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Stabilization/Solidification of Salt from a Waste Incinerator

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ABSTRACT

A laboratory procedure was developed and verified for stabilizing salt produced by an industrial waste incinerator. This procedure is based on salt stabilization by means of an asphalt binder. Conductivity values and relevant anion contents in leachates of stabilized waste with an asphalt coating were near zero. The pH value of these leachates equaled the pH value of the water used, so that the stabilized waste salt represented inert material, posing no environmental hazard. An unusually significant reduction in the volume of processed salt occurred during stabilization. After compacting under 10.4 MPa pressure, the volume of test specimens was almost 55% smaller than the initial salt volume. In practice, this would mean more than a doubling of landfill waste capacity. Volume reduction was successfully explained by means of a mathematical model.

INTRODUCTION

Salts produced in waste incinerators represent a loose and dusty secondary waste. For a number of reasons (e.g., the variability of incinerated waste leads to variation in salt compositions and pollutant contents), it has been impossible to utilize this waste in a reasonable manner. It must undergo stabilization/solidification (S/S) before disposal

IMPLICATIONS

This paper is intended to provide a basis for the stabilization of salt produced by solid waste incineration. These salts represent multi-contaminant waste, almost entirely soluble in water, whose chemical composition is dependent on the type of waste incinerated at that particular time. The successful stabilization/solidification (S/S) of such waste by means of cement binders is uncertain. It is evident that satisfactory S/S can be achieved by only using a universally effective method. Asphalt application appears to be an economically acceptable possibility. This binder represents an industrial product, and, as the results of leaching tests have demonstrated, it is capable of perfectly stabilizing and solidifying salts. Furthermore, a significant decrease in the stabilized salt volume has been achieved, which is a great advantage due to the lesser landfill space required.

in a landfill. Due to the chemical composition of these salts, stabilization technology based on the use of cements is questionable.^{1,2}

The work presented here describes a S/S procedure using an asphalt binder with positive features already discussed in previous work.3 All indications are that asphalt binder, as a highly hydrophobic substance, forms a complete immobilizing barrier capable of very efficiently preventing water leaching of pollutants from stabilized waste into the environment. Asphalt binder is marked by favorable properties such as creep, inertness, and stability in the environment. The use of an asphalt binder presents economic advantages due to its capability of being massproduced and its sophisticated and broad application in technical practice.^{4,5} Long-term strategic forecasts assume an abundance of asphalt in the future. On the other hand, when using asphalt for stabilization, the crucial observable quantity is the content of water-leachable organic pollutants (PAHs, phenols, and nonpolar hydrocarbons). At present, most technologically applied asphalt is produced from crude oil by gradual distillation of individual fractions, beginning under atmospheric pressure and finishing in a vacuum at temperatures up to 350 °C. Asphalt is thus a relatively pure binder because it contains very small proportions of chemical components with boiling points below 300 °C. In addition, a select type of asphalt can be employed for S/S technologies and may be further oxidized by the blowing process.^{6,7} The most important aspect, however, is the above-mentioned hydrophobic quality of asphalt, which prevents leaching of any pollutant with water. In this regard, it is encouraging that natural asphalt deposits themselves do not have a toxic effect on the environment.

EXPERIMENTAL WORK

Waste

The processed waste was salt from an industrial waste incinerator in the town of Chropyne, Czech Republic. The incinerated wastes were mainly PVC, polyurethane synthetic leathers, oils, solvents, and so on. The chemical composition of the salt consisted predominantly of sodium chloride and sodium sulfate. The salt sample was prepared by passing it through a sieve of about 2-mm mesh and homogenizing it by mixing in a closed vessel for several hours. The treated sample had an apparent density of about 0.476 g/cm⁻³, was 99.3% dry solids, and contained about 2.3% water-insoluble substances. Salt from incinerators represents a hazardous waste because it is almost entirely water-soluble and in its dry state, owing to its low apparent density and small particle size, is rather dusty.

Asphalt Binder

The asphalt binder used was Parafix, a product of the Paramo Company, Pardubice, Czech Republic, and was the same binder used in our previous paper on stabilization of toxic incinerator ash.³

Leaching Tests

Leaching parameters were established according to valid legislation of the Czech Republic, which is derived from the European test DIN 38414-S4. This test involved the addition of distilled water to the sample in the ratio of 1 L water to 100 g dry material. After 6 hr of shaking and an 18-hr rest, the leachate was filtered (using a $0.7-1.3-\mu m$ fine glass fiber filter without any binder) and subjected to chemical analysis.

Preparing Test Specimens of Stabilized Salt Waste

For preparation of test specimens, the intended quantity of binder was placed in a mixing vessel. This binder material was carefully heated and constantly stirred until melted. A calculated quantity of salt was then poured into the melted asphalt, and the mixture was continuously stirred until all the salt was incorporated. In this manner, a powdery blend was formed from which test specimens were compacted (at a pressure of 10.4 MPa for 30 sec). The pressed test specimens were formed into a cylindrical shape with a base diameter of about 60 mm and a height of 20 to 25 mm. The weight of each test specimen was about 100 g. For the purpose of volume balance, the dimensions of the prepared test specimens were measured with accuracy to 0.1 mm.

Forming the Asphalt Coating on Test Specimens of Stabilized Waste

Test specimens were hung on polyamide fiber and dipped into molten asphalt binder for the shortest possible time. After dipping, the excess binder was allowed to drip off the specimen, which was left hanging until the asphalt coat solidified. In this manner, an asphalt coating about 1 mm thick was formed on the stabilized waste test specimens. A block diagram of S/S technology for treating salt is presented in Figure 1.



Figure 1. Block diagram of the stabilization/solidification of salt from a waste incinerator.

Determining Anion Contents in Leachates

Anion concentrations in leachates (chlorides and sulfates) were determined by an ion chromatography method using a Waters liquid chromatograph (LC Module I) with a conductivity detector.

RESULTS AND DISCUSSION

Leachability Parameters of the Waste

As Table 1 shows, no pronounced quantities of important organic pollutants were found in the incinerator salt leachate sample. The fact that incinerator salt contains practically no organic matter can be explained as follows: most organic substances were burned away during waste incineration. Of the small quantity of organic substances that enter flue gases, only a small part is caught in the sodium hydroxide absorptive solution, probably due to a salting-out effect. When the absorptive solution is dried in a spray dryer, volatile substances evaporate, and only minimal quantities remain in the salt. Although no marked quantities of major pollutants were found in the salt sample, it should be understood that, contrary to other hazardous wastes containing pollutants in unacceptable concentrations, incinerator salt is composed of practically

Table 1. Values of selected leachability parameters of waste and binder.

Parameter	Waste	Binder
Conductivity (mS m ⁻¹)	1,637 ^a	0.419
Soluble substances (mg L ⁻¹⁾	97, 700	b
рН	9.96	6.37
NES (mg L ⁻¹)	0.14	0.12
PAH (ng L ⁻¹)	31.8	270
BTX (mg L ⁻¹)	0.015	b
Phenol index (mg L ⁻¹)	0.008	0.002

NES = nonpolar extractable substances; PAH = polycyclic aromatic hydrocarbons; BTX = benzene, toluene, and xylene; ^aConductivity of salt leachate diluted tenfold; ^bValues not determined.

100% pollutant, and, as has been shown, 97.7% of this incinerator salt sample is water-soluble.

The leachate of the PARAFIX asphalt binder meets most parameters of Class I/I leachability (legislation of the Czech Republic), which relates to the landfill disposal of inert materials. As shown in Table 1, the conductivity values and leachate pH are practically identical to those of distilled water. The negligible PAH content in the asphalt binder also makes it very favorable for use.

Leachability Parameters of Stabilized Waste Test Specimens

After a number of trials with prepared mixes, test specimens were prepared containing 10-50% binder. These specimens were coated with asphalt, and their leachates were collected. The conductivity and pH values of these leachates were measured, and concentrations of chlorides and sulfates were determined by ion chromatography. The dependence of conductivity, pH, and chloride content in leachate on the content of stabilized waste binder is depicted in Figures 2-4. The sulfate concentrations have been omitted since their dependence was analogous to chloride ion dependence. It is evident that the conductivity of leachate, as well as chloride concentrations in leachate, decreased to negligible values with all test specimens. The leachate pH values were also near the pH of the distilled water used. Since test specimens containing 15% binder produced leachate conductivity lower than specimens containing 20-36.5% binder, it follows that the leachability of salt from a stabilized waste specimen coated with asphalt depends on the quality of this coating, rather than on the stabilized waste binder content. It is also worth mentioning that the connection between chloride concentrations in leachates and the conductivity of these leachates is perfectly linear.

The leachate pH values indicated in Figure 3 deserve special attention. It should be realized that the leachate pH value of nonstabilized salt is about 10.0 (Table 1). The



Figure 2. Dependence of leachate conductivity on binder content in asphalt-coated test specimens; I/I = the value limit of leachate conductivity for leachability class I/I, which meets limits for landfill disposal of inert materials (legislation of Czech Republic).



Figure 3. Dependence of leachate pH on binder content in asphaltcoated test specimens.



Figure 4. Dependence of leachate chloride concentrations on binder content in asphalt-coated test specimens; I/II = the value limit of chloride concentrations for leachability class I/II, which meets limits for landfill disposal of inert materials in cases when waste comes into contact with ground water (legislation of Czech Republic).

fact that the leachate pH values of stabilized waste test specimens covered with asphalt coating were practically identical to the pH values of the distilled water employed in the preparation of these leachates, in our opinion, is of fundamental significance. Hydrogen (H⁺) and OH⁻ ions possess ion mobility values (and thus ion conductivity) greater than those of all other ions by almost one order. If the pH values of stabilized waste leachates maintain the pH value of water used, it is compelling proof that the asphalt coating provides an excellent immobilizing barrier against permeation and therefore leaching of any ion. Using the Atomic Absorption Spectrometry method, manganese, iron, and zinc were sought in the stabilized waste leachate with the greatest conductivity. Since no traces were found in the leachate despite a very low limit of detection (especially with zinc), other metals were not sought.

Besides the leachability parameters presented in Figures 2–4, the nonpolar substance content was determined in the test specimen leachate containing 20% binder. A value of 0.08 mg/L⁻¹ was measured, corresponding to Class I/I leachability (legislation of the Czech Republic). A comparison of this value with the nonpolar substance contents in the waste leachates and in the binder alone (Table 1) shows that this leachability parameter improved. This improvement probably occurred because the stabilized waste test specimen was compressed and thus had a smaller specific surface area than pieces of asphalt binder of the same mass.

As the above-mentioned measurements indicate, salt stabilization with an asphalt binder supplemented by an asphalt coat is highly efficient, thanks to reduced pH, conductivity, and anion concentrations in leachate from all test specimens. The fact that this decrease was virtually independent of stabilized waste binder content proves that asphalt coating on stabilized waste specimen forms an impermeable barrier to ions. Moreover, stabilized waste produced in practice would ordinarily have a smaller specific surface area and may even be verifiably expected to have a considerably smaller leachability.

Influence of Stabilization on Waste Volume

Waste volume is an important factor in the economic aspect of landfill disposal. Landfill construction is immensely costly, and thus efficient utilization of landfill volume capacity brings great financial savings. Therefore, a volume assessment of the stabilization procedure employed here was carried out. The apparent and absolute densities of salt were measured, as well as the density of asphalt binder. The measured values are summarized in Table 2.

The total waste volume might be expected to increase through stabilization, owing to the volume of added binder. In the stabilizing procedure used in this work,

Table 2. Measured densities (kg r	m⁻³) of	waste and	l binder
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Quantity	Symbol	Average Value of 3 Measurements	Standard Deviation
Apparent density of	ρ΄ _s	476	3
Absolute density of incinerator salt	$\boldsymbol{\rho}_{s}$	2,000	180
Density of asphalt binder	$\boldsymbol{\rho}_{b}$	1,033	0.5

however, volume decreased markedly from the initial waste volume. Thus, for example, a test specimen containing 20% binder demonstrated a decrease in volume to 47% of the initial salt volume, which would practically imply a more than doubled landfill service life. The following model was proposed to explain this volume decrease: While 1 m³ of incinerator salt has a mass of 476 kg (see Table 2), salt itself occupies volume

$$V_{\rm s} = \frac{476}{2000} = 0.238 \,\,{\rm m}^3 \tag{1}$$

For the sake of simplicity, let us assume that all salt granules are the same size, have a spherical shape, and are arranged within the stabilized waste specimen, as depicted in Figure 5.

As is obvious in the figure, each salt granule, including free space between granules, would occupy the



Figure 5. Model of salt granule arrangement in a compact stabilized waste specimen.

volume of a cube with its edge equal to the granule diameter (as is well known, there is a possibility of closer arrangement of identical spheres in space, a so-called hexagonal close-packed structure, but this does not concern us here). The real volume of salt granules would then be

$$V_{\rm S} = N \frac{1}{6} \pi d^3 \tag{2}$$

and the total volume including free space between granules would be

$$V_t = N d^3$$
 (3)

where *N* is the number of salt granules in the sample and *d* is the diameter of salt granules. The total volume of the sample would then be

$$V_t = \frac{6}{\pi}$$
 $V_s = \frac{6}{\pi}$ 0.238 = 0.455 m³ (4)

and the volume of the sample related to the initial salt volume would then be 45.5%. The volume of space between granules in this body would be

$$V_t = V_t - V_s = 0.455 - 0.238 = 0.217 \text{ m}^3$$
 (5)

Thus, in order to form a stabilized waste sample containing 20% binder (where w = binder content in stabilized waste, %), 1 m³ of salt would have to receive

$$m_b = m_s \frac{W}{100 - W} = 476 \frac{20}{100 - 20} = 119 \text{ kg of binder}$$
 (6)

The volume of additional binder would be, therefore,

$$V_b = \frac{119}{1033} = 0.115 \text{m}^3 \tag{7}$$

Here, it is obvious that binder would fill in only part of the free space between granules. If all intergranular space were to be filled in, the necessary quantity would be

$$m_{\rm b} = 0.217 \times 1,033 = 224 \ {\rm kg}$$
 (8)

Binder content in this body would then be

$$w = \frac{224}{476 + 224} \qquad 100\% = 32.0\% \tag{9}$$

All bodies containing less than 32% binder should, therefore, have a relative volume of 45.5% of initial salt volume under the above-mentioned assumptions. In bodies containing more than 32% binder, the volume of added binder would be greater than intergranular free space between salt granules in compact order, so this excess binder quantity would cause an increase in stabilized waste body volume. Since this body would not contain any other free space, its volume should be equal to the sum of real salt volume and added binder volume. In order to form a body containing, for instance, 50% binder, 1 m³ of salt would have to receive an added quantity

$$m_b = m_s \frac{w}{100 \cdot w} = 476 \frac{50}{100 \cdot 50} = 476 \text{ kg of binder}$$
 (10)

The volume of added binder would be

$$V_b = \frac{476}{1033} = 0.461 \,\mathrm{m}^3 \tag{11}$$

and total volume of the body should, therefore, be $V_t = V_s + V_b = 0.238 + 0.461 = 0.699 \text{ m}^3$. The relative volume of this body to initial salt volume (1 m³) would be 69.9%.

Figure 6 compares relative volume values measured on prepared stabilized waste test specimens with values calculated according to the presented model. As shown in the figure, the measured values of relative volume actually display a break at about 32% and these values are nearly the same with all test specimens at lower binder content. Keeping in mind experimental error (e.g., standard deviation in measured salt densities, as shown in Table 2), it is also evident that measured and calculated values of relative volume are practically identical. This successfully explains the very favorable reduction of waste volume during stabilization by means of the asphalt binder.

CONCLUSIONS

A laboratory procedure was developed and tested for stabilizing salt from a solid waste incinerator. It consisted of (1) mixing salt into a molten asphalt binder, (2) compacting test specimens from the produced mixture, and (3) the subsequent formation of an asphalt coating on the surface of these specimens.



Figure 6. Dependence of relative volume of stabilized waste test specimens on binder content.

The obtained values of conductivity, pH, and anion content in test specimen leachates were quite satisfactory and almost independent of the binder content in stabilized waste. From the results, it is obvious that stabilization with an asphalt binder and supplementary formation of asphalt coating can be regarded as a complete disposal of waste. From Figures 2, 3, and 4 it convincingly follows that formation of an asphalt coating on test specimens allows execution of S/S with a mere 10% asphalt binder. The quantity of necessary binder for producing a superficial asphalt coat can be practically negligible if stabilization is performed on a technological scale.³

Monitoring the volume balance was a very important feature of stabilization procedure development. During the stabilization procedure, a waste volume decrease to about 46% was observed. This very favorable occurrence was caused by the great difference between apparent and absolute densities of incinerator salt. To explain this volume reduction, a mathematical model was used, based on a simplified conception that all salt granules are the same size, spherical, and arranged in compact order in the stabilized waste. Relative volume values of stabilized waste calculated on the basis of this model and actual relative volume values measured at prepared test specimens were in accord. This indicated that the mathematical model corresponded relatively accurately with reality.

This study of salt stabilization from an industrial waste incinerator by means of an asphalt binder was conducted on a completely homogenized salt sample from one incinerator. In the future, it will be necessary to verify this stabilization method with salts from various incinerators and/or with simulated waste.

A long-term leaching test has been launched to assess the long-term stability of incinerator salt stabilized waste. Owing to the long duration of this experiment, results have yet to be established. Leachate conductivity will be systematically measured over approximately three years, and upon the conclusion of the test a mathematical and statistical forecast of stabilized waste leachability will be projected. This test should prove that stabilization of salt from a waste incinerator by means of an asphalt binder combined with an asphalt coating provides complete and truly permanent waste disposal.

Applied asphalt technology has been in development for about 60 years.⁴ We feel that the laboratory study presented here can be transferred to practice without problem. Further, it can open up possibilities for utilizing proven technologies and currently used machinery to solve a complex waste disposal problem.

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