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Identify driving forces of MBR applications in China

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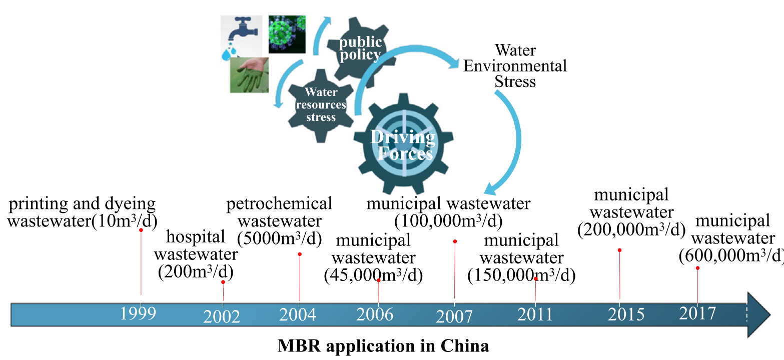
HIGHLIGHTS

- Provide a unique historic sequence of MBR application development in China
- Identify specific historic events roles to promote MBR applications in China
- Examine driving forces of MBR applications
- Explore the trend of MBR applications in China

GRAPHICAL ABSTRACT



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ABSTRACT

During the last two decades, MBR applications in China grow exponentially with the first pilot test of 10 m^3/d in 1999 and the first application with capacity of 110,000 m^3/d commissioned in 2009. It is critical to examine the drivers of MBR applications in China, which can provide sound scientific basis for future development of MBR applications. This study summarized the historical development of MBR applications and analyzed the driving forces by survey, literature review and interviews with MBR suppliers. The results showed that: (1) technical advantages of MBR and public policy related to water resources and environment promoted MBR beyond lab and pilot test into wide commercial applications in China; (2) petrochemical industry needs for wastewater treatment and reuse promoted medium-scale MBRs as public policy and regulation on water resources and environment tightens; (3) when the breakthrough of capacity of a single project above 10 thousand m^3/d, the Green Olympic Games and Asian Games and tightening effluent regulations in environmentally sensitive areas incentivized MBR applications; and (4) the emergence of 100,000 m^3/d MBR was mainly stimulated by water resources stress. Water resources stress and public policy related on resources and the environment are the primary driving forces in the last several decades. The future drivers of MBR applications in China appear to be decreasing operation cost.

1. Introduction

MBR applications in China started as early as 1990 (Zheng et al., 2003; Zheng et al., 2010; Huang et al., 2010; Abass et al., 2015; Xiao et al., 2014). In 1999, the first pilot scale membrane bioreactor (MBR) application in China was tested, which was used to treat industrial

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wastewater with a scale of only 10 m^3/d (Zheng et al., 2003). Since then, MBR research and applications in China have been growing dramatically in that the first MRB application with the treatment capacity of 100,000 m^3/d was commissioned within 8 years in Beijing (Zheng et al., 2010; Huang et al., 2010; Abass et al., 2015). The total capacity of large-scale MBRs (≥10,000 m^3/d) reached 1.7 × 10^6 m^3/d in 2010 (Fig. 1). Both the capacity and number of MBR applications increased rapidly. A national survey of membrane manufacturers and operators was conducted to characterize MBR applications in China. Based on the survey, the number of large-scale MBRs in China approached 192, with the total capacity exceeding 11.17 × 10^6 m^3/d by 2017. Taking the under-construction projects into account, the number of large-scale MBRs is expected to approach 210 with the total capacity exceeding 14.04 × 10^6 m^3/d by 2018. The MBR applications with a capacity of 50,000 m^3/d or more are shown in Appendix A.

Nowadays, MBR has been widely accepted and applied as an efficient wastewater treatment process in China, due to its clean effluent and rapid performance improvement in many aspects, such as membrane lifespan, fouling mitigation, and energy consumption reduction. The scientific and technical perspectives of MBR have received much attention in literature and engineering operations of MBR applications have also been investigated extensively in China (Wang et al., 2013; Liu et al., 2010; Zheng and Liu, 2006; Sun et al., 2014; Shen et al., 2012; Zheng and Liu, 2007; Zheng et al., 2005; Lv et al., 2006). A number of membrane materials and modules, such as hollow fiber membranes, flat-sheet membranes, tubular membranes, have been employed in municipal and industrial wastewater treatment facilities in China since the 2000s (Huang et al., 2010; Abass et al., 2015; Zhu et al., 2013; Zhang et al., 2008; Zhao et al., 2014; Yu et al., 2015; Wang et al., 2008). The various anaerobic-anoxic-aerobic MBR (AAO-MBR) processes for municipal wastewater treatment have been extensively investigated and denitrification on these occasions was enhanced since the 2010s, such as Hefei Tangxihe WWTP and Wuxi Chengbei WWTP (Xiao et al., 2014).

China's research on MBR technology started in 1990. The first paper on MBR technology was published in Chinese journals and introduced the application of MBR in other countries (Li, 1990). Since then, some universities and research institutes have involved in MBR research including Chinese Academy of Sciences, Tsinghua University, Tongji University, Tianjin University, Zhejiang University and Harbin Institute of Technology, etc.

The Chinese economy increased by about 9.7% per year from the Economic Reform in 1978 until 2014 to become the second largest economic body in the world (Lau and Zheng, 2017). In the last two decades, many historic events occurred in addition to the unprecedented long-term economic growth. In 2003, the severe acute respiratory syndrome (SARS), a contagious and sometimes fatal respiratory illness, occurred in

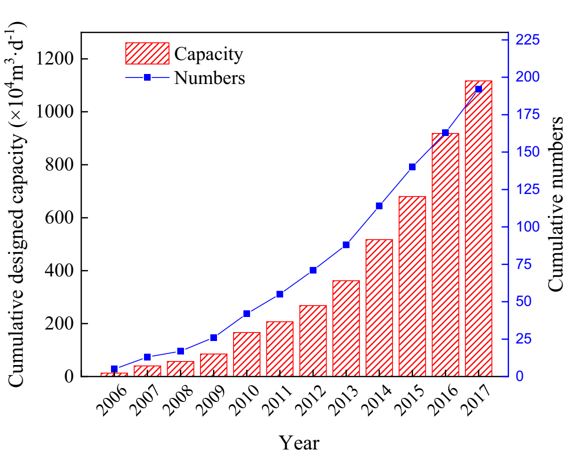

Fig. 1. Development of engineering application of large-scale MBRs (≥10,000 m^3/d) in China since 2006.

China, which highlighted the importance of public health management and drew the attention of government and public into sanitary safety (Sun and Gu, 2007). The Olympic Games in 2008 were held in Beijing and the Asian Games in 2010 took place in Guangzhou. Both events were aimed to be green games to improve the environment and promote the games (Zheng et al., 2016). In 2014, the South-to-North Water Transfer (SNWTP) project started transport water to northern China to relieve water resources stress in North China (Zheng et al., 2016). The SNWTP project is a mega-project and has far-reaching impact on social economic and environment. Are these historic events related to the rapid growth of MBR applications?

How the scientific and technical advancement of MBR and the social economic factors interact with each other and impact the MBR applications is not well understood. The driving forces and factors which have resulted in the rapid growth of MBR applications are rarely examined. The study is aimed to summarize the history of MBR applications in China since 1999. The driving forces and historic events' impact on MBR applications are examined, which is critical to the rapid growth of MBR applications. The MBR applications have been constantly impacted by the general factors in one way or another. Besides they have been promoted by the specific factors under specific historic context.

To fully analyze the driving factors, the historical development, general social economic development, water resources stress, water pollution, and historic events which may potentially impact on MBR applications are collected and examined. Published literatures are extensively reviewed to understand the research on MBR and a comprehensive national survey based on face-to-face or telephone interviews with senior scientists or executives of benchmark or major MBR applications was conducted to understand the context of those applications. Why MBR applications have been increasing dramatically in the last two decades in China? The study contributes to literature with the new understanding of MRB applications in China and provides insights of the driving forces of MRB applications. The study provides a unique observation and point of view of MBR applications in China.

2. Research on MBR

The initial researches and studies on MBR started in 1960s and the progress in the next several decades provided sound scientific and technical basis for industrial and commercial applications of large scale MBR.

In 1969, Smith first combined bench-scale membrane separation system and aerobic activated sludge process to treat municipal sewage (Smith et al., 1969). The first membrane bioreactors were developed commercially by Dorr-Oliver in the late 1960s, with application to ship-board sewage treatment (Bemberis et al., 1971). The initial designs, specifically the sidestream MBR configuration are tailored towards a direct hydrodynamic control of membrane fouling and offer the advantages of easier membrane replacement and high flux production but at the expense of high energy consumption. The typical energy consumption of sidestream MBR was 6–8 kWh·m^{-3}, almost ten times higher than conventional activated sludge process (CAS, 0.3–0.4 kWh·m^{-3}). The high energy consumption by sidestream MBR limited its applications (Le-Clech et al., 2006; Judd, 2012).

To expand MBR applications, it is vital to reduce the energy consumption by MBR. In 1989, Yamamoto invented submerged MBR and removed the circulating pump which greatly reduced energy consumption (Yamamoto et al., 1989). By the early 1990s, Zenon introduced a series of immersed hollow fiber membrane modules (Urbain et al., 1996). Over this period, Kubota also developed flat-sheet membrane products with improved overall energy efficiency, introducing a double-decker design in 2003. The energy consumption for sidestream systems is usually one or two orders of magnitude higher than that of submerged systems, regardless of whether the system is used for municipal or industrial wastewater treatments (Gander et al., 2000). Generally, the external configuration provides more direct hydrodynamic control of fouling and offers the advantages of easier membrane replacement