

METHOD FOR ELECTROKINETIC REMEDIATION OF INCINERATION ASH, INDUSTRIAL WASTE PRODUCTS AND SOFT SOIL

FIELD OF THE INVENTION

This invention relates to electrokinetic remediation for removal of heavy metal components and/or dewatering, incineration ash, other industrial waste products and soft soil in particular, a method of reusing incineration ash, other industrial waste and soft soil safely.

BACKGROUND

Excavated soil from construction projects may pose disposal problems, particularly when the soil is soft, such as marine or alluvial clay, which has low shear strength, for example 20 kPa or less, and is generally worthless as a civil engineering construction material.

Waste material arising from various industrial processes often result in soft consistency which requires both dewatering and elimination of heavy metals, such as sand blasting in shipbuilding industry, polishing process in CRT industry. Safe reutilization of these materials can be achieved with electro kinetic remediation.

Another waste product that has limited use is incineration ash. Domestic and industrial wastes that cannot be recycled are usually burnt at the municipal incineration plants. This has become a preferred method of disposal in most advanced countries, because incineration reduces about 70 - 90% of the original volume of waste. However, the incineration ash that remains after burning creates a different disposal problem.

Incineration of wastes destroys the organic matters, but leaves the inorganic materials relatively untouched. These inorganic materials include metals in fine particle form or ash collected at the bottom of the incinerator and suspended as dust in the incinerator's heat convection flume. Ash particles have a large surface area to mass ratio and cannot be disposed of indiscriminately, for example in a landfill, because the large surface area has affinity to interact with water readily and leach out, causing contamination of the environment and/or ecological food chain.

US Patent No. 6,086,739, issued on 11 July 2000 to Dalibor Hodko describes a method for prefield electrokinetic remediation of contaminated soil. The method includes determining the electric field distribution in the soil between and around several test electrodes positioned in the soil. A sufficient electric field to drive the electrokinetic remediation is from about 10 to about 300 V/m.

SUMMARY

According to a first aspect of the present invention, a method for treating incineration ash and industrial waste products is provided, the method comprising the steps of: mixing portions of incineration ash and/or industrial waste products and water, to yield a slurry having a bulk density between about 1000 kg/m³ and about 1800 kg/m³; and attracting at least heavy metal components in the slurry to an electrode for removal from the slurry so that the toxic levels of the heavy metal components in the slurry after treatment are reduced to predetermined and internationally accepted concentration levels.

According to a second aspect of the present invention, a method for treating a incineration ash and industrial waste products is provided, the method comprising the steps of: mixing portions of incineration ash and/or industrial waste products and water to yield a slurry having a bulk density between about 1000 kg/m³ and about 1800 kg/m³; inserting one or more pairs of cathode and anode into the slurry; and establishing current flowing between the one or more pairs of cathodes and anodes for a predetermined period of time.

Preferably, the slurry/mixture comprises 0-90% clay (less than 2µm), 0-90% incineration ash and/or industrial waste products (measured as weights, oven dried at 105°C) and 10-90% water.

Preferably, the method of treatment includes the step of applying a voltage to the one or more pairs of cathode and anode.

Preferably, the method of treatment includes attracting at least heavy metal components contained in the slurry to cathodes and occasionally to anodes for subsequent removal so that the toxic level of heavy metal components after treatment is reduced to internationally accepted concentration levels.

Preferably, where high content water is found in the slurry/mixture, the method of treatment includes attracting water molecules to the electrodes.

BRIEF DESCRIPTION OF THE DRAWINGS

The embodiments of the invention are described by way of non-limiting examples, with reference to the accompanying drawings, in which:

Fig. 1 illustrates pretreatment of incineration ash and/or industrial waste products according to an aspect of the present invention so that uniform and representative samples are used for determining the chemical compositions.

Fig. 2 illustrates the process of treating incineration ash and/or industrial waste products with soft clay by mixing and reducing the toxic metal contents according to another aspect of this invention.

Fig. 3 illustrates details of the electrokinetic treatment according to yet another aspect of the present invention.

DETAILED DESCRIPTION

Fig. 1 shows a flowchart of typical pretreatment process illustrating samples of incineration ash and/or industrial waste products and soft clay being collected and prepared for analysis to determine their pertinent characteristics. The incineration ash and/or industrial waste products is subjected to these pretreatment steps enabling creation of uniform and representative samples for the determination of their chemical compositions.

Step S10 involves drying a sample of incineration ash and/or industrial waste products in an oven at 105°C. After drying and cooling, the samples are separated by a 20-mm size sieve in step S20. The materials that are finer than 20 mm are sent directly to a grinder in step S40. The materials that are larger than 20 mm, such as metal, unburnt and non-incinerable materials, are sieved out and mechanically separated in step S22. These materials are then collected, weighed and the characteristics recorded in step S24, before the materials are sent for crushing, for example in a jaw crusher, in step

S30. The materials are further crushed in step S40, for example in a grinding mill. The product is further separated with a 2-mm size sieve in step S50. Ash particles that are larger than 2 mm are sent back in step S60 to the grinding mill to be further broken down into finer particles. This step S60 of further grinding may be stretched, for example, up to 30 minutes and the particles that are still coarser than 2 mm in size are separated, removed and weighed in step S62. Ash particles less than 2 mm are mixed thoroughly in step S70 and this preparatory process ends in step S80 when samples for chemical analysis to determine the content of heavy metal components that may be present are sent to the laboratory. A suitable chemical analysis method, for example, is fluorescent X-ray analysis.

The loss in mass of the materials in the process of oven drying at 105°C in step S10 indicates the moisture content, while the loss in mass of the materials with furnace heating at 400°C, after completing step S80, indicates the ignition loss of each sample. This ignition loss is related to the organic content of each sample of raw materials received from the incineration plant.

This pretreatment process standardises a method of preparing samples of incineration ash and/or industrial waste products so that the sample results are uniform and representative. The incineration ash and/or industrial waste products for use in this embodiment of the invention does not need to be pretreated in the same manner for preparing samples for chemical analysis.

Similarly, samples of soft clay are characterised to determine relevant physical properties. For example, some of the characteristics, such as the shear and compressive strengths, water contents, grain sizes, porosity, pH, and chemical contents, are determined and recorded.

Fig. 2 illustrates a method of remediating a mixture of pulverized incineration ash and/or industrial waste products and soft clay from step S80 in Fig. 1, and this involves a series of further steps. Step S110 involves collecting and delivering the incineration ash and/or industrial waste products and soft clay to a laboratory for treatment. Step S120 involves mechanical mixing of the incineration ash and/or industrial waste products and soft clay, if necessary, in a container. In Step S130, an amount of water to be added, if necessary, to the mixture of incineration ash and/or industrial waste

products and soft clay is estimated from the characteristics of the clay, and further water may be added, if necessary, to yield a slurry, for example with a specific density of between 1 and 1.8. This slurry may contain about 0-90% clay, 1-90% ash, and 10-90% water.

Step S140 involves analysis of the slurry, for example its pH, electrical conductivity, selection of additives, if necessary, to be added to the slurry, electrical voltage and current to be applied to the electrodes.

Step S150 involves the process of electrokinetic remediation by applying a DC voltage to the electrodes for a predetermined period of time. During the process, mainly three phenomena take place: electro-migration, electrophoresis and electro-osmosis. Effectively, heavy metal ions, for example, attracted to the cathodes and in some instances to the anodes, become deposited as metals and are concentrated around the electrodes for subsequent removal. Samples of the treated mixture are analysed in step S160, for example, for its chemical properties of heavy metal contents.

These samples are further cured by leaving the sample to air-dry for a period of up to 28 days, and the physical properties, for example, compressive strength, are then determined. The unconfined compressive strength of the treated clay after curing may reach up to about 300 kPa, if desired.

In step S170, quality control and assurance tests are made to ensure that the treated clay is suitable for reuse. If a particular sample is unsatisfactory, the sample is further treated in step S150 before the sample is released for use in step S180.

By mixing incineration ash and/or industrial waste products with soft clay, the physical properties of both materials will improve and may become a useful construction material. By removing the toxic heavy metals through this electrokinetic remediation process, the treated clay becomes safe for use, for example in backfills, reclaimed land or landfills.

Fig. 3 illustrates a method of electrokinetic remediation. Portions of incineration ash and/or industrial waste products and soft clay are mixed with water, if necessary, to

yield a cohesive slurry. The bulk density of this slurry is between about 1000 kg/m^3 to about 1800 kg/m^3 , and preferably between about 1250 kg/m^3 to about 1500 kg/m^3 .

Once the incineration ash and/or industrial waste products and clay have been prepared and formed in to consistency of a slurry, one or more pairs of electrodes (i.e. cathodes 10 and anodes 20) are dipped into the slurry, and a voltage is applied to the electrodes to form an electrolytic cell, as shown in Fig. 3. The voltage applied is in the range of up to about 500 V, yet below fusing/melting voltage gradients. The actual voltage applied depends on variables such as the electrode spacing and conductivity of the slurry, amongst others. The voltage need not be a steady direct current, but may be adjusted $\pm 50\%$ about a mean voltage, for example a step, sine, saw-tooth or other wave form superimposed on a constant DC voltage. It is noted that the relevant properties of the slurry to enable electrokinetic remediation process may be achieved by a mixture of incineration ash and/or industrial waste products and water only.

The current flow between the electrodes varies with the voltage applied, electrode spacing and conductivity of the slurry. For safety reasons, the current is set below a safe level which also depends on the heat generated by the current flow. Of course, the voltage or current is operable at a higher level if done in a controlled manner, such as in a laboratory where safety is assured. Furthermore, the power supply can also be switched to either constant voltage or constant current mode, but this has virtually no effect on the remediation process. If a constant current is set and the conductivity of the slurry is high enough to maintain the current, the voltage supplied depends on the current-voltage characteristics that may vary with time. If the power capacity of the electricity supply is limited, the voltage across the electrodes may be lower than that determined from the current-voltage characteristic of the power supply.

During this electro-kinetic treatment, positive ions (or cations) 12 in the slurry are attracted by the electric field to the cathodes 10. These positive ions 12 include the heavy metal ions, for example, Pb^{2+} , Cr^{2+} , Ni^{2+} , Cd^{2+} or the like, that render the incineration ash and/or industrial waste products toxic. These metal ions are reduced to their metals and are either accumulated or electroplated mainly around the cathode. If the slurry is predominantly acidic, hydrogen ions are attracted to the cathode and electrolysed to hydrogen gas.

Similarly, negative ions (or anions) 14 including some metal ions in the slurry are attracted by the electric field to the anode 20. The migration of the cations 12 and anions 14 towards the electrodes is reflected as a current flow between the electrodes.

The duration of current flow is directly proportional to the amount of heavy metal ions that are to be removed and their valencies, and the magnitude of the current flow generally obeys Faraday's law. For example, in a test that was carried out, the current density was varied up to about 100 A/m, and the duration of treatment varied from a few minutes to a few hours per batch of treatment.

The material suitable for electrodes depends on the type of ions that are present or the gases that are generated. When a metal electrode is used, for example, stainless steel, the metal ions become electroplated on the electrode. If it is made of graphite, the metal ions may accumulate around the electrode. To facilitate easier removal of the metal ions, each electrode may be surrounded with a perforated conductive sheath and any metal that may have accumulated around the electrodes can then be effectively removed. Other considerations determine the choice of electrode materials, for example, compatibility of the gas released at the electrodes and duration of treatment.

There are five principal phenomena occurring within a soil (for example, ash/clay mixture) during electrokinetic remediation: streaming potential, migration potential, electro-osmosis, ion migration and electrophoresis. The first two of these phenomena are concerned with the generation of electric potential due to the movement of charged particles. The remaining three phenomena deal with the transport mechanisms developed upon application of an electric field across a soil mass.

In *streaming potential*, water - under a hydraulic head difference - is caused to flow through a soil. Double layer charges in the clay within the soil are displaced in the direction of flow. The result is development of an electrical potential difference called "streaming potential" proportional to the hydraulic flow rate between opposite ends of the mass. Usefulness of this technique is inhibited by the fact that flow of water through clay is slow, and the potential developed, therefore, is low. However, if incineration ash comprises charged particles, and is relatively pervious, flow of water through ash/clay mixture can generate low voltages.

In *migration potential*, movement of charged particles through a solution leads to generation of an electrical potential. This is caused by the viscous drag of the water that retards the movement of the diffuse layer cations relative to that of the particles. In this situation, charged particles in the incineration ash, if allowed to fall through a column of water, can lead to generation of an electrical potential.

If an electric potential is applied across a wet soil mass, cations are attracted to the cathode and anions to the anode. As cations migrate they drag water with them, causing water movement towards the cathode. The drag of water by the anions to the anode is much slower; therefore there is a net flow of water to the cathode. This is known as *electro-osmosis*. Most useful in soils is this phenomenon which helps in removal of excess water in soft soil via electro-osmosis, to achieve an effective dewatering.

In *electrophoresis*, if a direct current is applied across a colloidal suspension, charged particles are attracted electrostatically to one of the electrodes and repelled from the other. Negatively charged clay particles move towards the anode. A test involving clay slurry in a cylindrical tube capped with two conducting plates as electrodes is used to demonstrate this. It involves discrete particle transportation through water. This is in a way similar to the principle of electrolysis or electroplating.

Ion migration is basically movement of free ions and ion complexes, which are present within the pore fluid, to the appropriate electrodes, when an electric field is applied across a soil mass.

Not all the above phenomena have been purposefully utilised for harnessing their fullest potential. As nature nurtures electric charges, all these phenomena are operational in many natural processes in living and non-living things at varying levels of efficiencies.

In this electrokinetic process particularly with incineration ash remediation, more than one phenomenon may occur at any given time. Attraction of heavy metals to the electrodes is the most desirable outcome of these processes.

United States Environmental Protection Agency (US EPA) has an updated set of standards for contamination levels in water. These will be used in the analysis of heavy metal content leached into water after treating incineration ash. These standards will be updated to stay on the safer side with the assistance of WHO standards.

Other optional non-toxic construction materials, such as, clay, sand, gravel, quarry dust or waste building materials may be blended with the treated incineration ash and/or industrial waste products so as to enhance the physical properties of the resulting mixture.

While only a method of electrokinetic remediation has been described and illustrated, it is to be understood that many changes, modifications and variations could be made to the present invention without departing from the scope of the invention. An example is a process of continuous remediation of flowing slurry inside an open or closed container.

CLAIMS:

1. A method of treating incineration ash and/or industrial waste products comprising the steps of:

- mixing portions of incineration ash and/or industrial waste products and water to yield a slurry having a bulk density between about 1000 kg/m³ and about 1800 kg/m³; and
- attracting at least heavy metal components contained in the slurry to an electrode for removal from the slurry so that the toxic levels of the heavy metal components in the slurry after treatment are reduced to predetermined and internationally accepted concentration levels.

2. The method according to claim 1, wherein the step of attracting at least heavy metals includes the steps of:

- inserting one or more pairs of cathodes and anodes into the slurry; and
- ~~maintaining current flow between the one or more pairs of cathodes and~~ anodes for a predetermined period of time.

3. A method of treating incineration ash and/or industrial waste products comprising the steps:

- mixing portions of incineration ash and/or industrial waste products and water to yield a slurry having a bulk density between about 1000 kg/m³ and about 1800 kg/m³; and
- inserting one or more pairs of cathodes and anodes into the slurry; and
- establishing current flow between the one or more pairs of cathodes and anodes for a predetermined period of time.

4. The method according to claim 3, wherein at least heavy metal components contained in the slurry are attracted to the one or more pairs of cathodes and anodes for removal so that the toxic levels of the heavy metal components in the slurry after treatment are reduced to predetermined and internationally accepted concentration levels.

5. The method according to any one of the preceding claims, further comprising mixing the mixture with clay.

6. The method according to any one of claims 2 to 5, wherein the step of maintaining or establishing a current flow includes the step of applying a constant or variable voltage to the one or more pairs of cathodes and anodes.
7. The method according to claim 6, wherein the voltage applied across the one or more pairs of cathodes and anodes ranges up to about 500 V at below fusing/melting voltage gradients.
8. The method according to claim 6 or 7, wherein the voltage comprises a steady voltage superimposed on a non-steady component.
9. The method according to claim 8, wherein the non-steady component is a pulse, sinusoidal, saw-tooth or any other waveform.
10. The method according to any one of the preceding claims, further comprising the step of adding and mixing an additive to enhance the electrical conductivity of the slurry.
11. The method according to any one of claims 5 to 10, wherein the slurry comprises a mixture in the proportions of 0-90% clay, 1-90% ash and 10-90% water.
12. The method according to any one of the preceding claims, wherein the clay before treatment has a shear strength of substantially 20 kPa or less.
13. The method according to any one of the preceding claims, wherein the slurry after treatment is cured to yield a material with compressive strength of up to about 300 kPa.
14. The method according to any one of the preceding claims, wherein the toxic levels of the treated slurry is within the guidelines of internationally accepted concentration levels.

15. The method according to any one of the preceding claims, wherein movement of at least the heavy metal components in the slurry comprises: streaming potential, migration potential, electro-osmosis, ion migration and electrophoresis, or any combinations thereof.

16. A mixture of clay and incineration ash and/or industrial waste products obtained after treatment according to any one of the preceding claims is suitable for use in landfills.