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Recovery and concentration of thermally hydrolysed waste activated sludge derived volatile fatty acids and nutrients by microfiltration, electrodialysis and struvite precipitation for polyhydroxyalkanoates production

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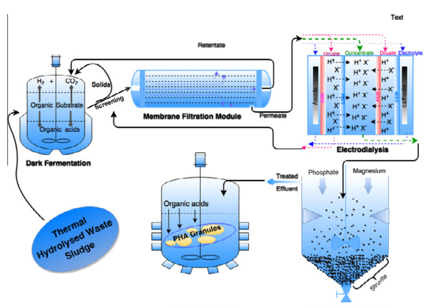
HIGHLIGHTS

- A novel process developed to convert waste activated sludge into valuable resources.
- VFA highly enriched effluent obtained from waste sludge by integration of MF and ED.
- A VFA concentration of 19.8 g/L achieved via MF/CED when targeting PHA production.
- Optimum ammonium level controlled through struvite precipitation was achieved.
- PHA accumulation increased approximately 7 times when using the product effluent.

GRAPHICAL ABSTRACT



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ABSTRACT

A novel chain of processes was proposed for the first time to convert thermally hydrolysed waste activated sludge (WAS) into concentrated volatile fatty acids (VFAs) and nutrient effluent stream for the production of biodegradable polyhydroxyalkanoates (PHAs). The integrated process involved a sequence of anaerobic fermentation followed by microfiltration (MF) and conventional electrodialysis (CED). The VFAs produced were primarily acetic and n-butyric acids, with concentrations of 3.27 and 4.37 g/L, respectively, within a total of 11.73 g/L of short chain organic acids produced from an organic loading rate of 20 g VS/L day and 2 days hydraulic retention time anaerobic fermentation. MF achieved over 80% recovery rates of VFAs and ammonium. CED concentrated effectively the MF recovered stream with 92% of VFAs and ammonium transferred to the concentrated stream i.e.19.82 g VFAs/L (~32 g COD_{VFAs}/L) and ammonium of 3.02 g/L. The excessive ammonium was removed through struvite precipitation before usage as substrate for PHAs production. This novel upfront process resulted in a 5-fold increase in PHA%/cell dry matter compared with the untreated thermally hydrolysed anaerobically acidified WAS stream. The results illustrate a promising market for the use of WAS through membrane and precipitation separation techniques for biomaterials production. The novel engineered processing system has much wider applications within the chemical industry and the potential for a very effective high rate methanogenesis.

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1. Introduction

In the UK, there is over 10 billion litres of sewage water being produced everyday, which equals to over 1.6–1.73 million dry tonnes of sludge every year [1]. In recent years, biological hydrolysis and acidification of waste activated sludge (WAS) has been widely recognised as an efficient way of treating sludge, as well as generating volatile fatty acids (VFAs) and nutrients enriched hydrolysate [2–4]. It is of environmental and economical interests to recover the produced VFAs and nutrients as resources for other biological processes, such as high rate anaerobic digestion, polyhydroxyalkanoates (PHAs) production and nutrients for the agriculture sector. For example, it is reported that VFAs and nutrients (e.g. NH_4^+-N and PO_4^{3-}-P) have been effectively recovered through microfiltration (MF) [5]. However, due to the complexity of waste-derived effluents, these usually require pre-treatment methods (e.g. acid and alkali wash) and certain times dilution of those effluents to improve the recovery rates, which results in large volumes of streams containing quite low concentration of nutrients and VFAs. In order to be further used, the VFAs and nutrients contained MF permeate needs to be refined to further increase the concentration of VFAs. Electrodialysis (ED) is a technology which applies an electrical field to promote transfer of ions across selective ion-exchange membranes, resulting in the transfer of ionic compounds from one effluent (diluate) to another effluent (concentrate) [6–8]. The fact that the interested VFAs and nutrients exist in ionic compounds makes ED a very promising technology to selectively concentrate VFAs and nutrients. Although there are reports of ED applied to remove VFAs from synthetic fermentation media [9], to our best knowledge, there is no report applying ED to concentrate VFAs and nutrients from complex waste streams such as anaerobically acidified WAS. Hence, ED was applied to concentrate the MF recovered VFAs and nutrients.

Although certain amount of nitrogen and phosphorous are essential for cell growth, the ED concentrated level of NH_4^+-N and PO_4^{3-}-P usually pose inhibitive effects for processes such as PHA production [10,11] and NH_4^+-N particularly in high rate methanogenesis. Therefore, the extra concentration of NH_4^+ and PO_4^{3-} needs to be removed/recovered before a further application. Among various ammonium removal methods, struvite precipitation was integrated within the chain of processes due to its advantages. First, the concentrations NH_4^+ and PO_4^{3-} are quite high after ED, thus recovering them via production of a fertiliser is of great interest from a resource recovery perspective. Furthermore, the precipitation process can be controlled through calculated magnesium addition to generate the optimum concentration of NH_4^+ and PO_4^{3-} for further biological processes.

Therefore, in the work, a novel chain of processes, with integration of MF, ED and struvite precipitation, was developed to demonstrate the feasibility of generating a highly concentrated VFA and optimum ammonium level controlled stream from WAS for further biological processes. The proposed process initially generated a concentrated VFA stream, through MF and CED. After the removal of excess ammonium from the VFAs enriched effluent, it was then utilised to produce PHAs through batch fermentation to demonstrate the promising applications of this process. The recovery rate of VFAs and nutrients by MF along with the efficiency of concentrating by ED were evaluated and the performance of PHA production using the resultant effluent was also investigated.

2. Experimental methodology

Fig. 1 illustrates the proposed chain of processes. Anaerobically fermented thermal hydrolysed sludge was screened so that coarse solids were removed before the stream was put through the

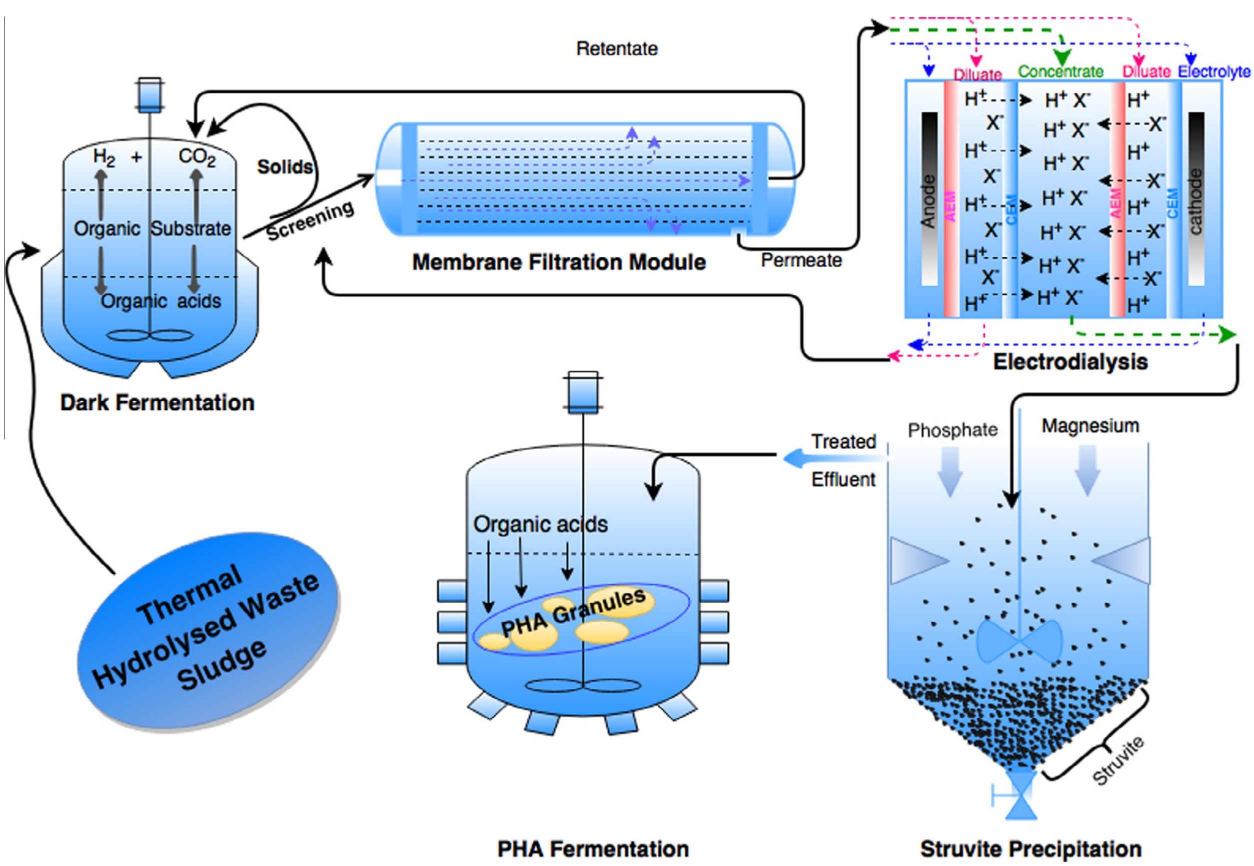

Fig. 1. Schematic illustration of the treatment processes applied in this work.