Nutrients Recovery Processes for Sewage: A Short Review

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Abstract. The abundance of untreated sewage that consists of valuable nutrients and water scarcity has motivated the community to process and recycle the waste through efficient and sustainable approach. The presence of dissolved nutrients and emerging contaminants are increasing lately due to the rapid anthropogenic activities. Over the years, many studies on sewage processing have been reported in the literature: bioaugmentation, membrane bioreactor, moving bed biofilm as well as adsorption technique for nutrients recovery. The advantages and limitations of these technologies are discussed in brief. Finally, the treated sewage that still contain useful nutrients can be recycled as irrigation water for crops and non-crops plantation, toilet flushing etc. Nutrients that were adsorbed in the filter can be utilized by plant when it is used as growing media.

Keywords: sewage processing, recycling, irrigation, process water

1. Introduction

In Malaysia, despite of existing legislation that protects water quality, there are variety of pollutants emerge increasingly and require serious attention. Based on the Malaysia Environmental Quality Report [1], 43 % of rivers in Malaysia which included Sabah and Sarawak area are slightly polluted and 50 % rivers are recorded to be polluted due to the high biological oxygen demand (BOD), suspended solid (SS) and ammonia nitrogen (NH$_3$-N) which mainly contributed by improper sewage discharge. Furthermore, several studies conducted by Ashraf et al. [2], rare earth elements were detected in core marine sediments of coastal East Malaysia such as cesium at (16.56 - 36.84) mg/kg and heavy metals. Pharmaceuticals residue are also detected along the coastal area in Selangor which is originated from the sewage discharge [3]. Hence, a better and proper sewage treatment is necessary to reduce the waste and environmental pollution as well as to protect public health.
Sewage treatment remains challenging in terms of removing the unwanted dissolved contaminant particles that are small in diameter or size [4]. Consequently, several advanced sewage processes have been explored in this paper: bioaugmentation, membrane bioreactor (MBR), moving bed biofilm reactor (MBBR) and adsorption.

2. Sewage characteristics

Sewage (domestic wastewater (DWW) or municipal wastewater (MWW)) contains mainly human excreta or wastewater from human activities mainly from toilet, restaurants, washing activities, kitchen water and etc. Sewage contains microbial pathogens that are excreted in the stools or washing water at high concentrations [5]. On top of that, sewage also contains important carrier medium for nutrients in the nutrient cycle such as nitrogen and phosphorus [6].

Sewage is characterized as low-strength wastewater with chemical-oxygen demand (COD), 250-800 mg/L; SS, 120 – 400 mg/L [7]. Characteristics of sewage in various countries are summarized in Table 1. The range of BOD, COD, ammonium – nitrogen (N-NH$_4^+$), total dissolved solid (TDS), total suspended solids (TSS) are 123 – 979.62 mg/L, 212- 7303 mg/L, 22 – 135.2 mg/L, 115 – 439 mg/L, 75.8 - 623 mg/L respectively.

| Country            | BOD  | COD  | TP   | TDS | TN   | Turbidity (NTU) | N – N$H_4^+$ | TSS | NO$_2^-$ | pH | E.coli (CFU/100ml) | Ref. |
|--------------------|------|------|------|-----|------|-----------------|--------------|-----|----------|----|-------------------|------|
| Selangor, Malaysia Johor, Malaysia Nagaoka City, Japan Harare, Zimbabwe Sao Carlos City, Brazil Cracow, Poland Vashi, India Palestine | NA   | 212  | NA   | 115 | NA   | 60              | NA           | 76  | NA       | 7.2 | NA                | [8]  |
|                   | 980  | 7303 | NA   | NA  | NA   | NA             | NA           | NA  | NA       | 5.2 | NA                | [9]  |
|                   | 240  | 532  | NA   | NA  | NA   | NA             | 22           | 262 | NA       | NA  | NA                | [10] |
|                   | 527  | 297  | 18   | NA  | NA   | NA             | 24           | 219 | NA       | 7.0 | NA                | [11] |
|                   | NA   | 436  | 14   | NA  | NA   | NA             | NA           | 176 | NA       | 6.9 | NA                | [12] |
|                   | 200  | 361  | NA   | NA  | NA   | NA             | 135          | NA  | NA       | 8.3 | 1.4 x 10^8        | [13] |
|                   | 123  | 227  | NA   | NA  | NA   | NA             | NA           | 167 | NA       | 6.7 | NA                | [14] |
|                   | 641  | 1267 | 13   | 439 | NA   | NA             | 58           | 623 | NA       | 7.4 | 3.9 x 10^7        | [15] |

BOD, COD, TP, TN, N – N$H_4^+$, NO$_2^-$ are in mg/L.

3. Sewage processing systems

3.1 Bioaugmentation

Bioaugmentation can be defined as adding endogenous or indigenous microorganisms, either selected strains/mixed cultures to wastewater to improve the catabolism of specific compound [16]. Bioaugmentation can be implemented in two schemes; (1) in situ augmentation, which provides internal process enhancements that add catabolism capability in the aerobic compartment by addition of immobilized selected strain of microorganism; and (2) external bioaugmentation, which augments the sludge with external selected strain of microorganism grown in a separate reactor [17]. Microorganisms that have been used in previous studies are microalgae [18], commercial bacteria [19], photosynthetic bacteria [20] and oleaginous bacteria [21].

Bioaugmentation is not limited to only aerobic digestion but also anaerobic digestion. However, implementation of any bioaugmentation strategy must be preceded by a successful isolation and identification of individual strains or microbial consortia that possess the unique metabolic capabilities required to biodegrade or biotransform target micropolllutants[22]. Also, the disadvantageous effects were largely reported being associated with bioaugmentation failures caused by the lack of acclimation for microorganisms to survive under harsh environmental conditions [16].
3.2 Moving-bed bioreactor (MBBR)

Aerobic MBBR is equipped with the biofilm carrier movement produced by the agitation. Anoxic and anaerobic biofilm reactors are useful for slow growth rate organisms like nitrifiers [23][24]. These reactor have been proven to be capable for carbon oxidation, nitrification, denitrification and deammonification [25][26]. Furthermore, separated process such as denitrification and nitrification can be carried out simultaneously in MBBR that will reduce space, cost and retention time[24]. MBBR can also be installed inside the sewer pipeline to enhance the removal of organic pollutants[27]. Type of media has been used such as polyurethane sponges [28], biodegradable polymer (PCL) [29], polyethylene (Aqwise ABC5 carrier), high-density polyethylene ring, Kaldnes (K1), porous polyurethane cuboid sprayed with activated carbon (BIOCONS)[30] with ammonia removal > 90%.

3.3 Membrane bioreactor (MBR)

MBR integrates membrane filtration into the activated sludge process for sewage. The use of the filters which can be submerged inside the bioreactor or arranged in dedicated external vessels has extensive effects on the process and the design of wastewater treatment which has two core benefits such as high effluent quality and low footprint [31]. MBR has already been utilized as a useful option to remove soluble organics, nutrients, and micropollutants from wastewater [32]. However, the membrane permeability has reported to decrease during successive filtration cycle due to the inorganic components that will seriously blocked membrane pores and physical and chemical cleaning, which then increasing the operating costs due to downtime incurred[33][34].

Efforts have been made to optimize the membrane process, such as development of cheaper membrane material, improvement of membrane life circle[35] and improvement of hydraulic condition in membrane tanks etc. [36][37], [38]. The modification of pores filtration membranes used in MBR is up to ultra and microfiltration membranes with a pore size of 0.2 µm or less which not only retain bacteria but also viruses[39]. Also, by installing an anoxic zone in MBR has impressive impact in reducing COD by 95 % and nitrification was complete and up to 82% [39]. Instead of that, magnetic activated sludge (MAS) has also been used to help mitigate the membrane fouling and it is inert and biocompatible that will not be detrimental to biological activity[40]. Recently, anaerobic membrane reactors (AnMBRs) for MWW has attracted attention. [41].

3.4 Adsorption

Adsorption has been used to treat volatile organic compounds (VOC), ester [42], heavy metal ions [43], synthetic dyes[44]. Adsorption is more suitable for wastewater treatment as compared to conventional methods that include less space requirement particularly in comparison to biological treatment, flexibility in design and operation, lower sensitivity to process variation, greater efficiency, insensitivity to toxic pollutants, no formation of harmful substances and wider applicability because it can remove or minimize different types of pollutants [45].

According to Meng et al., (2018), adsorption mechanism can be divided into three which are physisorption, chemisorption and ion-exchange adsorption. The principal types of adsorbents include activated carbon, bioadsorbent, synthetic polymeric, and silica-based adsorbents [47]. Nutrient removal from wastewater has been experimented by Kim et al. [48], where their experiment used an amine-grafted adsorbent for simultaneous phosphate ions (PO₄³⁻) and nitrate ion (NO₃⁻), and found out that the synthesized absorbent recovered 78% nitrate ion and 93% phosphate ion from wastewater.

Fruit waste adsorbent has been used by Zahrim et al. [49] to treat NH₃-N in synthetic wastewater which follows pseudo-second order with adsorption capacity, Qₑ of 1.2 mg/g. Low cost adsorbent such as langsat peels, jackfruit seeds, and moringa peels has been used for ammonia-nitrogen adsorption. The highest adsorption capacity was recorded by langsat peels with 3.58 mg/g followed by jackfruit seeds and moringa peels with 3.37 mg/g and 2.64 mg/g respectively[50]. The submerged adsorbent can be used as media for plant growth later (Figure 1).
Although a large number of studies have been performed to figure out the efficiency in adsorption by removing organic and inorganic pollutants there has not been any single report that provides a full comparative analysis between different adsorption processes. As a result, the adsorption process can be referred to be effective but the application is subjected only to remove a specific type of pollutants. In this connection, designing a hybrid adsorbent to remove a wide range of micropollutants can be potential area of future research [32]. Combination of inorganic and organic hybrid adsorbent such as using chitosan and copper can be considered as a promising candidate for efficient phosphate removal [51].

Material like graphene aerogel can be mixed with porous structure such as Fe$_2$O$_3$ nanocubes which recorded to have fast adsorption rate and outstanding reusability [52]. Porous material such as zeolite can be mixed with organic material such as chitosan. These two materials can either be composited into a film[53] and fine powder[54]. Result showed an improvement on adsorption of phosphate from using zeolite to composited zeolite with chitosan [55].

4. Sewage recycling
The five main types of use of recycled water indicated by Salgot et al. 2018 [56], which are irrigation, landscaping, water bodies recovery, groundwater recharge, drinking water supply as well as to be used in industry as cooling, in process and cleaning the machinery. Nowadays, applications of recycle water in vehicle washing, fire protection and air conditioning are being practiced [57]. However, reclaimed water being used as spray irrigation, cooling towers and toilet flushing are reported to cause potential fecal pathogen-associated health risks [58].

Water reclamation and reuse must follow the standards and recommendations issued at different administrative levels. As in China, Ministry of Construction and Standardization Administration issued a series of regulations and standards such as Reuse of Urban Recycling Water–Water Quality Standard for Urban Miscellaneous Water Consumption (GB/T 18920-2002) [59]. The majority of the suggested treatments are biological and such technologies can be efficient only at small sewage load[57]. In addition, the less contaminated sewage source e.g. kitchen wastewater is more favorable to be recycled compared to waste from toilet due to less process required prior to recycle [60]. The usage of recycle water is still rare and further studies are required to deeply understand the water resource and usage target[61].
5. Conclusion

Biological processes such as bioaugmentation and MBBR have relatively same limitations such as dependent on the temperature, types of selected strains and affected by toxic components. Membrane bioreactor is important for high quality of treated sewage. Due to its availability, development of adsorbent from waste material with high adsorption capacity and fast adsorption rate would be important in the future. Hybrid adsorbents are reported to have better performance compared to single adsorbent. If carried out properly, sewage recycling can be used as a sustainable solution for the benefit of mankind.

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