

**SLUDGE DEWATERING AND DRYING USING  
MICROWAVE HEATING**

**By**

**WISSAM N OMAR**

**Thesis Submitted to the School of Graduate Studies, Universiti  
Putra Malaysia, in Fulfillment of the Requirements for  
Degree of Master of Science**

**January 2004**

بسم الله الرحمن الرحيم

قل إن صلاتي ونسكي ومحياي ومماتي

لله رب العالمين

Abstract of the thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Master of Science

**SLUDGE DEWATERING AND DRYING USING  
MICROWAVE HEATING**

**By**

**WISSAM N OMAR**

**December 2003**

**Chairman: Pprofessor Azni Idris, Ph.D.**

**Faculty: Engineering**

Industrial and domestic activities produce large quantities of residual sludge. Nowadays a wide reduction of these waste volumes is necessary. Drying of the sludge which reduces its volume and mass is an important aspect for sludge management. The mechanical dewatering by pressure filters or centrifuges is not always sufficient to satisfy new environmental regulations and a thermal drying step is often needed. Microwaves are electromagnetic waves whose frequency ranges lie between that of radio waves and infrared radiation. Microwave is of rapid, volumetric and selective heating source. This study describes the evaluation of the possible use of microwave heating as a new sludge thermal treatment technology and faster sludge drying and dewatering technique.

In this study, a domestic microwave oven was modified and converted into batch microwave oven with continuous weight and temperature measurement. Four different types of sludge were microwave dried under different operating conditions to investigate the microwave potential in drying domestic, agriculture, and chemical sludge.

The study shows that microwave drying is more efficient than convective drying up to about 20 to 36 times and ohmic heating up to 2.5 times depends on the sludge type. Microwave is still slow and not efficient at final stage of drying or at low residual moisture content. Agriculture sludge (Palm Oil sludge) was dried faster than other types under microwave energy.

Volume of sewage and palm oil sludge reduces up to five times by the conventional drying process, eight times by the microwave drying process and eleven times by the incineration process.

Microwave treatment shows more stable end product than dried sludge but less than incinerated ash in terms of the leaching properties, and it is less than the maximum limits stated by US EPA for disposal of waste to landfill.

Finally, the effect of the sludge type on the gas emissions during microwave drying was investigated. Gas emissions fluctuate during microwave treatment of sludge. CO<sub>2</sub> and SO<sub>2</sub> emissions increase at the end of the microwave drying process due to the increase in the temperature and the burning of the dry sludge powder.

Abstrak tesis dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

**POTENSI DARIPADA PEMANASAN GELOMBANG MIKRO UNTUK  
PENGURANGAN AIR DAN PENGERINGAN LUMPUR SISA**

**Oleh**

**WISSAM N OMAR**

**December 2003**

**Pengerusi:     Profesor Azni Idris, Ph.D.**

**Fakulti:       Kejuruteraan**

Aktiviti industri dan tempatan menghasilkan lumpur sisa yang besar. Pada masa sekarang ini pengurangan isipadu daripada lumpur sisa adalah diperlukan. Pengeringan lumpur sisa untuk mengurangi isipadu dan jisim adalah penting dalam pengurusan lumpur sisa. Pengurangan air dengan penyaring bertekanan atau penggempar tidak selalu sesuai dengan peraturan alam sekitar, oleh karena itu pengeringan secara pemanasan adalah diperlukan.

Gelombang mikro adalah gelombang elektromagnetik yang mempunyai julat diantara gelombang radio dan pancaran infra merah. Kajian ini bertujuan untuk menilia mengevaluasi kemungkinan penggunaan gelombang mikro sebagai teknologi rawatan panas, pengeringan dan pengurangan daripada lumpur sisa.

Kajian ini menggunakan pemanas gelombang mikro (ketuhar) tempatan. Empat jenis lumpur sisa yang berbeza dikeringkan dengan gelombang mikro dengan keadaan operasi yang berbeza untuk mengetahui potensi gelombang mikro sebagai pengering tempatan, pertanian dan sisa bahan kimia.

Hasil kajian ini menunjukkan bahawa pengeringan dengan gelombang mikro lebih efisien daripada pengeringan secara “perolakan sehingga” sampai 20-36 kali, bergantung kepada jenis lumpur sisa. Lumpur sisa hasil pertanian (kelapa sawit) lebih cepat kering daripada jenis lumpur sisa yang lain. Isipadu daripada kotoran dan lumpur sisa kelapa sawit berkurang sehingga 5 kali dengan proses pengeringan gelombang mikro dan 11 kali dengan proses pembakaran.

Rawatan gelombang mikro menunjukkan hasil akhir yang lebih stabil daripada pengeringan dan lebih rendah daripada pembakaran dari segi ‘leaching properties’ dan juga lebih rendah daripada patas maksimum yang ditetapkan oleh US EPA untuk bahan sisa yang akan dibuang ke tanah.

Pengaruh daripada jenis lumpur sisa terhadap rawatan pengeluwan gas juga diselidiki. Pangeluwan gas didapati berubah-ubah selama rawatan lumpur sisa dengan gelombang mikro. Gas CO<sub>2</sub> dan SO<sub>2</sub> meningkat pada akhir proses pengeringan kerana disebabkan oleh meningkatnya suhu pembakaran tepung lupur sisa .

## **ACKNOWLEDGEMENTS**

First of all, Alhamdulillah for giving me the strength, patience, courage, and determination in completing this work.

I am very thankful to my supervisor Associate Professor Azni Idris, for his helpful guidance and suggestions. His continuous encouragement was essential in completing this work. I also appreciate all the cooperation and suggestions from the committee members, Professor Kaida khalid and Associate Professor Dr. Saari Mustapha. Thanks to every person who supported me to complete this work.

I would like to thank my lovely wife for offering her full support and encouragement during my research. Not forgetting my parents and whole my family in Iraq for their helps and encouragements.

I am very grateful to the Faculty of Engineering for offering all the facilities. Lastly, I would like to record special thanks for the Malaysian government for supporting this project under IRPA grant.

**WISSAM N OMAR**

**January 2004**

I certify that an Examination Committee met on date of viva to conduct the final examination of Wissam N Omar on his Master of Science thesis entitled “Sludge Dewatering and Drying Using Microwave Heating” in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

**Tan Ka Kheng, Ph.D.**  
Faculty of Engineering  
University Putra Malaysia  
(Chairman)

**Thomas Choong Shean Yaw , Ph.D.**  
Faculty of Engineering  
University Putra Malaysia  
(Member)

**Chuah Teong Guan, Ph.D.**  
Faculty of Engineering  
University Putra Malaysia  
(Member)

---

**GULAM RASUL RAHMAT ALI, Ph.D.**  
Professor/Deputy Dean,  
School of Graduate Studies  
Universiti Putra Malaysia.

**Date:**



This thesis submitted to the Senate of Universiti Putra Malaysia has been accepted as fulfillment of the requirement for the degree of Master of Science. The members of the Supervisory Committee are of follows:

**Azni Idris, Ph.D.**

Professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Chairman)

**Kaida Khalid, Ph.D.**

Professor  
Faculty of Science & Environmental Studies  
Universiti Putra Malaysia  
(Member)

**Saari Mustapha, Ph.D.**

Associate professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Member)

---

**AINI IDERIS, Ph.D.**

Professor/Dean,  
School of Graduate Studies  
Universiti Putra Malaysia.

**Date:**

## **DECLARATION**

I hereby declare that the thesis is based on my original work for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

---

**WISSAM N OMAR**

**Date:**

## TABLE OF CONTENTS

<b>ABSTRACT</b>	iii
<b>ABSTRAK</b>	v
<b>ACKNOWLEDGEMENTS</b>	vii
<b>APPROVAL</b>	viii
<b>DECLARATION</b>	x
<b>TABLE OF CONTENTS</b>	xi
<b>LIST OF TABLES</b>	xiv
<b>LIST OF FIGURES</b>	xv
<b>LIST OF ABBREVIATIONS</b>	xx

### CHAPTER

<b>1</b>	<b>INTRODUCTION</b>	<b>1.1</b>
	1.1 Background	1.1
	1.2 Objectives of the Study	1.4
	1.3 Scope of the Study	1.5
	1.5 Thesis Organization	1.6
<b>2</b>	<b>LITERATURE REVIEW</b>	<b>2.1</b>
	2.1 Introduction	2.1
	2.2 Wastewater Treatment	2.1
	2.2.1 Wastewater Treatment Plant	2.2
	2.3 Types of Sludge	2.5
	2.4 Sludge Characterization	2.6
	2.3 Processing of Sewage Sludge	2.7
	2.3.1 Stabilization	2.8
	2.3.2 Dewatering	2.10
	2.3.3 Air Drying Processes	2.11
	2.3.4 Mechanical Dewatering System	2.13
	2.4 Thermal Processing of Sludge	2.14
	2.4.1 Incineration	2.14
	2.4.2 Pyrolysis	2.15
	2.5 Microwave Fundamentals	2.16
	2.5.1 A Brief History of Microwave	2.16
	2.6 Microwave Heating	2.18
	2.6.1 Benefits of Microwave heating	2.19
	2.6.2 Microwave Heating Applications	2.21
	2.7 Basics of Microwave	2.25
	2.7.1 Polarization of Dielectric	2.27
	2.7.2 Dielectric Properties	2.30
	2.8 Microwave Oven and Power Measurements	2.33
	2.9 Water Content Measurements	2.37

2.10	Microwave drying literature	2.38
<b>3</b>	<b>MATERIALS AND METHODS</b>	<b>3.1</b>
3.1	Collection of Samples	3.1
3.2	Characterizations of raw Sludge	3.3
3.2.1	Moisture Content	3.3
3.2.2	Specific Gravity	3.4
3.2.3	Ash Content	3.5
3.2.4	C, H, N, S Contents	3.6
3.2.5	pH Test	3.7
3.2.6	Specific Heat	3.8
3.2.7	Dielectric Measurements from 0.2 to 20 GHz (Microwave Frequency)	3.9
3.3	Experimental Design	3.11
3.3.1	Modification of the House-hold Microwave Oven	3.12
3.3.2	Power Measurement	3.20
3.3.3	Microwave Drying Experiments	3.21
3.4	High Temperature Sludge Melting Process	3.22
3.5	Heavy Metals Analysis	3.24
3.5.1	Leaching test	3.25
3.5.2	Metals Analysis by Atomic Absorption or ICP Spectrometry	3.27
3.6	Air emission Studies	3.28
3.7	Theoretical Analysis of Microwave drying Process	3.30
<b>4</b>	<b>RESULTS AND DISCUSSION</b>	<b>4.1</b>
4.1	Introduction	4.1
4.2	Characteristic of Sludge	4.1
4.2.1	Physical and Chemical Properties of Sludge	4.1
4.2.2	Dielectric properties	4.2
4.2.2.1	Variation of Dielectric Properties with respect to Frequency	4.3
4.2.2.2	Variation of Dielectric Properties with respect to Temperature	4.6
4.3	Microwave drying Experiments	4.10
4.3.1	Measurements of Relative Microwave power Distribution	4.10
4.3.2	Microwave drying Characteristic of sludge	4.13
4.3.2.1	Variation of residual Moisture Content versus time	4.15
4.3.2.2	Comparison between conventional & Microwave drying Characteristic of sludge	4.23
4.3.2.3	Variation of drying rate with Residual Moisture Content	4.26
4.3.2.4	Estimation of Volumetric Heating rates	4.30
4.3.2.5	Temperature Variation with Drying Time	4.33
4.3.2.6	Comparison between Theoretical & Experimental Microwave drying Curves for Silica Sludge	4.35

4.4	Volume and Weight Reduction	4.38
4.5	Leachability of Heavy Metals	4.46
4.6	Air emission Study	4.51
<b>5</b>	<b>CONCLUSIONS AND FUTURE WORKS</b>	<b>5.1</b>
5.1	Conclusions	5.1
5.2	Recommendations	5.3
	<b>REFERENCES</b>	<b>R.1</b>
	<b>APPENDICES</b>	<b>A.1</b>
	<b>VITA</b>	<b>V.1</b>