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Fe-enhanced primary sedimentation, acidogenic sludge fermentation and electrodialysis for resource recovery from domestic wastewater

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ABSTRACT

In this study, a new chemical-biological process has been developed for municipal wastewater treatment. The new process utilises iron-based chemically enhanced primary sedimentation (CEPS) to concentrate organics and phosphorus (P) into sludge and hence reduces the load of pollutants on the downstream treatment process. A side-steam module for acidogenic sludge fermentation was applied to convert wastes in CEPS sludge to valuable resources. Results showed that over 70% of total organic carbon (TOC) and 83% of total phosphorus (TP) were removed by CEPS with an addition of 20 mg-Fe/L of $FeCl_3$ while the total nitrogen (TN) removal efficiency was limited. Acidogenic fermentation of Fe-sludge under the mesophilic condition produced volatile fatty acids (VFAs) at a ratio of 137.7 mg-C/g-volatile solids (VS) with 12% of TP dissolution. With 1 g/L of starch addition for co-fermentation, the VFAs yield and P dissolution increased significantly to 201.3 mg-C/g-VS and 60%, respectively. However, the addition of peptones did not improve the P dissolution, due to the higher ammonium release that prevented the pH drop and acidification in the fermenter. Through the electrodialysis (ED) treatment in a five-chamber cell, 50% of ammonium in the fermented sludge liquor was concentrated into catholyte, while 35%-43% of phosphate, acetate (Ac) and propionate (Pr) were separated into anolyte.

KEYWORDS Chemically enhanced primary sedimentation (CEPS); $FeCl_3$; acidogenic fermentation; co-fermentation; electrodialysis (ED); resource recovery; wastewater treatment

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1. Introduction

Facing serious shortage in water, food, resources and energy globally, municipal wastewater is now being known as a resource more than a stream of waste flow, a resource for reclaimed water, organic carbon, energy and plant fertilising nutrients (McCarty et al., 2011). For the conventional wastewater treatment process, however, a large amount of organics and nutrients has not been recovered but wasted instead due to degradation and sludge disposal. Chemically enhanced primary sedimentation (CEPS) is a wastewater treatment process that adds chemical coagulants to improve the pollutants removal by sedimentation (Neupane et al., 2008). Compared with simple sedimentation, CEPS shows particular advantages in removing suspended solids (SS), organics and phosphorus (P), thereby greatly reduces the pollutant load for the subsequent biological treatment. Moreover, CEPS concentrates these valuable materials into the sludge for potential recovery. As an energy-saving and cost-effective wastewater treatment process, CEPS can be particularly suitable for ever-growing mega-cities (Xu et al., 2009).

Stonecutters Island Sewage Treatment Works in Hong Kong is the largest CEPS treatment plant in the world, dosing 10 mg Fe/L_{sewage} - 12 mg Fe/L_{sewage} of $FeCl_3$ to treat 1.7 million m^3/d of sewage, with the production of 800 t/d of dewatered sludge for landfilling and incineration (Drainage Services Department, 2009). As a result, valuable resources, such as organics and nutrients, in CEPS sludge are wasted rather than recovered. Acidogenic fermentation of waste sludge can be a cost-effective method for P extraction and organic recovery. During acidogenic fermentation process, volatile fatty acids (VFAs) are produced from the particulate organics, leading to an anaerobic and acidic pH condition that would facilitate the P dissolution from the sludge (Meulepas et al., 2015). The produced VFAs are valuable organic carbon substrates suitable for wastewater denitrification or bioplastic (polyhydroxyalkanoates, PHA) production (Lee et al., 2014).

However, the high contents of ammonium (NH_4^+) and phosphate (PO_4^{3-}) released into the fermented sludge liquor limit the potential utilisation of VFAs in the supernatant. In other words, the nutrient elements must be removed first to reduce the nutrient loading in the wastewater treatment or biosynthesis system (Tong and Chen, 2009). Recently, the electrodialysis (ED) technology has drawn considerable attentions as an effective means to selectively separate anions and cations across the ion exchange membranes (IEM). ED of ions is driven by an applied electrical field between electrodes (Xu and Huang, 2008). The waste stream with low nutrient concentrations (< 2,000 mg/L) is preferred for treatment by the ED process for material separation and resource recovery (Mehta et al., 2015). Nowadays, ED has been used to recover ammonium and P

from urine separated at source (Pronk et al., 2006) and from pig manure hydrolytes (Mondor et al., 2008; Mondor et al., 2009). However, there are few studies on the ED process for treating sludge liquor and related resource separation and recovery.

This experimental research was carried out on the CEPS treatment of municipal wastewater for resource recovery via acidogenic sludge fermentation. Its aim was to determine the optimum $FeCl_3$ dosage for the CEPS process, and to investigate the beneficial effect of co-fermentation of organic wastes with the sludge for VFAs production and P release. In addition, ED was applied in batch tests for the separation of fermented products from the sludge supernatant. The overall efficiency of the system was evaluated for the recovery of organic carbon and nutrient resources from municipal wastewater.

2. Materials and methods

2.1. Experimental tests

2.1.1. Jar tests for the CEPS treatment

Raw domestic wastewater was collected from the Stanley Sewage Treatment Works in Hong Kong. The wastewater samples during the study period in terms of water quality were as follows: pH 6.9 ± 0.1, total organic carbon (TOC) 172 mg/L ± 15 mg/L, soluble organic carbon (SOC) 53 mg/L ± 3 mg/L, total phosphorus (TP) 6.0 mg/L ± 0.5 mg/L, orthophosphate-phosphorus (PO_4-P) 4.1 mg/L ± 0.4 mg/L, total nitrogen (TN) 45.4 mg/L ± 3.1 mg/L and ammonium-nitrogen (NH_4^+–N) 25.1 mg/L ± 1.0 mg/L. CEPS tests were first carried out on fresh wastewater using a lab-scale jar-tester, for which, 4 mg Fe/L_{sewage} - 25 mg Fe/L_{sewage} of $FeCl_3$ were dosed into several 1-L beakers, each filled with 500 mL wastewater. The jar-tester was performed with rapid mixing (200 rpm) for one minute, slow stirring (30 rpm) for 15 minutes, and then sedimentation for one hour. The pH was not controlled in jar-tests. The supernatant was taken for water quality analysis afterwards.

2.1.2. Batch fermentation of the CEPS sludge

According to the jar-test results, the $FeCl_3$ dosage of 20 mg Fe/L_{sewage} was chosen for the subsequent CEPS treatment. The coagulant was dosed into 20 L of raw wastewater in a water tank to perform the same coagulation, flocculation and sedimentation procedures as described above for the jar test. After sedimentation and supernatant discharge, the residual 1 L of sediment was obtained as Fe-sludge, with 20 times of volume reduction compared to the raw wastewater. The volatile solids (VS) concentration of the obtained sludge was 3.0 g/L ± 0.1 g/L. Serum bottles with volume of 550 mL were used for the subsequent sludge fermentation tests. Each bottle was filled with 470 mL of the Fe-sludge and 30 mL of fermented sludge from a laboratory acidogenic fermenter was added as inoculum. For the test fermenters, 1 g/L of starch or peptone was added, while the control fermenter had no organic addition. These fermenters were then placed in a chamber with temperature control at 37°C ± 1°C. The substrate in fermenters was mixed by magnetic stirring. To ensure an anaerobic condition for batch fermentation, the fermenters were sparged with nitrogen gas at the beginning of the test. The pH of the suspension was not controlled during the fermentation. The batch test was conducted in duplicate reactors for 11 days and was sampled every two days to monitor the progress. The supernatant of the fermented sludge was obtained by centrifugation at 8,000 rpm for 10 minutes.

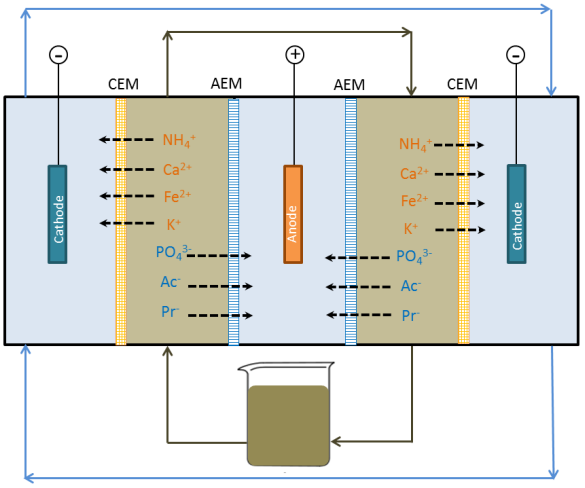

Figure 1. The schematics of ED treatment of the fermented sludge liquor for the separation and concentration of the fermentation products.

2.1.3. ED for separation and concentration of the products

As shown in Figure 1, the ED apparatus was composed of two repeating units, and each unit contained three compartments separated by a cation exchange membrane (CEM) and an anion exchange membrane (AEM) (Ultrex CMI-7000 and AMI-7001, Membranes International, the USA). By sharing one common anode compartment, the ED configuration has five components in total, including one anode, two feed chambers and two cathode compartments. The dimension of each cylindrical compartment is identical 1.5 cm in length and 8.3 cm in internal diameter with a working volume of 80 mL. Two stainless steel plates with a dimension of 4.2 cm × 4.2 cm × 0.1 cm were used as the cathodes, and a graphite plate with the same dimension was placed as the anode. The anode and cathode compartments were filled with 30 mM NaCl solution for conductivity. Magnetic stirring was applied in the anode compartment for mixing, while the two cathode

compartments were connected by silicone tubes (160 mL in total volume) for the electrolyte circulation via peristaltic pump at 100 mL/min. The feed solution of 400 mL was held in a beaker and circulated into the feed compartment by pumping at 100 mL/min. A stabilised DC power supply (IT6322, ITECH, Taiwan) was used to provide a constant voltage (6 V) during the experiment. The current of each individual ED reactor was recorded in a one-minute interval using a data logger (HOBO 4-channel analog logger, Onset, the USA). The synthetic solutions (10 mM of acetate, 10 mM of propionate, 13 mM of ammonium and 1.3 mM of phosphate) and the supernatant of the fermented sludge were processed by the ED units. Each batch ED test lasted for eight hours, which was sampled from the anolyte, catholyte, and the feed solution every half an hour for water quality analysis.

2.2. Analytical methods

A pH meter (Starter 3100, Ohaus, the USA) was used to measure the sludge pH in the fermenters. To measure the soluble parameters, the sludge mixture samples from the fermenters were taken and centrifuged immediately at 8,000 rpm for 10 minutes to obtain the supernatants. Measurements of SS, VS, NH_4-N and PO_4-P concentrations were conducted following the Standard Methods (American Public Health Association, 2005). A TOC analyser (Aurora 1 030, OI Analytical, the USA) was used to measure TOC in the sludge mixture and SOC in the supernatant. VFAs produced by acidogenesis, including iso-valeric acid (iso-HVa), n-valeric acid (n-HVa), iso-butyric acid (iso-HBu), n-butyric acid (n-HBu), propionic acid (HPr) and acetic acid (HAc), were measured using a gas chromatograph (6890A, Agilent, the USA), following the procedures previously described (Lin and Li, 2018). Besides, concentrations of Fe, Al, Na, Ca, K and Mg cations in the sludge supernatant were determined by inductively coupled plasma optical emission spectrometry (Optima 8000, PerkinElmer) after the HNO_3 digestion treatment (Ottosen et al., 2016). The measurement results were expressed as the average of triplicates, with the analytical errors of 10%.

3. Results and discussion

3.1. Pollutants removal by CEPS

The dosage of the chemical coagulant is one of the key factors for the CEPS performance, since the flocculation of particulate pollutants is primarily resulted from charge neutralisation and chain-bridging (Zhu et al., 2011). The jar-test results showed that only 21% of TOC and 3% of TP were removed from the wastewater by simple sedimentation (0 mg/L), with 135.8 mg-TOC/L and 5.8 mg-TP/L remaining in the effluent (Figure 2). In comparison, the efficiency of pollutant removals increased significantly with the $FeCl_3$-dosed CEPS. To decrease TOC and TP to less than 50 mg/L and 1 mg/L in the effluent, respectively, the effective $FeCl_3$ dosage was determined at 20 mg Fe/L_{sewage}. As expected, the CEPS was especially effective for the removal of particulate pollutants, rather than the soluble ones. Only 21 mg/L of SOC and 4 mg/L of NH_4-N were removed for the addition of 20 mg-Fe/L . The rest of 75%-83% removal was achieved by the reduction of particulate matters, suggesting that sweeping and bridging were the dominant mechanisms for the organic and nitrogen removals (Wei et al., 2009). Since NH_4-N amounted for 55% of TN, the removal efficiency of TN was comparatively lower at around 35%. Differently, $FeCl_3$ was rather effective to remove soluble PO_4-P from wastewater, with 85% of efficiency at a dose of 16 mg/L_{sewage}. That is because that ferric ions dosed and their hydrolysed complex in wastewater neutralised and adsorbed the negatively charged PO_4^{3-} rapidly, so as to remove the soluble P efficiently (Wilfert et al., 2015).

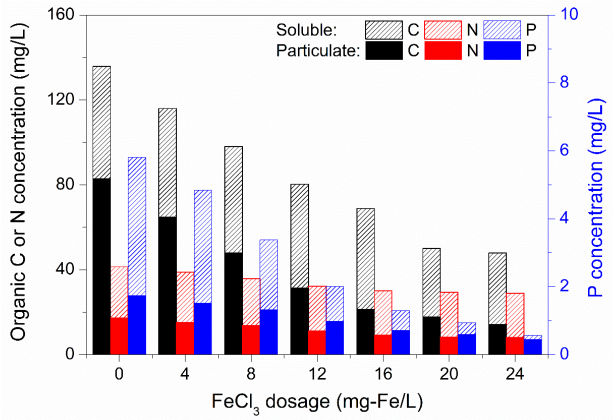

Figure 2. Removal of pollutants by the CEPS at different $FeCl_3$ dosages.

3.2. Acidogenic sludge fermentation for VFAs production and nutrients release

At the anaerobic environment, hydrolysis and acidogenesis occurred naturally in Fe-sludge with its high organic content, converting the solid organic compounds and macromolecules to soluble VFAs (Eastman and Ferguson, 1981). According to the results shown in Figures 3(a) and 3(b), the sludge pH kept decreasing with time, attributed to the VFAs accumulation in the fermenters. The maximum VFAs concentration of Fe-sludge was 413 mg-C/L at pH 5.4 on Day 7. The addition of starch or peptone as the supplementary organic into Fe-sludge significantly improved the level of VFAs productions to 805 mg-C/L and 773 mg-C/L, respectively. The VFAs yields in three respective fermenters were 137.7 mg-C/g-VS, 201.3 mg-C/g-VS and 193.3 mg-C/g-VS. Although the VFAs yields for the

starch-added and peptone-added reactors were similar, their pH conditions demonstrated obvious differences. The pH in the starch-added reactor displayed a rapid reduction from 6.4 on Day 0 to 4.6 on Day 11, while the pH in the peptone-added reactor showed a similar level of change as the control reactor, even slightly higher. The reason was that during the hydrolysis of peptone, a large amount of NH_4-N was released into the supernatant owing to the deamination reaction among proteins, which increased the buffering capacity of reactor (Wilson and Novak, 2009). As shown in Figure 3(b), the NH_4-N concentration in the control and starch-added reactors increased to 82 mg-N/L - 108 mg-N/L eventually, with about 100 mg-N/L released from the peptone added. The NH_4 released in the peptone-added reactor was nearly completed within the first five days, suggesting that the peptone could be easily hydrolysed and acidified. As for VFAs utilisation, however, the high level of ammonium released from peptone is not a favourable outcome. When returning the fermented liquor back to the main-stream wastewater treatment for denitrification, it would increase the N load and consume more VFAs. The TP and total Fe concentrations in Fe-sludge reached 103 mg-P/L and 350 mg-Fe/L, respectively, mainly in the form of chemical precipitates such as the Fe-PO_4 minerals and FeOOH-adsorbed P (Wu et al., 2015). As the solution pH decreased with time during the sludge fermentation, the solubility of Fe-P precipitates increased, leading to a continuous dissolution of P and Fe (Figure 3(c)). In addition, the reduction of Fe(III) to Fe(II) occurred rapidly under the anaerobic condition (Weber et al., 2006). As a result, the original Fe-P compounds in sludge were transformed to $Fe_3(PO_4)_2$ and $Fe(OH)_2$-adsorbed P. Since the solubility of Fe(II)-based precipitates was much higher than that of Fe(III)-based compounds (Stumm and Morgan, 2012), the dissolution of Fe and P were enhanced in the fermenters. For the control and peptone-added reactors, about 12 mg-P/L and 86 mg-Fe/L were dissolved into the fermented sludge liquor by the end of fermentation. However, the starch-added fermenter exhibited a significantly higher level of P and Fe dissolution, with the soluble concentrations reaching 59 mg-P/L and 189 mg-Fe/L, respectively, attributable to the enhanced dissimilatory iron reduction and more acidic environment. In other words, nearly 60% of P and Fe were extracted from the sludge in the starch-added reactor for potential resource recovery. The results further imply that the efficiency of P extraction from Fe-sludge can be effectively increased through co-fermentation with starch-rich food waste, such as rice and wheat-based food waste. Meanwhile, more VFAs can be produced for carbon (C) recovery and utilisation. According to the previous studies (Li and Li, 2017), over 99% of the dissolved P in the Fe-sludge liquor after fermentation can be readily recovered by precipitation via pH adjustment to 7-8, which led to re-precipitation of Fe(II)-P in forming vivianite, a valuable material for P fertiliser.

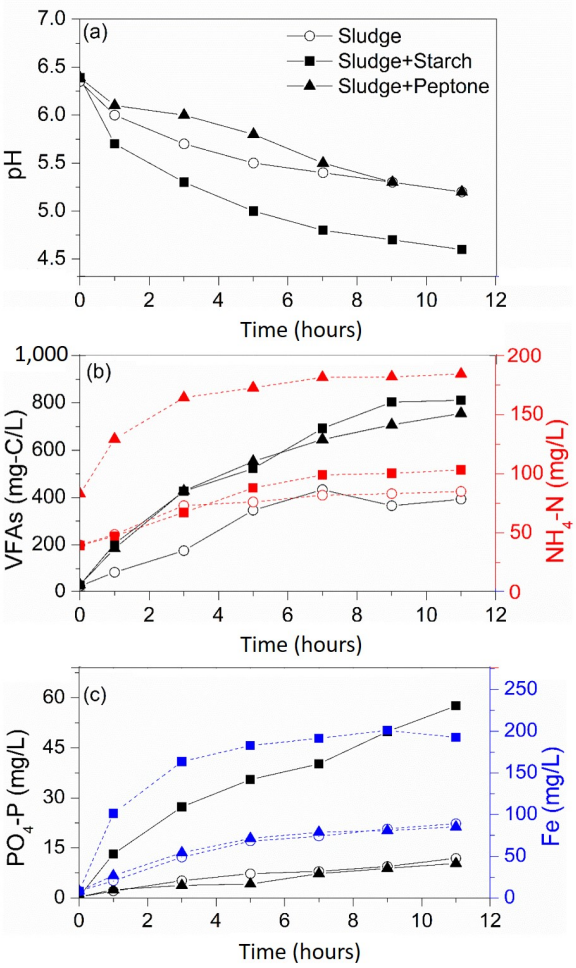

Figure 3. Performance of fermentation of the Fe-sludge with the addition of starch or peptone in batch test.

3.3. Separation of the fermented products by the ED units

Although Fe-P could be easily recovered from the fermented sludge liquor by vivianite precipitation, a large amount of ammonium still remained in the liquor which needed to be removed or recovered. In order to separate the nutrients and purify VFAs as a product, the ED units were applied first on the synthetic solutions and then the sludge liquor. Attributed to the electric migrations, the concentrations of acetate (Ac), propionate (Pr), NH_4^+ and PO_4^{3-} ions in the feed compartment all decreased with time, among which $NH4^+$ showed the fastest rate of transportation (Figure 4(a)). The removal efficiencies ($(C_0-C_t)/C_0$) of Ac, Pr, NH_4-N and PO_4-P by ED from the synthetic feed solution were 80%, 77%, 100% and 96%, respectively. Consistently, following the same pattern, the four products increased in the anolyte (Ac, Pr and PO_4-P) and the catholyte (NH_4-N). Figure 4(b) shows that about 76% of NH_4-N and 70% of PO_4-P removed from the feed solution were recovered as solutes. As a result, the anolyte and catholyte solutions were obtained with 340 mg-N/L and 130 mg-P/L, respectively. Moreover, Ac and Pr were also concentrated in the anolyte by 3.5 times - 3.8 times using the graphite anode.

Different performance was observed for the actual sludge liquor processed by ED. As shown in Figure 4(c), the removal efficiencies of organic acids and nutrients decreased notably compared to the synthetic wastewater solutions, especially for Pr (54.4%) and PO_4 (51.9%). Meanwhile, the current during the DE treatment fluctuated sharply after two hours. The membrane fouling might be the main cause, due to the deposition of large organic molecules and particles on the AEM and metal precipitation on the CEM surface. Correspondingly, the recovery efficiencies ($(m_{rec}-m_{rem})/m_{rem}$) of Ac, Pr, NH_4-N and PO_4-P all decreased to around 65%, which indicated that a considerable amount of products removed from the feed solution did not migrate into the electrolytes, but were probably adsorbed or trapped onto the membrane surface. Being the dominating metal cations in the fermented sludge liquor, the Ca and Fe contents decreased by 4.8 mM and 1.7 mM after the ED treatment. These cations were however not detected in the catholyte, suggesting the metal deposition on the membrane or cathode surface. This is particularly detrimental at the elevated pH level to as high as 12.0 in the catholyte. Lee et al. (2009) also suggested that the practical ED application in full-scale facilities may be hampered by the high energy consumption and the expense for IEM regeneration, due to the membrane contamination and fouling by metals and organics. Therefore, to improve the efficiency of recovery of various products from the fermented sludge liquor using the ED system, the membrane fouling problem needs to be further addressed.

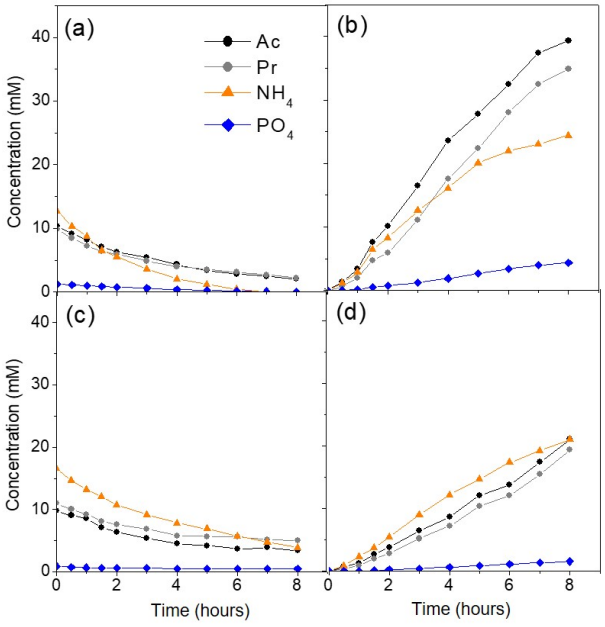

Figure 4. Variations of the concentrations of nutrients and organic acids in the feed solutions ((a) and (c)) and the recovered electrolytes ((b) and (d)) in the ED units for the synthetic solutions ((a) and (b)) and the actual fermented sludge liquor ((c) and (d)).

3.4. Mass balance of the wastewater and sludge treatment system

Hong Kong has a daily wastewater flow of 2.8×10^6 m^3/d. The following average values may be assumed for pollutants in Hong Kong sewage, which are also typical for normal municipal wastewater influents and treatment works: TOC = 150 mg/L, TN = 50 mg/L and TP = 5 mg/L. For a conventional secondary wastewater treatment plant (WWTP) integrated with sludge anaerobic digestion (AD), the overall mass balance and material flows for wastewater, C, nitrogen (N) and P are shown in Figure 5(a). After the primary treatment of simple sedimentation, pollutants decrease to TOC = 100 mg/L, TN = 40 mg/L and TP = 4 mg/L. Then the primary effluent goes to the anaerobic/anoxic/oxic (A/A/O) based activated sludge process (e.g. Shatin Sewage Treatment Works in Hong Kong) for the secondary treatment, to further reduce the pollutants to around 20 mg/L of TOC, 15 mg/L of TN and 2 mg/L of TP. For the biological treatment process, intensive energy is consumed for aeration and the mixed liquor recirculation (Q_r/Q_i = 300%). As more than 30% of the organic is oxidised by aeration, the C/N ratio would be too low (< 1) to ensure sufficient denitrification for N removal. Besides, the discharge standard of TP in the final effluent is below 1 mg/L for Class 1-B in China (GB 18918-2002), which would often require additional treatment for the secondary effluent before discharge.

For the proposed CEPS and add-on sludge fermentation module (Figure 5(b)), the primary effluent has significantly lower pollutant loads onto the downstream O/A based activated sludge process, with TOC = 40, TN = 30 and TP = 0.5 mg/L. Attributed to the decreased organic pollutants, the electricity consumption for aeration can be reduced by over 50% compared with the conventional system. Via hydrolysis and acidogenesis of the settled CEPS sludge, 30% of TOC in sludge will be converted into VFAs in the supernatant. The VFAs-rich supernatant would have TOC = 33 mg/L (converted to the equivalent concentration in the sewage influent flow), together with less than 0.5 mg/L of TN (NH_4-N). This organic input can remove at least 25 mg-N/L via denitrification. With the sludge liquor recirculation into the activated sludge basin, the secondary effluent would contain TOC = 20 mg/L, TN (NO_3-N) = 8 mg/L and TP = 0.2 mg/L, accounting for the nutrient (N and P) consumption by microbial growth in the activated sludge reactors. Thus, the wastewater treatment performance will be significantly improved, especially for nutrient removals, to meet the Class 1-A Standard well (GB 18918-2002).

Meanwhile, the proposed sludge processing will enable recovery of valuable resources from domestic wastewater, including organics, ammonium and P. For the conventional sludge AD, 20% of organic carbon in the wastewater influent can be recovered as methane gas (Figure 5(a)), which needs additional facilities for

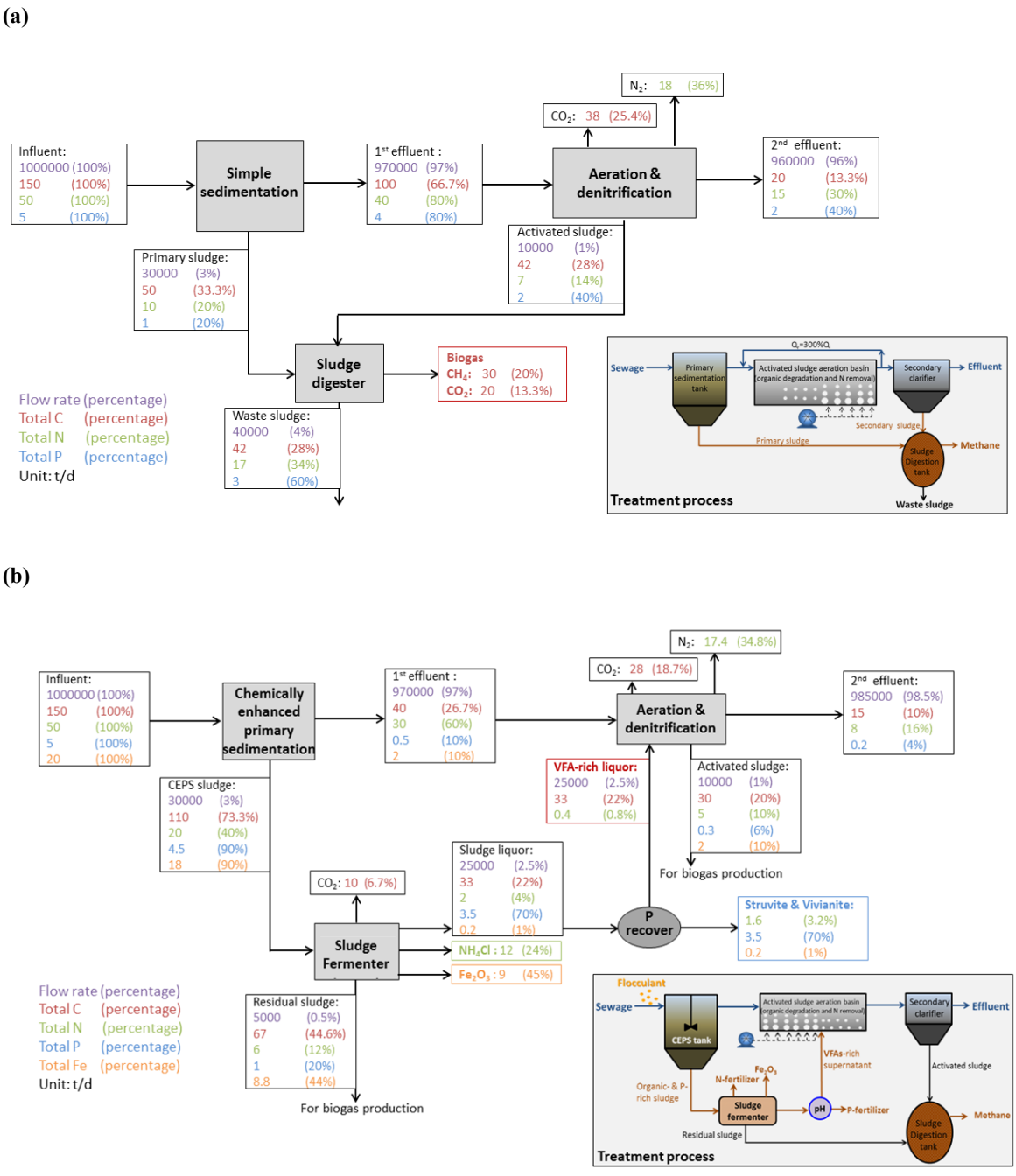

Figure 5. Material flow and mass balance analyses for the wastewater, C, N and P flows throughout (a) the conventional secondary treatment system with the predicted biogas production; and (b) the new treatment system with the predicted amounts of resource products to be recovered.

electricity generation. Only 30%-40% of CH_4 energy can be converted into electricity, while the rest is wasted as heat (Environmental Protection Agency, 2011). Using the system developed in this study, 22% of TOC in sludge can be utilised as an alternative to methanol for denitrification, reducing the operating cost and fire risk. The VFAs produced by CEPS sludge fermentation can also be used as the substrates for biosynthesis of PHAs and bioplastics. Another valuable product is the raw P-fertiliser recovered, amounting up to 70% of TP in the wastewater influent. Facing the depletion of phosphate rock in natural reserve, the large amount of recovered P-Fe (vivianite) and P-Mg (struvite) products will bring about significant economic and environmental benefits. Besides, in the sludge fermentation module, about 24% of N in wastewater influent can be recovered by ED into the concentrated NH_4Cl solution with over 1,000 mg-N/L at pH 9-10, which can be further processed to produce N-fertilisers.

4. Conclusions

For the Fe(III)-based CEPS treatment, over 70% of TOC and 83% of TP were removed from raw wastewater with an $FeCl_3$ addition at 20 mg-Fe/L, while the TN removal efficiency was limited at 35%. Acidogenic fermentation of Fe-sludge under that mesophilic condition produced VFAs at a ratio of 137.7 mg-C/g-VS, with dissolution of 12% of TP and 25% of total Fe from the sludge. Adding 1 g/L of starch for co-fermentation, the VFAs yield and P-Fe dissolution efficiency increased significantly to 201.3 mg-C/g-VS and 60%, respectively. However, the addition of peptones did not improve the P dissolution from the sludge, since a high level ammonium release kept the pH similar to that of the control reactor. Using a five-compartment ED system at a constant voltage of 6 V to treat the fermented sludge liquor, 50% of ammonium was concentrated into the catholyte, while phosphate, Ac and Pr transported to the anolyte with overall recovery efficiencies of 35%-43%. Membrane fouling appeared to be the main problem for the ED process. Mass balance analysis showed that this innovative chemical-biological treatment system can achieve effective pollutant removal, energy-saving and resource recovery in municipal wastewater treatment.

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Notes on Contributors

Dr Lin Lin received her bachelor and master degrees from Fudan University, People's Republic of China in 2011 and 2014, respectively. Then she obtained her Ph.D. degree from The University of Hong Kong in 2018, under the supervision of Prof Xiaoyan Li. She is currently the Post-doctoral Fellow at The University of Hong Kong. Her research interests include nutrients removal and recovery from wastewater, anaerobic treatment of organic solid wastes, and advanced electro-chemical technology. She has published 16 peer-reviewed journal papers, applied three Chinese patents, and gave seven presentations in international academic conferences. She is a member of the International Water Association, and has served as a reviewer for *Bioresource Technology*, *Process Biochemistry*, and *Environmental Science: Water Research & Technology*.

Prof Xiaoyan Li received his Ph.D. degree from the University of Arizona, the USA. His Ph.D. thesis won the Outstanding Doctoral Thesis Award from the Association of Environmental Engineering and Science Professors in 1997. He is currently the Director of Environmental Engineering Research Centre at The University of Hong Kong. He received the Outstanding Young Overseas Researcher Award from the National Natural Science Foundation of China in 2008, First-Class Scientific Research Outstanding Achievement Award (Science & Technology) from the Ministry of Education of China in 2012 and Second-Class State Natural Science Award of China in 2014. He has been an Institute of Scientific Information (ISI) top 1% highly cited author in the environmental field since 2009 and received an award of Top Cited Author 2007-2011 from *Water Research*. He has published more than 160 Science Citation Index (SCI) journal papers with over 6,000 citations and an H-index of 40. Prof Li is an expert in solid-liquid separation and membrane filtration in water and wastewater treatment and resource recovery from wastewater.

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