International Journal of Advanced Science and Research
www.allsciencejournal.com
ISSN: 2455-4227
Received: 25-06-2021; Accepted: 12-07-2021; Published: 25-07-2021
Volume 6, Issue 3, 2021, Page No. 01-07

Leachability of oily and salty materials from solidified petroleum wastes

Magdi H Almabrok[1, 2*], Robert G McLaughlan[2], Kirk Vessalas[2]
[1] Department of Civil Engineering, Faculty of Engineering and Petroleum, University of Benghazi, Libya
[2] School of Civil and Environmental Engineering, Faculty of Engineering and Information Technology, University of Technology, Sydney, Australia

Abstract
One environmental risk associated with the use and reuse of materials for construction purpose is the potential release and migration of contaminants from the material into the surrounding environment. Leaching tests were conducted on mortar containing oily and salty materials (Oil up to 10% by sand mass, saline water up to 226660 mg/L) generated from petroleum process to examine the effectiveness of cement-based mortar as a stabilisation/solidification method. The leachability data showed that although the chemical oxygen demand (from encapsulated oil) from 28-day mortar had increased with the increased oil content, the performance of all mortar mixes had successfully immobilised the oil content to be landfilled. By contrast, others displayed their suitability to be used in the construction industry subject to particular acceptance criteria. Furthermore, although there was variability in the 28-day leachate conductivity, it was not significantly different from the control. This suggests that the dissolved salt ions were successfully trapped within the solid matrix and that the Portland cement (PC) had good binding ability.

Keywords: mortar, oily and salty materials, leachability, COD, EC

Introduction

The oil industry provides essential products that have the potential to be major contributors to enhance the quality of our life. However, at the same time it generates pollution. The most common hazardous wastes related to the petroleum industry are oily and salty materials which usually disposed of in open pits. Recent environmental legislation has imposed restrictions on the release or discharge of these toxic materials [1, 2]. Proper management for oily and salty wastes resulting from petroleum operations is required to minimise their harmful potential to health and the environment. Social and government agencies adapted appropriate waste management practices to not only control the short term adverse environmental impacts but also help the waste management contractors to avoid any long term problems associated with waste disposal [3-5]. Additionally, the emphasis on reducing the environmental impact encouraged the petroleum industry to adopt the best and safest practices for handling, transferring, reusing, reprocessing and disposing of oily and salty wastes.

Cement-based stabilisation/solidification is a quick and inexpensive technology for petroleum waste through binding them in a structure formed by the cementing of pozzolanic materials to produce chemically/physically stable and mechanically handable products [6, 7]. However, the process of petroleum waste not only includes the removal or stabilision of oil and/or salt from soil but also the technological improvements to reduce the leachability [8, 9].

In general, it is recognized that one of the most important environmental risks associated with the use and reuse of materials for construction purposes is the potential release and migration of contaminants from the material into the surrounding environment [10]. Leaching can be defined as the process whereby a component of waste is transported mechanically or chemically into the solution from the S/S matrix by the passage of a solvent such as water [11]. So, leaching tests are conducted to examine the mass transfer from a solid (S/S material) to liquid (termed the leachant before contact with the solid, and the leachate afterwards) [1]. Leaching tests have been classified as extraction tests or dynamic tests based on whether the leaching fluid is renewed or not using either a pulverized or monolithic sample. The leaching solution, liquid to solid (L/S) ratio and duration, and the number of extractions represent the main differences amongst the various leaching tests. The leachate which is used for evaluating some specific property of the material is the common feature among all leaching tests. Analytical tests for liquid phase (leachate) from petroleum contaminated material can comprise leachate pH, chloride leachability and oil leachability. According to the UK landfill waste acceptance criteria [12], the limit value for the pH of the waste, in order to be classed as a stable non-reactive hazardous waste and disposal in a non-hazardous landfill, is fixed to be higher than 6; while no acceptance limit was stated for inert and hazardous waste landfills. Also, in accordance with the UK landfill waste acceptance criteria, the limit values for chloride concentration, in compliance leaching tests using BS EN 12457-1[13], are 80, 1,500 and 2,500 mg/L for inert waste, stable non-reactive hazardous waste (disposal in a non-hazardous landfill) and hazardous waste, respectively [12]. Moreover, in consonance with Germany, Scandinavia and UK landfill waste acceptance criteria, the limit values for Dissolved Organic Carbon (DOC) concentrations, in compliance leaching tests using BS EN 14405 [14] and BS EN 12457-1[13], are 50, 80 and 100 mg/L for inert waste, stable non-reactive hazardous waste (disposed in a non-hazardous landfill) and hazardous waste, respectively [12, 15]. Examples of DOC leaching from

Nordic construction waste streams ranged between 3 to 900 mg/kg [15]. The Dutch Building Materials Decree (BMD) sets limits for the content of polycyclic aromatic hydrocarbon (PAHs) in building materials (50–75 mg/kg). As a consequence, the regulations prohibit the direct use of these types of waste and large amounts of these materials have to be disposed of. From the environmental protection point of view, the amount of components in the leachate is the main concern rather than the total amount of these components in the material. So, it would be reasonable to base the regulations on leaching limits [16]. Unlike the case for chloride, no allowable maximum limits for the total oil or organic content in concrete and mortar whether arising from aggregates or any other sources were recommended in BS 5628-2 [17]. Similarly, no maximum oil content in concrete by mass of cement was specified in BS EN 206-1 [18]. In most cases, the effectiveness of the cement –based stabilisation/solidification process has been highly questionable and its applicability to organic wastes has been controversial [19]. This is mainly because little is known about the mechanism responsible for the immobilisation of organic contaminants in S/S materials and the subsequent strength development as well as leachability. Previous studies in the literature which use concentrations equivalent to those used in our study have reported different outcomes regarding the effect of organic compounds on the properties and behaviour of cementitious materials in terms of leachability. Yilmaz *et al*. (2003) [20] stabilised/solidified soil incorporating transformer oil at level of 5% by soil mass and found that the leachate concentration in TCLP leaching test reduced by 65.5% and 75% when the ratios of cement to contaminated soil are 20% and 35% respectively. Vipulanandan (1995) [21] reported a S/S study on phenol contaminated soil by 1%. Results indicated that, more than 70% of phenol was leached during TCLP test. Another study on cement-based S/S incorporating 2% phenol by cement mass by showed that the S/S released up to 100 % of Phenol in the TCLP [22]. The leachability of cement matrix incorporating 3% and 6% of motor oil by cement mass respectively indicated that The COD in the leachate produced from cement matrix increased from 60 mg/L to 80 mg/L respectively. The objective of this research work is principally to focus on understanding the impact of incorporation different types and percentages of oily and salty materials on the performance of the resultant cement matrix in terms of leachability. This knowledge is needed to determine the appropriate end-use of these materials. The primary goal of sustainable development is to responsibly meet the demands of today without jeopardizing opportunities for the next generation.

Experimental methodology and design

Materials Cement

An ASTM type 1 cement (Cement Australia) which meets general purpose (GP) requirements (AS 3972 –10) [23] was used.

Sand

Calga double washed sand from Calga Sands Quarry, NSW, Australia is a commercial concrete grade fine aggregate sourced from Rocla Quarry Products Pty Ltd, NSW, Australia. It complies with the grading requirements of standard specification ASTM C778 [24] and has been tested in accordance with the test method AS 1141.11.1 [25]. Calga double washed sand has an absorption capacity of 0.65%, specific gravity of 2.57 and a median particle size of 0.5 mm. It was used throughout most of this study. Prior to use, the fine aggregate was dried in ambient conditions to eliminate any free water. The particle size distribution by sieving method is illustrated in Figure 1.

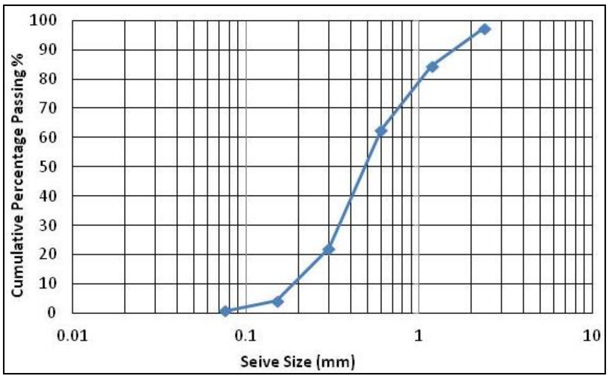

Fig 1: Particle size distributions (sieving method) of Colga double washed sand

High-range water reducing admixture (HWR)

Glenium, a polycarboxylate Ether polymer based high-range water reducing admixture (HWR) (BASF Construction Chemicals Pty Ltd) was used to ensure the same flow with different oils.

Oily materials

The vegetable oil (VO) was canola (Pure Vita brand, Aldi Incorporated) whereas the mineral oil (MO) was a refined product (Castrol motorcycle Fork W 10) developed for motorcycle hydraulic applications. These oils were selected because their viscosity is quite similar to medium crude oil [approximately 35 mm^2/sec (CST)] [26]. Secondly, these oils have minimal toxicity making them suitable for laboratory Experiments. Light Crude oil was used as realistic oily material related to the petroleum industry. The light crude oil was supplied by Wildcat Chemical Australia Pty Ltd at Imdex Group from the Kenmore oil field, Queensland, Australia. The oil samples are analysed at Oil Check Laboratory service, Sydney, Australia (Table 1).

Table 1: Properties of oily materials

Oil type	Viscosity (cSt@40°C) (ASTM D 445)	Density (mg/mL) (ASTM D 298)	Aniline point (°C) (ASTM D 611)	Iodine value (g1/100g) (ASTM D 1959)
VO	36	914	11.5	115.4
MO	32	866	103.8	7.2
LCO	5.96	800	87.2	3.8

Salts

Table salt (Reeva, Aldi Incorporated) and calcium chloride (Scharlau Chemical Pty Ltd, Barcelona, Spain) were utilised to simulate the effect of the total dissolved salts in the production water.

Water

Drinking grade tap water (TW) was used and conditioned at 22 ± 2 °C prior to use. Saline water was used to make up production water (samples 1 – 4) and was made up by adding salts to tap water. It was analysed by Environmental Analysis Laboratory, Southern Cross University, Australia (Table 2)

Table 2: Characterisation of tap and saline water

Parameter	Tap water	Saline water			
		Sample 1	Sample 2	Sample 3	Sample 4
pH	7.8	7.6	7.3	7.4	7.9
Conductivity (EC) (mS/cm)	0.19	47.4	142.1	180.3	333.5
Total dissolved salts (mg/L)	131	32220	96660	122589	226785
Total dissolved salts (%)	0.013	3.22	9.66	12.25	22.67
Sodium (mg/L)	14	13114	39342	40040	74075
Potassium (mg/L)	2	6	18	21	39
Calcium (mg/L)	14	24	72	7989	14770
Magnesium (mg/L)	5	6	18	20	37
Chloride (mg/L)	28	18996	56988	74560	137940
Sulphate (mg/L SO_4^{2-})	14	74	222	264	480

Mix proportions

The composition of the mortar was in accordance with AS 2350.12 [27] with the mix proportions being 1part of cement and 3 parts of sand (by mass) at a fixed water/cement ratio (w/c) of 0.50. Each mortar batch comprised cement (225 g), fine aggregate (675 g), water (112.4 g), HWR (0.2 ml) with between 0 to 67.5 g of added oil which has been reported as % by sand mass.

Preparing, casting and curing of test specimens

The mixing methodology followed the procedure outlined in AS 2350.12 [27] using the Hobart mixer (model N-50 G) except for oil addition. Oil was weighed (% by sand mass) and added to the sand and then premixed thoroughly with a spatula for 5 to 7 minutes prior to being added to the other ingredients. All laboratory work was conducted at 22 ± 2◦C. HWR has been used with all mixes to give reproducible flow (60 ± 10%) proven to be most suitable for proper consolidation of specimens by hand. The protocol for moulding the mortar (ASTM C109) [28] was adopted and modified minimise any impact of the protocol on any subsequent leaching tests. No mould release agents were used, instead the mould were lined with non-stick tape. The cube moulds were sealed using zip lock plastic bags to prevent water from evaporating and stored in a moist atmosphere for 24 h utilising a large plastic box. Demoulding took place after that and specimens having 50 × 50 × 50 mm dimensions were sealed in zip lock plastic bags and thereafter placed in a curing tank filled with water for up to 28 days at a temperature of 22.0 ± 0.5◦C (Figure 2).

Fig 2: Modification of ASTM standard for mortar technique

Leaching test

The NSW Environmental Protection Authority (EPA) in their guideline for the assessment, classification and management of non-liquid waste supports AS 4439.3 [29] (commonly known as the Standards Australian version of TCLP) as the preferable procedure [30]. However, as our samples contained oily materials and this test is not intended for samples incorporating oil, their modification was required. The procedure used was based on AS 4439.3 [29] with BS EN 12457-1 [13] as follows: The crushed samples from 28 days compressive strength were pulverised and sieved to pass through 4.75 mm and retained on 2.36 mm sieves. 100 grams of sieved sample was measured and mixed with the extraction fluid (distilled water) as a Liquid/Solid ratio of 10:1 in laboratory glass bottle (Figure 3). The sample was then agitated using a rotating agitator at 30 ± 2 rpm for 24 hours (Figure 4). Subsequently, the sample placed in a centrifuge to settle all the mortar. The centrifuge was used at 3000 rpm for at least 5 minutes (Figure 5). After centrifuging, the final pH was measured, and the mixture was filtered using a 1 µm syringe filter and collected in a centrifugal tube (Figure 6). Finally, the leachate sample obtained was then analysed for oil and salt constituents.

Fig 3: Weighting of 100-grams (right) prior to the sample being added to the bottle extractor (left) containing 1 - litre of distilled water

Fig 4: Rotary agitation device used for sample extraction

Fig 5: Centrifugal device

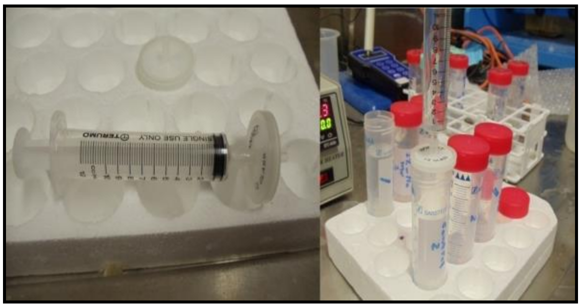

Fig 6: Filtration of eluates using 1 micron syringe filter

Leachate pH and electrical conductivity (EC)

The pH and EC of the filtered leachate were measured by Model WP-81 conductivity / TDS - pH meter.

Analysis of oil concentration

The Chemical Oxygen Demand (COD) method measured the leaching of oily materials from the mortar matrix. Hence, oil concentrations in the leachate of the mortar samples were measured as COD and expressed in mg/L then converted to oil leachate (mg). To convert the COD to a mass of oil, the COD of a known mass of each oil was measured. Therefore, when a COD for a mortar leachate was measured as mg/L it could be converted to an equivalent mass of the specific oil added to the mortar. These values are given in Table 3.

Table 3: Relationship between COD and oily materials

Oil type	Relationship (COD versus oil)	
	COD (mg/L)	Oil (mg) = (Density ÷ COD)
VO	2380	0.38
MO	640	1.35
LCO	600	1.33

Calculation of oil (mg) was done as following: (e.g. Mineral oil)
Oil (mg) = density ÷ COD
Oil (mg) $_{mineral}$ = [866 mg/mL x 1000] ÷ 640 mg/L = 1353 mg
So 1353 mg/L ÷ 1000 = 1.35 mg

The test procedure began with the vials heater set to a temperature of 150°C. In the meantime, the sample vials were prepared. The cap from wanted COD Digestion Reagent Vial (150 mg/L COD) was removed and by holding the vial at a 45-degree angle, a clean volumetric pipette was used to add 2.00 ml of filtered sample to the vial. The reagent blank was prepared by repeating the same steps where 2 ml of MQ water was used in place of the filtered sample. The vial was then capped tightly and inverted gently several times to mix contents. This ensured that all of the precipitate was suspended before proceeding. The sample vial became very hot during mixing. All the vials were labelled and placed in the vials heater (Figure 7a). The vials were then heated for two hours and then the vials were allowed to cool for 20 minutes (120 °C or less). Each vial was then inverted gently several times while still warm to mix the vial contents and then placed into a rack and allowed to cool to room temperature. Before being inserted into the COD photometer (Figure 7b), every vial was wiped on the outside with a clean paper towel. The reagent blank was then inserted into the 16-mm cell holder and zeroed in the instrument where the display showed 0 mg/L COD. The sample vial was subsequently inserted into the 16-mm cell holder and the result was taken in mg/L COD.

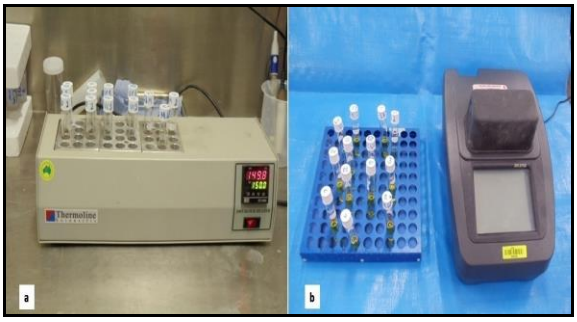

Fig 7: (a) vial heater, (b) COD photometer

Experimental Results and Discussion

Effect of oily materials on leachate pH, E.C and COD

Leachate pH and E.C

The leachate pH and E.C values for all mixes at 28 days are presented in Table 4. In general, the pH values of the leachate from all mixes were almost similar (12.74 – 12.78). An increase in oil addition and change in type of oil used in the mortars did not have a significant effect on the measured pH values. This slight variation of pH values could be a consequence of the calibration sensitivity of the pH meter. The high pH values noted in the different mixes can be attributed to release of hydroxyl ions from cement hydration, which are present in the pore solution of the system [31]. There were some differences in the E.C of the leachate for different oils. Of interest is that the mortar containing vegetable oil had less dissolved ions released than the control mortar while the mineral oil had more dissolved ions released.

Chemical oxygen demand (COD) analysis

Analysing the specific oil content in dissolved leachate was problematic and beyond the scope of this paper. Instead, the oil concentration in the leachate was estimated from the COD of the leachate. The oil in the mortar was the only variable that would affect COD between samples. The relationship between the COD and each specific oil assessed was measured (Table 3). Therefore, the_measured COD converted to oil leached which is equivalent to dissolved organic carbon (DOC). The COD and oil levels in the 28-day leachate from the mortar mixes containing different types and fractions of oily materials are presented in Table 5.

Table 4: Leaching pH and E.C from 28 days mortars containing different types and fractions of oily materials

Oil content		Vegetable oil (VO)			Mineral oil (MO)			Light crude oil (LCO)		
(%)	(g)	pH	E.C mS/cm	Calculated Leachate mg/L	pH	E.C mS/cm	Calculated Leachate mg/L	pH	E.C mS/cm	Calculated Leachate mg/L
0	0	12.78	8.20	5576	12.78	8.20	5576	12.78	8.20	5576
2	13.5	12.74	7.90	5372	12.75	8.27	5624	12.75	8.23	5596
6	40.5	12.75	7.07	4808	12.74	9.13	6208	12.77	8.37	5692
10	67.5	12.75	6.90	4692	12.76	9.70	6596	12.76	8.57	5828

Table 5: COD and equivalent oil leached data from 28 days mortars containing different types and fractions of oily materials

Oil content			Leachate data								
			Vegetable oil (VO)			Mineral oil (MO)			Light crude oil (LOC)		
Mortar sample		Leached sample	COD	Equivalent oil		COD	Equivalent oil		COD	Equivalent oil	
(%)	(g)	(mg)	(mg/L)	(mg)	(%)	(mg/L)	(mg)	(%)	(mg/L)	(mg)	(%)
2	13.5	1300	102	38.8	2.98	10	13.5	1.04	6	8.1	0.62
6	40.5	3846	116	44.1	1.15	12	16.2	0.42	10	13.5	0.35
10	67.5	6249	128	48.6	0.78	19	25.7	0.41	18	24.3	0.39

(%): Fraction of the oil added Leached sample: 100 g of crushed sample

The oil concentration in the leachate (equivalent oil) as presented in Table 5 was estimated from COD of the leachate and calculated as follows:

The next calculation applies when taking the 2% (13.5 g) of mineral oil addition as an example.

Total mass of one mix of mortar = 1026 g

The percentage of mineral oil per one batch = 13.5 g ÷ 1026 g = 0.013 = 1.32%

Total mass of crushed sample for leaching

Test = 100 g = 100000 mg

So the mass of mineral oil in the crushed sample (leached sample) = 100000 mg x 0.013 = 1300 mg

Thus the equivalent oil leached (mg) = COD $_{\text{(from test)}}$ x 1.35 mg $_{\text{(from Table 3)}}$ = 10 x 1.35 = 13.5 mg

Therefore the equivalent oil leached (%) = 13.5 mg ÷ 1300 mg = 0.014 = 1.04%

It can be observed that the COD and mass of oil leached increases with an increase in the content of oily materials. However, the percentages of oil leached were found to decrease with an increase in oil fraction used in the mortar.

The mortar containing vegetable oil has the greatest amount of leached oil at all concentrations. The light crude oil and mineral oil had almost similar results. The amount of oil leaching may be related to the cement bonding aspects of the CSH matrix, however, this needs further investigation. There is little published data to compare against the results obtained in this study. Hong (1997) [32] indicated that the leachability of the cement matrix (at 8 days curing) increased with increased oil content in cement. The COD in the leachate produced from the cement matrix increased from 60 mg/L to 80 mg/L when incorporating 3% and 6% of motor oil (by cement mass), respectively. As shown in Table 5, all mixes have successfully immobilised the oil to inert level complying with the UK, Germany and Scandinavia landfill waste acceptance criteria. Furthermore, other mixes displayed their suitability to be used in the construction industry.

Effect of saline water on leachate pH and E.C

It was observed from the results (Table 6) that the pH values of the mixes at 28 days decreased with increased addition levels of salt ions to mortar mixes. However, only a small difference of 0.08 units were observed in the leachate pH between the different saline mixes (Samples 1 to 4). This small variation may be attributed to the difference in pH values between the saline samples (Table 2) or could be a consequence of the calibration sensitivity of the pH meter.

The 28-day leachate shows a general tendency of increasing leachate electrical conductivity and TDS results for mortars containing greater salinity. Furthermore, it is clearly that the content of salt in the leachate not much different than the initial (Table 6).This can be attributed to the ability of chloride to deflocculate colloidal CSH and cause a permeable microstructure resulting in weakness of the sample [33]. As a result, the other ions (e.g. calcium and sulphate) which are not incorporated in CSH will leach out. Nevertheless, when the calculated mg/L in the leachate is compared to the control, the result suggests that the dissolved salt becomes successfully trapped within the solid matrix at higher saline water concentrations. Chloride was not measured but instead the total dissolved salt (TDS) was considered in this research. Although this is not exactly comparable, the TDS was used to give insight about the limits. From the results, it can be observed that the TDC leachate concentrations for samples 1 to 3 (Table 6) were within the limit for the stable non-reactive hazardous wastes; hence comply with the UK waste acceptance criteria for non-hazardous waste landfill.

Table 6: Leachate pH and E.C from 28 days days mortars containing saline water

Mix	TDS (mg/L)	Salt content in leached sample (mg)	pH (units)	Leachate data E.C (mS/cm)	Calculated lachate (mg/L)	Salt content (mg)
Control	131	-	12.78	8.2	5576	-
Sample 1 (Na-Cl water)	32220	358	12.22	8.93	6072	496
Sample 2 (Na-Cl water)	96660	1074	12.20	9.75	6630	1054
Sample 3 (Na-Ca-Cl water)	122589	1362	12.15	10.10	6868	1292
Sample 4 (Na-Ca-Cl water)	226785	2520	12.15	11.20	7616	2040

Conclusion

Leaching tests were conducted on mortars containing oily and salty materials to examine the effectiveness of cement-based mortar as a stabilisation /solidification method. Screening level data showed that the amount of oil leached from the mortar was not always proportional to the amount of oil incorporated into the mortar. This shows there is a need to better understand these leaching processes. Unfortunately, more sophisticated inorganic and organic chemical analysis would be needed to better understand these mechanisms. This requires collection of both dissolved and non-aqueous phases of organic contaminants. Furthermore, it was observed that various inorganics in the leachate are at greater than the initial. All mixes have successfully immobilised the oil to a satisfactory level (24.3 – 48.6 mg/L) to classify as inert waste according to the UK, Germany and Scandinavia landfill acceptance criteria (50 mg/L). Furthermore, based on the Dutch Building Materials Decree limits (50 – 75 mg/L), all mixes can be used in the construction industry. The TDS leachate concentrations (190 – 1292 mg/L) for all samples were within the limit for the stable non-reactive hazardous wastes (1500 mg/L) complying with the UK acceptance criteria for non-hazardous landfills.

Recommendation and further study

The main objective was achieved in this research. However, the findings clarified areas that have potential for future technical and experimental investigation. All leachate studies done in this work were based on crushed samples in order to gain the most insight (i.e. highest leachate concentration) from the limited analytical equipment available. This gave a focus on oil-cement bonds rather than mortar permeability. However, in practice mortar monoliths are likely to be developed for oil-contaminated aggregate re-use and therefore tests on monoliths will be important. Furthermore, longer term studies (>28 days) are needed to see the impact of oil at longer time periods.

Reference

1. Almabrok MH. Cement- based stabilisation/ Solidification of oil and salt contaminated materials, in Faculty of Engineering and Information Technology 2014, University of Technology, Sydney (UTS): Sydney, Australia, 2014, 270.
2. Aguwa A. Waste management in the oil industry, New York: Universe, Inc, 2007.
3. Mohammadi M *et al.* Drilling waste management: Improvements to the dewatering process through chemical optimisation – Results of pilot test, in SPE/IADC Indian Drilling Technology Conference and Exhibition: Mumbai, India, 2006.
4. Nilssen I, Johnsen S. Holistic Environmental management of discharges from the oil and gas industry—Combining quantitative risk assessment and environmental monitoring, in SPE International Conference on Health, Safety, and Environment in Oil and Gas Exploration and Production, Society of Petroleum Engineers SPE 111586: Nice, France, 2008.
5. Stilwell C. Area waste-management plans for drilling and production operation. Journal of Petroleum Technology,1991:43(1):67-71.
6. Leonard S, Stegemann J. Stabilisation / solidification of petroleum drill cuttings: Leaching studies. Journal of Hazardous Materials,2010:174:484-491.
7. Tuncan M, Koyuncu H. Stabilisation of petroleum contaminated drilling wastes by additives. In The Seventh International Offshore and Polar Engineering. Honolulu, USA: International Society of Offshore and Polar Engineers, 1997.
8. Al-Ansary M, Al-Tabbaa A. Stabilisation/solidification of synthetic North Sea drill cuttings containing oil and chloride. In International RILEM Conference on use of recycled materials in building and structures. Barcelona, 2004.
9. Minton R. Strategic management of waste stream generated by exploration and production drilling operation, 2004.
10. Sloot H, Dijkstra J. Development of horizontally standardised leaching tests for construction materials: A material based or release based approach? Identical leaching mechanisms for different materials, UK Environmental Change Network, ECN-C--04-060, 2004.
11. Tuncan A, Tuncan M, Koyuncu H. Use of petroleum - contaminated drilling wastes as sub-base material for road construction. Waste Management Resource, 2000, 489-505.
12. EA. Environment agency guidance on sampling and testing of wastes to meet landfill waste acceptance procedures, version 1, Environment Agency, UK, 2005.
13. BS EN12457-1, Characterisation of waste, leaching, compliance test for leaching of granular waste materials and sludges, British Standards Institution: London, UK, 2002.
14. BS EN14405, Characterization of waste. Leaching behaviour test. Up-flow percolation test (under specified conditions), British Standard Institution (BSI): London, UK, 2017.
15. Ylijoki J *et al*. Tests for DOC leaching from waste materials, Nordic Innovation Centre, Norway, 2005.
16. Mulder E, Feenstra L, Brouwer J. Stabilisation/solidification of dredging sludge containing polycyclic aromatic hydrocarbons. In The International Conference on Stabilisation/Solidification Treatment and Rememdiation. University of Cambridge, United Kingdom, 2005.
17. BS 5628-2: Code of prectice for the use of masonry - Part 2: Structural use of reinforced and prestressed masonry, British Standards Institution: London, UK, 2005.
18. BS EN 206-1: Concrete- Part 1: specification, performance, production and conformity, British Standards Institution: London, UK, 2000.
19. Rho H et *al*. Decomposition of hazardous organic materials in the solidification / stabilisation process using catalytic – activated carbon. Waste Management,2001:21:343-356
20. Yilmaz O *et al*. Solidification / Stabilisation of hazardous wastes containing metals and organic contaminants. Journal of Environmental Engineering,2003:129:366-376.
21. Vipulanandan C. Effect of clays and cement on the solidification of phenol - contaminated soils. Waste Management,1995:15:399-406.
22. Vipulanandan C. Krishnan S. Solidification/Stabilisation of Phenolic waste with cementitious and polymeric materials. Journal of Hazardous Materials,1990:24:123-136.
23. AS, Portland and blended cements (AS3972), Standards Australia International Ltd, 2010.
24. ASTM C778, Standard specification for standard sand, ASTM International, 2006.
25. AS, Methods for sampling and testing aggregates, method 11.1: Particle size distribution – sieving method (AS 1141.11.1), Standards Australia International Ltd, 2009.
26. Albasharah J, Salman O, Akashah A. Viscosity of crude oil blends. Industrial & Engineering Chemistry Research,1987:26:2445-2449.
27. AS, Methods of testing portland, blended and masonry cements method 12: Preparation of a standard mortar and moulding of specimens (AS2350.12): Standards Australia International Ltd, 2006.
28. ASTM C109/C109M, Standard test method for compressive strength of hydraulic cement mortars (Using 2-in. or [50-mm] cube specimens), American

Society for Testing and Materials, USA, 2013.
29. AS, Wastes, sediments and contaminated soils. Part 3: Preparation of leachates - Bottle leaching procedure (AS 4439.3), Standards Australia International Ltd, 1997.
30. ALS, Leachate analysis, in Environmental News, ALS environmental testing group, ALS Environmental Testing Group, 2000.
31. Diamond S. Effect of microsilica (silica fume) on pore-solution chemistry of cement pastes. Journal of the American Ceramic Society,1983:66(5):82-84.
32. Hong L. Evaluation of oil and freeze-thaw effects on cement hydration for waste solidification, in Department of Civil Engineering and Applied Mechanic, McGill University: Montreal, Canada, 1997.
33. Jensen H, Pratt P. The binding of chloride ions by pozzolanic product in fly ash cement blends. Advances in Cement Research,1989:2(7):121-129.