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Hazardous events in membrane bioreactors – Part 1: Impacts on key operational and bulk water quality parameters

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ABSTRACT

In this series of articles, the potential impacts of a number of operational 'hazardous events' on membrane bioreactors (MBRs) removal performance were investigated. The hazardous events assessed included salinity shock, 2,4-dinitrophenol (DNP) shock, ammonia shock, organic carbon shock, feed starvation, loss of power supply, loss of aeration, complete wash out of biomass, defective fibres, and physical membrane damage. This initial study focuses on the removal of key bulk water quality and operational parameters, i.e. changes in pH, turbidity, chemical oxygen demand (COD), dissolved organic carbon (DOC), biomass concentrations, capillary suction time (CST) and membrane fouling rate. DNP, salinity and organic carbon shock conditions were shown to significantly impact removal of organic matter (in terms of COD and DOC). These findings suggest that changes in COD and DOC concentrations were determined to be effective parameters for monitoring the impacts of these shock load events. Feed starvation significantly impacted biomass concentrations but the overall system performance remained relatively resilient, as it continued to achieve effective COD and DOC removals. The results from physical membrane damage experiment confirm that turbidity is an effective indicator for online monitoring of physical membrane damage. The results of this study can assist with validation of MBR processes.

1. Introduction

In many countries, meeting stringent water quality discharge requirements for sensitive streams or the implementation of water recycling treatment processes first requires validation that the process is capable of achieving water quality requirements. In order to fully validate the performance of membrane bioreactor (MBR) systems, frequently used for these applications, it is necessary to investigate their performance under various operational conditions. In the field of risk assessment, a deviation from normal operational conditions is commonly termed a 'hazardous event' [1] and investigating impacts of hazardous events on process performance is an important aspect of treatment process validation. Hazardous event is a key aspect of the risk assessment philosophy adopted by the World Health Organisation (WHO) for the application of Water Safety Plans [2] and the Guidelines for Drinking Water Quality [3]. The formalised consideration of hazardous events has been applied for a range of risk assessment and risk management applications including managing waterborne diseases [4] and managing chemical accidents [5]. Hazardous events that may affect the operation of wastewater treatment systems can include sudden changes in source water composition, extreme weather events, human error and mechanical malfunctions [6,7]. There have been a number of studies previously reporting the use of chemical shock experiments to assess the performance of conventional activated sludge (CAS) wastewater treatment processes [8–12]. However, there are currently no studies on the contribution of such hazardous events to the risk of treatment failure or underperformance in MBRs. This paper presents the first part of a series of complementary studies addressing the impacts of hazardous events including salinity shock, 2,4-dinitrophenol (DNP) shock, ammonia shock, organic carbon shock, feed starvation, loss of power supply, loss of aeration, complete wash out of biomass, defective fibres and physical membrane damage. The present work focuses on the impact of those hazardous events on the removals of

Abbreviations: MBR, membrane bioreactor; WHO, World Health Organisation; CAS, conventional activated sludge; DNP, 2,4-dinitrophenol; WWTPs, wastewater treatment plants; ATP, adenosine triphosphate; TN, total nitrogen; HRT, hydraulic retention time; SRT, solids retention time; MLSS, mixed liquor suspended solid; TMP, transmembrane pressure; PVDF, polyvinylidene-difluoride; COD, chemical oxygen demand; DOC, dissolved organic carbon; MLVSS, mixed liquor volatile suspended solid; CST, capillary suction time; SMP, soluble microbial products; EPS, extracellular polymeric substances

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key operational parameters and bulk water quality using a laboratory-scale MBR system.

Salinity shock, ammonia shock and organic carbon shock scenarios were selected for this study as they are commonly reported to exhibit short peak loads in full-scale wastewater treatment plants (WWTPs) [9,13,14]. DNP shock was selected as a representative peak load caused by electron inhibitors as it is a well-known inhibitor of efficient energy production in cells with mitochondria [15,16]. It uncouples oxidative phosphorylation by carrying protons across the mitochondrial membrane, leading to a rapid consumption of energy without generation of adenosine triphosphate (ATP) and, at high concentrations, can disrupt a variety of important bacterial metabolic processes [17–21]. The other hazardous events for MBRs selected for this investigation were identified through an expert workshop at the beginning of the study. These hazardous event studies can assist with validation of MBR processes and facilitate better environmental and human health risk management for MBR systems.

2. Materials and methods

2.1. Chemical substances

NaCl, NH_4HCO_3, DNP, glucose and glutamic acid (analytical grade) were purchased from Sigma-Aldrich (Castle Hill, NSW, Australia).

2.2. Experimental MBRs

A laboratory-scale MBR test system was comprised of four identical experimental MBRs (30 L each), fed from a single continuously-mixed influent tank (Fig. 1). Each MBR was designed to operate with a solids retention time (SRT) of 30 days, a hydraulic retention time (HRT) of 1 day resulting in an average organic loading rate of 0.32 kg COD m^{-3} d^{-1}, and a flux of 10 L m^{-2} h^{-1}. The HRT of 1 day was selected as full-scale package MBR plants in previous baseline studies usually operate at this long HRT and relatively low organic loading rate [1,22–24].The test systems were located at a local WWTP to facilitate testing with the use of primary treated effluent filling a common influent tank (200 L) daily. This filling process involved screening through a 1 mm fine screen mesh. The screened contents of the influent tank are subsequently referred to as the 'influent' to the MBR systems. Mixing in the influent tank was maintained with gentle stirring from a mechanical mixer. Characteristics of the influent is presented in Table 1. Initially, the four bioreactor tanks were seeded with biomass from an existing pilot-scale MBR operating at the same WWTP. This system had mixed liquor suspended solid (MLSS) concentrations ranging from 5 to 12 g L^{-1} and had been treating the same primary effluent for approximately one year. As such, the biomass was well acclimatised to the feed.

The influent was fed from the influent tank to the MBRs by gravity. A cistern valve was used to control the influent flow for each reactor. The aerobic chamber (20 L) of each MBR was intermittently aerated with 15 min on/off cycles to stimulate nitrification (aerobic) and denitrification (anaerobic) microbial processes. A further mechanical mixer in each aerobic chamber was used to maintain a well-mixed solution. The membrane chambers (10 L each) were

Table 1
Characteristics of the influent ($n=40$).

Quality parameters	Unit	Influent (mean ± stdev)
pH		7.4 ± 0.4
Chemical oxygen demand (COD)	mg.L^{-1}	321 ± 89
Dissolved organic carbon (DOC)	mg.L^{-1}	61 ± 32
Total nitrogen (TN)	mg.L^{-1}	87 ± 46

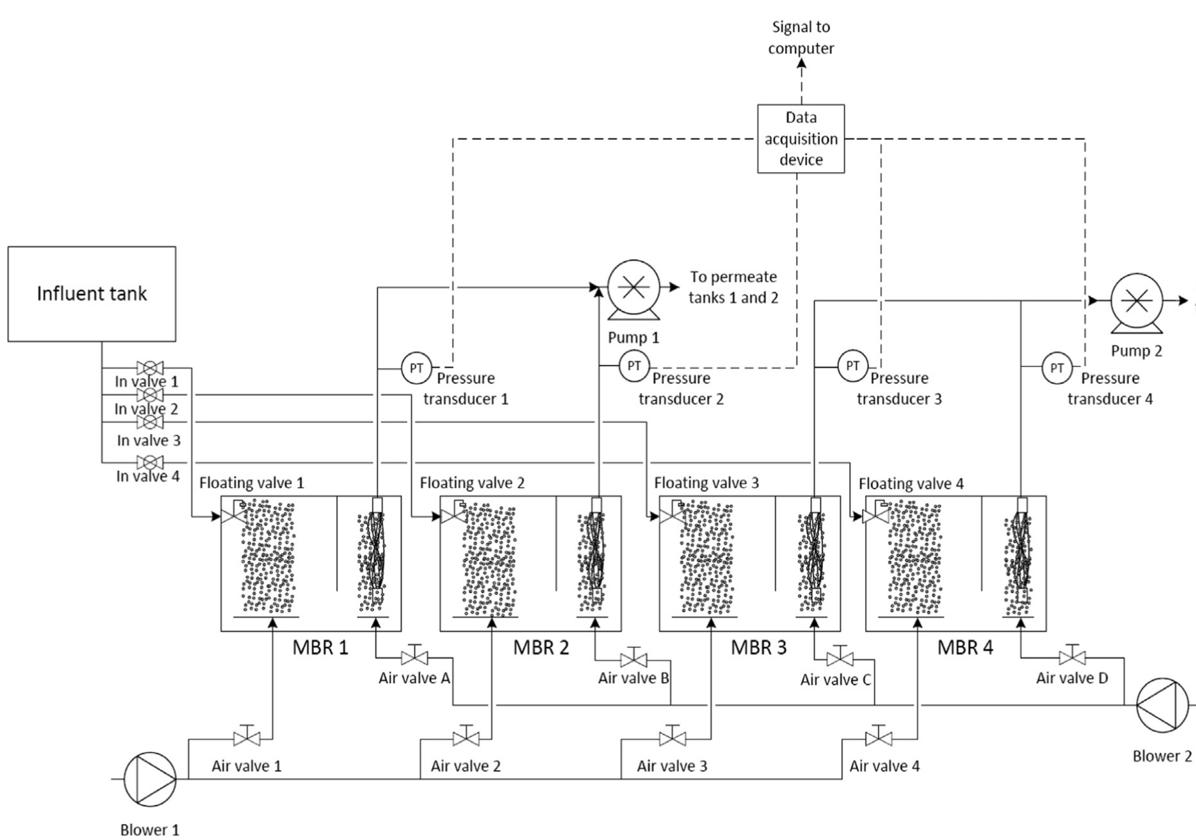

Fig. 1. Schematic illustration of the MBR system.