A MATHEMATICAL MODEL DESCRIBING DENITRIFICATION COUPLED TO AEROBIC METHANE OXIDATION

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1. Introduction
Methane could potentially be used as external carbon source for denitrification of wastewaters or leachates. There are methanotrophic denitrifiers (e.g. Kampman et al. 2014); however, they are slow-growing and difficult to enrich. In this study, we instead focus on aerobic methane oxidation coupled to denitrification.

2. Aerobic methane oxidation coupled to denitrification
The process is carried by aerobic methanotrophs that oxidize methane and release soluble microbial products, which are organic substances that can be used by co-existing facultative heterotrophs for denitrification (see Fig. 1 below).

3. Goal of the study
Aerobic methane oxidation coupled to denitrification has been investigated in several studies using different types of reactor systems. Membrane biofilm reactors have been shown to be especially effective (Modin et al. 2008). Methane (and optionally oxygen) are supplied from the interior of a membrane, to a biofilm growing on the membrane surface (Fig. 2).

The goal of this study is to develop a mathematical model describing aerobic methane oxidation coupled to denitrification, and use the model to investigate how factors such as intramembrane partial pressures of methane and oxygen affect nitrate removal in the process.

4. Results of model simulations
We used the model to simulate the growth of a biofilm on a tubular silicone membrane (ID=0.5mm, OD=1.0mm) for a time period of 35 days. The effect of changing the intramembrane partial pressures of CH₄ and O₂ between 21 and 42 kPa was investigated. If both CH₄ and O₂ are fed from the interior of the membrane at 21 kPa, an anoxic layer is formed in the outer part of the biofilm and denitrification accounts for 82% of the total nitrate removal rate, which is 0.29 mol/m²·d. If the intramembrane oxygen pressure is increased to 42 kPa, the entire biofilm is aerobic and denitrification only accounts for 23% of the total nitrate removal rate, which is 0.07 mol/m²·d. (Note that the calculation of denitrification also includes NO₃⁻ assimilation by facultative heterotrophs).

Fig. 1. The aerobic methane oxidation coupled to denitrification process.

If O₂ is fed from the bulk liquid instead of the membrane, the concentration profiles change significantly (Fig. 5). The interior of the biofilm becomes anoxic and allows denitrification to take place.

5. Comparison to experimental data
We used data from Modin et al. (2010) who operated a membrane biofilm reactor for 37 days with both CH₄ and O₂ fed from the interior of the membrane. The first 23 days the CH₄/O₂ partial pressures were 24/46 kPa. From day 23 to 37 the partial pressures were 37/78 kPa. Although the biofilm thickness is similar to the experimental values, the predicted nitrate removal is initially significantly lower than the measured values in the initial period of the run.

6. Discussion and conclusions
This is the first attempt to develop a mathematical model describing the aerobic methane oxidation coupled to denitrification process. Here, we have used the model to investigate the effect of different gas supply regimes on nitrate removal and denitrification in membrane biofilm reactors. The model could potentially also be used to examine different types of reactor setups and to investigate the microbial interactions in the process in greater detail (e.g. to quantify the carbon transfer between methanotrophs and heterotrophs). When the model was applied to experimental data it underpredicted nitrate removal rates despite realistic prediction of biofilm thickness. Further work is needed to analyze the sensitivity of various model outputs to the input parameters.

References