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Ammonia removal in the carbon contactor of a hybrid membrane process

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ABSTRACT

The hybrid membrane process (HMP) coupling powdered activated carbon (PAC) and low-pressure membrane filtration is emerging as a promising new option to remove dissolved contaminants from drinking water. Yet, defining optimal HMP operating conditions has not been confirmed. In this study, ammonia removal occurring in the PAC contactor of an HMP was simulated at lab-scale. Kinetics were monitored using three PAC concentrations (1–5–10 g L^{-1}), three PAC ages (0–10–60 days), two temperatures (7–22 °C), in ambient influent condition (100 μg $N-NH_4$ L^{-1}) as well as with a simulated peak pollution scenario (1000 μg $N-NH_4$ L^{-1}). The following conclusions were drawn: i) Using a colonized PAC in the HMP is essential to reach complete ammonia removal, ii) an older PAC offers a higher resilience to temperature decrease as well as lower operating costs; ii) PAC concentration inside the HMP reactor is not a key operating parameter as under the conditions tested, PAC colonization was not limited by the available surface; iii) ammonia flux limited biomass growth and iv) hydraulic retention time was a critical parameter. In the case of a peak pollution, the process was most probably phosphate-limited but a mixed adsorption/nitrification still allowed reaching a 50% ammonia removal. Finally, a kinetic model based on these experiments is proposed to predict ammonia removal occurring in the PAC reactor of the HMP. The model determines the relative importance of the adsorption and biological oxidation of ammonia on colonized PAC, and demonstrates the combined role of nitrification and residual adsorption capacity of colonized PAC.

1. Introduction

Ammonia is commonly found in surface waters and groundwater. If ammonia is not removed during drinking water (DW) treatment, its presence at the final chlorination stage will be responsible for an increase in chlorine demand. Furthermore, its oxidation by free chlorine may yield taste and odor issues due to trichloramine formation. In DW production, both chemical and biological oxidation processes can be applied to

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Abbreviations: DW, Drinking water; DWTP, Drinking water treatment plant; HMP, Hybrid membrane process; HRT, Hydraulic retention time; PAC, Powdered activated carbon; PSO, Pseudo-second order; PNA, Potential nitrifying activity; SW, Settled water.

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remove ammonia. Biological treatment of DW has gained acceptance in the last 20 years because of its attractive cost and ability to meet multiple water quality criteria (e.g. reducing organic carbon concentration allowing lower disinfection byproducts formation at the post chlorination stage and DW biostability in distribution systems) (Prévost et al., 2005). Ammonia removal by nitrification (Andersson et al., 2001) is another advantage of biological treatment.

The hybrid membrane process (HMP), which couples a high concentration powdered activated carbon (PAC) contactor with low-pressure membranes, stands out as one of the most promising solutions to reach the targeted low concentrations of dissolved contaminants (Kim et al., 2005). Most of the published literature on HMPs is based on the use of PAC as adsorbent (Stoquart et al., 2012), which allows efficient removal of natural organic matter (NOM) as well as trace organic contaminants (e.g. algal toxins, pesticides, pharmaceuticals) by maintaining a low PAC retention time (PAC age < 7-d). Although adsorption of ammonia on activated carbon is typically considered marginal (Bandosz and Petit, 2009), increasing the PAC retention time in the carbon contactor allows its colonization by heterotrophic and nitrifying bacteria (Stoquart et al., 2013). Under such operating condition, it is hypothesized that NOM and ammonia removals are achieved by a combination of adsorption and biodegradation. Increasing the PAC age offers the additional benefit of drastically reducing the operating costs by minimizing the virgin PAC consumption rate.

Under warm water conditions (i.e. superior to 8.5 °C as defined in Léveillé et al. (2013), nearly complete ammonia removal was observed inside the reactor of an HMP containing 10 g L^{-1} of colonized PAC. However, as temperature drops, the metabolism of nitrifying bacteria slows down (Andersson et al., 2001) and the efficiency of the HMP using colonized PAC is reduced (Suzuki et al., 1998). Nevertheless, the HMP was demonstrated to have the potential to enhance its performance in cold waters by increasing the PAC concentration and/or contact time (Markarian et al., 2010). Adsorption and, to a larger extent, nitrification are the mechanisms potentially responsible for ammonia concentration mitigation in the HMP. However, no information is presently available in the literature to distinguish the respective contribution of both mechanisms to ammonia removal. Previous studies highlighted that PAC age, PAC concentration and the hydraulic retention time (HRT) were key variables to predict the removal of dissolved compounds (Markarian et al., 2010). We hypothesize that these variables as well as temperature influence the relative importance of both adsorption and nitrification. Discriminating the role of each mechanism is thus crucial to describe the performance of the HMP.

In this study, experiments simulating the kinetics of ammonia removal occurring in the PAC reactor of an HMP were conducted at lab-scale. The contact time, the temperature, the age and the PAC concentration inside the reactor were the parameters under investigation. Efficiency of the PAC contactor was studied using settled water (SW) originating from a full scale surface water treatment plant. Based on the experimental data, a kinetic model was developed accounting both for adsorption and nitrification. The proposed model provides a better understanding of the process and thus will allow enhancing the quality of the treated water while reducing the operating costs.

2. Material and methods

2.1. *Powdered activated carbon samples*

A wood-based PAC (Picahydro LP 39) was used (median diameter 15–35 μm). This meso-to macroporous PAC was chosen to favor biomass growth. PAC colonization was realized in two industrial HMP pilot facilities described in Léveillé et al. (2013). Briefly, ultrafiltration membranes were immersed in a PAC suspension. Daily purges of a fraction of the PAC content and its replacement by the same amount of virgin PAC allowed maintaining the average age of PAC stable in the carbon contactor of the pilot-plant. Ages referred to in this manuscript thus correspond to the average PAC retention time of a distribution of ages in the suspension. Theoretical age distributions are presented in Fig. 1. In both parallel reactors, PAC ages were maintained respectively at 10-d and 60-d with the following targeted operating concentrations: 4 g L^{-1} (3.5 ± 1.2 g L^{-1}) for the 10-d and 10 g L^{-1} (9.8 ± 1.1 g L^{-1}) for the 60-d. These ages allowed the PAC colonization by heterotrophic and autotrophic nitrifying bacteria. Both HMP contactors were operated with an HRT of 67 min. The PAC contactors were fed with settled water from the Ste-Rose DW treatment plant (DWTP) (Laval, Qc, Canada) (pH = 6.77 ± 0.24; turbidity = 0.7 ± 0.1 NTU (method 2130B, (American Public Health Association (APHA) et al., 2012)); UV254 = 0.062 ± 0.009 cm^{-1} (method 5910B, (American Public Health Association (APHA) et al., 2012)); DOC = 3.44 ± 0.24 mgC L^{-1} (method 5310C, (American Public Health Association (APHA) et al., 2012)); alkalinity = 20 ± 2 mg $CaCO_3$ L^{-1} (method 2320B, (American Public Health Association (APHA) et al., 2012))). The water temperature in the pilot-plant varied with the temperature of the feed water (3 °C–25 °C). Operating the PAC contactor under contrasted temperature conditions produced aged PACs acclimated to these temperature conditions.

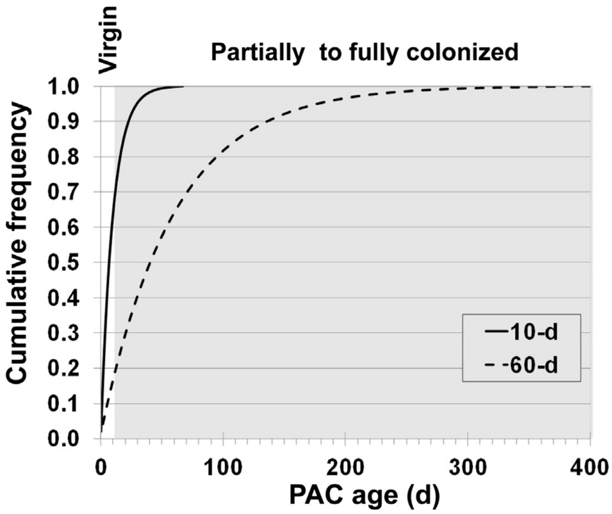

Fig. 1 – Theoretical cumulative frequency distribution of PAC age for the 10-d and 60-d PAC suspensions.