STRUVITE RECOVERY FROM ANAEROBICALLY DIGESTED LIQUOR OF FOOD WASTE BY USING PRECIPITATION TECHNIQUE

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DECLARATION

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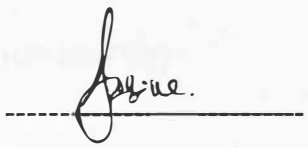

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ABSTRACT

The growing number of human population throughout the world is proportional to the amount of wastes produced. Previous research showed that food waste has been the main components and the highest waste contributor of municipal solid waste. The common disposal technique of food waste is by landfilling and incineration. However, these techniques lead to environmental problems including the greenhouse gas (GHG) effect and odour problem. The effort of separating recyclable waste which include glass, plastics and paper was great, however it is best to also gain benefits from food waste thus decreasing the amount of waste being landfilled. In this study, food waste was chosen as a substrate of anaerobic digestion in recovering struvite which is a mineral rich in phosphorus. Different composition of food waste (carbohydrate rich- food waste, fibre rich- food waste and protein rich- food waste) undergone series of analysis and treatment including determination of ions concentration and anaerobic digestion before the final of recovering process. Before anaerobic digestion was performed some physical and chemical properties of all composition of food waste were conducted. Anaerobic digestion of food waste was performed at controlled temperature (37°C) and pH (6.8-7.2) for 15 days. The total and volatile solids were then again determined as well as the reduction after anaerobic digestion. The struvite precipitation using the digested liquor was carried out at room temperature for 1 hour. The total and volatile solids contents and also its reduction after anaerobic digestion were found the highest in carbohydrate-rich food waste with value of 51.26% and 97.48% for the content, and 46.69% and 89.19% for the reduction, respectively. The results show that protein-rich food waste attained the highest phosphorus recovery after anaerobic digestion process with concentration of 500.86 mg/L. Fifty one percent of calcium content in protein-rich food waste was successfully removed using EDTA chelation treatment. The anaerobically digested liquor of protein-rich food waste was then used to undergo precipitation process using molar ratio 1:1:1 of Mg: NH_4:PO_4:NH_4. About 58% of struvite was successfully recovered from the protein-rich food waste and it was calculated that every 1g of wet food waste can produce 170 mg struvite. The struvite precipitate was then applied to lettuce and tomatoes plants to investigate its effect towards plant growth. The results show that struvite was able to enhance the plants growth by increasing the weight yield (lettuce), length (tomatoes) and also leaves counts (tomatoes) of the plants. Overall, this study indicates that food waste can be a suitable substrate for anaerobic digestion for phosphorus recovery in the form of struvite, a slow-release fertilizer, thus, promotes waste to wealth concept.

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ABSTRAK

PEROLEHAN-SEMULA STRUVITE DARIPADA CECAIR SISA MAKANAN YANG TELAH DICERNA SECARA ANAEROBIK MENGGUNAKAN TEKNIK PEMENDAKAN

Kadar penduduk dunia meningkat sejajar dengan kadar sisa buangan yang terhasil. Kajian terdahulu menunjukkan komponen utama yang menyumbang kepada peningkatan sisa pepejal buangan adalah sisa makanan. Biasanya, sisa makanan dilupuskan dengan cara dibiarkan di tapak pelupusan ataupun menggunakan kaedah pembakaran. Walaubagaimanapun, teknik pelupusan sebegini menyumbang kepada pencemaran alam seperti penghasilan gas rumah hijau (GHGs) dan pencemaran bau. Usaha pihak berkaitan mengenai kesedaran untuk mengitar semula bahan buangan berasaskan plastik, kertas dan kaca adalah langkah yang bijak, namun begitu adalah lebih baik juga sekiranya sisa makanan termasuk di dalam kitaran tersebut. Dalam kajian ini, sisa makanan dipilih sebagai bahan asas untuk penghasilan struvit iaitu sejenis mineral yang kaya dengan fosforus. Komposisi yang berbeza di dalam sisa makanan (sisa kaya karbohidrat, sisa kaya protein, sisa kaya serat) melalui pelbagai siri analisis sebelum dan selepas penghasilan struvit. Sebelum pencernaan anarobik dilakukan, pencirian fizikal dan kimia bagi kesemua komposisi makanan dilakukan. Pencernaan Anarobik dilakukan dalam keadaan suhu (37°C) dan pH (6.8-7.2) yang terkawal selama 15 hari. Jumlah pepejal dan pepejal teruap serta pengurangannya ditentukan selepas pencernaan anarobik. Pemendakan melalui cecair tercerna kemudiannya dilakukan setelah 15 hari dalam keadaan suhu bilik selama sejam. Jumlah pepejal dan pepejal teruap serta pengurangannya selepas pencernaan anarobik didapati paling tinggi pada sisa kaya karbohidrat dengan peratus 51.26% dan 97.48% untuk jumlah dan 46.69% dan 89.19% untuk pengurangannya. Didapati bahawa, sisa kaya protein mengandungi kandungan fosforus yang tertinggi iaitu sebanyak 500.86mg/L. Sebanyak 51% kalsium berjaya dikeluarkan dari cecair tercerna sisa kaya protein melalui kaedah rawatan perlekatan EDTA. Sisa tercerna yang telah dirawat ini kemudiannya digunakan dalam penghasilan struvit menggunakan kadar konsentrasi 1:1:1 NH_4:PO_4:NH_4. Sebanyak 58% struvit berjaya dihasilkan, iaitu kira-kira 170 mg struvit terhasil daripada 1g berat basah sisa makanan. Struvit yang terhasil seterusnya digunakan sebagai baja dalam penanaman pokok tomato dan selada bagi mengkaji kesannya terhadap pertumbuhan tanaman tersebut. Hasil pemerhatian didapati bahawa struvit yang dihasilkan melalui sisa makanan memberi kesan positif terhadap pertumbuhan tanaman tersebut antaranya meningkatkan berat hasil tanaman (selada), tinggi (pokok tomato) serta bilangan daun tumbuhan (pokok tomato). Secara keseluruhannya, kajian ini menunjukkan sisa makanan adalah bahan yang sesuai untuk melalui proses pencernaan anarobik bagi pemulihan-semula fosforus dalam bentuk struvit, seterusnya mengangkat konsep sisa kepada aset.

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LIST OF ABBREVIATIONS

P	Phosphorus
Ca/Ca^{2+}	Calcium
NH_4	Ammonium
Mg/Mg^{2+}	Magnesium
WL	Waste Liquor
WDL	Waste Digested Liquor
FW	Food Waste
AD	Anaerobic Digestion
TS	Total Solid
VS	Volatile Solid
VFA	Volatile Fatty Acid
SS	Sewage Sludge
OLR	Organi Loading Rate
PAO	Phosphorus Accumulating Organism
PHB	Polyhydroxylbutyrate
CRFW	Carbohydrate-rich Food Waste
PRFW	Protein-rich Food Waste
FRFW	Fibre-rich Food Waste

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LIST OF SYMBOLS

γ	Yield
%	Percentage
^{o}C	Degree Celsius
g	gram
mL	milliliter
cm^{-1}	Frequency or wavenumber
M	Molarity

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CHAPTER 1

INTRODUCTION

1.0 Introduction

The recovery of phosphorus from anaerobically digested food waste, through struvite or magnesium ammonium phosphate hexahydrate ($MgNH_4PO_4.6H_2O$) precipitation offers an innovative and novel approach for waste industry. It not only alleviates the chances of unwanted struvite deposits in anaerobic digestion and post digestion processes and return lines, but also ensures environmental sustainability. Anaerobic digestion (AD) appeared to be one of the best treatment for organic waste. It occurs naturally or through controlled environment. Industrial sectors usually use AD as a treatment for effluent waste due to its low cost operation. As a results, AD generates a number of products and by-products ranging from liquids, solid to gaseous form along its process. In this study, food waste was treated using AD to enhance the nutrients content in the digested liquor hence increase the possibility of struvite formation. After treated by AD the digested waste will undergo phosphorus (P) removal to recover the P in the digested waste in the form of struvite.

There are a few recognized P removal technologies such as chemical precipitation, biological phosphorus removal, crystallization, tertiary filtration, and ion exchange (Morse *et al.*, 1998). Most of these technologies produce waste that needed to be landfilled or incinerated. Among all of these, precipitation process found to be more beneficial since it is not only achieve high phosphorus removal but also recover phosphorus from waste in a useable form as a useful products, including struvite and calcium phosphate. Struvite is a white crystalline mineral compound which formed under condition of elemental supersaturation within liquid. When magnesium (Mg), ammonium (NH_4) and phosphate concentration exceed solubility levels, supersaturation occurs and minerals combine and precipitate into solid form (Wu & Bishop, 2004). Predicting precipitation of struvite is complex as it

solid form (Wu & Bishop, 2004). Predicting precipitation of struvite is complex as it is controlled by combination of many factors such as thermodynamics of liquid-solid equilibrium, phenomena of mass transfer between solid and liquid phases and kinetics of reaction. Besides that, there are also some other physio-chemical parameters that also affecting the formation of struvite precipitation which are pH of solution from which struvite may precipitate, supersaturation, mixing energy, temperature and the presence of foreign ions such as calcium ions (Ca^{2+}) (Corre *et al.,* 2005).

1.1 Problem statements

The main problem that leads into this research was the mass generation of waste especially food waste which became the main source of municipal waste composition. The waste which mostly is dumped on landfill may cause problems to the environment of the surrounding area since the waste contains high organic content and will petrify rapidly, hence produce odour problem. Phosphorus (P) is one of the nutrients that released from food waste, and may cause eutrophication if released excessively. This problem has become a major consideration in Malaysia since 40 years ago (Latifah and Zalina, 2011). One of the methods to reduce the amount of food waste is by performing anaerobic digestion (AD). AD is a biological process that can solubilise P into liquid form that can be precipitated in a form of struvite. It will not only to reduce the amount of waste, but also to recover P which is reported to be depleted in 50-100 years (Cordell *et al.,* 2009). Hence, the production of struvite through anaerobic digestion of food waste has a promising results in recovering a new source of P with unlimited source since the generation of food waste occurs daily worldwide.

The production of struvite especially in UK, Belgium and Japan has started a few years back (Forrest *et al.,* 2008; Munch & Barr, 2011; Geerts *et al.,* 2015). However, in Malaysia, the research of struvite is still at infant stage. In the mentioned countries, they have already established plants specifically for struvite production, in which their main substrate was mostly sludge produced from wastewater treatment plant (Forrest *et al.,* 2008; Munch & Barr, 2011; Geerts *et*

al., 2015). Malaysia still needs a long journey of research in order to have a production plant for struvite due to limited knowledge and technology. First and foremost, the quality of our waste was differ due to culture, economical, lifestyle and also technology factors, hence a thorough research on struvite precipitation using our waste need to be done. The main challenge for struvite precipitation is the presence of foreign ions which is the Calcium (Ca) ion. In every research of struvite, the presence of Ca at high concentration leads to the formation of other precipitates instead of struvite, such as hydroxyapatite. In addition, until now, food waste has never been tested to recover struvite. Previous researches in anaerobic digestion of food waste were only focus on physical and chemical properties and its potential for volatile fatty acids (VFAs), biogas and P recovery (determination of P concentration) only (Shin *et al.,* 2004; Kubaska *et al.,* 2010; Qin *et al.,* 2016; Wid & Selaman, 2017; Li & Li, 2017). FW may consist of different types of food which rich in nutrients, including Ca. In summary, precipitating struvite by using FW as the substrate is challenging since the concentration of Ca need to be reduced in order to increase the probability of gaining struvite recovery. Hence, the current study aimed to systematically investigate the potential of FW as substrate for struvite production for the recovery of phosphorus.

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1.2 Potential research contribution

It is estimated that the total available of phosphorus sources in Earth is 7000 million tonnes. Since it is non-renewable sources, these sources is expected will be finished in less than 200 years (Cordell *et al.*, 2009). According to Florida Institute of Phosphate Research (2005), the total consumption of rock phosphate for fertilisers and human use is 40 millions tonnes yearly. Since phosphate is an essential mineral source and nutrients that is important to not only plants but also to the entire living things in this earth, an alternative sources for phosphate recovery should be discovered.

The increase of world population and also the growth of industrial sectors have proportionally increased with the volume of waste produced where it becomes a worldwide problems and concerns. By narrowing the scope of research area to

only Malaysia, specifically Sabah, here also having these problems since the waste disposal sites will be fully occupied in few more years. Interestingly, based on the report provided by Dewan Bandaraya Kota Kinabalu (DBKK), it shows that food waste is the highest contributor of solid waste and this kind of waste is scientifically rich in nutrients especially phosphorus. Recently, food waste has been used in a few researchers as the source of organic matters for biogas and nutrients recovery (Chen *et al.*, 2016; Zhang *et al.,* 2014; Wang *et al.*, 2013; Rajagoal *et al.,* 2013; Wid *et al.,* 2017; Selaman & Wid, 2016).

As this research of phosphorus recovery through struvite precipitation from food waste is quite a new perspective of research in Malaysia (Rahman *et al.,* 2014), it would give positive impact towards our green environment especially in agricultural sectors since the recovery may give them an alternative fertiliser which is non-odorous, non-sludgy crystal which release nutrients slowly. Struvite has lower solubility towards water hence eutrophication problems can be prevented (Zhang *et al.,* 2012). Other than that, through this research, an international trend of promoting pollution prevention through cleaner solution could be achieved. To be into this feat, 5R policy has been introduced which are reduction, replacement, reuse, recovery and recycling of waste into resource (Wu *et al.,* 2009) which in this study resource recovery is highlighted.

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1.3 Objectives

This study aims to investigate the potential of FW in recovering P in a form of struvite by reducing the effect of calcium interference. By converting FW into struvite, waste generation can be reduced, consequently minimize environmental problems. Therefore, in order to achieve the aims, the specific objectives of this study are to:

i. determine the physical properties (pH, TS and VS) and chemical (concentration of Mg, NH_4 , P and Ca) of FW for P recovery,