Understanding Problems of High Polymer Demand in Sludge Dewatering for Better Sludge Management

by

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Certificate of Original Authorship

I, Vu Hien Phuong To, declare that this thesis is submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the Faculty of Engineering and IT at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise reference or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

This research is supported by the Australian Government Research Training Program.

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This thesis is deeply dedicated to the following people:

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To my brother TO VU THANH, my sister NGUYEN THU HIEN,

and my niece TO NGUYEN HIEN ANH

To my aunts, uncles, and cousins

Format of Thesis

This is a thesis by compilation that comprises a combination of chapters and published/publishable papers.

This thesis includes 7 chapters:

- Introduction: Chapter 1
- Literature review: Chapter 2
- Published papers: Chapters 3, 4, 5
- Publishable papers: Chapter 6
- Conclusions: Chapter 7

In order to link all result/paper chapters in a logical and coherent way, there is a preamble to each chapter which states its purpose, aims, and justification. The preambles also specify titles, authorships, publication outlets, and current status of the published papers.

Publications and Conference Presentations

Publications included in this work

To, V. H. P., Nguyen, T. V., Bustamante, H., Vigneswaran, S., Effects of Extracellular Polymeric Substance fractions on polyacrylamide demand and dewatering performance of digested sludges, Separation and Purification Technology (2020) 116557.

To, V. H. P., Nguyen, T. V., Bustamante, H., Vigneswaran, S., Deleterious effects of soluble extracellular polymeric substances on polyacrylamide demand for conditioning of anaerobically digested sludge, Journal of Environmental Chemical Engineering 7 (2019) 102941.

To, V. H. P., Nguyen, T. V., Vigneswaran, S., Bustamante, H., Higgins, H., M. J., Derek, R., Novel methodologies for determining a suitable polymer for effective sludge dewatering, Journal of Environmental Chemical Engineering 6 (2018) 4206–4214.

Other publications

To, V. H. P., Nguyen, T. V., Vigneswaran, S., Ngo, H. H., A review on sludge dewatering indices, Water Science and Technology 74 (2016) 1 – 16.

To, V. H. P., Nguyen, T. V., Vigneswaran, S., Nghiem, L., Murthy, S., Bustamante, H., Higgins, M. J., Modified centrifugal technique for determining polymer demand and achievable dry solids content in the dewatering of anaerobically digested sludge, Desalination and Water Treatment 57 (2016) 25509–25519.

Conferences, Showcases and Workshops

To, V. H. P., Nguyen, T. V., Vigneswaran, Fates of extracellular polymeric substances and soluble cations in two-stage anaerobic digestion, Proceeding of 4th Asia Conference on Environment and Sustainable Development, Yokohama, Japan, oral presentation, November 2019.

Bustamante, H., **To, V. H. P.**, Nguyen, T. V., Vigneswaran, S., Extracellular Polymer – Reaction with Flocculants and Polymer Demand, Dewaterability Workshop, USA, oral presentation, July 2018.

To, V. H. P., Nguyen, T. V., Vigneswaran, S., Bustamante, H., Higgins, M. J. Higgins, Contribution of Soluble Extracellular Polymeric Substances to Polymer Demand for Conditioning of Anaerobically Digested Sludge, Proceeding of Sludge Management in Circular Economy, Rome, Italy, oral presentation, May 2018.

To, V. H. P., Understanding Problem of High Polymer Demand in Sludge Dewatering for Better Sludge Management, Faculty of Engineering and IT Showcase, University of Technology Sydney, oral presentation, June 2018.

To, V. H. P., Understanding Problem of High Polymer Demand in Sludge Dewatering for Better Sludge Management, School of Civil and Environmental Engineering Showcase, University of Technology Sydney, oral presentation, April 2018.

To, V. H. P., Novel Methodologies for Determining Suitable Polymer for Effective Sludge Dewatering, School of Civil and Environmental Engineering Showcase, University of Technology Sydney, poster presentation, April 2017.

To, V. H. P., Modified centrifugal technique for determining polymer demand and achievable dry solids content in sludge dewatering, Conference of

Environmental Engineering and Management for Sustainable Development, Anniversary Celebration of 60th Year, Hanoi University of Science and Technology, Hanoi, Vietnam, oral presentation, October 2016.

Awards

Research Exchange to Poznan University of Technology in Poznan, Poland granted by Polish National Agency for Academic Exchange (NAWA), August 2019.

Runner-up (oral presentation) at Research Showcase of School of Civil and Environmental Engineering, Faculty of Engineering, University of Technology Sydney, April 2018.

One of the short-listed projects for International Water Association Award under the Category of Breakthrough in Research & Development, 2018.

International Research Scholarship from University of Technology Sydney & Sydney Water Corporation Scholarship, 2016 – 2020.

Table of Content

Nomenclature

% w/v = Weight/Volume percentage

Al^{3+} = Aluminum ion

Ca^{2+} = Calcium ion

Cl^- = Chloride

Cu^{2+} = Copper ion

$Fe^{2+/3+}$ = Ferrous/Ferric ion

HCO_3^- = Bicarbonate

HS^- = Bisulfide

K^+ = Potassium ion

Mg^{2+} =Magnesium ion

M_w = Molecular weight

Na^+ = Sodium ion

NH_4^+ = Ammonium

OH^- = Hydroxide

PO_4^{3-} = Phosphate

R = Radius of the centrifugal rotor

R^2 = Correlation coefficient

S^{2-} = Sulfide

SO_4^{2-} = Sulfate

wt % = Weight/Weight percentage

xg = times gravity

Abbreviations

3D = Three Dimensional

Abs = Absorbance

AD = Anaerobic Digestion

ADS = Anaerobically Digested Sludge

AEDS = Aerobically Digested Sludge

AU = Absorbance Unit

COD = Chemical Oxygen Demand

CRT = Centrifugal Residence Time

CST = Capillary Suction Time

DLVO = A theory proposed by Derjaguin, Landau, Verwey, and Overbeek

EBPR = Enhanced Biological Phosphorus Removal

EPS = Extracellular Polymeric Substances

Higgins MCT = Higgins Modified Centrifugal Technique

LB-EPS = Loosely Bound Extracellular Polymeric Substances

M/D ratio = Ratio of Monovalent cations to Divalent cations

N = Nitrogen

OPD = Optimum Polymer Demand

OPD_{CST} = Optimum Polymer Demand determined by CST test

P = Phosphorus

PD = Polymer Demand

RCF = Relative Centrifugal Force

RPM/rpm = Round Per Minute

sEPS = Soluble Extracellular Polymeric Substances

SMP = Soluble Microbial Products

sPN = Soluble Protein

sPN/sPS = Ratio of soluble Protein to soluble Polysaccharides

sPS = Soluble Polysaccharides

SRF = Specific Resistance to Filtration

SS = Suspended Solids content

SVI = Sludge Volume Index

TB-EPS = Tightly Bound Extracellular Polymeric Substances

THP = Thermal Hydrolysis Process

TPN = Total Protein

TPS = Total Polysaccharides

TS = Total Solids content

WAS = Waste Activated Sludge

WWTPs = Wastewater Treatment Plants

ZP = Zeta Potential

List of Tables

List of Figures

Abstract

High polymer demand in sludge conditioning and dewatering is an unavoidable aspect of the water industry. Understanding interaction mechanisms between sludge particles and conditioning polymers in sludge dewatering is necessary to: firstly, maximize dewatered cake solids content; and secondly, to minimize polymer demand for conditioning. **In the first part of this PhD research**, two scientific methodologies, namely the ‘y-intercept’ concept and Higgins modified centrifugal technique (Higgins MCT) were used to identify the optimum polymer demand and type for effective conditioning and dewatering. Results from the ‘y-intercept’ concept show that a large amount of polymer required during conditioning of anaerobically digested sludge (ADS) is mainly due to the neutralization of soluble biopolymers or extracellular polymeric substances (EPS) in sludge. In contrast, conditioning of aerobically digested sludge (AEDS) and waste activated sludge (WAS) is mostly controlled by a polymer bridging mechanism. The results indicated that, in order to achieve maximum dewatering performance with minimum conditioning polymer requirement, high charge density polymers are suitable for ADS while branched (or cross-linked) polymers can be used for AEDS and WAS. In addition, the new lab-scale technique, Higgins MCT, was successfully established and implemented for measuring cake solids content achievable by centrifuge and determining the optimum polymer demand (OPD). The Higgins MCT also helped to understand the relationship between digestion, conditioning, and dewatering.

It has been demonstrated that excess amounts of soluble EPS released in digestion can lead to high polymer demand for sludge dewatering. Elucidation of how much soluble EPS contribute to polymer demand for conditioning is important to identify pathways to

minimize chemical usage without compromising dewatering performance. Thus**, in the second part of this PhD research,** a simple and unique yet effective method for quantifying the contribution of soluble EPS to polymer requirement was developed. This was achieved through measuring the absorbance of the supernatant derived from conditioned digested sludge at the 191.5 nm wavelength. In addition, the role of tightly bound EPS in determining the dewatering performance of digested sludges was also investigated. Specifically, the study examined ADS and AEDS from seven full-scale wastewater treatment plants (WWTPs). Results showed that the concentrations of soluble EPS in the sludges varied between 92–1148 mg/L. The EPS in ADS was much higher than those of AEDS. Experimental results also demonstrated that higher amounts of polymers were wasted in "parasitic" reactions with soluble EPS. For example, for ADS, it was as high as 40–86% of the cationic polymer dose) while for AEDS, it was less in the range of 25–33%. The residual cationic polymer left in solution, after the parasitic reactions, was substantial and varied between 35–254 mg/L. Despite that, zeta potential values of dewatered sludge cakes remained negative, i.e. between -24 – -35 mV. This indicated that the residual soluble cationic polymers would not have been absorbed on the negatively charged sludge particles. This explained the relatively poor performances of the dewatering in the plants studied. The study results also suggested that the tightly bound EPS attached to the sludge particles would be responsible for the low dewatering performance. It is postulated that the tightly bound EPS would gelify and immobilize the water surrounding the sludge particles.

In the final part of this PhD research, inter-relationships between wastewater and sludge treatment, specifically among Enhanced Biological Phosphorus Removal (EBPR), anaerobic digestion, and dewatering, were investigated to identify feasible approaches to reduce both chemical and transportation costs for the EBPR plants. EBPR

and non-EBPR WWTPs were compared in this study in order to determine the effects of EPBR and anaerobic digestion (AD) on sludge conditioning and dewatering. Experimental results show that EPBR and AD resulted in significant decreases in divalent cations and generation of soluble EPS, leading to a deterioration of bio-flocculation of ADS particles and requiring extra polymer dose for effective ADS conditioning and dewatering. In the two-stage AD, acid phase led to significant increases in concentrations of soluble biopolymers (more than double) due to hydrolysis reactions which converse non-soluble biopolymers to soluble organic compounds. Therefore, proper control of the acid phase can help reduce the content of soluble EPS to an optimum value that could favor both flocculation while minimizing the chemical cost for conditioning.