

## Phosphorus Recovery from Anaerobic Co-Digestion of Waste Activated Sludge and Food Waste: Effect on Molar Ratio of Mg/Ca and Mg, Ca, Fe/P

Kay Thi Khaing<sup>1,2,3</sup>, Chongchin Polprasert<sup>1,2</sup>, Suwisa Mahasandana<sup>1,2,\*</sup>

<sup>1</sup>Department of Sanitary Engineering, Mahidol University, Bangkok 10400 Thailand.

<sup>2</sup>Center of Excellence on Environmental Health and Toxicology (EHT), OPS, Ministry of Higher Education, Science, Research and Innovation, Bangkok 10400, Thailand.

<sup>3</sup>Department of Geology, Lashio University, Lashio 06301, Shan State, Myanmar.

\*Corresponding author: suwisa.mah@mahidol.ac.th

**ABSTRACT-** The aim of the study was to evaluate the effect of mixing ratios and Hydraulic Reaction Time (HRT) on Phosphorus (P) recovery from waste activated sludge through pretreatment of anaerobic co-digestion to chemical precipitation processes. P recovery efficiency was improved in association with an increase of HRT. Molar ratios were carried out using Anaerobic Co-Digestion. The results showed that the molar ratios, improvement of recoverability were simultaneously achieved. Compared with anaerobic digestion pretreatment system, the molar ratios of Mg/Ca, Mg/P, Ca/P and Fe/P were observed in the anaerobic co-digestion pretreatment system. At 7, 10, 15 and 20, P was recovered into solid precipitates at 2-8%, 19-29%, 39-52%, and 40-72%, respectively with a P content in solid of about 0.8-1.4%, 0.9-2%, 1-7%, and 7-11%, P dry weight which is superior to commercial fertilizer (8.80% P). Results therefore indicate that recoverable P from urinal wastewater can be effectively used to produce fertilizer for agricultural cultivation by common ion precipitation and adsorption processes.

**Key words :** Food waste, Phosphorus recovery, Precipitation, Waste activated sludge.

### 1. INTRODUCTION

Phosphorus (P) is an excellent source of nutrients for all living species and is used extensively throughout modern farming as such a fertilizer. Furthermore, P is a finite and exhaustible resource, with 90 percent of P necessary for livestock farming [1-3]. It is the principal source of phosphate livestock feed, accounting for more than 85% of all mined phosphate rock (PR)[4]. The demand for P fertilizer has been observed to increase dramatically as a result of the world's burgeoning population, which is expected to reach 9 billion people by 2050 [5, 6]. PR reserves are expected to dwindle in the next 50-100 years [7]. As a result, challenges with diminishing and degrading P resources have posed a vulnerability to global

food security in the future. To avoid such the aforementioned problems of food security for human living, sustainable P management needs to be implemented by not only maximizing utilization efficiency of P fertilizer in food production sector, but also recovering P from wastes, such as domestic waste, septage sludge, crop residues, animal manure and human wastes [4, 8-10]. Accordingly, significant actions on P recovery and recycling to produce fertilizer for food cultivation must be realized than its removal from waste streams.

Waste activated sludge (WAS) from wastewater treatment plants (WWTP) and industrial sources is rich in carbon and nutrients, making it a viable bioenergy source [11-13]. As a result, phosphorus resources, as well as waste activated sludge, would be discharged (WAS). WAS is, of course, a combination of environmental wastes and P-rich resources [14]. Anaerobic digestion (AD) is a technique for recovering energy and reducing WAS [15]. Therefore, determining the effect of sludge anaerobic co-digestion methods on P recovery was necessary.

P recovery from waste activated sludge by chemical precipitation has recently received a lot of attention. Many different types of precipitating dose include Mg [16, 17], Ca [18, 19] and Fe [20]. Acelas et al. [21] has reported that Mg/Ca < 0.2 delayed HAP formation, and Mg/ Ca > 2 counterbalanced the undesirable effect of Ca during struvite crystallization. While dosing magnesium chloride to recover phosphorus is effective [22], at a typical Mg/P ratio of 1.2/1, magnesium dosing can account for between 10 and 75% of the cost of P production, depending on the phosphate concentration of the stream [23]. As the Ca/P activity ratio increased to more than 1, struvite purity reduced considerably. This finding is consistent with work done by Moerman et al.[24], which concluded that the Ca/P molar ratio should be less than 1.0 for effective P formation. Similarly, Wang et al. [25] concluded that the Ca/P molar ratio should be less than 0.5 to maximize struvite purity.

The presents huge economic and environmental challenged to the communities worldwide, especially megacities like Bangkok Metropolis. One of these challenges is P recovery from waste activated sludge and food waste so as to close the loop of P cycle for food production in the human ecosystem. In the Bangkok Metropolitan Administration (BMA) area, 211,6.7 tons P per year and FW of about 5,340 tons per year is transported to be disposed of directly in landfills [26]. Besides, P extraction is accompanied with P extractability and bioavailability of Phosphorus (P) recovered during chemical pretreatment process [27], which is beneficial for avoiding potential pollution risks during the subsequent WAS treatment and disposal. On the other hand, if this quantity can be recovered to produce P-composite material with quality equivalent to that of commercial fertilizer, such as single superphosphate (8.80% P) or N-P-K of 16-20-0, this could generate scale income of about 780 million baht per year [28] and, help prolong the life-span, of landfill operation. As a result, applying WAS directly to agricultural areas is forbidden. From the statement of problems mentioned above, the main objective of this research is to carry out the techno assessment of P recovery from waste activated sludge and food waste via anaerobic co-digestion. The specific objectives include: (1) to develop engineering criteria for design and operation of anaerobic co-digestion to molar ratio of supernatant from WAS and FW and simultaneously reduce calcium ratio phosphorus and Iron ratio phosphorus and (2) to assess the overall economy of anaerobic co-digestion to produce P fertilizer. The outcome of this research is prototype of a process for P recovery from wastes to produce simultaneously P fertilizer to supply the country's demand of renewable maintain food security, respectively. Successful results obtained from this study are expected to pave the way to the future of full implementation of P recovery from WAS and FW. These will, not only create hundreds of jobs associated with P recovery businesses in the cities nationwide, but also help save money from less imported P fertilizer, protect the water environment from eutrophication due to excessive P discharge, and contributing to sustainable P-for-food management.

## 2. MATERIALS AND METHODS

The precipitation tests were conducted for P recovery. The supernatant obtained from each condition of the anaerobic digestion process was used as P stock solution. In the experiment, Mg/Ca, Mg/P, Ca/P, and Fe/P molar ratios at pH-9 were used.

### 2.1 Substrates and inoculum

The WAS referred to the return sludge which was collected from the secondary sedimentation tank at Nong Khaem water quality control plant. This central treatment plant received and treated domestic sewage generated in Bangkok Metropolitan Administration (BMA) areas. FW referred to the leftover food, it was collected once a week from the Faculty of Public Health's canteen, Mahidol University, Ratchawithi campus,

Bangkok, Thailand. Non-biodegradable wastes include bones, salad, eggshells, wastepaper, and plastics were removed manually. The residual FW was grinded by a kitchen blender. Seed sludge (SS) was obtained from the bottom of AD tank at the same treatment plant as WAS. It was used as inoculum for all reactors. Previous initial utilization, all samples were maintained in a sealed plastic container at 4°C. The main characteristics of WAS, FW, and SS as shown in Table 1, which demonstrates that the sample contains P, Ca, and Mg as the major elements.

### 2.1 Experimental of anaerobic co-digestion

All 20l lab-scale CSTR reactors were operated at room temperature. A mechanical stirrer was placed on the top of the reactor with 80rpm motor. The operating conditions were a cycle of 30 min mixing and 120 min settling. Feeding for all reactor were prepared with the same P concentration of 100 mg P/l/day at different HRT range from 10 to 20 days, meaning that the reactors were respectively fed with 2.9l, 2l, 1.33l, and 1l of different ratio of WAS/FW:(100/0,75/25, 50/50, and 25/75).

### 2.2 Phosphorus precipitation experiments from AD

The supernatants obtained from AD processes were used as the P-stock solution. The precipitation tests were conducted 500 ml P-stock solution in 1000 ml beakers. The pH of all instances in the experiment was adjusted to pH 9 with a dropwise 50 percent sodium hydroxide solution at the start, according to [27]. These tests were carried out in triplicate at room temperature. The stirring speed was set to 200 rpm for 15 minutes and it then was reduced to 75 rpm for 30 minutes, followed by 1 hour of settling. The P-containing particles were separated from the liquid using 10 µm papers (Whatman number.93). Finally, the precipitates generated during this process were filtered and oven-dried for 24 hours at 103°C. The dried solids precipitates were then identified as P-containing solids.

### 2.3 Analytical methods and Calculation

The characteristics including total solids (TS), total suspended solids (TSS), total volatile solids (TVS), and COD in WAS, FW, and effluents used in this work were measured with standard methods [29]. The determination of total P and soluble-P was measured by the colorimetric method using vanadomolybdophosphoric acid and UV-spectrophotometer. The elemental composition, including Ca and Mg were determined using an atomic absorption spectrophotometer (AAS). In addition, the pH of solutions was determined using a benchtop pH meter. The data is usually expressed in terms of mean and standard deviation (SD).

Hydraulic retention time HRT was calculated according to Eq. (1).

$$HRT = \frac{V}{Q} \quad (1)$$

In which HRT is hydraulic retention time (day), Q is the flow rate (ml/d), and V is the working volume in the AD reactor. The organic loading rate (ORL) was calculated according to Eq. (2).

$$OLR = \frac{Q \times C_{vs}}{V} \quad (2)$$

In which ORL is organic loading rate, Q is the flow rate (ml/d),  $C_{vs}$  is P concentration (mg/l)

The elimination efficiencies of TS, TSS, and COD were estimated using Eq. (3).

$$(\%) \text{Removal efficiency} = \left[ \frac{\rho_{inf} - \rho_{eff}}{\rho_{in}} \right] \times 100 \quad (3)$$

In which  $\rho_{inf}$  (mg/l) and  $\rho_{eff}$  (mg/l) represent influent, and effluent of TS, TSS or COD concentration, and effluent TS, TSS or COD concentration, respectively.

### 3. RESULTS AND DISCUSSION

#### 3.1 Molar concentration from the supernatant

Anaerobic digestion (AD) was used in this section to see how mixing ratios (WAS/FW: 100/0, 75/25, 50/50, and 25/75) and hydraulic reaction time (HRT) affected the molar ratio of Mg/Ca, Mg/P, Ca/P, and Fe/P. Figure 1, discusses the experimental performance results. The following sections need to be in the specifics.

##### A. Effect of mixing ratio and HRT on Mg/Ca

The results obtained from the analysis Mg/Ca are shown in Figure 1 (a). It was found that the ratio of Mg/Ca molar was at range 0.6-1.8 throughout different HRT of 7 days to 20 days at ratios (100 WAS), 0.8-2.0 of 7 days to 20 days at (75 WAS/25 FW), 0.6-1.5 of 7 days to 20 days at (50 WAS/50 FW), and 0.2-1.1 of 7 days to 20 days at (25WAS/75FW), respectively. The amorphous content generated for all  $NH_4$  concentrations was extremely high for a Mg/Ca molar ratio of 1:1, and it reduced as Mg concentration increased. This demonstrates the importance of calcium-containing elements in the formation of crystals [18]. The highest Mg/Ca ratio molar achieved up to 2.0 when co-AD was performed at a ratio of 75/25% (WAS/FW) 20 days, while the lowest was 50% of WAS with 0.6 molar at 7 days. The results suggest that both mono-AD and co-AD can help in molar ratio concentration, and achieved the lowest when FW was used as the main substrate and co-digested with WAS at ratio 75WAS/25FW. As a result, the results suggested that an increase throughout Mg/Ca during anaerobic conditions, such as those found in waste activated sludge and food waste, might result in the creation of P stock solution, with the best concentration forming P-solid precipitates.

##### B. Effect of mixing ratio and HRT on Mg/P

For Mg/P, the ratio molar ranged from 0.2-1.9 (Figure 1 (b)). The highest value of molar ratio was at a ratio 100 of WAS/FW which was 1.9 at 20 days, followed by 50/50 of WAS/FW, 75/25, and 25/75 at 20 days which values were 1.5, 1.4, and 1.03, respectively. While dosing magnesium chloride to recover phosphorus is effective [22], at a typical Mg/P ratio

of 1.2/1, magnesium dosing, depending on the phosphate concentration of the stream [23].

##### C. Effect of mixing ratio and HRT on Ca/P

The resulting Ca/P molar ratios are shown in the radar plots in Figure 1 (c). It was found that the ratio of Mg/Ca molar was at range 0.28 to 1.32 throughout different HRT of 7 days to 20 days at ratios (100 WAS), 0.51-1.42 of 7 days to 20 days at (75 WAS/25 FW), 0.60-1.50 of 7 days to 20 days at (50 WAS/50 FW), and 0.54-1.03 of 7 days to 20 days at (25WAS/75FW), respectively. Different operation parameters, such as P concentration, Ca/P ratio, pH, temperature and presence of different impurities in the rejected water stream can affect the process of crystallization of calcium phosphates [30, 31]. The Ca/P molar ratio has also been used to determine the purity of struvite. When the Ca/P molar ratio was more than zero, calcium phosphates were responsible for decreasing struvite purity; greater declines occurred with purity greater than 0.5 to 1.0. This discovery is also in line with previous research [25, 32].

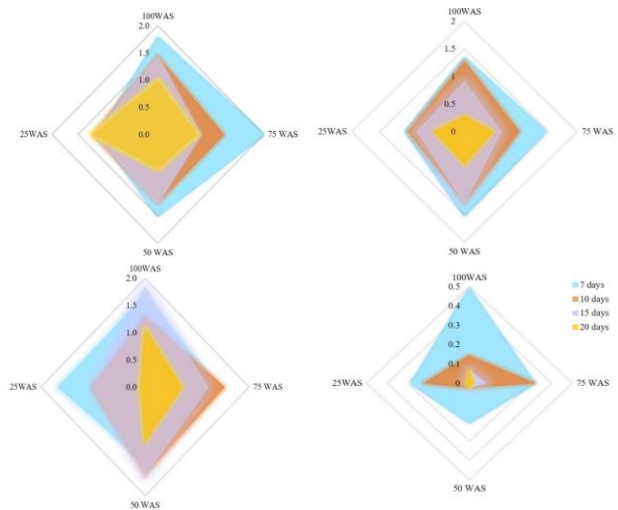


Figure 1 Radar plots for the via HRT (days) wherein each of the four axes shows the different mixing ratios of (a) molar ratio of Mg/Ca, (b) molar ratio of Mg/P, (c) molar ratio of Ca/P, (d) molar ratio of Fe/P.

##### D. Effect of mixing ratio and HRT on Fe/P

The results were similar to Fe/P molar ratios where the highest Mg/P was achieved when FW was the main substrate in co-AD. Longer thickening residence times would increase vivianite production and allow for complete iron reduction, which would assist mitigate vivianite scaling [33]. The resulting Fe/P molar ratios are shown in Figure 1 (d). The Fe/P were found ranged from 0.01 to 0.4 at 20 days to 7 days. The molar ratios Fe/P were found the 20 days is lower than the 7 days. The result suggested that the lowest HRT have significantly higher than that the long-term HRT. The lowest Fe/P ratio feasible, as well as the availability of phosphorus, are critical conditions for its usage.

### 3. 2 P recovery as Alternative P Fertilizer from supernatant

In this section, P precipitation without external metal addition was conducted so as to observe the effects of pH and Mg/P variations and ionic strength on the percentage of P recovery formation. Experimental results are illustrated in Figure 1. Details are discussed as follows. The result indicated that the P recovery from AD supernatant highly effluent molar ratios of Mg/Ca. Moreover, the content of P-solid precipitated was found highly significantly than that the lower molar ratio of Mg/Ca. However, lower Fe/P and Ca/P achieved the highest P recovery and P-solid precipitates than the higher molar ratios of Ca/P and Fe/P. Moreover, the result indicated that the efficiency of P recovery and P-solid precipitates of 20 days at 75WAS/25FW were significantly higher than that the other condition. Importantly, the proportion of P in its solid precipitate is a critical metric for developing an alternative P fertilizer. In

Figure 2, the highest recovery at 20 days HRT was found. From 100WAS/0FW, 75WAS/25FW, 50WAS/50FW to 25WAS/75FW, P was recovered into solid precipitates 2-8% at 7days, 19-29% at 10 days, 39-52% at 15days, and 40-72% 20days, respectively with a P content in solid of about 0.8-1.4%, 0.9-2%, 1-7%, and 7-11%, P dry weight which is superior to commercial fertilizer (8.80% P).

Figure 3 shows a comparison of the % of P content in this study's solid precipitates and commercial P fertilizers. Thailand's food security is bolstered by sustainable P management. To help achieve this goal, recoverable P can be utilized to make fertilizers for farmland.

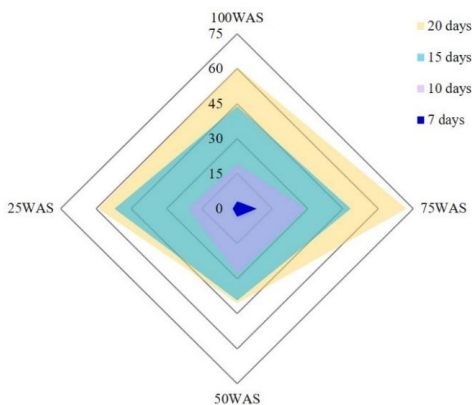


Figure 2 Radar plots for the different % P recovery, wherein each of the four axes show the supernatant from AD of WAS and FW.

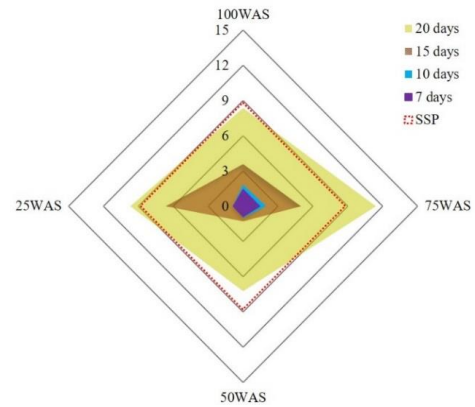


Figure 3 Radar plots for the different of solid-P precipitates, wherein each of the four axes show the supernatant from AD of WAS and FW.

### 4. CONCLUSIONS

The efficiency of the molar ratios Mg/Ca and Mg/P from the anaerobic digestion process improved at the HRT. However, the molar ratio of Ca/P and Fe/P declined from 7 days to 20 days. The efficiency of P recovery from the precipitation process improved at higher Mg/Ca levels of supernatant. However, the percent formation of P crystal declined from 72% at Mg/Ca 2.0 to 60, 59, and 40% at Mg/Ca 1.8, 1.5, and 1.1, respectively. P in solid precipitates was found in the range of 10 and 11% from 75WAS/25FW and 25WAS/75FW which is superior to that of commercial single superphosphate fertilizer (8.80% P). This method will not only molar ratios, but it will also help to shut the P loop in the food ecosystem by recycling the P initially contained in WAS as fertilizer for plantation fields. Reduced ash disposal costs to landfills and decreased operational costs at municipal wastes and wastewater treatment plants could provide additional benefits.

### 5. ACKNOWLEDGEMENT

The Mahidol-Norway Capacity Building Initiative for Myanmar Phase 2 provided financial support for this research.

### REFERENCES

- 1.D. Cordell, J.O. Drangert, and S. White. Drangert, and S. White, The story of phosphorus: global food security and food for thought. Global environmental change, vol. 19, no. 2, pp. 292-305, 2009.
- 2.P. Withers et al. A global perspective on the history of phosphorus management decision support approaches in agriculture: Lessons learned and directions for the future. 07/15, 2019, doi: 10.2134/jeq2019.03.0107.
- 3.P. J. Withers, J. J. Elser, J. Hilton, H. Ohtake, W. J. Schipper, and K. C. Van Dijk. Greening the global phosphorus cycle: how green chemistry can help achieve planetary P sustainability. Green Chem, vol. 17, no. 4, pp. 2087-2099, 2015.
- 4.B. Geissler, L. Hermann, M. C. Mew, and G. Steiner. Striving toward a circular economy for phosphorus: The

- role of phosphate rock mining. *Minerals*, vol. 8, no. 9, pp. 395, 2018.
- 5.M. Chen and T. Graedel. A half-century of global phosphorus flows, stocks, production, consumption, recycling, and environmental impacts. *Global Environmental Change*, vol. 36, pp. 139-152, 2016.
- 6.P. W. Geissler. *Para-states and medical science: Making African global health*. 2015: Duke University Press.
- 7.D. Cordell and S. White. *Life's Bottleneck: Sustaining the World's Phosphorus for a Food Secure Future*. *Annual Review of Environment and Resources*, vol. 39, no. 1, pp. 161-188, 2014.
- 8.A. Amann, O. Zoboli, J. Krampe, H. Rechberger, M. Zessner, and L. Egle. Environmental impacts of phosphorus recovery from municipal wastewater. *Resources, Conservation and Recycling*, vol. 130, pp. 127-139, 2018/03/01/ 2018.
- 9.B. Macura et al. Effectiveness of ecotechnologies in agriculture for the recovery and reuse of carbon and nutrients in the Baltic and boreo-temperate regions: a systematic map. *Environmental Evidence*, vol. 8, no. 1, pp. 1-18, 2019.
- 10.M. Mourad. Recycling, recovering and preventing "food waste": Competing solutions for food systems sustainability in the United States and France. *Journal of Cleaner Production*, vol. 126, pp. 461-477, 2016.
- 11.R. Avila, Á. Justo, E. Carrero, E. Crivillés, T. Vicent, and P. Blánquez. Water resource recovery coupling microalgae wastewater treatment and sludge co-digestion for bio-wastes valorisation at industrial pilot-scale. *Bioresource Technology*, vol. 343, p. 126080, 2022.
- 12.N. Lambert, P. Van Aken, I. Smets, L. Appels, and R. Dewil. Performance assessment of ultrasonic sludge disintegration in activated sludge wastewater treatment plants under nutrient-deficient conditions. *Chemical Engineering Journal*, vol. 431, p. 133-979, 2022.
- 13.J. Michalska, J. Turek-Szytow, A. Dudło, and J. Surmacz-Górska. Characterization of humic substances recovered from the sewage sludge and validity of their removal from this waste. *EFB Bioeconomy Journal*, vol. 2, p. 100026, 2022/11/01/ 2022.
- 14.Z. Yuan, S. Pratt, and D. J. Batstone. Phosphorus recovery from wastewater through microbial processes. *Current opinion in biotechnology*, vol. 23, no. 6, pp. 878-883, 2012.
- 15.D. Ikumi and T. Harding. Kinetics of biological and chemical processes in anoxic-aerobic digestion of phosphorus rich waste activated sludge. *Water Research*, vol. 170, p. 115333, 2020.
- 16.Y. Chen et al. Three birds with one stone: Lower volatile fatty acids (VFAs) reduction, higher phosphorus (P) removal, and lower alkali consumption via magnesium dosing after waste activated sludge (WAS) alkaline fermentation. *Journal of Cleaner Production*, vol. 258, p. 120687, 2020.
- 17.D. Lu, B. Xing, Y. Liu, Z. Wang, X. Xu, and L. Zhu. Enhanced production of short-chain fatty acids from waste activated sludge by addition of magnetite under suitable alkaline condition. *Bioresource Technology*, vol. 289, pp. 121713, 2019.
- 18.C. Moragaspiya, J. Rajapakse, and G. J. Millar. Effect of Ca: Mg ratio and high ammoniacal nitrogen on characteristics of struvite precipitated from waste activated sludge digester effluent. *Journal of Environmental Sciences*, vol. 86, pp. 65-77, 2019.
- 19.N. Yu, H. Sun, A. Mou, and Y. Liu. Calcium hypochlorite enhances the digestibility of and the phosphorus recovery from waste activated sludge. *Bioresource Technology*, vol. 340, p. 125658, 2021/11/01/ 2021
- 20.R.h. Li et al. Acidogenic phosphorus recovery from the wastewater sludge of the membrane bioreactor systems with different iron-dosing modes. *Bioresource Technology*, vol. 280, pp. 360-370, 2019/05/01/ 2019.
- 21.N. Y. Acelas, E. Flórez, and D. López. Phosphorus recovery through struvite precipitation from wastewater: effect of the competitive ions. *Desalination and Water Treatment*, vol. 54, no. 9, pp. 2468-2479, 2015.
- 22.N. Cullen, R. Baur, and P. Schauer. Three years of operation of North America's first nutrient recovery facility. *Water science and technology*, vol. 68, no. 4, pp. 763-768, 2013.
- 23.T. Dockhorn. *About the economy of phosphorus recovery*. in International conference on nutrient recovery from wastewater streams. 2009. IWA Publishing, London, UK.
- 24.W. Moerman, M. Carballa. Phosphate removal in agro-industry: pilot-and full-scale operational considerations of struvite crystallization. vol. 43, no. 7, pp. 1887-1892, 2009.
- 25.J. Wang, J. G. Burken, X. Zhang, and R. Surampalli. Engineered struvite precipitation: Impacts of component-ion molar ratios and pH. *Journal of Environmental Engineering*, vol. 131, no. 10, pp. 1433-1440, 2005.
- 26.B. Thitanuwat, C. Polprasert, and A. J. Englande Jr. Quantification of phosphorus flows throughout the consumption system of Bangkok Metropolis, Thailand. *Science of the Total Environment*, vol. 542, pp. 1106-1116, 2016.
- 27.K. T. Khaing, C. Polprasert, S. Mahasandana, W. Pimpeach, W. Patthanaissaranukool, and S. Polprasert. Phosphorus Recovery and Bioavailability from Chemical Extraction of Municipal Wastewater Treatment's Waste Activated Sludge: A Case of Bangkok Metropolis, Thailand. *Environment and Natural Resources Journal*, vol. 20, no. 4, pp. 369-378, 05/03 2022.
- 28.OAE.go.th. Office of Agricultural Economics. 2022; Available from: <http://www.oic.go.th/Ginfo/moreinfo.asp>.
- 29.APHA, *Standard methods for the examination of water and wastewater*. Vol. 2. 2012: American Public Health Association.
- 30.J. F. Ferguson and P. L. McCarty. Effects of carbonate and magnesium on calcium phosphate precipitation. *Environmental Science & Technology*, vol. 5, no. 6, pp. 534-540, 1971.
- 31.C. Sekar, P. Kanchana, R. Nithyaselvi, and E. Girija. Effect of fluorides (KF and NaF) on the growth of dicalcium

- phosphate dihydrate (DCPD) crystal. *Materials Chemistry and Physics*, vol. 115, no. 1, pp. 21-27, 2009.
- 32.X.D. Hao, C.C. Wang, L. Lan, and M. Van Loosdrecht. Struvite formation, analytical methods and effects of pH and Ca<sup>2+</sup>. *Water Science and technology*, vol. 58, no. 8, pp. 1687-1692, 2008.
- 33.T. Prot et al. Efficient formation of vivianite without anaerobic digester: Study in excess activated sludge. *Journal of Environmental Chemical Engineering*, vol. 10, no. 3, pp. 107-473, 2022.