LEACHING CHARACTERISTIC OF RED GYPSUM UNDER COLUMN AND OEDOMETRIC CONDITIONS

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I hereby declare that the work in this thesis is based on my original work except 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 Universiti Malaysia Pahang or any other institutions.

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ABSTRACT

Red gypsum (RG) is a by-product produced during the extraction of titanium dioxide (TiO_2) from ilmenite ores. Unregulated and rampant disposal activity of RG might be an issued due to waste gypsum arising from chemical industry or power plant annually without being utilize. The leachability of heavy metals of this waste will be leach into the soil groundwater. The main objective of this study is to determine the leaching characteristics of RG under Column and Oedometric conditions and comparing the concentration of elements with Toxicity Characteristic Leaching Procedure (TCLP), Total Threshold Limit Concentration (TTLC) and Drinking Water Quality Standards (NDWQS). The concentrations and types of heavy metals were analyzed using the Inductively Coupled Plasma Mass Spectrometry (ICP-MS) method. Experimental results demonstrated that only a few of the major elements that are traced from both leaching tests carried out by Column leaching test and Oedometer leaching test such as Mg, Ca, Na, Al and K. The highest concentration of major element is Mg (129.5 mg/L). In addition, some of heavy metals produced are Mn, Ni, Cu, Zn and Pb. The highest concentration of these five heavy metals is Zn (0.031 mg/L). However, the value of this concentration still does not exceed the limits provides in TTLC and NDWQS with the value of 5000 mg/L and 3 mg/L respectively. The results recorded element concentration under Column leaching test were higher than Oedometer leaching test. Overall, all element concentrations of RG were found to all relevant consideration standards of TCLP, TTLC and NDWQS as the elements that leach out were found to be less than allowable limits.

ABSTRAK

Gipsum Merah adalah merupakan sisa daripada proses pengekstratan titanium dioksida (TiO_2) dari bijih ilmenit. Di Malaysia, lebih daripada 1000000 ton setahun gipsum merah terhasil. Justeru, aktiviti longgokan RG di tapak pelupusan terkawal semakin berleluasa disebabkan oleh peningkatan sisa gypsum daripada industri kimia dan jana kuasa tanpa dikitar semula. Oleh itu, keterlarutan sisa ini akan diserap masuk ke dalam tanah apabila berlakunya hujan di tapak-tapak pelupusan tersebut. Objektif utama kajian ini dijalankan adalah untuk mengkaji ciri-ciri larutan sisa RG yang mengandungi beberapa logam berat di dalamnya samada menepati piawaian yang ditetapkan oleh Prosedur Penyulingan Ciri Ketoksikan (TCLP), Jumlah Kepekatan Had Ambang (TTLC) dan Piawai Kualiti Air Minuman (NDWQS) melalui ujikaji Larutan Lajur dan ujikaji Larutan Penyatuan. Kepekatan dan jenis logam berat dianalisa menggunakan kaedah Spektrometri Jisim Plasma yang digabungkan secara Induktif (ICP-MS). Keputusan ujikaji menunjukkan hanya beberapa jenis elemen utama yang terhasil daripada kedua-dua kaedah ujikaji yang dijalankan melaui ujikaji Larutan Lajur dan ujikaji Larutan Penyatuan seperti Mg, Ca, Na, Al dan K. Selain itu, antara logam berat yang terhasil adalah seperti Mn, Ni, Cu, Zn dan Pb. Namun, nilai kepekatan yang tertinggi antara kelima-lima logam berat tersebut adalah Zn (0.031 mg/L). Walaubagaimanapun, nilai kepekatan ini masih tidak melebihi had yang ditetapkan di dalam TTLC dan NDWQS iaitu masing-masing dengan nilai 5000 mg/L dan 3 mg/L. Kajian ini juga menunjukkan keputusan kepekatan logam berat dan elemen utama adalah lebih tinggi di dalam ujikaji Larutan Lajur berbanding ujikaji Larutan Penyatuan. Secara keseluruhan, keputusan kepekatan elemen-elemen gipsum merah adalah mematuhi semua piawaian yang dirujuk iaitu TCLP, TTLC dan NDWQS yang mana kesemua nilai kepekatannya adalah tidak melebihi had yang dibenarkan.

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LIST OF SYMBOLS

°C	Degree Celsius
%	Percent
Mv	Coefficient of volume change
Cv	Coefficient of consolidation
Cα	Coefficient of secondary compression
Cc	Compression index
Cs	Swell index
Cu	Undrained Shear Strength
Na	Sodium
Mg	Magnesium
Al	Aluminium
Ca	Calcium
K	Potassium
Cr	Chromium
Mn	Manganese
Fe	Iron
Co	Cobalt
Ni	Nickel
Cu	Copper
Zn	Zinc
As	Arsenic
Mo	Molybdenum
Cd	Cadmium
Ba	Barium
B	Boron
P	Phosphorus
Pb	Lead
Si	Silicon
Al_2O_3	Aluminium(III) Oxide
SiO_2	Silicon Dioxide
SO_3	Sulfur Trioxide

CaO	Calcium Oxide
TiO_2	Titanium Dioxide
V_2O_5	Vanadium(V) Oxide
Cr_2O_3	Chromium(III) Oxide
MnO	Manganese Oxide
Fe_2O_3	Iron(III) Oxide / Ferric Oxide
CuO	Copper(II) Oxide
ZnO	Zinc Oxide
SrO	Strontium Oxide
ZrO_2	Zirconium(II) Oxide
RuO_2	Ruthenium(II) Oxide
Re_2O_7	Rhenium(VII) Oxide
HgO	Mercury(II) Oxide
$CaCO_3$	Calcium Carbonate
$FeCO_3$	Iron Carbonate
CO_2	Carbon Dioxide
$CaSO_4$	Calcium Sulphate
$TiOSO_4$	Titanyl Sulphate
$FeSO_4$	Iron Sulphate

LIST OF ABBREVIATIONS

ASTM	American Society for Testing Material
BS	British Standard
CBR	Californian Bearing Ratio
CEC	Cation Exchange Capacity
DOE	Department of Environment
GGBS	Ground Granulated Blast furnace Slag
ICP-MS	Inductively Coupled Plasma Mass Spectrometry
LL	Liquid Limit
MPW	Mineral Processing Waste
NDWQS	National Drinking Water Quality Standard
PDF	Permanent Disposal Facility
PL	Plastic Limit
SL	Shrinkage Limit
SW	Schedule Waste
TCLP	Toxicity Characteristic Leaching Procedure
TTLC	Total Threshold Limit Concentration
XRD	X-Ray diffraction
XRF	X-Ray fluorescence

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Red gypsum (RG) is a by-product during the extraction of titanium dioxide (TiO_2) from the ilmenite ores (Kamarudin and Zakaria, 2007; Azdarpour et al., 2014; Azdarpour et al., 2015a; Azdarpour et al., 2015b; Azdarpour et al., 2015c Azdarpour et al., 2017; Mahazam and Azmi, 2016; and Fauziah et al., 1996). The red colour of this waste product is due the presence of iron (Fauziah et al., 1996). In Malaysia, RG produced is more than 1000000 tonnes annually and generate a large amount of volume (Sidek et al., 2017). Most of this waste is dumped in secured landfills without being utilized (Sidek et al., 2017). With the current trend of production, eventually there will be a new application from RG waste generator to build an additional landfill to cater the growing demands of its RG waste handling.

Malaysia is considered one of the major RG producers in the world (Azdapour et al., 2015b). In recent years, a lot of research have been come out to determine the applicability of RG. By using RG in an effective way, landfill problem can be reduced as well as make benefit on it. For example, utilizing RG in cement brick manufacturing can reduce the piling of RG at landfills significantly (Sidek et al., 2007). According to Ahmad et al., (2012), gypseous soils are usually stiff in their dry state due to the cementing action provided by gypsum, but great loss of strength and pronounced increase in compressibility occur when gypsum is dissolved by partial or full saturation. This problem becomes more severe when the water flows through such soils causing loss of mass due to the leaching of gypsum.

An assessment of the leachability of toxic substances from contaminated soils is crucial for evaluating their environmental impact on soil and groundwater. Leaching test

are commonly used to assess the leaching potential of toxic substances and understand the leaching behaviour. Several standards of Column Leaching tests (ISO/CD 21268-3, 2017; DIN 19528, 2009; USEPA Method 1314, 2013) enable contact between contaminated soil and flowing leachant and used to indicate the leaching behaviour of target substance under simulated field conditions. Column tests are well-suited to determining the concentrations of constituents that can be released over a relatively small number of pore volumes, which corresponds to shorter time periods and desorption or dissolution rates of contaminants from various materials (Manoj et al., 2015).

In this study, the leaching characteristic of RG will be tests under Column and Oedometer conditions and compare with the Toxicity Characteristic Leaching Procedure (TCLP), Total Threshold Limit Concentration (TTLC) and National Drinking Water Quality Standard (NDWQS). The TCLP is designed to determine the mobility of both organic and inorganic analytes present in liquid, solid, and multiphasic wastes (TCLP Method 1311, 1992). While, TTLC is an analysis to determine the total concentration of each target analyte in a sample (Micro Analytical Laboratories, Inc., 2018). The NDWQS describes the quality parameters set for drinking water. This guidelines are intended to support the development and implementation of risk management strategies that will ensure the safety of drinking water supplies through the control of hazardous constituents of water (World Health Organization, 2006). All the concentration of elements need to be comply to all these three allowable limits to assess the potential for land application.

1.2 Problem Statement

Red gypsum (RG) is known as waste gypsum produced from chemical industry or power plant such as Hunstman Tioxide, Kemaman, Terengganu, Malaysia which process a production and manufacturing. This waste has been categorized as schedule waste as comply in Environmental Quality Act 1974, under the Environmental Quality (Schedule Waste, SW 205); waste gypsum arising from chemical industry or power plant (DOE, 2010). Meanwhile, the schedule waste need to be disposed in hazardous landfill or permanent disposal facility (PDF). In fact, there are some heavy metals found in RG which may cause pollution (Fauziah et al., 1996).

Anyhow, there is no minor or major case reported yet regarding this hazardous, but still it has to be investigated as this thing labelled as perilous waste. In this study,

this waste going to be tests under some leaching condition in the laboratory to conclude if there is no harmful substances at all then it could be good to reuse it to benefit others, but leaching maybe an issue. So, leaching characteristic of RG is crucial for determination assessment of environmental hazard.

1.3 Research Objectives

The purpose of this study is to test either the waste of RG known as scheduled waste as listing in SW 205 by DOE is classified as stable or unstable waste characteristic by conducting all the testing in laboratory. This study also covers the following objectives:

(i) to determine the leaching characteristic of red gypsum under Column and Oedometric conditions.

(ii) to compare leaching characteristic with Toxicity Characteristic Leaching Procedure (TCLP), Total Threshold Limit Concentration (TTLC) and Drinking Water Quality Standard (NDWQS).

1.4 Scope of Study

In this study, Red Gypsum from Huntsman Tioxide Sdn. Bhd. in Kemaman, Terengganu, Malaysia was considered. Samples were transported from the site to the laboratory. Several laboratory test were carried out to obtain the geotechnical waste properties and the parameters required to determine the leaching characteristic of RG. Two major laboratory tests need to consider to obtain the leaching water of sample by conducted column test while oedometer test should applied some different loading for the sample used. The leaching water sample, then will be tested in Central Laboratory of University Malaysia Pahang using Inductively Coupled Plasma Mass Spectrometry (ICP-MS) analyser to determine the parameter of the sample. From the results of sample parameters by ICP-MS testing, then compared the leaching characteristic of RG under Column and Oedometer conditions with the Toxicity Characteristic Leaching Procedure (TCLP), Total Threshold Leaching Concentration (TTLC) and National Drinking Water Quality Standard (NDWQS) to consider the leaching contamination environment hazard.

REFERENCES

Ahmad F., Said M. A., Najah L. (2012). Effect of Leaching and Gypsum Content on Properties of Gypseous Soil. *International Journal of Scientific and Research Publications, 2*(9), 1-4.

Al-Abed, S. R., et al. (2006). *Science of the Total Environment, 364*, 14e23.

ASTM D4874-95. (2014). *Standard test method for leaching solid material in a column apparatus*.

Azdapour A., Asadullah M., Junin R., Mohammadian E., Hamidi H., M., Daud A. R., & Manan M. (2014). Direct carbonation of red gypsum to produce solid carbonates. *Fuel Processing Technology*, 429-434.

Azdapour A., Asadullah M., Junin R., Mohammadian E., Hamidi H., Manan M. & M. Daud A. R.,. (2015a). Mineral carbonation of red gypsum via pH-swing process: Effect of CO2 pressure on the efficiency and products characteristics. *Chemical Engineering Journal*, 425-436.

Azdapour, A. (2015b). Direct and indirect aqueous mineralization using red gypsum for carbon dioxide sequestration. *Petroleum Engineering*, 23-26.

Azdapour A., Asadullah M., Junin R., Mohammadian E., Hamidi H., M., Daud A. R., & Manan M. (2015c). Extraction of Calcium from red gypsum for calcium carbonate production. *Fuel Processing Technology*, 12-19.

Azdapour A., Karaei M.A., Hamidi H., Mohammadian E., Barati M., & Honarvar B. (2017). CO2 sequestration using red gypsum via pH-swing peocess: Effect of carbonation temperature and NH4HCO3 on the process efficiency. *International Journal of Mineral Processing*, 27-34.

Barna, A., Sanchez, F., Moszkowicz, P., & Mehu, J. (1997). Leaching behavior of pollutants in stabilized/solidified wastes. *Journal of Hazardous Materials, 52*(2e3), 287e310.

Barman, P. J. (2012). A study on leaching behavior of Na, Ca and K using column leach test. *World Academy of Science, Engineering and Technology, 70*.

Bernd S. and Peter G. (2014). Column Leaching Tests for Groundwater Risk Asseseement: Concept Interpretation of Results, and Reproducibility. *Center for Applied Geoscience, Eberhard-Karls-University of Tübingen, Germany* , 1-5.

Borhan M. Z., & Nee T. Y. (2015). Synthesis of TiO2 nanopowders from red gypsum using EDTA as complexing agent. *Journal of Nanostruct Chemical*, 71-76.

Burlakovs J., Arina D., Rudovica V., & Klavins M. (2013). Leaching of Heavy Metals from Soils Stabilized with Portland Cement and MSWI Bottom Ash. *Heavy Metal Remediation Technology*.

Chen, X. (2014). Titanium Dioxide Nanomaterials. *Chemical Reviews*, 9281-9282

Chezom, D., Chimi, K., Choden, S., Wangmo, T., & Gupta, S. K. (2013). Comparative study of different leaching procedures. *International Journal of Engineering Research and General Science, 1*(2).

Danielowska, D. S. (2006). Heavy metals in fly ash from a coal fired power station in Poland. *Journal of Environmental Studies, 15*(6), 943e946.

Delay, M., Lager, T., Schulz, H. D., & Frimmel, F. H. (2007). Comparison of leaching tests to determine and quantify the release of inorganic contaminants in demolition waste. *Waste Management, 27*, 248e255.

Demotica, J. S., Amparado, R. F., Jr., Malaluan, R. M., & Demayo, C. G. (2012). Characterization and leaching assessment of ferronickel slag from a smelting plant in Iligan City, Philippines. *International Journal of Environmental Science and Development, 3*(5).

DOE. (2015). Malaysia Environmental Quality Report 2010.

Ecaterina, M., Cristian, P., Mirela, S., & Andrei, B. (2007). Method for assessment of potentially pollution of slag from iron and steel industry. In *Proc. of the 3rd IASME/WSEAS int. conf. on energy, environment, ecosystems and sustainable development*.

Environment Canada. (1990). *Compendium of waste leaching test, Environ. Protection Series, Report EPS3/HA/7*. Ontario, Canada.

Environmental Quality Act 1974. (2005). Retrieved from Environmental Quality (Schedule Wastes) Regulations.

EPA/600/R-10/170. (November 2010). *Background information for the leaching environmental assessment framework (LEAF) test methods*.

Garrabrants, et al. (2012). *Inter laboratory validation of the leaching environmental assessment framework (LEAF) method 1314 and method 1315*. EPA-600/R-12/624.

Garrabrants, A. C., & Kosson, D. S. (2005). Leaching processes and evaluation tests for inorganic constituents release from cement-based matrices. In R. Spence, & C. Shi (Eds.), *Solidification/Stabilization of Hazardous, Radioactive and Mixed Wastes*. CRC Press.

Georgakopoulos, A. (2002). Leachability of major and trace elements of fly ash from Ptolemais Power Station, Northern Greece. *Energy Sources, 24*, 103e113.

Goswami R.K. & Mahanta C. (2007). Leaching characteristics of residual lateritic soils stabilised with fly ash and lime for geotechnical applications. *Waste Management*, 466-481.

Hassett, D. J., Pflughoeft-Hassett, D. F., & Heebink, L. V. (2005). Leaching of CCBs: observations from over 25 years of research. *Fuel, 84*, 1378e1383.

Hesbach, P. A., Kim, A. G., Abel, A. S. P., & Lamey, S. C. (2010). Serial batch leaching procedure for characterization of coal fly ash. *Environmental Monitoring and Assessment, 168*, 523e545.

Hughes, P. N. (2011). *Use of red gypsum in soil mixing engineering.* Scotland: ICE Publishing.

Jankowski, J., Ward, C. R., French, D., & Groves, S. (2006). Mobility of trace elements from selected Australian fly ashes and its potential impacts on aquatic ecosystems. *Journal of Fuel, 85*, 243e256.

Juvelyn, S. D., Amparado, R. F., Malaluan, R. M., & Demayo, C. G. (2012). Characterization and leaching assesment of ferronickel slag from a smelting plant ini iligan city Philippines. *International Journal of Environmental Science and Development, 3*(5), 470e474.

Kalembkiewicz, J., & Sitarz-Palczak, E. (January 2015). Efficiency of leaching tests in the context of the influence of the fly ash on the environment. *Journal of Ecological Engineering, 16*(1), 67e80. http://dx.doi.org/10.12911/22998993/589.

Kamaraudin R. A and Zakaria S. (2007). Utilization of Red Gypsum waste for Glazes. *The Malaysian Journal of Analytical Sciences*, 57-64.

Kazi, T. G., Jamali, M. K., Siddiqui, A., Kazi, G. H., Arain, M. B., & Afridi, H. I. (2006). An ultrasonic assisted extraction method to release heavy metals from untreated sewage sludge samples. *Chemosphere, 63*, 411e420.

Kazonich, G., & Kim, A. G. (1999). *The Release of Base Metals during Acidic Leaching of Fly Ash*. http://www.flyash.info. Kazonich, G., et al. (1999). *The Release of Base Metals during Acidic Leaching of Fly Ash*. http://www.flyash.info.

Kim, A. G. (2002). *Physical and chemical characteristics of cub. proc. coal combustion byproducts and western coal mines, US department of interior, office of surface mining coal research center* (p. 18). Southern Illinois University at Carbondale.

Kosson, D. S., & van der Sloot, H. A. (2014). *Laboratory to field relationship and recommendations for leaching assessment*. WACAU-2014, Israel International Workshop on Agricultural Coal Ash Uses.

Kosson, D. S., van der Sloot, H. A., Garrabrants, A. C., & Seignette, P. F. A. B. (2014). *Leaching test relationships, laboratory to-field comparisons and recommendations for Leaching Evaluation using the Leaching Environmental Assessment Framework (LEAF)*. EPA 600/R-14/061 September 2014 www.epa.gov/ord.

Mahazam. N.H and Azmi. N. S. (2016). Evaluation of Physical and Chemical Properties of Red Gypsum from Terengganu, Malaysia. *International Journal of Engineering Research & Technology (IJERT)*.

Manoj K. T., Samir B., Dewangan U.K., Raunak K.T. (2015). Suitability of leaching test methods for fly ash and slag. *Journalof Radiation Research and Applied Sciences*, 1-15.

Menghini, M. J., Hornberger, R. J., & Dalberto, A. D. (2005). *The use of Leachate Data Factors in Evaluating CCB's for Placement at Coal Mine Site in Pennsylvania*, 2005, World of Coal Ash (WOCA), April 11e15, 2005, USA.

Morar, D. L. (2011). Leaching of metals from fly ash-amended permeable reactive barriers. *Journal of Environmental Engineering*.

National Order no. 876/2002 of environment ministry: classification criteria of the waste in order to be accepted in national list of the waste and into different deposits.

Oram, B. (2014). *Water Testing Total Dissolved Solids Drinking Water Quality*. (B. Oram, Editor, & B.F Environmental Consultant Inc) Retrieved from Water Research Centre

Petrus J. , Van S., Andrei V., Kolesnikov, Jachen P. (2016). Comparative assessment of heap leach production data- 1.A procedure for deriving the batch leach curve. *Minerals Engineering*.

Prasad, B. (April 2008). Heavy metal leaching in Indian fly ash. *Journal of Environmental Science & Engineering, 50*(2), 127e132.

Preliminary EPA Method 1313. (2009). *Leaching test (liquid-solid partitioning as a function of extract pH) of inorganic species in solid materials using a parallel batch extraction test*. USA: Environmental Protection Agency.

Querol X. & Alvarez A. E. (2008). Study of the use of coal fly ash as additive to minimise fluoride leaching from FGD gypsum for its disposal. *Chemosphere*, 140-146.

Shun-an Z., Xianggun Z., & Chun C. (2012). Leaching Behavior of Heavy Metals and Transformation of Their Speciation in Polluted Soil Receiving Simulated Acid Rain. *National Institute of Health*, 7(11).

Sidek M.A.H, Yunus R.M., Yahya F.M. (2017). Properties of Mortar with Red Gypsum as Cement Replacement Material by Using Industrial Approach Method. *Australian Journal of Basis and Applied Sciences*, 115-121.

Sorini, S. S. (1997). An overview of leaching methods and their application to coal combustion by-products. In *Proc. 12th international symposium on coal combustion by-product (CCB) management and use* (pp. 43-1e43-17). EPRI. V2.

Tadza, M. Y. (2011). Soil-Water Characteristic Curves and Shrinkage Behaviour of Highly Plastic Clays: An Experimental Investigation. *Geoenvironmental Research Centre, Cardiff School of Engineering*, 30-257.

Thorneloe, S. A. Improved leaching test methods for environmental assessment of coal ash and recycled materials used in construction. In *Proceedings Sardinia 2009, twelfth international waste management and landfill symposium*.

Tsiridis, V. (2006). Application of leaching tests for toxicity evaluation of coal fly ash. www.interscience.wiley.com.

van der Sloot, H. A. (1984). *A standard leaching test for combustion residues*. The Netherlands: BEOP-31, SOSUV.

van der Sloot, H. A. (1996). Developments in evaluation environmental impact from utilization of bulk inert wastes using laboratory leaching test and field verification. *Ware Management, 16*(1e3), 65e81.

Wilson, L. (1995). *Leach Test Protocols for Slags, Proc, Sudbury '95 Conference on Mining and the Environment*, 187 Sudbury Ontario, May 28th - June 1, 1995 (pp. 89e98).

Zachara, J. M., & Streile, G. P. (1990). Use of Batch and Column Methodologies to Assess Utility Waste Leaching and Subsurface Chemical Attenuation. *Report to EPRI, Palo Alto, CA, EN7313* (pp. 3e5). B-1-B-14.

Zheng S-a, Zheng X, Chen C (2012) Leaching Behavior of Heavy Metals and Transformation of Their Speciation in Polluted Soil Receiving Simulated Acid Rain. *PLoS ONE 7(11)*: e49664. https://doi.org/10.1371/journ