Numerical investigations of the hydrodynamics and the oxygen mass-transfer in aerated tanks

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The present work concentrates on numerical investigations of the hydrodynamics, the oxygen mass-transfer, and the biochemical reactions in a pilot-plant-scale aeration tank, engaging the Euler-Euler method and the Activated Sludge Model No. 1. The oxygen concentration, the ammonium concentration, and the nitrate concentration are discussed using results from the experimental investigations at the pilot-plant-scale aeration tank in the waste-water-treatment plant Ebersbach carried out by the HZDR.

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Proceedings in Applied Mathematics & Mechanics published by Wiley-VCH Verlag GmbH & Co. KGaA Weinheim

1 Introduction

Aeration tanks represent a major energy consumer in municipal waste-water-treatment plants. To increase their efficiency, numerical investigations are conducted to capture the hydrodynamics, the oxygen mass-transfer, and the biochemical reactions in the aeration tank. Numerical computations offer the opportunity to test system configurations and operating modes without cost-intensive reconstruction work. To generate a reliable foundation for these investigations, measurement data from a pilot-plant-scale aeration tank are compared with the results of the numerical computations.

2 Numerical Model

To compute the hydrodynamics, the oxygen mass-transfer, and the biochemical reactions in the pilot-plant-scale aeration tank with a stationary simulation the model of Meier [1] is adapted. This model engages the Euler-Euler method and calculates the activated sludge as continuous phase and air as mono-disperse phase within ANSYS CFX. The biochemical reactions in the activated sludge are calculated using the Activated Sludge Model No. 1 [2].

In the experimental setup, the inflowing activated sludge is taken from the denitrification region out of the real-scale aeration tank in the Ebersbach waste-water-treatment plant. This waste-water-treatment plant uses an aeration tank with preceding denitrification. In contrast to the simulations by Meier [1], in this case the composition of the inflowing activated sludge differs from that of waste water. For this reason, the composition of the chemical oxygen demand (COD) in the activated sludge after preceding denitrification in an aeration tank.

Table 1: Composition of the chemical oxygen demand (COD) in activated sludge after preceding denitrification in an aeration tank.

| Component                  | \(w/\) \(g\) \(g\) \(\text{COD}^{-1}\) |
|----------------------------|-------------------------------------|
| Slowly biodegradable organic matter | 0.014                                |
| Readily biodegradable organic matter | 0.006                                |
| Heterotrophic biomass       | 0.343                                |
| Inert particulate organic matter | 0.387                                |
| Soulable inert organic matter | 0.011                                |
| Autotrophic biomass         | 0.025                                |
| Particulate products        | 0.214                                |

Table 2: Inlet boundary condition for the activated sludge.

| \(V_{\text{air}}/m^3\) \(h^{-1}\) | 4.3 | 6.3 | 7.6 | 10.0 |
|-----------------------------------|----|----|----|-----|
| COD /mg L\(^{-1}\)               | 2264 | 2340 | 2283 | 2264 |
| \(c_{\text{ammonium}}/\text{mg L}^{-1}\) | 4.30 | 3.53 | 3.14 | 3.60 |
| \(c_{\text{nitrate}}/\text{mg L}^{-1}\) | 4.10 | 7.38 | 3.09 | 2.65 |
| \(d/\text{mm}\)                 | 2.77 | 2.98 | 3.12 | 3.38 |

3 Results

The following figures show the results of the numerical calculations with an volumetric air flow rate \(V_{\text{air}} = 10 m^3 h^{-1}\) and a bubble diameter of \(d = 3.38 mm\). Figure 1 (a) shows the streamlines of the air bubbles and the flow structure of the...
activated sludge as vectors. The air rises from the diffuser surfaces to the top of the tank and the bubbles are distracted to the middle of the tank. The flow structure of the activated sludge can be described by two vortexes. Figure 1 (b) shows the dissolved oxygen concentration. A higher dissolved oxygen concentration can be recognized in the second vortex. Figure 1 (c) shows the ammonium concentration and figure 1 (d) the nitrate concentration. A high ammonium inlet concentration and an almost complete ammonium degradation appears already in the first vortex. Consequently, the nitrate concentration rises in the first vortex and is higher in the second vortex. This correlates with the results of the dissolved oxygen concentration in figure 1 (b). The nitrification process consumes oxygen to oxidize ammonium to nitrate. Hence, both ammonium and oxygen are degraded, while nitrate is produced. Due to the almost complete ammonium degradation in the first vortex, the oxygen concentration is higher in the second vortex.

Fig. 1: Vector plot of the activated sludge velocity (a), oxygen concentration (b), ammonium concentration (c), and nitrate concentration (d) in vertical sections above the diffusers in the back part of the tank and in a horizontal section at half tank height. Additionally, the bubble streamlines are shown in (a). The activated sludge inlet and outlet are shown by arrows. The measurement point is marked by a cross.

Figure 2 shows a comparison of the ammonium concentration (left) and the nitrate concentration (right) at the measurement point, marked in figure 1, for different volumetric air flow rates. A decreasing ammonium concentration for rising volumetric air flow rates can be seen. The ammonium concentration is well calculated by the simulations, except for the lowest volumetric air flow rate. The simulation calculates higher nitrate concentrations in comparison to the measurements but the trend of the nitrate concentration is well represented.

Fig. 2: Comparison of the measured ammonium concentration (left) and nitrate concentration (right) with the simulation results at the measurement point, shown in figure 1.

4 Conclusion and future works

Numerical calculations of the hydrodynamics, the oxygen mass-transfer, and the biochemical reactions in pilot-plant-scale aeration tank following the Euler-Euler method are presented. To characterize the inflowing activated sludge, the composition of the activated sludge after the denitrification of the real-scale aeration tank with preceding denitrification is determined. The flow structure in the pilot-plant-scale aeration tank is discussed, as well as the dissolved oxygen concentration, the ammonium concentration, and the nitrate concentration. The computed results show the expected behavior.

In further work, simulations for the optimization of the aeration tank shall be the focus.

Acknowledgements This research was supported by DBU with the reference number 30799. We thank our colleagues from HZDR for the experimental data and the fruitful collaboration.

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