An overview of pressure-driven membrane technologies for a sustainable recovery of volatile fatty acids (VFAs)

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Abstract. Currently, petroleum-based volatile fatty acids (VFAs) sources are not acceptable towards sustainable development goals (SDG); therefore, biobased-derived VFAs are of interest. Anaerobic digestion has been identified as a useful technology for the production of biobased VFAs from organic waste residue because of their environmental sustainability, easy operation and affordability. The anaerobically digested liquid comprises several inorganic and organic compounds/particles, including VFAs, which is one of the main challenges nowadays since the particles/compounds free VFAs are highly demanded. Hence, pressure-driven membrane filtration technologies (microfiltration, ultrafiltration, nanofiltration and reverse osmosis) is being widely used due to their higher VFAs recovery efficiency. Microfiltration and ultrafiltration usually applied as pretreatment for removing coarser particles, while nanofiltration and reverse osmosis possess a remarkable role in recovery performances. This report is highlighted on the various types of membrane used for VFAs recovery percentages and critically discuss their influence. Afterwards, it was confirmed that lower pore size membranes offer better recovery percentages of VFAs over higher pore size membranes due to their permeability rate.

Keywords: Anaerobic digestion, membrane chemistry, pressure-driven membrane filtration, volatile fatty acids, resource recovery

1. Introduction

The utilization of environment-friendly products is one of the principal requirements to accomplish the Sustainable Development Goals (SDGs). The 2030 agenda for SDGs is strongly harmonized with a circular economy action plan, which includes resource recovery, reuse and recycling strategies (Abou Taleb and Al Farooque 2021; Rodriguez-Anton et al. 2019). Priorities have been given to the organic waste streams-based materials as a feedstock for the production of value-added products towards a resource recovery society establishment. Large amounts of organic waste are often collected from different sources, and it is advisable to use them effectively to save the environment and human health from their adverse effects (Lag-Brotons et al. 2020; Moustakas et al. 2020; Pervez et al. 2021).

Food waste (FW) is composed of organic compounds and nutrients riched material, which are beneficial for the resource recovery concept. The conventional management of FW was carried out in mainly three ways, such as landfill, composting, and incineration, which is not sustainable and uneconomical (Esparza et al. 2020; Girotto et al. 2015). In recent years, the conversion of FW to value-added products through the use of anaerobic digestion (AD) technology has been gaining more attention due to their feasibility and economic benefits. The full-scale AD process generally takes place in four steps, mainly (hydrolysis, acidogenesis, acetogenesis and methanogenesis) (Wainaina et al. 2020; Xu et al. 2018). The production of important intermediate chemical compounds, namely, volatile fatty acids (VFAs), is considered a promising chemical feedstock for several industrial applications (Figure 1) (Wainaina et al. 2021; Wainaina et al. 2019). Nevertheless, anaerobically digested VFAs enriched complex effluents need to be purified from other unwanted substances due to their potential market opportunities (Atasoy et al. 2018; Aydin et al. 2018).

Till now, various approaches such as adsorption (Reyhanitash et al. 2017), solvent extraction (Schlosser et al. 2005), electrodialysis (Zhao et al. 2021), membrane filtration (Zacharof and Lovitt 2013), esterification (Plácido and Zhang 2018) and so on have been attempted to recover VFAs from anaerobic fermentation broth. However, pressure-driven membrane filtration has particularly been selected as an effective option for the sustainable recovery of VFAs because of their numerous advantages (Aghapour Aktij et al. 2020; Zhu et al. 2021).

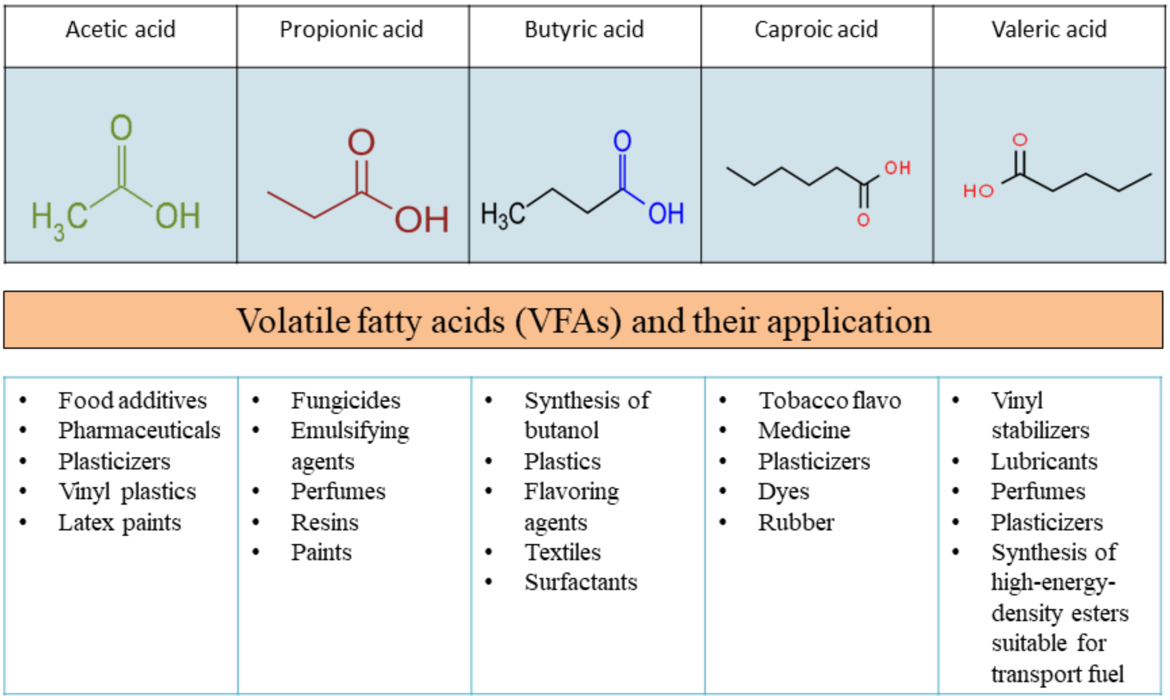

Figure 1. Volatile fatty acids and their application (Wainaina et al. 2021)

2. Progress on pressure-driven membrane filtration assisted VFAs recovery

The regulation of pressure is the main driving force in the pressure-driven membrane filtration process, in which the measurement of membrane pore size also plays a role in their performances. Generally, four types such as microfiltration (MF) (0.1–5 μm, 1–10 bar), ultrafiltration (UF) (500–100,000 Da, 1–100 nm, 1–10 bar), nanofiltration (NF) (100–500 Da, 0.5–10 nm, 10–30 bar), and reverse osmosis (RO) (<0.5 nm, 35–100 bar) have commonly been used for VFAs recovery (Cui et al. 2010; Van der Bruggen et al. 2003).

As a primary recovery step, the microfiltration and ultrafiltration process has been employed for controlling the presence of macromolecules, suspended particles, bacteria and protein in the effluent. For example, some studies successfully removed larger particles and produced a particle-free solution with an amount of more than 80% of recovered VFAs after the microfiltration process, while the addition of ultrafiltration enhanced the concentration of VFAs in the solution, as shown in Table 1. The main reason for this phenomenon that the pore size of MF/UF membranes is bigger than the size of VFAs compounds, thereby filtered solution contains a higher amount of VFAs and reducing the recovery rate (Jänisch et al. 2019).

The nanofiltration process is revealed as a key technology for a higher amount of VFAs recovery. The major advantage of this process is their low pore size (1 nm) membrane, which is favourable for small molecular weight-based VFAs compounds retentate. As shown in Table 1, the recovery percentage of VFAs compounds are varied when the used membranes pore size are different. For example, the recovery percentage of acetic acid was 78% when 200-300 Da based nanofiltration membrane used, but the recovery percentage significantly increased to 96.1% in the presence of 100 Da membrane (Table 1). Also, another important factor is solution pH. Higher pH provided better recovery percentages in the nanofiltration process. In this case, membrane surface charge dominant the separation process. Generally, negatively charged compound retention percentage enhanced when the transport flow of nanofiltration deals with larger charged compounds retentate. Acetic acid has a low pKa value which means this compound will easily be dissociated and ionized than butyric acid, thereby the retention ability is more for acetic acid. Nanofiltration membrane with a negative surface charge can reject negatively charged compounds significantly because of the electrostatic repulsions.

Reverse osmosis also a solution-diffusion mechanism-based membrane process. The recovery efficiency of VFAs by the treatment of RO membranes is also constituted through the combination of pore size and surface charge trend. RO membranes are more loosely, and the interaction between the membrane surface charge and solution components exhibited dominance over molecular weight and size exclusion properties. On the other hand, dense RO membranes are most likely less affected by the size retention mechanism (Aghapour Aktij et al. 2020; Mollahosseini and Rahimpour 2014).

Table 1. Pressure-driven membrane filtration process on VFAs recovery percentages

Filtration mode	VFAs recovery performance	References
MF	87%	(Kim et al. 2005)
	92.8%	(Tao et al. 2016)
UF	Total VFAs concentration 52 g/L	(Trad et al. 2015)
	VFAs concentration 7453 mgCOD/L	(Longo et al. 2015)
NF	Butyric acid,100%	(Xiong et al. 2015)
	Acetic acid, 78%	(Afonso 2012)
	Acetic acid, 96.1%	(Ecker et al. 2012)
	Butyric acid, 88%	(Zhu et al. 2020)
	Acetic acid, 40%	(Zacharof et al. 2016)
	Acetic acid, 45%	(Han and Cheryan 1995)
	Propionic acid, 84%	(Jänisch et al. 2019)
	Acetic acid, 85%	(Bellona and Drewes 2005)
RO	Isobutyric acid, 100%	(Hausmanns et al. 1996)
	Acetic acid, 81.92%	(Liu et al. 2020)
	Acetic acid, 90%	(Zhou et al. 2013)
	Acetic acid, 41%	(Malmali et al. 2014)
	Acetic acid, 70%	(Lyu et al. 2016)

3. Conclusion

In this review, it is clearly quantified that the pressure-driven membrane filtration process offers great promises in recovering VFAs compounds. The NF/RO membrane process is the best-suited technologies in terms of recovery rate, while the MF/UF process is effective for complex effluents purification. Research on scalable (long term operation and pilot plant) and economical methods are needed to be developed in the upcoming days for VFAs recovery. We are optimistic that the pressure-driven membrane filtration process may overcome the limitation of the conventional recovery process.

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