

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

by

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A thesis submitted to fulfilment  
of the requirements for the degree of  
Doctor of Philosophy

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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.

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This thesis is deeply dedicated to the following people:

*To my mother VU NGOC CHIEM and late father TO VAN HOAN*

*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.

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## Nomenclature

% w/v = Weight/Volume percentage

$\text{Al}^{3+}$  = Aluminum ion

$\text{Ca}^{2+}$  = Calcium ion

$\text{Cl}^-$  = Chloride

$\text{Cu}^{2+}$  = Copper ion

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

$\text{HCO}_3^-$  = Bicarbonate

$\text{HS}^-$  = Bisulfide

$\text{K}^+$  = Potassium ion

$\text{Mg}^{2+}$  = Magnesium ion

$M_w$  = Molecular weight

$\text{Na}^+$  = Sodium ion

$\text{NH}_4^+$  = Ammonium

$\text{OH}^-$  = Hydroxide

$\text{PO}_4^{3-}$  = Phosphate

R = Radius of the centrifugal rotor

$R^2$  = Correlation coefficient

$\text{S}^{2-}$  = Sulfide

$\text{SO}_4^{2-}$  = 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<sub>CST</sub> = 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



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## 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.