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Oxygen transfer in membrane bioreactors treating synthetic greywater

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ABSTRACT

Mass transfer coefficients (k_La) were studied in two pilot scale membrane bioreactors (MBR) with different setup configurations treating 200 L/h of synthetic greywater with mixed liquor suspended solids' (MLSS) concentrations ranging from 4.7 to 19.5 g/L. Besides the MLSS concentration, mixed liquor volatile suspended solids (MLVSS), total solids (TS), volatile solids (VS), chemical oxygen demand (COD) and anionic surfactants of the sludge were measured. Although the pilot plants differed essentially in their configurations and aeration systems, similar α-factors at the same MLSS concentration could be determined. A comparison of the results to the published values of other authors showed that not the MLSS concentration but rather the MLVSS concentration seems to be the decisive parameter which influences the oxygen transfer in activated sludge systems operating at a high sludge retention time (SRT).

1. Introduction

Water scarcity, poor water quality and water related catastrophes are the three main concerns related to current and future water resources. Improving water quality and reducing water scarcity may be reached throughout a consequent greywater management, since greywater comprises 30–70% of the total urban water demand.

Within the project "semi-centralized supply and disposal systems for urban areas" two membrane bioreactor pilot plants were built up and operated in parallel to study their performance for greywater treatment.

The α-factor, the ratio of process water to clean water oxygen mass transfer coefficient, is important for the design of any aeration device in wastewater treatment plants. Hence it was one aspect of this project to study its dependency on different aeration devices (coarse bubble, fine bubble), the MLSS concentrations and the effect of high anionic surfactant concentrations in the influent.

Many factors influence oxygen transfer mechanisms in activated sludge systems. Kessener and Ribbius (1935) reported about the negative impact of surfactants on the α-factor. Stenstrom and Gilbert (1981), Gurol and Nekouinaini (1985), Wagner and Pöpel (1996), Steinmetz (1996) and Chern et al. (2001) summarized and investigated the effects of various parameters like aeration systems, surfactants, suspended solids, turbulence, scale up, salt content, temperature, dissolved organic carbon, nitrogen and phosphorous compounds, substrate shocks and DNA content on the α-factor. Krampe and Krauth (2003), Rosenberger (2003), Krause (2005) and Germain et al. (2007) were among others who investigated the role of the MLSS concentration on the oxygen

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transfer in membrane bioreactors. They all conclude that with increasing MLSS concentration the α-factor is reduced. However, comparing the obtained results, a large variation of α-factors ranging from 0.2 to 0.6 at a similar MLSS concentration of 13 g/L can be found. This wide range made any prediction of α-factors impossible.

The aim of this paper is to introduce a method for a better correlation of the α-factor at high SRT at different MLSS concentrations. Two membrane bioreactor pilot plants (Fig. 1) were operated in parallel and fed with the same greywater influent. Oxygen transfer tests were performed at different MLSS concentrations and with different aeration devices (fine bubble, coarse bubble, combination of both). Additionally oxygen transfer test was conducted in a lab scale column with sludge, washed sludge, filtrated supernatant and the supernatant after oxygen transfer test in sludge to study the influence of the liquid phase and the solid phase separately.

2. Materials and methods

2.1. Oxygen transfer measurement methods

Mainly three different ways of determining the oxygen transfer in activated sludge systems are applied in praxis: the off gas method, the absorption/re-aeration method and the desorption method.

Gillot et al. (2005) and Krause et al. (2003) described the theoretical principles in detail. Capela et al. (2004) compared these three methods under different process conditions. The experiments revealed that the re-aeration method showed the greatest deviation compared to the results obtained from the off gas and desorption method. Finally it is concluded that the off gas method is the method of choice. However the off gas method is limited to an oxygen concentration of <50% of the oxygen saturation concentration in the liquid (Krause et al., 2003; DWA, 2007). As the oxygen concentration ranged from 8 to 5 mg/L and the saturation concentration was around 8.4 mg/L during the experiments, the off gas method was not applicable and the desorption method described by Wagner et al. (1998) was chosen as the appropriate method for measuring the k_La. During this test it is compulsory to maintain constant respiration rates. To avoid an effect of inflow variations on the oxygen transfer measurements, the inlet and effluent of the membrane bioreactor were shut off.

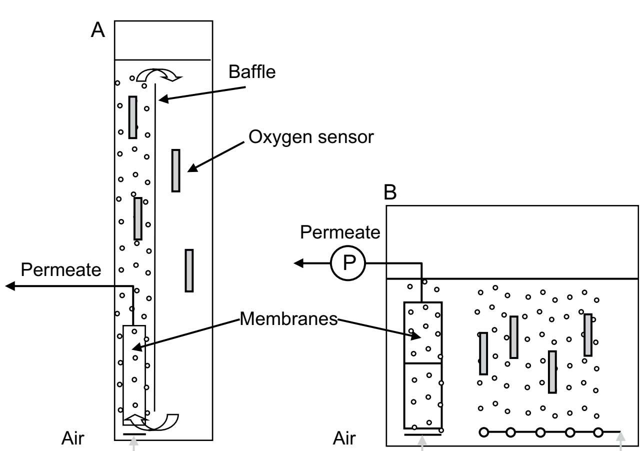

Fig. 1 – Membrane bioreactor configuration and oxygen transfer sensor position.

2.2. Concept of the membrane bioreactors

Fig. 1 shows the concept of the two membrane bioreactor. Reactor A had a water volume of 2.6 m^3 (2.5 m water depth) and was equipped with only one diffuser for crossflow and biological aeration. The aeration system induced a recirculation flow, superseding an additional mixing device (airlift reactor). A fine and a coarse bubble diffuser were tested during the experiments. The membrane area of the hollow fibre module was 20 m^2 with a pore size of 0.1 μm.

Reactor B was equipped with five fine bubble diffusers, which were homogeneously distributed and six coarse bubble diffusers for the crossflow. The water volume was 3.15 m^3 (1.25 m water depth). The flat sheet membranes (12 modules) had an area of 24 m^2 with a pore size of 0.1 μm. The net flux in both systems was approximately 10 L/(m^2 h).

The greywater load was 1.7 $m^3_{greywater}/(m^3_{reactor}\,d)$ for reactor A and 2 $m^3_{greywater}/(m^3_{reactor}\,d)$ for reactor B. The organic load was 1.5 kg COD/d and 1.8 kg COD/d, respectively. The calculated SRT ranged between 110 d (MLSS = 19.5 g/L) and 24 d (MLSS = 4.7 g/L).

3. Experimental procedure

3.1. Pilot scale experiments

The composition of the synthetic greywater was chosen according to the consumption of personal care products in private households in Germany (Chang, 2007). The mixture contained toothpaste, shower gel, soap, oil, shampoo, bubble bath, washing powder, other washing agents and softener. 3% raw wastewater was added to simulate the hygienic contamination.

The total operation time of the pilot plants was 18 months and the oxygen transfer measurements in the sludge took about 6 months.

Clean water tests with drinking water were performed before beginning the inoculation with activated sludge and at the end of the total operation time.

Four test series were performed: Reactor A with coarse bubble crossflow, reactor A with fine bubble crossflow, reactor B with fine bubble aeration, and reactor B with fine bubble aeration and coarse bubble crossflow. The bubble size from the fine bubble diffusers was smaller than 3 mm. The coarse bubble diffusers produced bubbles bigger than 20 mm.

For the test series both membrane bioreactors were operated for about 3 months without sludge removal until the maximum tested MLSS concentration was reached. After each test, the MLSS concentration was lowered by sludge withdrawal to the desired MLSS concentration for the next test. After withdrawal the pilot plant was operated for 2–3 days under normal conditions before the oxygen transfer tests were started.