USE OF STABILIZED PCS FOR A LANDFILL CAP

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Abstract: Petroleum contaminated soils (PCS) are the waste products produced by cleaning up petroleum spills. Left unattended, these soils pose a threat to human health and the environment. These soils fail EPA requirements for VOCs and must be landfilled or stabilized by treatment. One stabilization process is to add asphalt to the PCS by the cold-mix asphalt emulsion process (CMAE). The asphalt binds up the organic materials to produce an environmentally safe material. Asphalt-stabilized PCS typically exhibits the qualities of a plastic soil with a hydraulic conductivity of 10^{-5} to 10^{-6} cm/sec. It makes an excellent road base or surface cover for temporary roads and has been widely used as daily landfill cover material. By adding clay to mix, the hydraulic conductivity can be further reduced to less than 10^{-7} cm/sec. The resulting mix can potentially provide the source material for the low permeability layer in landfill liners and covers. This paper describes the lab and field studies conducted to determine the feasibility of using such a mixture, called LANLOC-7, for the low permeability soil in the cover of a landfill. Bench scale testing was carried out on different mixes to determine a mix which would yield a material with a permeability less than 10^{-7} cm/sec. The resulting mix, called LANLOC-7, had suitable physical characteristics to permit field placement and compaction. The field test section was monitored for two years following construction to determine the effects of wet-dry and freeze-thaw cycles on the permeability of the LANLOC-7 and on an adjacent section made of clay. The test results showed that the LANLOC-7 performed at least as well as the virgin clay in retaining its ability to provide a low permeability layer for the landfill cap. These positive results demonstrate that PCS materials may be recycled into useful construction materials rather than being wasted and confined to costly disposal by landfilling.

1. BACKGROUND

Over 3.0 million underground storage tanks (USTs) existing in the United States are prone to leakage of the petroleum products they store (Dowd, 1984). Accidents, previous dumping at old sites, and overfilling only add to the release of petroleum products into the environment. Petroleum hydrocarbons, once in contact with the surrounding soil, pose a significant health and environmental risk. Petroleum products are characterized by volatile organic compounds (VOCs) and Semi-VOCs which include many constituents that the USEPA has determined to pose significant health hazards (e.g., benzene, toluene, xylene, naphthalene, etc.). The amounts of petroleum contaminated soil (PCS) generated annually are enormous. In the state of Massachusetts alone, amounts of PCS in need of treatment annually were estimated to be well over 440,000 tons in 1995 (MADEP, 1996). Levels of contamination can approach 60,000 ppm Total Petroleum Hydrocarbons (TPH).

Another well known environmental issue that must be dealt with responsibly is the closing of landfills around the United States, and particularly the northeast with it's comparatively large population density. The EPA has stipulated that landfills receive a final capping system which includes a low hydraulic conductivity layer, typically 0.6-0.9 meters (2-3 feet) thick (USEPA, 1989). The EPA has set the required hydraulic conductivity for this layer at less than 10^{-7} cm/s. Often 100% virgin clay is used. Clay must be excavated, mixed with water, and compacted. One of the drawbacks of using 100% clay is the difficulty in obtaining the correct moisture content prior to compaction. Clay often becomes difficult to handle and achieve compaction once that moisture content is obtained, especially on slopes. The other obvious drawback is that the natural environment is disturbed by excavation. Use of a recyclable material would certainly be an attractive alternative, especially if it offered easier handling and with as good or better performance.

Numerous remedial technologies are available to eliminate or significantly reduce the risk that PCS poses. One of the most effective in terms of environmental benefits, product-type versatility, and cost effectiveness is the cold-mix asphalt emulsion (CMAE) process. This technology can treat PCS with contamination ranging upwards of 60,000 ppm TPH, but typically, soils received for treatment fall below 10,000 ppm with 80% containing less than 5,000 ppm and with an overall average of 1,000 ppm. Tipping fees for soils accepted at permitted CMAE facilities range $33 to 44 per metric tonne ($30-40 per ton). The CMAE process can be used to produce products ranging from conventional asphalt paving to asphalt-stabilized soil. All products produced from PCS by the CMAE process are routinely subjected to the Toxicity Characteristic Leaching Procedure (TCLP) with the effluent tested for both VOCs and Semi-VOCs. The products are tested in the uncured, unconsolidated state. This provides for a worst-case scenario because significantly greater surface area is exposed than in actual field application where the materials are compacted and exist as relatively impermeable layers. Regardless, analytical results on the loose material usually meet applicable criteria and are almost always below detection limits.

Products have very uniform and consistent physical properties because the incoming soils are blended together during initial processing to produce a fairly uniform PCS-aggregate source, and any variations are addressed in standard quality control operations (AMREC, 1993-1997). Over the years, data from the American Reclamation Corporation (AMREC) has shown excellent uniformity, certainly enough to design uniform products within specifications on a routine basis.

One of the more successful uses of asphalt-stabilized soil has been as a daily and intermediate cover material for landfills. This product, trade named "LANLOC," has been found to perform better than virgin sand and gravel because it compacts better, does not create dust problems, is more economical, and provides resistance to erosion, among other benefits. This use was permitted by the Massachusetts Department of Environmental Protection (MADEP) in 1993 under a Beneficial Use Determination (BUD) (MADEP, 1993).

Since LANLOC has hydraulic conductivity's in the 10^{-5} to 10^{-6} cm/s range, we theorized that adding clay could lower the hydraulic conductivity below the requirement for landfill caps. The resulting product, called "LANLOC-7," consists of a blend of asphalt-stabilized PCS, natural clay and water. A bench-scale study indicated that this was possible. Subsequently, under the encouragement of MADEP's Central Region Office, we conducted a field demonstration.

2. BENCH-SCALE STUDY

A composite sample of standard asphalt-stabilized PCS (LANLOC) was prepared and blended with clay in two ratios: 40/60 and 60/40 LANLOC/Clay. Results of tests for hydraulic conductivity on these mixtures and the neat LANLOC and clay are presented in Table 1. Results indicated that the addition of clay to asphalt-stabilized soil would in fact yield a material suitable for use as the low permeability layer in a landfill cap.

Table 1. Results of Bench-Scale Testing

Sample	Dry Density at Compaction, pcf (g/cc)	Moisture Content at Compaction, %	Moisture over Optimum, %	Permeability cm/sec
100% LANLOC	----	---	---	$3.0 * 10^{-7}$
100% Clay	127.8 (2.05)	9.4	2.1	$0.3 * 10^{-7}$
40% LANLOC/60% Clay	123.6 1.98)	10.8	2.7	$0.7 * 10^{-7}$
60% LANLOC/40% Clay	124.0 (1.99)	10.4	3.0	$0.8 * 10^{-7}$

These results clearly showed that mixing clay with LANLOC could produce a permeability less than the required maximum value of 10^{-7} cm/sec. The required blending was straight-forward to achieve and the resulting product was relatively easy to compact.

3. FIELD DEMONSTRATION

3.1 Production

The site selected for the demonstration project was the Ballard Street Landfill in Worcester, Massachusetts, USA. This landfill was undergoing closure using a conventional clay cap. The clay being used for the conventional cap on this landfill was from a source different than that used in the bench-scale testing. For comparison purposes the clay used for this site was blended with LANLOC. The initial mix design called for a 40/60 Clay/LANLOC blend. A small batch was produced at this ratio, and evaluated for workability and hydraulic conductivity at various moisture contents above optimum. This was done by constructing small test pads at the plant using mixtures of LANLOC at different moisture contents. After mixing with water, the material was held for 24 hours to allow the water to be fully absorbed into the clay. Beyond about 4-5% moisture the mixed material became too soft to be compacted in the field but the hydraulic conductivity was in the low 10^{-8} cm/s range. Based on the observations of these test pads, a mixture of 50% clay and 50% LANLOC with water to bring the moisture content to 3% above optimum moisture determined by ASTM D698 was chosen for the landfill test section.

Approximately 270 metric tonnes (300 tons) of LANLOC-7 were produced at 3% above optimum moisture content. The LANLOC-7 product was then stockpiled and covered for 2-days prior to shipping to the demonstration site. Since LANLOC-7 was produced from aggregate materials (i.e., asphalt-stabilized PCS) that posed no significant risk to human health or the environment, analyzing the LANLOC-7 product for leachability was unnecessary.

3.2 Construction

The test section was a 15 by 30 meter (50 x 100 foot) area immediately adjacent to the Ballard Street Landfill. The subgrade consisted of 3.8 cm (1½ inch) minus recycled gravel, compacted to a firm condition. Construction of the LANLOC-7 test section took place at the end of November 1994 with ambient temperatures from 4° to 10°C (40-50° F) over the course of the day, and close to freezing at night. All work was conducted under a Quality Control Plan. The material arrived at the site with the predetermined moisture content so that construction could begin immediately. LANLOC-7 was dumped in piles and spread out with a D-4 dozer at about 20 cm (8 inches) thick. The material was easy to place and compact with a pad foot self-propelled compactor followed by a self-propelled smooth drum compactor. Compaction occurred rapidly since there was no need to adjust the moisture content in the field. The top of the first lift was scarified with the pads of the D-4 before spreading the second lift.

The complete test section consisted of two lifts, each with a nominal compacted thickness of 15 cm (6 inches). Each lift was tested for density and moisture content by ASTM D1556. The goal was to achieve a dry density of at least 90% of the maximum dry density determined by ASTM D698. This was so readily accomplished using the previously determined maximum dry density of 123.1 pcf (2.08 g/cc) that the field personal questioned the validity of the D698 test. It has been previously determined on a trial mix with different source materials. Following completion of construction of the test section, an additional sample was taken, the maximum dry density determined by D698, and the percent compaction recomputed. The maximum dry density for the mix actually used for the test section was 129.6 pcf and the recomputed percent compaction was 89 to 97% with an average of 91.5% in the first lift and 92.8% in the second lift. The moisture content varied from 11 to 15% with an average of 13.8% in the first lift and 13.0% in the second lift. Shelby tube samples were pushed through the completed LANLOC-7 layer to obtain undisturbed samples for permeability testing. The holes were filled with bentonite and the entire test section was covered with 15 cm (6 inches) of sand and 15 cm (6 inches) of seeded loam.

Concurrent with this work, the Contractor was completing construction of a standard cap over the landfill. It was immediately adjacent to the LANLOC-7 test section. It consisted of 60 cm (24 inches) of clay covered by 30 cm (12 inches) of the same cover soil as that placed over the test section.

Table 2 compares the physical characteristics of the LANLOC-7 material with those given in the Massachusetts Department of Environmental Protection Landfill Technical Guidance Manual (1993). The most important characteristic of the low permeability layer in a cap is that it have an acceptably low permeability throughout its thickness and that it have plasticity characteristics that make it resistant to environmental changes. Table 2 shows that the LANLOC-7 material for this test section met the MDEP requirements for permeability and plasticity. The MDEP guidelines also include limits on gradation. These limits on gradation are an indirect way of forcing the selection of a material that is likely to meet the permeability requirements. LANLOC-7 does not meet all of the gradation requirements, but since it consistently meets the permeability requirements, this difference is not significant.

Table 2: Comparison of LANLOC-7 Properties to State Guidelines

Property	Units	MDEP Guidelines	LANLOC-7 Test Section
Permeability	cm/sec	$\leq 10^{-7}$	$0.5\text{-}1.0 * 10^{-7}$
Plasticity Index	%	≥10 and ≤40	13-17
Percent Retained on #4 sieve	%	<10	17-29
Percent Passing #200 sieve	%	≥40	23-30
Percent less than 2μm	%	≥20	4-8
Maximum clod size	inches	<6	<2
Maximum rock size	inches	<3	<1

The test section clearly showed that LANLOC-7 could be manufactured to a consistent quality, successfully placed in the field with conventional construction equipment, and compacted to yield a permeability less than the maximum permissible value of 10^{-7} cm/sec.

3.3 Follow-Up Testing

Despite the success of the field test program, some questioned the long-term performance of the LANLOC-7 material. There was concern that the LANLOC-7 material might show more sensitivity to damage from freeze-thaw and wet-dry cycles than a conventional clay cap. To address these concerns, a test program was conducted to evaluate the permeability of both the LANLOC-7 and virgin clay caps over a two year period. Block samples were hand cut from portions of the test section and the adjacent clay covered section. These samples were transported to the laboratory where test specimens were hand cut for permeability testing.

Samples were obtained and tests run in the spring and fall of each of two years. Table 3 summarizes the test results on LANLOC-7. Table 4 gives the results obtained on samples from the clay cap. We did not test the clay at the time of installation. We received data on tests by others that indicated a permeability of $0.5 * 10^{-7}$ cm/sec.

Table 3: Permeability Tests on Undisturbed Samples from LANLOC-7 Test Section

Sample #	Sample Date	Sample Depth, in (cm)	Moisture Content, %	Dry Density, pcf (gm/cc)	Permeability, 10^{-7} cm/sec
Tube 1C	11/30/94	6-12 (15-30)	12.4	118.5 (1.90)	1.0
Tube 1E	11/30/94	6-12 (15-30)	10.7	118.2 (1.89)	1.0
Tube 1F	11/30/94	6-12 (15-30)	11.3	119.6 (1.92)	0.99
Tube 2A	11/30/94	0-6 (0-15)	11.0	118.9 (1.90)	1.0
Tube 2B	11/30/94	0-6 (0-15)	11.2	120.1 (1.92)	0.94
Tube 2C	11/30/94	0-6 (0-15)	12.1	119.3 (1.91)	0.54
Block 1	4/5/95	0-2 (0-5)	9.1	119.3 (1.91)	3.5
		4-6 (10-15)	11.2	119.2 (1.91)	3.9
Block 2	4/5/95	7-13 (18-33)	11.1	119.2 (1.91)	0.92
Block 5	4/17/95	0-2 (0-5)	9.9	120.9 (1.94)	3.9
		4-6 (10-15)	10.4	115.8 (1.85)	10.**
Block 6	4/17/95	6-12 (15-30)	10.5	119.8 (1.92)	1.0
Block 7	10/4/95	0-2 (0-5)	10.8	123.0 (1.97)	1.5
	10/4/95	3-6 (8-15)	10.1	124.1 (1.99)	10.**
Block 8	10/4/95	6-11 (15-28)	10.6	120.0 (1.92)	1.2
Block 11	4/19/96	0-2 (0-5)	9.7	122.7 (1.97)	0.45
	4/19/96	4-6 (10-15)	9.7	124.5 (1.99)	0.25
	4/19/96	9-11 (22-27)	10.2	116.1 (1.86)	0.55
Block 13	11/27/96	0-2 (0-5)	10.2	122.1 (1.96)	8.0
	11/27/96	4-6 (10-15)	11.4	116.1 (1.86)	1.4
	11/27/96	8-10 (20-25)	10.4	120.5 (1.93)	3.0

**cracks in sample from trimming activities

Table 4: Permeability Tests on Undisturbed Samples from Clay Section

Sample #	Sample Date	Sample Depth, in (cm)	Moisture Content, %	Dry Density, pcf (gm/cc)	Permeability, 10^{-7} cm/sec
Block 3	4/5/95	0-2 (0-5)	11.0	129.1 (2.07)	0.1
	4/5/95	7-9 (18-23)	111.4	125.0 (2.00)	0.46
Block 4	4/5/95	12-15 (30-38)	12.8	121.1 (1.94)	0.55
Block 9	10/4/95	0-2 (0-5)	9.1	124.5 (1.99)	2.0
	10/4/95	3-5 (8-13)	10.0	123.2 (1.97)	8.3**
Block 10	10/4/95	5-11 (13-28)	10.7	121.2 (1.94)	5.3
Block 12	4/19/96	0-2 (0-5)	9.2	128.2 (2.05)	0.83
	4/19/96	4-6 (10-15)	11.1	124.1 (1.99)	0.92
	4/19/96	10-15 (25-38)	12.4	121.8 (1.95)	0.68
Block 14	11/27/96	0-2 (0-5)	10.4	120.5 (1.93	1.0
	11/27/96	4-6 (10-15)	9.9	124.6 (2.00)	6.5
	11/27/96	8-10 (20-25)	11.2	121.4 (1.94)	6.5

**cracks in sample from trimming activities

We were concerned that variability in the materials used in construction of the caps might have as much influence on the measured permeability as would environmental factors, so we performed tests to measure gradation and plasticity of the block samples as well. Table 5 summarizes these data. The variability in these index properties is similar for both materials and similar to that found in the materials typically used for construction of low permeability layers in landfills in the Northeastern United States.

Table 5: Summary of Classification Tests on Block Samples from Test Sections

Property	LANLOC	Clay
Percent Passing #4 Sieve	66-90	68-96
Percent Passing #200 Sieve	23-40	32-46
Plasticity Index, %	13-19	12-16

Significant freeze-thaw and wet-dry effects on materials that are susceptible to damage result in orders of magnitude increases in permeability. Typically, the permeability increases 10 fold after 2-3 cycles and 100-1000 fold after 10-30 cycles. Figure 1 plots the permeabilities measured on the block samples of LANLOC-7 and those of clay. There appears to be a possible trend for the permeability of both LANLOC-7 and clay to increase in the summer-fall season and decrease in the winter-spring season. In our opinion, the differences in permeability measured in the LANLOC-7 and clay cap at this site were due primarily to variations in the as-placed material with some tendency for seasonal variation. Over two years of weathering by wet-dry and freeze-thaw cycles had no detrimental effect no the permeability of the as-placed LANLOC-7 or of the clay cap.

We did not determine the extent to which this site experienced alternating cycles of freezing and thawing and wetting and drying. The winter of 1994-1995 was a relatively mild winter in terms of freeze-thaw cycles at the site, the summer of 1995 was very dry, the winter of 1995-1996 was relatively wet and cold with several freeze-thaw cycles, and the summer of 1996 produced average amounts of rainfall.

LANLOC must pass TCLP testing before it can leave the production facility so there was no reason to believe the clay/LANLOC mixture would leach contaminants. Nevertheless, we secured a sample from the test section in April 1996. This sample was subjected to the TCLP procedure followed by analysis of the effluent for Volatile Organic Compounds (VOCs), semi-VOCs, and Lead. Total Lead was also determined, and results are shown in Table 6.

Table 6: Results of Analytical Tests Conducted on LANLOC-7

Component	units	Measured Amount
Total Lead	mg/kg	20.1
TCLP/Lead	mg/L	ND
TCLP/VOCs	µg/L	ND
TCLP/Semi-VOCs	mg/L	ND

ND = None Detected

These tests showed the expected result that the PCS in LANLOC-7 is sufficiently stabilized that organic compounds do not leach from it after time.

4. CONCLUSIONS

Petroleum contaminated soil (PCS) can be stabilized by the cold-mix asphalt emulsion (CMAE) process. The resulting material when mixed with clay can produce a product that has characteristics making it suitable for the low permeability soil layer in a landfill cap. Bench-scale tests supplemented with testing of small test pads at the plant site showed that the LANLOC-7 product, when mixed with natural clay and water, yielded a permeability less than the required maximum value of 10^{-7} cm/sec.

Construction of the field test section showed some benefits of using the LANLOC-7 material. Field placement occurred faster with LANLOC-7 than with clay, primarily because the LANLOC-7 arrived at the site at a uniform and desirable moisture content. The LANLOC-7 could be spread and compacted immediately; whereas the clay had to be wetted and mixed or worked and dried on-site to get it to the required moisture content. In a finished condition the LANLOC-7 had much more uniform moisture and density than the clay. Since permeability is directly related to moisture and density, the LANLOC-7 should also have had a more uniform permeability over the entire layer than did the clay. (However, we did not perform sufficient testing to demonstrate this deduction.)

The completed cap was monitored for two years following construction to determine the effects of wet-dry and freeze-thaw cycles. Block samples were taken from both the LANLOC-7 and clay caps. These samples were tested for moisture content and permeability. The test results show that the LANLOC-7 performed at least as well as the virgin clay in retaining its ability to provide a low permeability layer for the landfill cap. These positive results demonstrate that PCS materials may be recycled into useful construction materials rather than confined to costly disposal by landfilling.

Many landfills in Northeastern United States do not have a nearby source of clay with which to construct the low permeability layer of the final cover. Correspondingly, significant quantities of PCS are produced each year. Results of this work have shown that PCS can be ammended to produce a material that meets the permeability requirements for the low permeability soil in landfill liners and covers. Thus a material that formerly took up expensive space inside the landfill can now be used as a material in the construction of the landfill.

5. REFERENCES

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