Energy savings by reduced mixing in aeration tanks: results from a full scale investigation and long term implementation at Avedoere wastewater treatment plant

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ABSTRACT

The aim of this project was to investigate the potential of reducing number of mixers in the biological treatment process and thereby achieve energy and economical savings and contribute to cleaner environment. The project was carried out at Avedoere wastewater treatment plant and a full scale investigation was conducted to study the effect of reduced mixing on flow velocity, suspended solid sedimentation, concentration gradients of oxygen and SS with depth and treatment efficiency. The only negative effect observed was on flow velocity; however the velocity was above the critical velocity. The plant has been operating with 50% of its designed number of mixers since September 2007 and long term results also confirm that reduced mixing did not have any negative effect on treatment efficiency. The estimated yearly electricity saving is 0.75 GWh/year.

Key words | aeration tanks, biological treatment, electricity saving, energy, mixing

INTRODUCTION

Every effort to reduce energy consumption will help in stabilizing atmospheric GHG concentrations (IPCC 2007) and wastewater treatment is one of the areas with great potential for energy savings. Based on experience from various projects, the Danish Hydrological Institute estimated that approximately 40% of energy savings can be achieved at wastewater treatment plant (WWTP) and the greatest potential (66–68%) lies in aeration and mixing in the biological reactor (DANVA 2010). This is due to several factors like high safety design factors resulting in excess mixing capacity, improved knowledge about treatment processes with time, and availability of new and improved technologies.

The Avedoere wastewater treatment plant (AWWTP) is the third largest WWTP in Denmark, serving a population of about 260,000 inhabitants plus industry, and Figure 1 shows the % energy consumption for various processes. The figure shows that mixing in the aeration tanks alone accounts for 9% of the total energy consumption at AWWTP. There are many treatment plants in Denmark, that are operated with no mixing during denitrification phase, whereas the mixers at Avedoere run all the time except when the plant operates with aeration tank settling (ATS) process during high hydraulic loads. During this process the mixers are partially stopped to allow settling. The results from studies operating with ATS show that the ATS operation did not deteriorate the effluent quality (Bundgaard et al. 1996; Nielsen et al. 1996; Pedersen et al. 2007). The results from ATS operation cannot directly be applied to WWTP under normal operation, because ATS is a control strategy only active during stormwater events, where the quality of the incoming wastewater is different from normal wastewater and the main aim during ATS operation is to treat as much water as possible to avoid overflows. Both the operation of other WWTP in Denmark without mixing during denitrification phase and the results from ATS at Avedoere show some potential of energy savings by reduced mixing.

The main purpose of the mixers in aeration tanks at AWWTP is to give sufficient flow velocity and to attain complete mixing. Reducing number of mixers could result in decrease in flow velocity and insufficient mixing. Decrease in flow velocity may further result in sedimentation of suspended solids (SS). Further, insufficient mixing may
also result in adverse conditions such as increase in unaerated zones during nitrification and stratification of suspended solids both during nitrification and denitrification, and in the end affect the treatment efficiency. The available literature shows that (study by Wett et al. cited in Williams & Beresford 1998; Nielsen et al. 2000) introduction of mixing in the denitrifying clarifiers had no effect on the reaction rates, whereas another study by Kazmi & Furumai (2000) demonstrated that denitrification rate was reduced by 40% with no mixing and under mass transfer limiting conditions. According to Henze et al. (2008), there is an upper limit for unaerated mass fraction, above which an increase in unaerated zone may result in reduced nitrification capacity, filamentous bulking, and poor sludge settling properties. Changes in nitrification/denitrification also affect the biological P-removal (Ingildsen et al. 2006).

A project was initiated in 2006 at AWTP to investigate the potential of reducing number of mixers in the biological treatment process without compromising on effluent quality and thereby achieve energy and economical savings and contribute to a cleaner environment. Full scale investigations were conducted to investigate the potential of reducing number of mixers and the effect of reduced mixing was evaluated by studying the effect on flow velocity, sedimentation of SS, concentration gradients with depth for oxygen and SS, electricity consumption, chemical consumption and treatment efficiency with respect to chemical oxygen demand (COD), total nitrogen (TN) and total phosphorus (TP).

**METHODS AND PLANT DATA**

The plant’s designed capacity is 345,000 PE (1 PE = 60 g BOD/d) and it has tertiary treatment with biological nutrient removal as well as chemical phosphate (P) removal using iron. The plant has four parallel lanes, each consisting of two aeration tanks and two secondary settlers. The biological nutrient removal is based on the BioDenitro principle (Bundgaard et al. 1989). Iron based chemical (PIX 118 from Kemira) is added for removal of remaining phosphorus. Both the biological and chemical processes run in practice by online control using STAR® Control (Nielsen & Lynggaard-Jensen 1993), where one of the lanes is chosen as master lane and the other three lanes run as slave lanes.

Each aeration tank is 175 m long, 8 m wide and 3.5 m deep with a total volume of 9,700 m³. Figure 2 shows the position of mixers, surface aerators and dissolved oxygen sensors in aeration tanks. Aeration is achieved by mechanical surface aerators. According to the design guidelines, a mixing intensity of 3 W/m³ is required to keep the solids in suspension (Krüger 2009), and in practice this is achieved by eight mixers (Flygt 4430) with 4 kW effect resulting in a
mixing intensity of 3.3 W/m³. The yearly electricity consumption for the mixers is 1.5 GWh/year. The difficulty in conducting full scale experiments is unpredictability in load, and therefore two lanes were chosen for conducting the experiments: one lane as a reference lane (RL) and the other lane as an experimental lane (EL). Except for mixing capacity all the other factors were kept identical for both the lanes. The experiments were conducted with a Reference Period followed by an Experimental Period. In the Reference Period both the lanes were operated with identical number of mixers, i.e., eight mixers in each tank. The Experimental Period was conducted in two stages. In Stage 1 mixers 7 and 8 were completely stopped and in Stage 2 an additional two mixers (mixers 3 and 4) were stopped in EL. These mixers were chosen in collaboration with the manufacturer Flygt and, according to the manufacturer, the effect introduced by these mixers is less than the other mixers (Jensen 2007). The effect of reduced mixing was evaluated by comparing the results for RL with results for EL for: flow velocity, sedimentation of SS, concentration gradients with depth for oxygen and SS, electricity consumption, chemical consumption and treatment efficiency with respect to COD, TN and TP.

The effect of reduced mixing on flow velocity, oxygen concentration and SS concentration is investigated along sections XX', YY', AA' and BB' in Figure 2 both during nitrification and denitrification phases.

To study the effect on oxygen concentration gradient, the sections XX', YY', AA' and BB' were divided into five horizontal positions similarly to the study with flow velocity, whereas only three vertical (0.5; 1.8; 3.1 m below water level) positions were chosen because of restrictions in points for data transfer. For each horizontal position the oxygen concentration was measured simultaneously at the three vertical positions for 2 days using an assembly unit with three Hach-Lange LDO. Apart from these LDO sensors the cross section is equipped with an oxygen meter, which is permanently placed at the middle of the section (4 m from centre wall) and 0.4 m from water level.

The experiments to study the effect on SS concentration gradient were conducted by collecting 100 ml samples simultaneously from the three depths using a peristaltic pump at similar positions, as in the case of oxygen, and SS was analysed according to Danish standard method DS 207 (DS 207 1985).

The effect on treatment efficiency was investigated by intensive measuring campaigns, where 24 h time proportional samples were collected for at least 3 days for both inlet and outlet water samples from the two lanes. Inlet wastewater samples were collected to investigate the difference between the loads and the investigated parameters were: flow, NH₄-N, TN, TP, PO₄-P and COD. The parameters investigated in the effluent were: flow, NH₄-N, NO₃-N, TN, TP, PO₄-P and COD. The test kits (from Hach-Lange) used for the analyses of these parameters were: NH₄-N: LCK 303 and LCK 304; NO₃-N: LCK 339; TN: LCK 138; TP and PO₄-P: LCK 349; COD: LCI 500.

The long term effect of reduced number of mixers was evaluated based on the daily measurements for flow, electricity consumption and iron dosage data.
RESULTS AND DISCUSSION

Flow velocity

The obtained flow velocities during nitrification and denitrification with complete stop of mixers 7 and 8 at section XX' are shown in Figures 3(a) and (b) respectively. These results show that the flow velocity was always above 0.2 m/s except during denitrification and at 0.4 m depth. When the plant was designed in 1989, the number (in 1989) and type of mixers were chosen based on a design critical flow velocity of 0.3 m/s. However, since AWTTP consists of primary settlers, new evidence shows that the critical flow velocity can be reduced to 0.2 m/s (Krüger 2009). Since it is the velocity in deeper layers that is more critical with respect to sedimentation of SS, it could be concluded that the achieved flow velocities during nitrification and denitrification due to stopping of four mixers are acceptable.

The results further show that the flow velocities decrease with increase in depth during nitrification phase, whereas they increase with depth during denitrification. The decrease in velocity with increase in depth is due to the fact that the aeration during nitrification is achieved by surface aerators, and running of surface aerators increases the surface velocity.

Oxygen concentration gradient

Effect of reduced mixing on oxygen concentration along section XX' is shown in Figure 4, where Figure 4(a) shows results for RL without stopping of mixers and Figure 4(b) shows results for EL with complete stopping of mixers 7 and 8. The measured oxygen concentration at different depths (O_2D) is normalized by dividing oxygen concentration measured using the stationary oxygen meter (O_2S) and is shown on Y-axis. Oxygen concentration at each horizontal position is shown as a plot on X-axis, where the length of the X-axis is proportional to the duration of measured nitrification phase, which in turn is proportional to the load. Since load to the treatment plant depends on the time of the day, the plotted oxygen concentration at each horizontal position was selected at the same time of the day to achieve as much similar loads as possible for all the horizontal positions. However, this was not possible for the horizontal positions 2.85 m and 3.85 m from the centre wall. The obtained results show that the highest oxygen concentration gradient with depth is in the middle of the tank and gradually decreases towards the end irrespective of number of mixers running. The results further show that the oxygen concentration in the middle of the tank is only 20% or lower at depth ≥1.3 m below water level for a substantial period of a nitrification phase irrespective of number of mixers running. The results from horizontal positions 0.4 m and 7.3 m, i.e., near the ends of the tank, show that the oxygen concentration was constant throughout the depth in EL (reduced mixing) compared to RL, indicating better conditions for nitrification with reduced mixers compared to full mixers. Therefore, based on this, it could be concluded that reduced mixing will not result in any negative effect on nitrification in the form of increased oxygen concentration gradients with depth resulting in increased anoxic zone.

SS concentration gradient

Figure 5 shows % difference in SS concentrations at depths 1.8 m and 3.1 m (SS_d) compared to SS concentration at

![Figure 3](https://iwaponline.com/wst/article-pdf/64/5/1089/444505/1089.pdf)
depth 0.5 m ($SS_{0.5}$) with reduced mixing by complete stopping of mixers 7 and 8 during nitrification and denitrification phases. The results show that the % difference between $SS_{0.5}$ and $SS_d$ is below 5%, which is below the analytical accuracy, and there is no indication of decrease in SS concentration with increased depth. Therefore, based on this, it can be concluded that the changes occurring due to reduced mixing will not result in decreased SS concentrations with increased depth.

**COD, TN and TP treatment efficiency in full scale experiments**

The effect of reduced mixing on COD, TN and TP treatment efficiency is investigated by comparing the results for RL with EL, and the obtained results for COD, TN and TP are shown in Figure 6. The figure shows average difference in % removal between RL and EL and standard deviation for Reference Period, Stage 1 and Stage 2. Difference is
calculated using the formula \((RL-EL)/RL\). The results show that the % COD removal is generally better in EL compared to RL for all the three experiments and there is an indication that the COD removal efficiency increases with reduced mixing. The results for TN show better removals with stopping of two mixers (Stage 1) compared to all mixers running, whereas stopping of four mixers (Stage 2) resulted in lower TN removals compared to Reference Period and Stage 1. The standard deviation for the results for Stage 2 was also very high. The results for TP show slightly better removal for Reference Period compared to Stage 1, whereas better removals were obtained for Stage 2 compared to Stage 1 and Reference Period. This is in contrast to the results obtained for TN. Based on the conducted experiments it is difficult to explain the observed trends for COD, TN and TP removals. However, since the obtained results did not show any considerable negative effect on treatment efficiency for all the parameters, it was concluded to run the treatment plant with reduced number of mixers.

**Long term results from implementation of 50% reduced mixing at the WWTP**

Based on the results from full scale investigations it was decided to reduce the number of mixers in all the lanes at the WWTP, and this was implemented in two stages: Stage 1 with 25% reduced mixing in three lanes (i.e. stopping of two mixers in each tank) during February–September 2007 and stage 2 with 50% reduced mixing in all lanes (i.e. stopping of mixers in each tank) since September 2007. The results from stage 2 are only shown until March 2008, because the WWTP underwent some process changes after this period and hence the results after March 2008 cannot be compared. COD, TN and TP concentrations in the outlet were measured approximately every fourth day and electricity and chemical consumption were measured

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**Figure 6** | Effect of reduced mixing on COD, TN and TP in the effluent during Reference Period (no Reduced mixing) and Experimental Period with Stage 1 (two mixers stopped) and Stage 2 (four mixers stopped).

**Figure 7** | Long term results on effect of reduced mixing on COD, TN and TP in effluent.

**Figure 8** | Long term results on effect of reduced mixing on electricity consumption and consumption of Fe\(^{3+}\) for removal of phosphate.
every day and the results are shown in Figures 7 and 8, respectively. Figure 7 shows slightly lower TN, COD and TP concentrations in the outlet, indicating better removal efficiency. Figure 8 shows clearly that the electricity consumption was decreased during reduced mixing. The long term effect of reduced mixing on sedimentation of SS was investigated at the end of 6 months experimental period (four mixers stopped) and the results from these experiments showed no such effect.

CONCLUSIONS

Based on the results from extensive full scale investigations and long term operation of the WWTP with reduced mixing in aeration tanks, it can be concluded that at AWWTP the mixing capacity can be reduced by 50%. The only negative effect observed with reduced mixing was decreased flow velocity; however, the flow velocity did not decrease below the critical limit of 0.2 m/s. The results did not show any negative effect on oxygen concentration gradients with depth, SS concentration gradients with depth, or effluent quality. As a result of these investigations the entire plant is operating with 50% of its designed mixing capacity since September 2007 and the estimated electricity savings is 0.75 GWh/year. This study demonstrates that reconsideration of design standards based on experimental investigations can be fruitful, resulting in better environmental conditions and at the same time economic savings.

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