

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	DECLARATION	ii
	DEDICATION	iv
	ACKNOWLEDGEMENT	v
	ABSTRACT	vi
	ABSTRAK	vii
	TABLE OF CONTENTS	viii
	LIST OF TABLES	xiii
	LIST OF FIGURES	xv
	LIST OF ABBREVIATIONS	xviii
	LIST OF SYMBOLS	xxi
	LIST OF APPENDICES	xxii
1	INTRODUCTION	
1.1	General Introduction	1
1.2	Problem Statement	4
1.3	Objectives of Research	5
1.4	Scope of Research	6
1.5	Significance of Research	7

2	LITERATURE REVIEW	
2.1	Hazardous Waste Management	8
2.1.1	Classification of Hazardous Waste	8
2.1.2	Hazardous Waste Regulation and Management in Malaysia	10
2.2	Heavy Metals	13
2.2.1	Heavy Metals In Raw Untreated Water	15
2.3	Drinking Water Treatment Processes	15
2.3.1	Coagulation, Flocculation and Sedimentation Process	16
2.3.2	Filtration Process	17
2.3.3	Disinfection and Water Storage	17
2.4	Alum Derived Water Treatment Sludge (WTS)	17
2.4.1	Removal of Hazardous Contaminants by Alum	19
2.4.2	Reuse of Water Treatment sludge (WTS)	21
2.5	Characterization of WTS	22
2.5.1	Methods of Physicochemical Characterization	23
2.6	Stabilization/solidification (S/S) of WTS in Portland Cement	24
2.6.1	Portland Cement S/S	26
2.6.2	Leaching Tests	26
3	EXPERIMENTAL	
3.1	Chemicals and Instruments	30
3.2	Sampling and Preparation of River Water and WTS	31
3.3	Preparation of Metal and Coagulant Solutions	36
3.3.1	Preparation of Metal Solutions	36

3.3.2	Preparation of Alum and PAC Solutions	37
3.4	Determination of Optimum pH for Heavy Metal Removal by Coagulation using Alum and PAC	37
3.5	Preparation of Artificial Water Treatment Sludge (ATS)	38
3.6	Determination of Metal Leaching from Alum Sludge	39
3.7	Construction and Testing of Stabilization/ Solidified (S/S) Cement Mortar-Water Treatment Sludge (CMWTS)	39
3.7.1	Preparation of the CMWTS Bricks	40
3.7.2	Compressive Strength Test on CMWTS Bricks	42
3.8	Leaching Test on CMWTS Bricks	43
3.8.1	Leach Test on Whole CMWTS Brick	43
3.8.2	Leach Test on Powdered CMWTS Brick Material	44
3.9	Characterization of Sludge and S/S Samples	44
3.9.1	Determination of Functional Groups by Fourier transformed infrared spectroscopy (FTIR)	45
3.9.2	Total Organic Carbon (TOC) Analysis	45
3.9.3	Microstructural Analysis	46
3.9.4	Determination of Elemental Composition Using XRD	46
3.9.5	Thermal Analysis of Samples	47
3.9.6	Determination of Surface Area using Branauer-Emmet-Teller (BET) N ₂ adsorption	47
3.9.7	Determination of Moisture and Total Solids	49
3.9.8	Determination of pH	50
3.9.9	Determination of bulk density (ρ_b)	50
3.9.10	Determination of particle density (ρ_s)	51
3.9.11	Determination of Total Porosity (ϵ)	51

3.9.12 Determination of Heavy Metals Using AAS	52
--	----

52

RESULTS AND DISCUSSION

4	4.1	Introduction	
	4.2	Optimum pH for the Removal of Heavy Metal by Coagulation using Alum and PAC	54
	4.3	Sludge Generation at Optimum pH	59
	4.3.1	Heavy Metal Content of River Water Sample	59
	4.3.2	Mass and Characteristics of Artificial Sludge (ATS) Generated by Simulation	60
	4.4	Leachability of Heavy Metals from Artificial Sludge and Water Treatment Sludge	62
	4.4.1	Effect of pH on Heavy Metal Leachability from Artificial Sludge	62
	4.4.2	Effect of pH on Heavy Metal Leachability from Water Treatment Sludge (WTS)	66
	4.5	Characterization of WTS	69
	4.5.1	Physicochemical Properties and Chemical Composition of WTS	69
	4.6	Characterization of CMWTS	73
	4.6.1	Chemical Composition of CMWTS	74
	4.6.2	Physicochemical Properties of CMWTS	75
	4.7	The Effect of Curing on pH of CMWTS	80
	4.8	Leaching of Metals from CMWTS Bricks	82
	4.9	Leaching of Metals from CMWTS Powder	85
	4.10	Compressive Strengths of CMWTS Blocks	86

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions 90

5.2 Recommendations 94

REFERENCES 96

APPENDICES 104

LIST OF TABLES

TABLE NO.	TITLE	PAGE
2.1	Sources of heavy metals	14
2.2	Guidelines for disposal of scheduled waste directly to the Kualiti Alam Landfill	18
3.1	Concentrations of metal standard solutions	36
3.2	Feed concentrations of heavy metals	38
3.3	Components of CMWTS brick samples	41
4.1	Heavy metal content of raw river water and spiked river water	59
4.2	Characteristics of sludge generated using Alum and PAC at various pH conditions	60
4.3	Effect of pH on leachability of heavy metal ions from AAIS	63
4.4	Effect of pH on leachability of heavy metal ions from APS	63
4.5	Effect of pH on leachability of heavy metal ions from AAIPS	64
4.6	Concentration of heavy metal ions leached out from WTS by various types of eluent	67
4.7	Heavy metals composition of WTS	69
4.8	Physical properties of WTS	70
4.9	Thermogravimetry data for WTS	73
4.10	Heavy metals compositions of CMWTS samples	74
4.11	Thermogravimetry data for CM and CMWTS	79
4.12	pH of solutions containing CM and CMWTS	81

4.13	Concentration of metals in the curing solutions containing CM and CMWTS bricks	83
4.14	Concentration of metals in the curing solutions containing CM and CMWTS powder	85
4.15	Compressive strength data of CM and CMWTS bricks	88

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
1.1	Generation and treatment steps for WTS in a water treatment plant.	2
2.1	Production and disposal of 'drinking water sludge' in a typical water processing flow of a water treatment plant	16
2.2	Metal hydroxide solubility curve	20
3.1	Photographic view of river water sampling location	31
3.2	Location of water sampling along the Johor River.	32
3.3	The surroundings near to sampling point	33
3.4	Photographic view of a WTS storage lagoon, Semangar Water Treatment Plant, Johor	34
3.5	(a) Wet natural water treatment sludge (WTS) and (b) dry natural water treatment sludge (WTS) [Drying condition: Air dried for 24 hours and oven dried until constant weight at 100°C]	35
3.6	(a) Brick mould (b) Dimensions of the CMWTS	40
3.7	(a) Mortar bricks in the mould, (b) and (c) Mortar bricks were removed from mould and (d) Image of mortar bricks before curing process [Re-moulding process of the mortar bricks after 24 hours of casting]	42
3.8	Compressive strength tester	43
4.1	Removal of Al, Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn by Alum at pH 2 to 12 [Temp: ~25°C, Coagulant: 30 ppm Alum]	55
4.2	Removal of Al, Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn by PAC at pH 2 to 12 [Temp: ~25°C, Coagulant: 15 ppm PAC]	55
4.3	Solubility test on metals at pH 2 to 12	56

4.4	Percentage of metal ions removed from solution by Alum and PAC at pH 8 and pH 10.	58
4.5	Effect of pH on mass of sludge generated using Alum and PAC	61
4.6	Leachability profile of metal ions from AAIS using various eluents [50 mL eluent, 0.5 g sludge, 1 hr, 24°C]	64
4.7	Leachability profile of metal ions from APS using various eluents [50 mL eluent, 0.5 g sludge, 1 hr, 24°C]	65
4.8	Leachability profile of metal ions from AAIPS using various eluents [50 mL eluent, 0.5 g sludge, 1 hr, 24°C]	65
4.9	Leachability profile of metals from WTS using various eluents	67
4.10	The FTIR spectrum for WTS	71
4.11	Morphological structure of WTS determined using (a) SEM, (b) FESEM and (c) XRD	72
4.12	TGA Thermogram of WTS	73
4.13	Metal Compositions of CM, WTS and CMWTS [Note: CMWTS1, CMWTS2 and CMWTS3 contains 5%, 10% and 20% WTS, respectively.]	75
4.14	Comparison of the FTIR spectra of WTS, CM and CMWTS [Note: CMWTS1, CMWTS2 and CMWTS3 contains 5%, 10% and 20% WTS, respectively.]	76
4.15	Microscopic observation on the development of (a) CM, (b) CMWTS1 (c) CMWTS2 and (d) CMWTS3 [Note: CMWTS1, CMWTS2 and CMWTS3 contains 5%, 10% and 20% WTS, respectively.]	77
4.16	Diffractiongram of CM and CMWTS [Note: CMWTS1, CMWTS2 and CMWTS3 contains 5%, 10% and 20% WTS, respectively.]	78
4.17	Thermograms of CM and CMWTS [Note: CMWTS1, CMWTS2 and CMWTS3 contains 5%, 10% and 20% WTS, respectively.]	79
4.18	The effect of curing solution and curing time on pH of CM and CMWTS samples	81

4.19	The effect of curing time and curing solution on leachability of metals from CM and CMWTS brick samples [Note: CMWTS1, CMWTS2 and CMWTS3 contains 5%, 10% and 20% WTS, respectively.]	84
4.20	The effect of curing time and curing solution on leachability of metals from CM and CMWTS powder samples [Note: CMWTS1, CMWTS2 and CMWTS3 contains 5%, 10% and 20% WTS, respectively.]	87
4.21	Compression strength of bricks as a function of amount of WTS added and pH. [Note: CMWTS1, CMWTS2 and CMWTS3 contains 5%, 10% and 20% WTS, respectively.]	88

LIST OF ABBREVIATIONS

AAIPS	-	Artificial alum- PAC sludge
AAIS	-	Artificial alum sludge
Al	-	Aluminium
Al (NO ₃) ₃ .9H ₂ O	-	Aluminium nitrate
Al ₂ (SO ₄) ₃ .18H ₂ O	-	Aluminium sulphate
APS	-	Artificial PAC sludge
ASTM	-	American society for testing and materials extraction
ATS	-	Artificial water treatment sludge
Cd	-	Cadmium
Cd (NO ₃) ₂ .4H ₂ O	-	Cadmium nitrate
CH ₃ COOH	-	Acetic acid
Cr	-	Chromium
Cr (NO ₃) ₃ .9H ₂ O	-	Chromium (III) nitrate
CMWTS	-	Cement mortar-water treatment sludge
Cu	-	Copper
Cu (NO ₃) ₂ .3H ₂ O	-	Copper (II) nitrate
DDDW	-	Double distill deionized water
DOE	-	Department of environment
EPX	-	Extraction procedure toxicity
FAAS	-	Flame atomic absorption spectrophotometer
Fe	-	Iron
Fe (NO ₃) ₃ .9H ₂ O	-	Iron (III) nitrate

FESEM	-	Field emission scanning electron microscope
FT-IR	-	Fourier transform infrared spectroscopy
HCl	-	Hydrochloric acid
ICP-MS	-	Inductively coupled plasma-mass spectrometry
MEP	-	Multiple extraction procedure
Mn	-	Manganese
Mn (NO ₃) ₂ .4H ₂ O	-	Manganese (II) nitrate
N ₂	-	Nitrogen
NaOH	-	Sodium hydroxide
ND	-	Not detectable
NH ₄ OH	-	Ammonium hydroxide
Ni	-	Nickel
Ni (NO ₃) ₂ .6H ₂ O	-	Nickel (II) nitrate
PAC	-	Polyaluminium chloride
Pb	-	Lead
Pb ₃ (NO ₃) ₂	-	Lead (II) nitrate
OPC	-	Ordinary Portland cement
S/S	-	Stabilization/solidification
SAJ	-	Syarikat Air Johor
<i>S_{BET}</i>	-	Branauer-Emmet-Teller surface area
SEM	-	Scanning electron microscope
SPLP	-	Synthetic precipitation leaching procedure
SW	-	Scheduled waste
TCLP	-	Toxicity characteristic leaching procedure
TGA	-	Thermal gravimetric analysis
TOC	-	Total organic carbon

USEPA	-	United States environmental protection agency
WET	-	Waste extraction test
WTS	-	Water treatment sludge
XRD	-	X-ray diffraction
Zn	-	Zinc
Zn (NO ₃) ₂ · 6H ₂ O	-	Zinc nitrate

LIST OF SYMBOLS

mg /L	-	Milligrams per litre
M	-	Molar
ppm	-	Parts per million
ρ_b	-	Bulk density
ε	-	Porosity
ρ_s	-	Particle density

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	EPA listed wastes	104
B	Publications	107
C	Presentations	108
D	Bulk density, particle density and porosity of WTS	109
E	Heavy metals compositions in WTS	110
F	Moisture and ash content of WTS	111
G	Total organic carbon of WTS	112