal.
ions/sand contamination (500, 1000, 1500 mg/kg). This method was accomplished by applying to the weight of the sand sample a measured volume (ml) of a concentrated ion solution as shown in table 2. The contaminated samples are stored in a dark container and left in the dark at room temperature. Artificially Contaminated (HM) sand samples now represent contaminated media and need to be solidified.

- **Solidification Method Procedure**: The Solidification of sand contaminated with heavy metal ions was done by following the ASTM C31/C31M standard procedure. The Nanosilica percentage varied from 3%, 5%, and 7% by mass of the cementation’s and water were mixed first by using a manual mixer for 2 min. All the mortars had the ratio of water to cementitious material (W/C) of 0.45, then added to cement and contaminated sand at two mix ratios (10% and 15% percent of dry soil) as shown in table 2. The Mortars were mixed manually for (5 minutes) using a steel trowel instrument and a plastic container with an ambient temperature of about 30°C. A homogeneous consistency was achieved in the mixture. The mortar was then cast and compacted into cube molds (5×5×5) cm. The mixture is placed in the mold in three parts, each part is infused with a rod (Tamping Rod) in the mixture to expel the air trapped inside the mixture. The specimens were covered with wet burlap (humidity above 90%) for 28 days to prevent moisture. After 28 days the specimens were taken to the various tests and measurements set by the study plan.

**Table (2)**: Mix designs used for fixing Heavy metal ions contaminated sand samples to form the monolith Specimens

| Treatment                             | Amount of sand Used (g) | Amount of Cement Added (g) | Amount of Nanosilica Added (g) | Volume of heavy metal concentrated 10000 ppm solutions Added (ml) | *Amount of water Added (ml) |
|--------------------------------------|-------------------------|---------------------------|-------------------------------|-------------------------------------------------|-----------------------------|
|                                      | 3% | 5% | 7% | 3% | 5% | 7% | 3% | 5% | 7% | 3% | 5% | 7% | 3% | 5% | 7% |
| 10% Cement 500 mg/kg H.M Ion contamination | 220 | 23.67 | 23.18 | 22.7 | 0.73 | 1.22 | 1.7 | 11 | ≈ 11 |
| 10% Cement 1000 mg/kg H.M Ion contamination | 220 | 23.67 | 23.18 | 22.7 | 0.73 | 1.22 | 1.7 | 22 | ≈ 11 |
| 10% Cement 1500 mg/kg H.M Ion contamination | 220 | 23.67 | 23.18 | 22.7 | 0.73 | 1.22 | 1.7 | 33 | ≈ 11 |
| 15% Cement 500 mg/kg H.M Ion contamination | 220 | 37.64 | 36.86 | 36.1 | 1.16 | 1.94 | 2.7 | 11 | ≈ 17.5 |
| 15% Cement 1000 mg/kg H.M Ion contamination | 220 | 37.64 | 36.86 | 36.1 | 1.16 | 1.94 | 2.7 | 22 | ≈ 17.5 |
| 15% Cement 1500 mg/kg H.M Ion contamination | 220 | 37.64 | 36.86 | 36.1 | 1.16 | 1.94 | 2.7 | 33 | ≈ 17.5 |

*Water to cement ratio (W/C) equal to 0.45 and main

2.3. Preparation specimens and Test Methods

2.3.1. **Unconfined Compression Strength Test (UCS)**: The unconfined compressive strength tests were performed on the specimens after the completion of 28 days of curing, following the Standard Test Method for Compressive Strength of Mortar ASTM C 780. In the unconfined test of compression, assume during the test that no pore water is lost from the sample. Three specimens’ cubes of each
treatment were present for compression and the mean compressive values for each treatment were then taken to reflect the (UCS) value.

2.3.2. **Semi-dynamic Tank Leaching Test.** The Semi-dynamic tank leaching test used to determine the leaching mechanism of heavy metals and the effectiveness of the solidification process. The leaching test followed The EPA 1315 2013 standard method that involved the Mass transfer rate of inorganic components As a function of the leaching time, under diffusion-controlled release conditions, in a monolithic granular material test. Cube molds (5×5×5) cm of solidifying specimens were immersed in a container of leaching liquid (distill water) with a maximum conductivity of 6 μS/cm and pH equal to 7.3. The diffusion leaching test was carried out for ten sequential steps of specified lengths 0, 1, 2, 4, 7, 14, 28, 42, 49, 63, and 90 days. The specimens were submerged in such a way as to obtain a liquid-surface area ratio (L/A) of approximately 10 ± 0.3 ml water per cm² of the sample area was used. For semi-dynamic leaching, a total of (36) specimens were examined to reflect the various treatments and mixed designs. In order to analyze the concentration of lead and cadmium ions, the leachate obtained during this experiment was analyzed. Parameters such as leaching rate (LR), leached cumulative fraction (CFL), leachability index (LI) and effective diffusivity (De) were determined according to the ANS 16.1 equation That was mentioned by [10].

3. **Results and discussion**

3.1. **Unconfined Compressive Strength Analyses**

This test focuses on the compressive strength performance of mortar with NS in the mix design of the solidification heavy metal ions contaminated samples have been evaluated. In the unconfined test of compression, assuming during the test that no pore water is lost from the sample. Where the sample remains saturated during the test with no variation in the sample volume, void ratio, or water content [11]. several parameters affect the shear strength of solidification treated, The primary factors can be summarized as a composition of the binder, type of heavy metal, and condition of curing [12]. Fig. 1 shows the UCS test (28 days) of samples contaminant with lead, cadmium and samples without heavy metals, all results in Mpa (N/mm²). The minimum compressive strength criteria for secondary waste from landfills are (0.4MPa) and the strength of solidified wastes must have a mean unconfined compressive strength of at least 1 MPa after 28 days of curing [13]. From the results shown in Fig. (1), it is seen that all the solidified specimens’ samples have passed this regulatory mandatory requirement. The results obtained from this study indicate that the use of cement-based 15 % OPC by weight and 5% Nanosilica as replacement of cement mixtures in the solidification process can be very suitable for the treatment of contaminated wastes, sites, and landfills Even when the initial concentration of heavy metal ions is relatively high (1500 mg/kg). The results of compressive strength were analyzed to study the effect of heavy metal ions type and concentration, binder to media composition ratio, and the Nanosilica percentage as replacement of OPC.

3.1.1. **Binder to the media composition ratio.** From Figure 1 A-F, 28 day cured of compressive strengths for solidification samples, clearly shows increasing in compressive strength with the increase in OPC content. For example, the UCS of samples without HM at 10% OPC and (3%,5%,7%) ratio of Nanosilica as shown Figure (1-E) was (9.25,16.65,13.21) Mpa respectively. Those values increased to record (14.34, 20.83, 18.71) Mpa when using 15% OPC in the same condition Figure (1-F). This means when using higher quantities of (OPC) during the solidification process, higher compressive strength values can be obtained [13].
Figure 1: Unconfined Compression Strength for metal ion contaminated specimens of lead, cadmium and solidification with Nanosilica at 3%, 5%, 7% ratio as replacement of OPC; A) 500 mg/kg metal ions conc., 10% OPC; B) 500 mg/kg metal ions conc., 15% OPC; C) 1000 mg/kg metal ions conc., 10% OPC; D) 1000 mg/kg metal ions conc., 15% OPC; E) 1500 mg/kg metal ions conc. 10% OPC; F) 1500 mg/kg metal ions conc. 15% OPC cured for 28 day.

3.1.2. Nanosilica percentage as replacement of OPC. The percentage of Nanosilica applied to the cement mortar in the solidification process is another aspect that impacts the compressive strength results. By observing the strength of the mortar with different NS percentages prepared, From fig. (1) it can be seen that mortar mixtures with a (5%) percentage of NS displayed higher compressive strength than their peers. For instance, Fig. (1-E) the mixture of solidification of lead and cadmium ions with 1500 mg/kg, 15% OPC, and 3% of Nanosilica have UCS value equal to (9.42, 12.44) Mpa, while recorded (14.82, 19.54) Mpa at 5% NS at the same conditions, on another hand UCS value was decreased at 7% content of Nanosilica to be (12.15, 17.97) Mpa of lead and cadmium in the sample with
1500 mg/kg and 15% OPC. The explanation behind this improvement in strength is primarily the efficient packing of (NS) into the pores of the mortar mixture, which increases its compressive force resistance and makes it more effective in packing the voids with the small size of (NS) particles. The effect of (NS) on the promotion of the pozzolanic reaction is another important factor that explains the strength improvement when adding (NS) to cement mortar, and this explanation was previously stated [14]. It is also advantageous to increase strength by increasing the percentage of Nanosilica to a certain limit, after which a further increase in the percentage of NS leads to a decrease in compressive strength. The explanation behind this fact is the extra percentage of NS that in the current dispersion situation could lead to agglomeration of its particles. This agglomeration takes place because the nanoparticles’ high surface area increases the tendency of these particles to attract weak clogs that form each other, thus decreasing the compressive power. These clogs often cover the mortar voids, preventing nanoparticles from filling these voids and, as a result, reducing the strength of the mixture[15]. Another potential reason is that the mixing water is not adequate to coat, this large percentage of smaller NS particles cause hydration defects and C-S-H gel formation and thus decrease compressive strength. It can be inferred that minor changes in NS percentage or particle size lead to drastic changes in compressive strength, ensuring that a high degree of quality control should be achieved to control these changes as needed [14].

3.1.3. The Effect of Heavy Metal Ion Type and Concentration. Based on mortar strength results obtained after 28 days, the strongest state in samples contaminated with a high concentration of metal ions is different from those samples without heavy metal ions, on another hand, it's slightly different from samples with low concentration. For instance, the compressive strength of samples in fig. (1-B and C) when (15% OPC) with the same percentage of cement and 5% of Nanosilica was used to solidify samples with different concentrations (500 and 1500 mg/kg ) the UCS at the 28 days cured of samples contaminated with (Pb, Cd) ions was (14.14,18.91) Mpa increase to (14.82,19.54) Mpa respectively, Meanwhile sample without metal contamination and at the same mix, the ratio had a compressive strength of (20.83) Mpa. The result reflects the slight impact of the dosage concentration of HM ions on cement hydration and strength development mixed with Nanosilica at early ages. [16] Heavy metal ions (Pb, Cd) present in contaminated soil can migrate to the porous structures of Nanosilica. And form upon the secondary aggregation and this leads to reduce the effect of heavy metals ions on compressive strength. On the other hand, cadmium ions contaminated specimens had a positive effect on the final compressive strength as seen in Figure 1, and lead usually resulted in a decrease in strength overall mix ratio of the solidification process. According to the analysis, the results agree with [17] and stated that salts such as lead, chromium, and zinc can form complexes with calcium and Retard the mechanism of hydration. The mechanical properties of the mortars suggest that the examined matrices are of good quality, which would definitely be useful for the degree of immobilization of the structure of the heavy metals.

3.2. Semi-Dynamic Leaching Extraction
To evaluate the efficacy of Lead and Cadmium immobilization after solidification and the leaching process of contaminants from monolithic solidified waste and mass transfer rates (release rates) for inorganic analytes found in monolithic samples of granular material as monolithic samples function of leaching time, semi-dynamic leach tests were performed for (36) experiments according to test ANS 16.1.

3.2.1. Leaching Rates of Heavy Metals Ions. The leaching of heavy metals ions rate in (cm /s), can be assessed from the semi-dynamic leaching test data after each leaching interval. Leaching rates (LR) were plotted as a time function in Figure 2 and 3.
Figures 2: Lead Ions Leaching rates of solidificatio samples at 3%, 5%, and 7% Nanosilica with A) 10% OPC, 500 mg/kg ions conc. B) 15% OPC, 500 mg/kg ions conc. C) 10% OPC, 1000 mg/kg ions conc. D) 15% OPC, 1000 mg/kg ions conc. E) 10% OPC, 1500 mg/kg ions conc. F) 15% OPC, 1500 mg/kg ions conc.
Figures 3: Cadmium Ions Leaching rates of Solidification samples at 3%, 5%, and 7% of Nanosilica with A) 10% OPC, 500 mg/kg ions conc. B) 15% OPC, 500 mg/kg ions conc. C) 10% OPC, 1000 mg/kg ions conc. D) 15% OPC, 1000 mg/kg ions conc. E) 10% OPC, 1500 mg/kg ions conc. F) 15% OPC, 1500 mg/kg ions conc.

The plots in Figure (2-A-F) showed the leaching rate of lead from Solidify samples with attaching to time under three various ratios of Nanosilica. The results demonstrated the leaching rate of lead ions in the first four intervals was unsteady throughout this period, and it was very much observed in specimens with a high concentration of contamination. In the first interval, the rapid loss of heavy metals was observed, and this was possibly due to surface washing of the solidified specimens [18]. The leach rate of all specimens after the 14-day leaching period metals decreased with time increased. It was visually observed that specimens with 5% Nanosilica were below the limit of LR in all the ratios investigated. For example, Figure (2-E) of 10% OPC and 1500 mg/kg ions concentration in the first interval, the LR
of a sample with 3% Nanosilica was 7.47707E-09, this value decline to be 6.43829E-09 with 5% NS, and increasing to 7.62315E-09 at 7%, due to the excessive dosage of Nanosilica that led to agglomeration and increase the void ratio. As a result, the contact between Nanosilica and cement became weaker, and that reduced the ability to immobilize heavy metals. On another hand, the result shows a positive effect of increase the cement content on reducing the leaching rates. For instance, fig. (2-C and D) with 10% and 15% OPC, the LR of 5% Nanosilica in first day was (2.89723E-09, 2.6213E-09) and in the last interval was (5.60212E-10, 2.98556E-10) respectively. This discovery correlates with other studies concerning the fixation of cement-based heavy metals [19].

For cadmium treated samples in Figure (3-A-F) shown a decrease in the leaching rate with the increase in time. The cadmium samples demonstrated a similar leaching trend to treated lead samples, according to nanoparticle ratio and cement content. The leaching rate of cadmium metal ions from (S/S) matrixes for 90 days was low mobile than lead ions in the same condition at the semi-dynamic leaching test. It took the following pattern Cd < Pb [20]. The graphs also showed that that the initial amount of heavy metal ions initially present leaching rate increases concerning the (mg) in the monolithic (S/S) sample [21].

3.2.2. Cumulative Fraction Leached (CFL). To better understand and evaluate what happens during lead and cadmium semi-dynamic leaching periods, a graph is drawn between the cumulated leached fractions (CLF) versus the leaching time square root ($tn^{1/2}$). Many parameters behind the leaching process and phenomena can be described in the graphics. As demonstrated in Figure (4-A-F) and (5-A-B) there was rapidly leaching through the first four intervals (1, 2, 7, and 14 days). In the following times, much slower leaching occurred. The CFL is nearly semi-linearly connected to the leaching time square root. This behavior meaning during the leaching period, there is more than one diffusion coefficient and/or other leaching mechanisms the control the process, the (CLF) Vs. square leaching timeline trend may describe the mechanisms behind species leaching phenomena from the (S/S) process.

From the (CLF) value obtained in the fig. (4) and (5) it can be seen at (1500 mg/kg) contaminated samples with 10% by weight OPC and 3% Nanosilica ratio were (0.00086 and 0.00502) for (cadmium and lead ions) specimens after 7 days of leaching consecutive. Those (CLF) values dropped to (0.00075, and 0.00451) in the samples when 5% Nanosilica was shown in the (S/S) of the specimens. And at 7% Nanosilica the (CLF) value return to increase to be (0.00088, 0.00501) for (cadmium and lead ions). Furthermore, it can be noticed when increasing the ratio of OPC by weight to 15%. The CLF values of contaminated samples declined as the cement loading increased, for example at (1500 mg/kg) contaminated samples with 15% OPC and 3% Nanosilica in fig. (5-F) and (4-F) reached to (0.000380 and 0.00237) for (cadmium and lead ions) from above values of 10% at the same conditions. Similar patterns were observed with 5% Nanosilica the CLF values were the decrease, and back to increase at 7% for leads and cadmium ions as shown in fig. (5-A-F) and (5-A-F).

In Figure (4-C and F), the CFL values for lead can be observed at 7% NS was lower than 3% NS, also in Figure (5-C, E, and F) for cadmium, this happens due to the inconsistency in the distribution of the Nanosilica particles, when mixed Nanosilica with ingredients in a solidification mixture. Cement can effectively immobilize cadmium, and lead ions in contaminated media such as sands, sediment clays, and sludge. Other studies support this observation [5], [10]. Also, Nanosilica at an optimum level, shown positive effects on improving the efficiency of the (S/S) process and immobilize heavy metals [16].
Figure (4): Cumulative Fraction of Lead ions Leached verses the Square Root of Time at 3%, 5%, and 7% of Nanosilica with A) 10% OPC, 500 mg/kg ions conc. B) 15% OPC, 500 mg/kg ions conc. C) 10% OPC, 1000 mg/kg ions conc. D) 15% OPC, 1000 mg/kg ions conc. E) 10% OPC, 1500 mg/kg ions conc. F) 15% OPC, 1500 mg/kg ions conc.
3.2.3. Effective Diffusion Coefficients and Leachability Index. The effective diffusivity (D) and Leachability Index (LI) significantly used to assess the effectiveness of a solidification process, which they calculated according to ANSI 16.1. After the (LI) value was obtained for each leaching interval, the average of those values for each full-run monolith of the total (90 days) of the semi-dynamic leaching test was calculated by dividing the sum of the average values by the number of leaching intervals set in the experiment.

Effective diffusion coefficients (De) calculated from the mean of De for all intervals, confirmed with ANSI/ANS 16.1 [22] and listed in Table (3), the result showed mean De values ranged from 2.99E-09 to 6.43E-12 depending on the concentration of heavy metals ions and the ratios of OPC and
Nanosilica in S/S mixture, for example, the De values for 15% OPC samples were markedly lower than those for 10% OPC in all the samples investigated in this study. The diffusion coefficients indicate the release rate of the contaminant, according to [23] it generally ranges from $10^{-15}$ (immobile) to $10^{-5}$ cm$^2$/s (highly mobile) and $10^{-10}$ to $10^{-13}$ cm$^2$/s (very low mobility). The diffusion coefficients for Pb ranged from 2.99E-09 at (1500 mg/kg ,10% cement, and 3% NS) to 4.65E-11 at (500 mg/kg ,15% cement, and 5% NS), where the treatment of Pb classify as low mobility. On another hand, the diffusion coefficients for Cd in treated ranged from 3.55E-11 at (500 mg/kg ,10% cement, and 3% NS) to 5.72E-12 cm$^2$/s at (1500 mg/kg ,15% cement, and 5% NS), and shown less mobility from lead ions. This finding is in agreement with the results of the cumulative release of the two heavy metal ions from specimens of the S/S treated mixtures and confirmed that, In mixed designs, the addition of nano-silica to the cement ratio is an important parameter for minimizing diffusivity in matrix monoliths and for chemical stabilization of inorganic ions.

| Heavy Metal Ions Type and Cement ratio | Effective diffusion coefficients (De) Mean Values Cm$^2$/S | Inertial ION Contamination in the (S/S) Sample mg/kg | Nanosilica Content |
|---------------------------------------|----------------------------------------------------------|--------------------------------------------------|--------------------|
|                                       | $500$ mg/kg | $1000$ mg/kg | $1500$ mg/kg |
| Lead 10% OPC                          | 1.28E-10  | 8.00E-11  | 1.38E-10  | 1.70E-09  | 1.01E-09  | 1.37E-09  | 2.99E-09  | 1.61E-09  | 2.79E-09  |
| Lead 15% OPC                          | 7.35E-11  | 4.65E-11  | 7.35E-11  | 5.47E-10  | 4.30E-10  | 5.35E-10  | 3.35E-10  | 1.98E-10  | 2.96E-10  |
| Cadmium 10% OPC                       | 3.55E-11  | 1.53E-11  | 3.55E-11  | 3.03E-11  | 2.19E-11  | 2.67E-11  | 3.16E-11  | 1.85E-11  | 2.77E-11  |
| Cadmium 15% OPC                       | 1.95E-11  | 1.54E-11  | 2.09E-11  | 1.12E-11  | 6.43E-12  | 1.25E-11  | 8.96E-12  | 5.72E-12  | 7.89E-12  |
| Mean of Leachability Index Values (LI)| 11.14     | 10.88     | 10.70     | 9.91      | 10.04     | 9.91      | 9.22      | 9.39      | 9.23      |
| Lead 10% OPC                          | 10.95     | 11.08     | 10.94     | 9.91      | 10.04     | 9.91      | 9.91      | 10.07     | 9.91      |
| Lead 15% OPC                          | 11.04     | 11.24     | 11.02     | 10.95     | 11.07     | 10.98     | 10.89     | 11.05     | 10.91     |
| Cadmium 15% OPC                       | 11.43     | 11.53     | 11.40     | 11.43     | 11.62     | 11.37     | 11.51     | 11.65     | 11.55     |

The Leachability Index can be considered a performance criterion for the usage and disposal of solidification treated waste. The S/S treatment process is considered as the effective process when the LI value of the waste is larger than 9, and the S/S product would be acceptable for a controlled specific utilization, such as road base, quarry rehabilitation, and lagoon closure. When the LI value is between 8 and 9, the S/S treated waste could be disposed of in sanitary landfills and for subsurface burial and disposal. Also, If the LI value of solidification wastes is less than 8, they can not be disposed of. [22]. Table (3) demonstrate the LI values are all ≥ 9, even with relatively high initial metal ions concentrations (1500 mg/kg) and low cement and Nanosilica content (10 % OPC and 3 % NS) indicating that the S/S treatment is effective and that the treated soil competent for controlled utilization, and High Leachability Index values led to the mechanical retention was successfully achieved.

4. Conclusions

In summary, the use of OPC in (S/S) technology is an appealing option for managing heavy metal-bearing media to facilitate handling as well as final disposal and reduce the release of pollutants into the environment. Cement is relatively cheap, available, easy to operate, safe, and has a good efficiency in trapping and immobilizing heavy metals. Using Nanosilica in solidification gives both pozzolanic activity and the ability to reduce the mobilize of heavy metals. 5% Nanosilica is the optimum level added to cement in the mix designs where it’s an Efficient parameter for the reduction of diffusivity in matrix monoliths and chemical stabilization of inorganic ions. The 90-day semi-dynamic leaching showed that cadmium ions were less mobile from lead ions and increased stabilization with increasing OPC content. The optimization results of mechanical properties proved that an improvement in compressive strength at optimum conditions (5% adding percent and 15% cement) in 28 days age. The mortar incorporating with heavy metal contaminated soil is safe regarding the susceptibility to leachability of heavy metal ions and can be used for controlling specific utilization.
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