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Sustainability evaluation and implication of a large scale membrane bioreactor plant

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ABSTRACT

Membrane bioreactor (MBR) technology is receiving increasing attention in wastewater treatment and reuse. This study presents an integral sustainability evaluation of a full scale MBR plant. The plant is capable of achieving prominent technical performance in terms of high compliance rate, low variation in effluent quality and high removal efficiency during long term operation. It is also more responsive to the new local standard with rigorous limits. However, electricity consumption is found to be the dominant process resulting in elevated life cycle environmental impacts and costs, accounting for 51.6% of the costs. As such, it is suggested to optimize energy use in MBR unit and implement sludge treatment and management. The prolonged membrane life span could also contribute largely to reduced life cycle environmental concerns and expenses. This study is of great theoretical significance and applicable value in guaranteeing the performance and sustainability of large scale MBR schemes.

1. Introduction

Given the rapid pace of population growth, urbanization, industrialization, social and economic growth, climate change and living standard enhancement, water scarcity and water contamination have become prominent around the globe (Jiménez-Cisneros, 2014; UNWWAP, 2015). Water related issues are closely linked to human health, food, agriculture, energy, industrial activity and social stability (Oh and Lee, 2018). It is estimated that global water demand will increase by over 50% by the year 2050 which inevitably challenges water security for human society and the environment (UNDESA, 2015). In this regard, turning wastewater into a resource is an essential part to promote efficient use and move towards a more circular economy approach (Makropoulos et al., 2018). Notably, reclaimed water is being widely practiced in many water-scarce regions as an alternative water resource not only for non-potable applications but also for indirect and direct potable water reuses (Herman et al., 2017).

As for existing water treatment and reuse technologies, membrane bioreactors (MBRs) have been widely applied in more than 200 countries over the last 20 years because of their apparent strengths including the reduced chemical use, superior effluent quality, operational flexibility and reliability, lower excess sludge production and small footprint (Huang and Lee, 2015; Barreto et al., 2017). It is estimated that by 2019 more than 5 million m^3/d of wastewater will be treated by MBR plants worldwide and the global market value for MBR technology by that time is projected to reach 3 billion US dollars (Judd, 2016). Noticeably, the compound annual growth rate for MBRs during the period 2014–2019 is expected to be 17.4% in Asia-Pacific region, compared to 15%, 9.6% and 11.9% in globe, Europe and North America respectively (Krzeminski et al., 2017). It is predicted that China and Brazil will attain the fastest growth rates within the given forecast period (Abass et al., 2015). To be more specific, the number of large scale MBRs in

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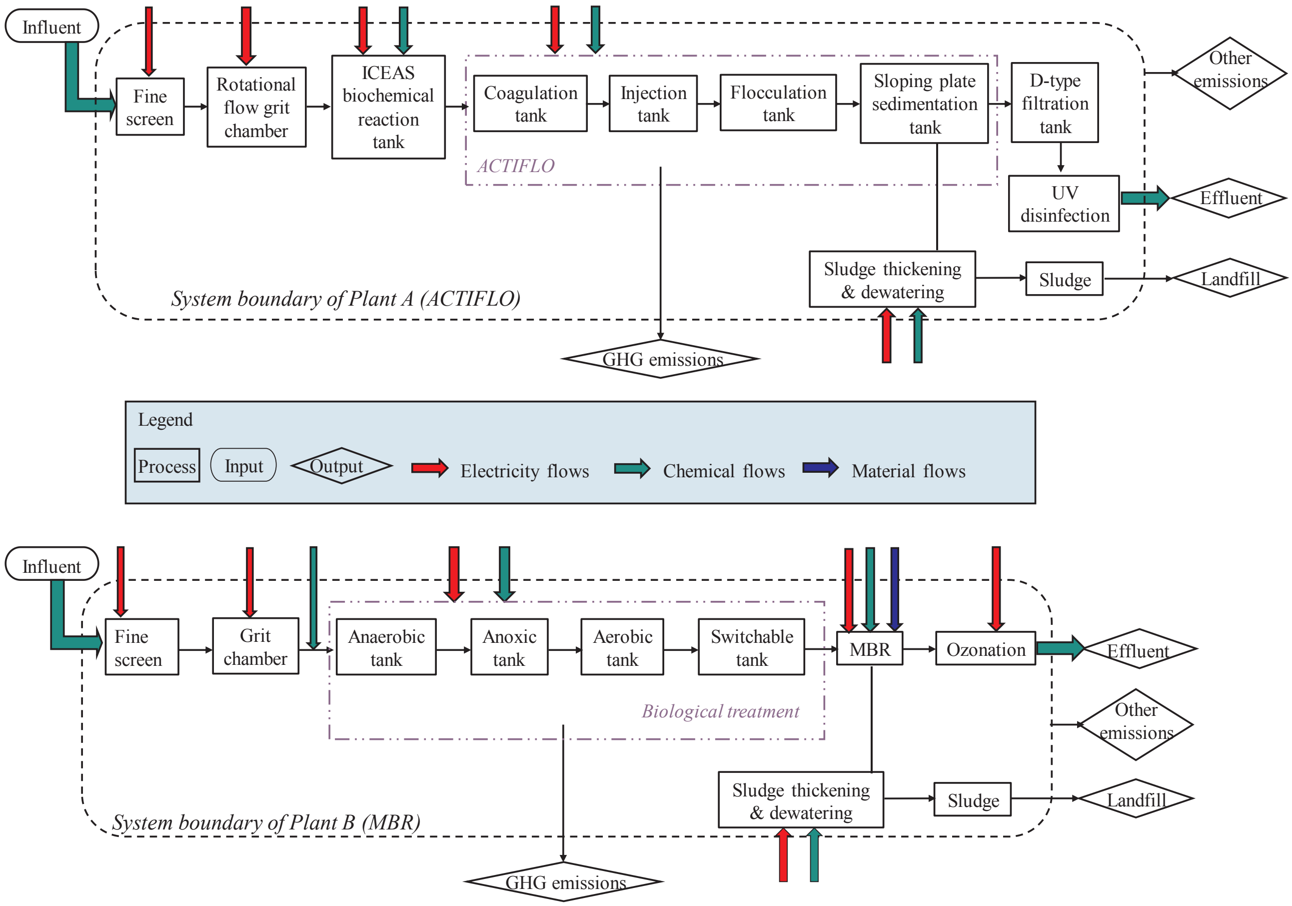

Fig. 1. Generic flow chart and system boundary of two WRPs.

China was about 200 by the end of 2017, with a capacity of over 4.5 million m^3/d and an expected market value of 1.3 billion US dollars (Xiao et al., 2014; Hao et al., 2018; Li et al., 2019).

The above-mentioned figures further drive a boom in scientific research and industrial applications of full scale MBRs in a sustainable pathway. Particularly, barriers with respect to energy consumption, high capital and operational costs, membrane fouling, membrane life span and full scale operational experiences are highly concerned and are likely to restrain MBR market expansion (Ma et al., 2017; Bagheri and Mirbagheri, 2018). A large quantity of studies has already devoted to membrane fouling control through the design of new configurations (Yan et al., 2015), the addition of granular media such as activated carbon, zeolite, sludge-based adsorbent, plastic barriers and quorum quenching enzymes (Iorhemen et al., 2017; Nahm et al., 2017) or the modification of membrane material by nanomaterials (Meng et al., 2017). Nowadays, multi-faceted challenges can no longer be solved by traditional limited scale and monotonous factor approaches. However, the sustainability assessment of MBRs in terms of technical, economic and environmental aspects is limited to few studies (Krzeminski et al., 2017).

Memon et al. (2007) and Ortiz et al. (2007) analyzed environmental aspect of water reuse systems at small scales and concluded that MBRs provoked higher environmental impact than conventional activated sludge and natural treatment systems (e.g. the reed beds and green roof water recycling system) due to higher energy demands. Similarly, Hospido et al. (2012) evaluated the environmental profiles of different MBR configurations on a pilot scale and identified an inverse relation between the environmental impact and technological complexity. Likewise, Ioannou-Ttofa et al. (2016) examined the environmental footprint of an MBR pilot unit without consideration of its sludge treatment and disposal. It is found that energy consumption and membrane unit's material are main impact contributors. Besides, Molinos-Senante et al. (2012) integrated the environmental assessment tool with a cost-benefit approach of several technologies in small WWTPs and addressed the advantages of MBRs in terms of high effluent quality production. Nevertheless, there is a continuous doubt that whether experiences based on small or pilot scale MBR studies could actually offer a reliable view since the limited scale could negatively influence the energy performance (Fenu et al., 2010; Krzeminski et al., 2017; Salgot and Folch, 2018).

In addition, Høibye et al. (2008) proposed the concept of holistic assessment of advanced treatment technologies considering technical, economic and environmental aspects. Likewise, Plakas et al. (2016) suggested a multi-criteria analysis of advanced treatment technologies from a perspective of economic, environmental and social concerns. Furthermore, Hao et al. (2018) and Akhoundi and Nazif (2018) established corresponding models to evaluate the sustainability of MBRs. However, their effectiveness and applicability to full scale MBR applications need further research. Presently, there is still a significant challenge to identify the benefits of large scale MBRs for sustainable water reuse under risk and uncertainty while addressing the technical, economic and environmental implications. Hence, this study aims to investigate experiences of full scale MBR via a case study and evaluate performances and advances based on integrative analyses that involve multiple dimensions and indexes concurrently. The results can be beneficial to real practices and expansion of MBRs and offer a better understanding of the interlinkages among water, energy, nutrient and material towards maximum use and recovery.