UNIVERSITI PUTRA MALAYSIA

THERMAL TREATMENT AND UTILISATION OF SEWAGE SLUDGE

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By

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DEDICATION

This work is dedicated to my father and mother

Abstract of thesis presented to the Senate of Universti Putra Malaysia in fulfilment of the requirements for the degree of Doctor of Philosophy

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Thermal process has become one of the major technologies for the treatment of sewage sludge to secure final products. The incinerated ash and molten slag as products of thermal treatment contain various types of heavy metals at high concentrations. Incineration and melting processes can reduce the sludge volume and stabilize the chemical compounds in the final product, which can be utilized beneficially as construction materials.

In this study, dewatered sewage sludge was examined to investigate its properties when subjected to different heat treatment processes, up to the temperature of 1550 8C, in terms of chemical, physical, and micro-structure properties, degree of stabilization and the possibility of utilizing the final products in different applications.

The study shows that the volume of dewatered sewage sludge reduces up to five times by the drying process, twenty times by the incineration process and fifty five times by the melting process. It was shown that heavy metals can be stabilized during the incineration process by conditioning the dried sludge with $CaCO_3$.

Heating temperature, holding time and cooling rate are the controlling parameters for the melting process, to produce different needed materials, in terms of chemical, physical, micro-structure and stability of the final products. Incinerated ash and molten slag show stable end products in terms of the leaching properties, and it is within the limit of Japanese regulation for soil environmental limit.

Incinerated ash and molten slag are shown to be very good products that can be utilized as alternatives to cement and sand in concrete. By replacing 5 percent of cement with incinerated ash, the compressive strength can be improved by 50 percent compared to the standard product for the period of 3 days by getting a compressive strength of 30.80 $N.mm^{-2}$. Similarly, by replacing a 50 percent of sand with molten slag, the compressive strength can be higher than the standard product for the period of 7 days with a compressive strength of 26.36

Abstrak yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

RAWATAN HABA DAN PENGGUNAAN ENAPAN BUANGAN

Oleh

ZIAD MAHMOUD ABU-KADDOURAH

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Proses haba telah menjadi salah satu teknologi utama untuk rawatan enapan buangan untuk mendepatkan produk akhir. Abu yang telah dibakar dari slag cairan sebagai hasil rawatan haba yang mengandungi pelbagai jenis logam berat pada kepekata yang tinggi. Proses-proses pembakaran dan pelupusan boleh mengurangkan isi pada enapan dan menstabilkan sebatian-sebatian kimia pada produk terakair yang boleh digunakan faedahya sebagai bahan-bahan penbinaan.

Dalam kejian ini, enapan buagan yang dicairkan telah diperhatikan untuk mengkaji sifat-sifatnya yang mana apabile dikenakan proses-proses rawatan haba sehingga 15508C, sebagai sifat-sifat kimia, fizikal, dan struktur mikro, tatap pensterilan dan kemungkinan menggunakan produk-produk akhir dalam pelbagai penggunaan.

Kajian ini telah menunjukkan bahawa isi pada bahan buangan yang tercair berkurangan sehingga lima kali ganda melalui proses pergeringan, dua puluh kali ganda menerusi proyes pelupusan dan lima puluh lima kali ganda melalui proses

peleburan logam-logam berat menujukkan ianya boleh distabilkan semase proses pelupusan secara “conditioning” enapan yang sudah kering bersama $CaCO_3$.

Suha memanas, masa menahan dari kadar perdinginan boleh digunakan sebagai pergawal-pergawal semasa proses melabur, untuk menghasilkan bahan-bahan berbeze yang diperlukan dari segi sifat-sifat kamia, fizikal, struktur mikro dan kestabilan produk-produk akhir. Abu yang telah dibakar dari slag tercair menunjukkan produk-produk akhir yang stabil dari segi kepekatan logam berat dalam “leachate”, dengan lebih stail untuk slag tercair.

Abu yang terbakar/terlupus dari “slag” tercair menunjukkan kemingkinan kuat digunakan sebagai gentian untuk simen dan pasir dlam konkrit. Dengan menggantikan 5 peratus simen dengan abu tersebut, kekuatan tekenan telah meningkat 50 peratus lebih daripada produk standard, dimana dengan menggantikan 50 peratus pasir dengan slag tercair, kekuatan tekenan adulah lebih tinggi daripada produk standard.

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LIST OF ABBREVIATIONS

AAC	Annual Average Treatment Cost
AD	Anaerobic Digestion
ADIC	Anaerobic Digestion Incineration System
ADMT	Anaerobic Digestion Melting System
Alite	Tricalcium silicate
Aluminate	Tricalcium aluminate
AS	Air-cooled Slag
ASTM	American Standard for Testing Material
Aver.	Average
Belite	Dicalcium silicate
b.p.	Boiling point
BS	British Standard
BSI	Backscattered Electron Imaging
CC	Construction Cost
CS	Scrubber With Condensation
DEMT	Direct Dewatering Melting System
DS t/a	Dried Sludge per annum
DTG	Differential Thermogravimetry
DW	Dewatering
DWIC	Direct Dewatering Incineration System
DWICMT	Direct Dewatering Ash Melting System
ESP	Electrostatic Precipitator
ESS	Electrostatic Scrubber
Ferrite	Tetracalcium alumioferrite
FF	Fabric Filter
Fin. Wt.	Final Weight
GC	Gas Treatment
GE	Gas Engine
GT	Gravity Thickening
HE	Heat Exchanger
HT	Heat Treatment
HTADMT	Thermal Pretreatment Anaerobic Digestion Melting System
HTIC	Heat Treatment Dewatering Incineration System
HTMT	Heat Treatment Dewatering Melting System
ICP	Inductively Coupled Plasma
ID	Indirect Drying
INC	Incineration
Ini. Wt	Initial Weight
JPA	Japanese Environmental Agency
KN	Kilo Newton
MT	Melting
MARDI	Malaysia Agricultural Research and Development Institute
m.p.	Melting point
n	Number of samples
n̲	Number of durable years
NA	Not Available
ND	Not Detected

N/mm^2	Newton per square millimetre
OC_K	Annual Operating and Maintenance Cost
ppb	part per billion
ppm	part per million
PS	Primary Raw Sludge
PWF	Current Price Coefficient
r	Correlation coefficient
rpm	round per minute
SEM	Scanning Electronic Microscope
TG	Thermogravimetry
TH	Mechanical Thickening
US.EPA	United State Environmental Pollution Agency
WAS	Waste Activated Sludge
WC	Water Content
WHB	Waste heat boiler
WS	Water Cooled Slag
XRD	X-ray Diffraction

CHAPTER 1

INTRODUCTION

1.1 Background

Sludge is the residual slurry of settleable solids from wastewater treatment plants. Its handling and disposal are of major environmental and economic concern. In recent decades, environmental issues have increasingly focused on sewage sludge treatment. As wastewater treatment standards have become more stringent, and with the widespread use of integrated sewage systems, the volume of sludge to be treated has increased and more stringent regulations have made its allowable disposal increasingly difficult.

Sewage sludges have been previously disposed by means of utilisation as fertilisers or "land filling" for conditioning of barren earth. However, more effective measures for the disposal of sewage sludge need to be implemented as the use of chemical fertilisers is more preferred in farming than organic fertilisers. This is further compounded by the difficulty in securing reclaimed land in large city areas and protecting it from the secondary environmental pollution, and leachability of wastes to groundwater table if it is disposed in sanitary landfills.

Instead of simply treating and disposing sewage sludge, other options should be considered to utilise sewage sludge as reusable materials. Burning and melting sewage sludge result in solidified and stabilised final products, which in turn help in utilising the final products in different applications such as construction and building materials (Hiraoka, 1994; Nagaharu et al., 1997; TSK, 1995.A; and Tsunemi and Sasaki, 1984).

Previous studies have presented full scale plants with operation procedures including a general specification and advantages of the treatment processes they used, which mainly consist of treatment methods, treating temperature, degree of stabilisation, chemical and physical properties of the final products (Hisashi et al., 1997; Kazunori et al., 1997; and TSK, 1995.A). Some other works have compared different treatment processes and the properties of the final products (Oku et al., 1990 and Tsunemi and Sasaki, 1984).

Even though full scale plants are being built by some companies, there is still a lack of understanding related to the control parameters namely, heating temperature, cooling rate and holding time, which are the main parameters affecting the quality and the stability of the end products (Bolton, 1996). There are some published works on the thermal treatment of sewage sludge but details on temperature control and cooling are still not clear.

By understanding these controlling parameters and how they affect the properties of the final products, a better, higher quality and safe end products can be produced from sewage sludge.

Incinerated ash and molten slag contain various types of heavy metals in high concentrations. Some heavy metals do not evaporate on incineration and melting despite their high volatility (Masaki et al., 1997 and Vogg et al., 1986).