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Full scale performance of the aerobic granular sludge process for sewage treatment

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ABSTRACT

Recently, aerobic granular sludge technology has been scaled-up and implemented for industrial and municipal wastewater treatment under the trade name Nereda®. With full-scale references for industrial treatment application since 2006 and domestic sewage since 2009 only limited operating data have been presented in scientific literature so far. In this study performance, granulation and design considerations of an aerobic granular sludge plant on domestic wastewater at the WWTP Garmerwolde, the Netherlands were analysed. After a start-up period of approximately 5 months, a robust and stable granule bed (>8 g L^{-1}) was formed and could be maintained thereafter, with a sludge volume index after 5 min settling of 45 mL g^{-1}. The granular sludge consisted for more than 80% of granules larger than 0.2 mm and more than 60% larger than 1 mm. Effluent requirements (7 mg N L^{-1} and 1 mg P L^{-1}) were easily met during summer and winter. Maximum volumetric conversion rates for nitrogen and phosphorus were respectively 0.17 and 0.24 kg $(m^3\ d)^{-1}$. The energy usage was 13.9 kWh $(PE_{150}\cdot year)^{-1}$ which is 58–63 % lower than the average conventional activated sludge treatment plant in the Netherlands. Finally, this study demonstrated that aerobic granular sludge technology can effectively be implemented for the treatment of domestic wastewater.

1. Introduction

Aerobic granular sludge (AGS) technology is an upcoming technology for the treatment of domestic and industrial wastewater (Heijnen and Van Loosdrecht, 1998; Morgenroth et al., 1997; de Bruin et al., 2004; de Kreuk et al., 2007; Coma et al., 2012; Show et al., 2012; Morales et al., 2013). AGS technology for combined carbon, nitrogen and phosphorous removal is based on a repeated fed batch process and relies on microorganisms selected to grow in granules rather than flocs. As a result of the high settling rate of the sludge granules, separate settling tanks are not needed and an 80% reduction in area use is possible (de Bruin et al., 2004).

Aerobic granules are characterised by a compact structure, without the need for carrier material, resulting in high settling velocities and a low sludge volume index (SVI). A good indication of granulation is the limited difference between SVI after 5 and 30 min (Etterer and Wilderer, 2001). Aerobic granules are also characterised by their layered structure. The presence of an aerobic outer layer and an anaerobic or anoxic core, facilitates co-existence of nitrifying organisms in the outer layers of the granules and denitrifying phosphate accumulating organisms (dPAO), as well as (facultative) anaerobic organisms towards the centre of the granules (Gieseke et al., 2001; Winkler et al., 2012; Pronk et al., 2015). Due to this structure, aerobic granular sludge can simultaneously remove phosphorus, nitrogen and COD (chemical oxygen demand) from the liquid (de Kreuk et al., 2005; Gonzalez-Gil and Holliger, 2011).

Aerobic granular sludge technology was developed during the last decade at laboratory scale (Morgenroth et al., 1997; Beun et al., 1999; Tay et al., 2002; Zeng et al., 2003), as well as pilot scale (Morales et al., 2013; Liu et al., 2010; Isanta et al., 2012; Wei et al.,

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2012; Li et al., 2014). Aerobic granular sludge is applied by Royal-HaskoningDHV in the Nereda® technology which was first adapted for industrial applications and then further scaled-up for domestic sewage treatment. Valuable scale-up experience gained from full-scale demonstration plants in Gansbaai, South Africa and Frielas, Portugal were used for optimization of the process design and construction in 2010 of the first full-scale AGS wastewater treatment plant in Epe, The Netherlands (van der Roest et al., 2011; Giesen et al., 2013). The AGS technology used relies on a sequencing fed-batch process with a constant working volume. This is possible due to simultaneous feeding and effluent discharge, that relies on a plug-flow pattern for displacement of effluent from the reactor (de Kreuk et al., 2005). In addition, as a result of an oxygen gradient within the granular sludge particle during aeration, extensive biological phosphate removal and simultaneous nitrogen removal can be achieved during one aeration step. The absence of conventional recycle pumps, sludge return pumps and mixers provides a significant reduction in electricity consumption compared to standard nutrient removal plants.

In July 2013, a full scale installation based on the aerobic granular sludge process was taken into operation in Garmerwolde, the Netherlands.

Few papers have been published so far describing full scale operation of the AGS process on domestic wastewater. Li et al. (2014) showed the performance of an full-scale AGS plant fed with 30% domestic and 70% industrial wastewater (BOD/COD = 0.23). The full-scale installation in Epe, the Netherlands briefly described by Giesen et al. (2013) also treats wastewater that is derived for a large part (35%) from industry (mainly slaughterhouses). Moreover, data provided in these studies are very general. More detailed descriptions of the process, conversions, energy usage and design considerations when treating domestic wastewater are lacking.

After start-up and more than one year of operation, this paper reflects not only on the performance, but also on granulation, COD, nitrogen and phosphorus conversions and especially design considerations. The measured energy requirement of the AGS process is compared to conventional activated sludge systems. Furthermore, differences between the full scale granular sludge process, conventional activated sludge and laboratory reactors are discussed in detail.

2. Materials and methods

2.1. Description of plant

In 2012 water board Noorderzijlvest decided that the treatment plant in Garmerwolde would be upgraded with the aerobic granular sludge process. The extension of the existing activated sludge based sewage treatment process (STP) was necessary to meet the effluent requirements. The STP in Garmerwolde treats approximately 27 million m^3; of wastewater per year and 0.8 MW of electricity is generated by the use of the biogas formed during sludge digestion. The existing WWTP consists of a two-stage activated sludge plant (so-called AB-process), with chemical phosphorus removal and either glycerol or methanol for denitrification (Böhnke, 1978) and an SHARON reactor to treat side-streams from the plant's digester and sludge thickeners (Hellinga et al., 1998).

The AGS plant was designed by Royal HaskoningDHV and is operated in parallel with the existing AB-plant. The AGS plant treats 41% (28,600 $m^3\ d^{-1}$) of the total influent received at Garmerwolde WWTP during dry weather flow with a maximum of 4,200 $m^3\ h^{-1}$. The average flow received by AGS and the AB-plant totals approximately 70,000 $m^3\ d^{-1}$ with a peak flow of 11,600 $m^3\ h^{-1}$.

Wastewater characteristics are given in Table 1. The designed sludge loading rate was 0.10 kg COD (kg TSS d)$^{-1}$ at an expected sludge concentration of 8 kg m^{-3}. The sludge-loading rate is calculated by dividing the treated kg COD per day by the total biomass present in the reactor (Table 2). The volumetric loading rate of the AGS reactors is 1.5 m^3 (m^3 d)$^{-1}$. Wastewater enters the plant by a pressure main. After screening by 6 mm screens, the wastewater goes to a grit removal plant and an influent buffer (4,000 m^3) (Fig. 1). From the influent buffer, the wastewater is fed to two AGS reactors (height 7.5 m, volume 9,600 m^3 each) that are equipped with an internal recirculation system (top to bottom of reactor) with a capacity of 2,500 $m^3\ h^{-1}$ for each reactor. Treated effluent is directly discharged from the reactors to the surface water via static fixed overflow weirs.

Biological phosphate removal in the AGS process can be supplemented by metal salt addition directly in the bulk if necessary. Surplus sludge is stored in a sludge buffer tank (400 m^3). To prevent anaerobic phosphorus release and to ensure continuous discharge towards the mechanical belt thickeners, the retention time in the surplus sludge buffer is kept to a minimum.

The AGS plant is operated as a sequencing fed batch process, consisting of a simultaneous feeding and effluent withdrawal period, a reaction period, and a settling/sludge withdrawal/idle period. Nitrogen removal is predominantly established by simultaneous nitrification and denitrification, but for maximisation of nitrogen removal (non-mixed) anoxic periods with a recycle from top to bottom can be provided. The cycle can be adjusted to the influent characteristics (rain or dry weather conditions), the actual sludge conversion rates, the desired effluent conditions and the granular sludge selection pressure. During aeration periods, the dissolved oxygen concentration was maintained between 1.8 and 2.5 mg L^{-1}. The total operational cycle time of the reactors is 6.5 h at dry weather conditions. During rainy weather, the cycle time is shortened to 3 h by decreasing the aeration and increasing the feeding time in order to treat the increased influent flow (Fig. 2). The reactor was seeded with surplus sludge from an existing full-scale AGS plant in Epe, the Netherlands, treating wastewater that consist out of a large industrial part (slaughterhouses) to a concentration of 1 g L^{-1}. In this surplus sludge, no granules were present (SVI_{30} 140 mL g^{-1}).

2.2. Online measurements

Each reactor is equipped with measurements for dissolved oxygen concentration, redox potential, temperature, water level, dry matter and turbidity. Ammonium and phosphate are semi continuously measured (5–10 min interval) during the cycle by an automatic sampling and analysis device (Hach Lange; Filtrax, AMTAX and PHOSPHAX). Sampling points for ammonium and phosphate are located on 0.5 m under the water surface in the reactors. This means that during feeding, when the reactor is not mixed the concentrations of ammonium and phosphate in the effluent can be followed. During the feeding, the liquid an S:CAN spectro:lyser^{tm} probe from Interline was used to continuously monitor nitrate concentrations at 0.5 m under the water surface. This means that during feeding, when the reactor is not mixed the concentrations measured are the effluent concentrations.

2.3. Grab samples

Periodic sampling for the determination of the concentration of the biomass present in the reactor is performed by a grab sampler. Samples can be acquired pressureless at various depths to account for possible segregation over the depth of the reactors due to granulation. Normally, samples are only taken when the reactor is well mixed during the reaction period.