



# Removal of indicator bacteriophages from municipal wastewater by a full-scale membrane bioreactor and a conventional activated sludge process: Implications to water reuse

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## HIGHLIGHTS

- ▶ MBR process is more effective than CASP in the removal of bacteriophages.
- ▶ SOMCPH proves to be more resistant to MBR treatment than FRNAPH.
- ▶ BFRAGPH are not always detectable in the pre-treated effluent.
- ▶ SOMCPH are the most suitable indicators to evaluate the MBR process performance.
- ▶ SOMCPH are the most suitable indicators to evaluate the safety of the MBR effluent.

## ARTICLE INFO

### Article history:

Received 21 September 2012

Received in revised form 22 November 2012

Accepted 25 November 2012

Available online 3 December 2012

### Keywords:

Wastewater treatment

Membrane bioreactor

Water reuse

Bacteriophages

Fecal indicators

## ABSTRACT

The effectiveness of a full scale membrane bioreactor (MBR) in the removal of bacteriophages and bacterial fecal indicators from municipal wastewater was compared with that obtained by conventional activated sludge process (CASP). Somatic coliphages (SOMCPH) and F-RNA specific bacteriophages (FRNAPH) were always detected in the pre-treated effluent (mean:  $6\text{Log}_{10}$ ), while phages infecting *Bacteroides fragilis* were not always present (mean:  $3.9\text{Log}_{10}$ ). The MBR process was able to achieve respectively 2.7 and  $1.7\text{Log}_{10}$  higher reductions of SOMCPH and FRNAPH compared to CASP (significant differences:  $P < 0.05$ ). SOMCPH were found to be the most suitable indicators for assessing MBR performance, since they showed greater resistance to biofiltration than FRNAPH and a more regular distribution in pre-treated effluent than BFRAGPH. Moreover, since the traditional bacterial indicators were almost totally removed by biofiltration, SOMCPH proved to be the best indicators to evaluate the microbiological risk when MBR effluent is discharged into natural waters or reused.

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## 1. Introduction

Municipal wastewater is usually treated by a complex process that includes primary settling, biological degradation and secondary clarification. The efficiency of conventional activated sludge process (CASP) in removing pathogenic microorganisms has been investigated in several studies, which have concluded that these treatments may not be sufficient to achieve microbiologically safe effluent to be discharged into natural waters or to be reused (Koivunen and Heinonen-Tanski, 2005; Simmons and Xagorarakis, 2011; Zhang and Farahbakhsh, 2007). Notable pathogens common in secondary wastewater effluents include the environmentally resistant oocysts of *Cryptosporidium parvum*, cysts of *Giardia lamblia* and a variety of enteric bacteria and viruses. In order to reduce the po-

tential microbiological risk, the secondary effluent is generally subjected to a further tertiary treatment by sand filtration (Zanetti et al., 2006), ultraviolet and ionizing radiation (Taghipour, 2004), or, more frequently, by chemical disinfection with chlorine, ozone, and peracetic acid (Chen and Wang, 2012; De Luca et al., 2008; Koivunen and Heinonen-Tanski, 2005; Zanetti et al., 2007). The generation of harmful disinfection by-products (e.g. THM) and the persistence of disinfection residues are considered adverse environmental effects of chemical disinfection processes (Chen and Wang, 2012; Wert et al., 2007), so that increased attention has been focused on the development of techniques alternative to the conventional activated sludge treatment.

The membrane bioreactor (MBR) is considered an effective, non-hazardous advanced treatment alternative (van Nieuwenhuijzen et al., 2008). MBR is a modification of CASP, in which separation of solids is achieved without the requirement of a secondary sedimentation in settling basins. Instead this function is carried

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