CONSTRUCTION-GRADE CEMENT PRODUCTION FROM CONTAMINATED SEDIMENTS USING CEMENT-LOCK™ TECHNOLOGY

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ABSTRACT

The Institute of Gas Technology (IGT) has developed the Cement-Lock™ Technology a versatile, cost-effective, and environmentally friendly manufacturing technology for producing construction-grade cements from a wide variety of contaminated waste materials, such as sediments, concrete and building debris, town gas site soils, Superfund site soils, sludges, chemical wastes, petroleum refinery wastes, and incinerator residues. Organic and inorganic contaminants are present in these wastes across a broad range of concentrations. In the Cement-Lock process, contaminated materials and proprietary modifiers are fed to a reactive melter operating under oxidizing conditions where all the organic compounds are completely destroyed and converted to innocuous carbon dioxide and water. Chlorine and sulfur compounds are sequestered and heavy metals are locked within the molten matrix to completely immobilize them.

During processing, the melt (Ecomelt™) is imparted with latent cementitious properties that allow it to be transformed into construction-grade cement. The Cement-Lock Technology is unique because it not only decontaminates the sediment but also converts it into a beneficial commercial commodity, namely, construction-grade cement. The effectiveness of the technology for remediating contaminated sediments has already been verified in bench- and pilot-scale test programs. Currently, a large-scale sediment decontamination project is underway in the New York/New Jersey harbor area to demonstrate the technology at a processing capacity of 30,000 cubic yards per year.

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Keywords: Dredging, dredged material, beneficial use, manufacturing process

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INTRODUCTION

Sediments must be routinely dredged from the New York/New Jersey harbor to maintain water depths for shipping channels, berthing areas for commercial vessels, and to insure safe navigation. In the past, most dredged sediments have been barged out into the open ocean and dumped. These dredged materials often contain a variety of contaminants from different anthropogenic sources including polynuclear aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), insecticides, chlorinated dioxins and furans, and heavy metals. The concentrations of some of the contaminants in the sediment are high enough to render the sediments hazardous to benthic organisms through biotoxicity and/or bioaccumulation. Further, the ocean dumping area commonly known as the "Mud Dump Site" was closed to further dumping of contaminated material as of September 1, 1997. These contaminated dredged sediments must be rendered innocuous to the environment before being disposed of, or, as in the case of the Cement-Lock™ process, converted into a salable product for beneficial use.

In addition to the contaminated sediments, many different types of contaminated wastes can be treated via Cement-Lock Technology. Several million tons of wastes are being generated annually around the world. The wastes are often either being landfilled or stockpiled in nearby localities. Depending upon the nature of these wastes, they can pose environmental problems that warrant an economical and environmental compatible disposal. In addition to contaminated sediments, these wastes include concrete and building debris, town gas site soils, Superfund site soils, sludges, soils and debris from DOD and DOE sites, chemical waste, petroleum refinery waste, and incinerator residues.

The Cement-Lock Technology being developed by the Institute of Gas Technology (IGT) and its wholly owned subsidiary, ENDESCO Services, Inc., offers a one-step solution for remediating these contaminated materials in which the organic contaminants are completely destroyed, inorganic contaminants are immobilized, and the resultant solid product from the treatment can be put to beneficial use. The technology is flexible enough to accommodate the complex and varying nature and levels of contaminants and their widespread spatial distribution within the estuarine environment. The Cement-Lock Technology simultaneously immobilizes the heavy metals and destroys the organic contaminants such as PCBs, PAHs, dioxins, furans, chlorinated pesticides, and herbicides.

CEMENT-LOCK™ TECHNOLOGY DESCRIPTION

The Cement-Lock™ Technology is an advanced management system for remediating contaminated dredged sediments from estuarine and river environments, hazardous and non-hazardous wastes, and municipal solid wastes (MSW). In addition to decontamination, Cement-Lock converts the wastes into construction-grade cement, which can be sold on the open market. Depending upon the waste stream and its composition, other beneficial products could be produced, for example, steam for power generation. Further, there are no secondary hazardous waste streams produced during Cement-Lock processing as in some other treatment processes.

The beneficial use of sediments and wastes through the application of Cement-Lock Technology has many advantages over conventional waste processing. These include: a) additional revenues generated from the sale of construction-grade cement product, b) the ability to accept materials with fairly low tipping fees because of the secondary revenue streams, and c) environmental superiority when compared to conventional incineration technologies.

The Cement-Lock Technology should not to be confused with either cement manufacturing plants or with MSW incineration technologies. The Cement-Lock Technology is considerably simpler than a portland cement manufacturing plant and bears little or no resemblance to the actual complex cement plant. Unlike a cement plant, the Cement-Lock Technology does not have the extensive sizing requirements for the materials being processed; it does not have the extreme temperature requirements of a cement plant; it does not produce waste streams (such as cement kiln dust); it does not require complex energy management to save energy; it does not produce high NOx; it does not have stringent requirements for materials of construction; and finally, the starting raw materials are entirely different.

Nor is the Cement-Lock Technology an incineration process either. Rather it is a thermo-chemical manufacturing process that utilizes the inherent properties of sediments and wastes as feedstocks for producing economically attractive products (Figure 1). Conventional MSW incinerators do not produce a salable product. Rather, they generate ash that may contain leachable heavy metals, which must be disposed of as hazardous waste. Further, MSW incinerators have been shown to generate dioxins and dioxin precursors.

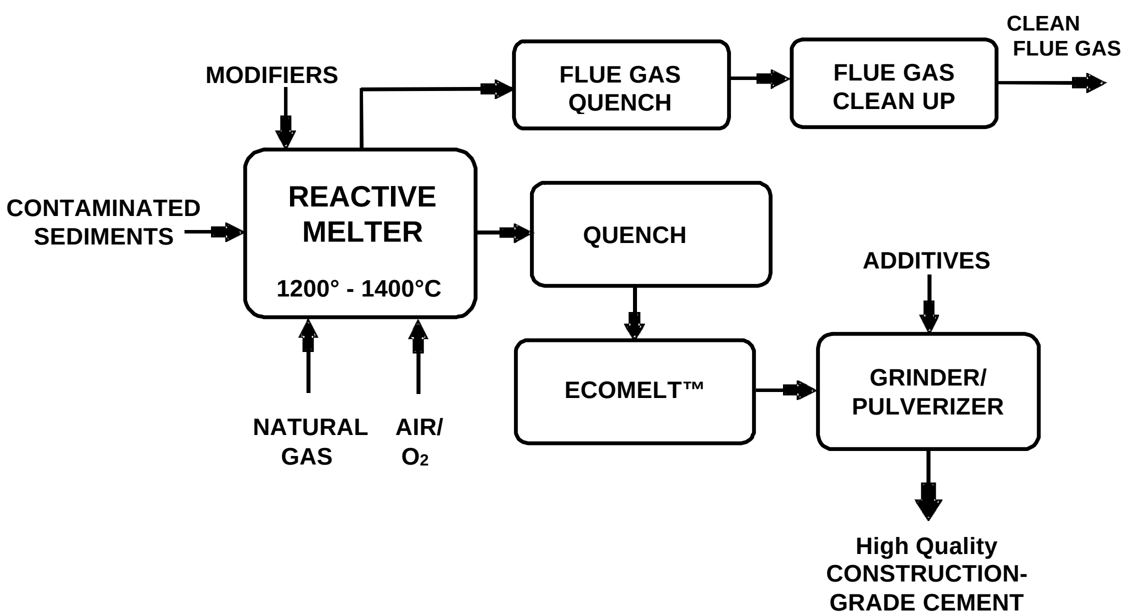

Figure 1. SCHEMATIC DIAGRAM OF THE CEMENT-LOCK PROCESS FOR TREATING DREDGED ESTUARINE SEDIMENTS

The Process

Contaminated materials are reacted in a melter with suitable modifiers in proportions required for producing materials with latent cementitious properties. The proprietary modifiers are inexpensive materials that are commonly used in conventional cement manufacturing. The melter for carrying out this process is operated at temperatures in the range of 1200° to 1400°C (2192°-2552°F) or temperatures sufficient to completely melt the sediment-modifier mixture. At these temperatures in the presence of oxygen, organic contaminants originally present in the sediment are completely destroyed and converted to innocuous carbon dioxide (CO_2) and water (H_2O). Chlorine present in some of the organic compounds (dioxins, furans, PCBs, pesticides, etc.) is converted to hydrogen chloride (HCl), which can be readily scrubbed from the flue gas by direct injection of powdered lime. The flue gas could also be passed through a solid media filter containing calcium oxide (operating at 540° to 595°C; 1004° to 1100°F) to capture HCl. Preliminary laboratory-scale tests (Goyal *et al.*, 1999) have also demonstrated that some of the chlorine will be sequestered within the stable matrix of the melt. Sodium and potassium chlorides (NaCl and KCl) from seawater will be volatilized and captured in the downstream flue gas processing stages.

The melt, which contains the heavy metals present in the contaminated sediment, is quickly quenched. The metals are locked into the matrix of the melt that completely immobilizes them. The solidified melt can be crushed and pulverized by conventional methods or it can be drawn into micrometer-size fibers by fiberization techniques. The fibers can then be easily pulverized and mixed with another appropriate additive to yield construction-grade cement as a product for beneficial use.

Flue gas from the melter enters a secondary combustion chamber (SCC), where it is subjected to an additional two (2) seconds residence time at temperature to ensure complete combustion of any organic compounds. The flue gas exiting the SCC is cooled by direct water injection to a temperature of about 177° to 204°C (350° to 400°F) to prevent the formation of dioxin and furan precursors. Powdered lime (CaO) is injected into the flue gas to capture HCl, SO_2 and other acid gases. The flue gas then passes through a bag house to capture the spent lime, fine particulates, and NaCl and KCl volatilized from the estuarine sediments. From the bag house, the flue gas passes through a fixed bed of activated carbon to capture volatile metal species. In an alternative process configuration, powdered activated carbon can be injected into the flue gas stream to capture volatile metals and be removed by a second bag house. The clean flue gas is vented to the atmosphere.

All of the components required for applying the Cement-Lock Technology to the remediation and beneficial use of dredged sediments have been adapted from commercially available equipment. No equipment development was required. The following sections describes the major process equipment, the feed system, the reactive melter, and the melt fiberizer or granulator.

Feed System

The system for feeding dredged estuarine sediments into the reactive melter is a simple screw conveyor. Dredged sediments containing 60-weight percent water are scooped from the barge and dumped into the screw conveyor feed hopper. The rate of sediment feeding into the reactive melter can be controlled by regulating the screw rotation rate. Depending upon the pumpability of the sediments (from different geographical locations), it may be possible to use a sludge pump (reciprocating piston) to transport sediments from the barge to the reactive melter. Since sediments are essentially sandy, silty, or clayey in nature, the only feed pretreatment required is to remove large objects (such as automobile parts, timber, fencing, etc.) from the feed using a scalper.

Reactive Melter

Any suitable natural gas-fired melter can be adapted to the Cement-Lock Technology. IGT has considered three vendors for providing melters, which are described below. The current pilot-scale testing was conducted in a rotary kiln melter.

1). A rotary kiln-type melter as manufactured by ABB or Svedala Industries is suitable for the Cement-Lock Technology. The rotary kiln-type melter is very forgiving of variations in the size of feed materials that it can process. Through the years, rotary kilns have been installed in hundreds of locations worldwide.

The rotary kiln melter employed for the pilot-scale testing was designed and built by ABB. During pilot-scale operation, sediment containing 60-weight percent water was readily processed without predrying. ABB has subsequently quoted and is willing to provide the required guarantees for a rotary kiln melter with a processing capacity of 100,000 cubic yards per year of harbor sediment.

2). The reactive melter developed by Ausmelt Technology Corporation, is a vertically oriented, refractory-lined cylinder. The melter is constructed with water-wall cooling to minimize refractory thickness. A layer of frozen slag coats the internal walls of the melter to extend refractory life. Feed material and modifiers are fed into the melter through a port at the top of the melter. The energy required to melt the sediment-modifier mixture is supplied through a submerged lance, which is comprised of concentric tubes for feeding air or oxygen and natural gas into the melt. The lance can be moved up or down depending upon the depth of the melt. Typically, air (or enriched air) is fed through the outer shell of the lance thereby cooling the lance somewhat. Natural gas is fed through the inner tube.

Combustion products bubble vigorously throughout the melt. The flow of gas from the lance instills a circulating pattern through the melt ensuring complete mixing. During initial melter operation, the lance becomes coated with a layer of frozen slag, which extends its life. When the lance must be replaced, a spare can be installed within about 30 minutes.

3). Other melters, such as the submerged combustion melter, commercialized in the Ukraine for mineral wool manufacturing and being developed in the U.S. by the Institute of Gas Technology, is also suitable for Cement-Lock Technology. A pilot-scale submerged combustion melter has recently been installed and tested at IGT's Energy Development Center.

Melt Granulator or Fiberizer

The melt (Ecomelt™) from the reactive melter flows from the reactor into a flowing stream of quench water or high-velocity air which quickly freezes the melt and effectively disperses it into fibers or granules. In IGT's pilot-scale tests, the water-quencher effectively produced fibers from the melt. The fibers were readily crushed to the particle size required for blending with the final additive to produce the construction-grade cement product.

Fiberization techniques are well known in industry, however it appears that specific industries have developed their own proprietary processes. Fiberglass and mineral wool are produced utilizing existing fiberization techniques.

BENCH AND PILOT STUDY DATA

Several bench-scale studies have been conducted with the following contaminated materials using the Cement-Lock Technology.

- Dredged sediments from the Newtown Creek estuary in New York (NY/NJ Harbor)
- Dredged sediment from the Detroit River
- Contaminated building debris (concrete)
- Fly ash

Pilot-scale studies have also been conducted with the following contaminated materials using the Cement-Lock Technology.

- Dredged sediments from the Newtown Creek estuary in New York (NY/NJ Harbor)
- Hydrocarbon-contaminated soil
- Municipal solid waste

The harbor sediments are contaminated with polynuclear aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), pesticides, insecticides, chlorinated dioxins and furans, and heavy metals. The river sediments also contain similar contaminants. The concrete waste was spiked with oil and chromium.

The results of the laboratory- and pilot-scale test programs for evaluating the Cement-Lock Technology have been very favorable. The results obtained with the dredged estuarine sediments, dredged river sediment, and contaminated building debris (concrete) are summarized below.

- All hazardous organic contaminants, including oil and grease, PAHs, PCBs, pesticides, insecticides, chlorinated dioxins and furans, were destroyed to well below regulatory limits. The destruction of organic contaminants is shown in Table 1.
- All heavy metals were immobilized within the cement matrix. The construction-grade cement (the end product) passed the U.S. EPA TCLP (Toxicity Characteristic Leaching Procedure) test (Table 2). The leachability of metals is several orders of magnitude below regulatory limits.
- Samples of mortar were prepared from the cement product, sand, and water according to ASTM (American Society for Testing and Materials) C 109 procedures. The compressive strengths of these mortar samples were determined according to the ASTM procedure after 3, 7, and 28 days of curing (Table 3). The compressive strength tests were conducted by Construction Technology Laboratories, Inc. (CTL - the research arm of the Portland Cement Association, USA). The mortar produced from the cement product exceeded ASTM compressive strength requirements. It can replace portland cement for general construction applications.
- The process did not generate any secondary hazardous waste streams.

Table 1. Organic Contaminant Destruction Achieved With Different Waste Materials

Contaminant	Estuarine Sediment: Untreated Sediment	Estuarine Sediment: Cement Product	Estuarine Sediment: DRE*	River Sediment: Untreated Sediment	River Sediment: Cement Product	River Sediment: DRE	Concrete: Untreated Concrete	Concrete: Cement Product	Concrete: DRE
	----- mg/kg(dry) -----		-- % --	------- mg/kg(dry) -------		-- % --	------- mg/kg(dry) -------		-- % --
Oil & Grease	--	--	--	18,000	< D.L.**	> 99.99	5,000	< D.L.	> 99.9
SVOCs	370	0.22	99.93	51.2	< D.L.	99.99	--	--	--
	----- µg/kg(dry) -----			------- µg/kg(dry) -------			------- µg/kg(dry) -------		
PCBs	8,585	< D.L.	> 99.99	1,100	< D.L.	> 99.99	--	--	--
	----- ng/kg(dry) -----			------- ng/kg(dry) -------			------- ng/kg(dry) -------		
2,3,7,8-TCDD/TCDF	262	< D.L.	> 99.99	--	--	--	--	--	--
Total TCDD/F	2,871	< D.L.	> 99.99	--	--	--	--	--	--
Total PeCDD/F	4,363	< D.L.	> 99.99	--	--	--	--	--	--
Total Hx/Hp/OCDD/F	34,252	< D.L.	> 99.90	--	--	--	--	--	--

* Destruction and removal efficiency.
** Less than detection limit of the analytical procedure used.

Table 2. Metal Immobilization in Construction-Grade Cement Produced from Different Waste Materials

	Untreated Material			TCLP* Cement Produced From			
Metal	Estuarine Sediment	River Sediment	Concrete	Estuarine Sediment	River Sediment	Concrete	Regulatory Limit
	mg/kg (dry)			mg/L			
Arsenic	39	7.8	--	< 0.005**	< 0.01	--	5
Cadmium	27	9.5	--	< 0.001	< 0.002	--	1
Chromium	298	138	500	0.15	< 0.072	0.097	5
Copper	--	180	--	--	< 0.01	--	--
Lead	542	218	--	< 0.002	< 0.01	--	5
Mercury	2.9	0.55	--	< 0.0004	< 0.0004	--	0.2
Selenium	6.2	--	--	< 0.003	--	--	1
Silver	13	--	--	< 0.001	--	--	5

* Toxicity Characteristic Leaching Procedure.
** Less than the detection limit of the analytical procedure used.

Table 3. Compressive Strength of Construction-Grade Cement Produced From Different Waste Materials

Test Period	Cement-Lock Cement From: Estuarine Sediment Lab-Scale	Estuarine Sediment Pilot-Scale	River Sediment Lab-Scale	Concrete Lab-Scale	ASTM Requirements: Blended Cement C 595	Portland Cement C 150
Days	psi (MPa)					
3	1,950 (13.4)	2,230 (15.4)	2,245 (15.5)	2,530 (17.4)	1,890 (13.0)	1,740 (12.0)
7	2,730 (18.8)	2,885 (19.9)	2,910 (20.1)	3,370 (23.2)	2,900 (20.0)	2,760 (19.0)
28	4,620 (31.9)	5,270 (36.3)	4,600 (31.7)	5,475 (37.7)	3,480 (24.0)	4,060 (28.0)

- The pilot-plant data were consistent with the laboratory-scale data in terms of organic destruction, leachability, and the quality of the cement generated from the estuarine sediment.
- The total metal contents in the cement product from the Cement-Lock Technology are usually within the range of total metals found in ordinary portland cement.

These findings confirm that the final product from the Cement-Lock Technology meets all environmental requirements and the cement produced from this technology is of commercial quality.

DEMONSTRATION PROJECT

Following successful testing of the Cement-Lock Technology at the laboratory- and pilot-scale levels, a 30,000 cubic yard per year (yd^3/yr) capacity demonstration-scale plant is being constructed in the New York/New Jersey harbor area. The primary objective of this program is to demonstrate integrated operation of the Cement-Lock process while converting contaminated dredged estuarine sediment into construction-grade cement. The demonstration facility will be completely integrated with a ready-mix concrete plant that will utilize the cement produced from the plant. The demonstration will also confirm the environmental benefits of the technology through sustained operation; it will also demonstrate that the plant meets all the regulatory requirements and that no secondary waste streams are generated during processing, and the plant does not adversely impact the air quality in the surrounding neighborhood.

The rotary kiln melter for the demonstration-scale project was ordered from Andersen 2000 (Peachtree City, Georgia). The melter (Figure 2) is 10 feet in diameter and 30 feet long. The entire system consists of raw sediment storage bunker, hoppers for modifiers, screw conveyors for moving material to the melter, a pug mill for blending all of the feed materials before charging, the rotary kiln melter, quench/granulator, secondary combustion chamber, flue gas quench system, lime injection, bag house, and activated carbon adsorption system. Other equipment items, such as the Ecomelt grinder and construction-grade cement blender will be rented for the demonstration project.

Figure 2. Andersen 2000 Rotary Kiln Melter for the Cement-Lock™ Demonstration Project (Two kilns shown)

The demonstration plant will be capable of processing other materials including contaminated soils, petroleum refinery wastes, and various other industrial wastes. Also, with process enhancements and improvements, the capacity of the demonstration plant can be increased to 100,000 cubic yards per year.

Significant public input has already been incorporated into this project based on numerous public outreach meetings.

The next stage of Cement-Lock Technology development will be the construction of a commercial-scale plant having a treatment capacity of 500,000 cubic yards per year of contaminated sediments and wastes. Other opportunities are also being pursued with different clients in the U.S. and around the world.

CEMENT QUALITY

The cements produced from contaminated sediment, brownfield debris, and fly ash have been tested by the Construction Technology Laboratories (technical arm of the Portland Cement

Association, USA), a private cement manufacturing company, the State of New Jersey Department of Transportation, and another independent testing laboratory in New Jersey (on behalf of a private client). In all cases the cement product exceeded compressive strength requirements per ASTM C 150 standards; therefore, it can be used in general construction projects. The cement readily passed the EPA leachability test demonstrating that the heavy metals are locked within the cement matrix. Also, the total heavy metal contents in the cement product are within the range found in the conventional portland cement. Gaining market acceptance for Cement-Lock cement is expected to be straightforward for these reasons.

ECONOMICS

Process economics are extremely favorable. Revenues are derived from both ends of the process. Currently, tipping fees for dredged sediment in the NY/NJ Harbor are in the range of $35 to $50 per cubic yard. Tipping fees for other waste materials that can be directly co-processed with sediment in the Cement-Lock Technology range from $70 to $500 per ton of material. The construction-grade cement product commands a market price between $50 to $70 per ton. The processing cost is approximately $50 per ton. Therefore through waste co-processing, a full-scale plant has the potential for significantly reducing the cost for sediment treatment through offsetting costs. Equally important, the Cement-Lock Technology remediates the contaminated materials and demonstrates beneficial use for otherwise wasted materials.

CONCLUSIONS

The Cement-Lock Technology has been successfully demonstrated at the laboratory- and pilot-scale levels with various types of waste materials. A 30,000 cubic yard per year capacity plant is being constructed to demonstrate integrated operation of the technology at a larger scale. The demonstration facility will be completely integrated with a ready-mix concrete plant that will utilize the cement produced from the plant. Other opportunities are being pursued with different clients in the U.S. and around the world.

ACKNOWLEDGMENTS

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REFERENCE

Goyal, A. *et al.*, "Remediation and Beneficial Reuse of PCB-Containing Wastes Using the Cement-Lock Technology," Final report for the Gas Research Institute under preparation.