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Enhancing nitrogen removal efficiency of domestic wastewater through increased total efficiency in sewage treatment (ITEST) pilot plant in cold climatic regions of Baltic Sea

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Abstract

The temperatures of sewage water were too low in cold climatic regions of Baltic Sea, which resulted in inefficiency of denitrification in sewage treatment process (STP). This is not prescribed to meet the effluent nitrogen levels (<10 mg/l) as per Urban Wastewater Treatment Directive 98/15/EC. In order to improve the denitrification efficiency and the subsequent removal of nitrogen from the municipal wastewater as per the above European Commission guidelines, modified process was formulated with pre-anaerobic and post-aerobic activated sewage treatment processes. The modified process includes the rise in ambient temperature up to 20 ± 2 °C by using heat exchangers in Increased Technology and Efficiency in Sewage Treatment (ITEST) pilot plant at the Swedish Environmental Research Institute (IVL) laboratory. The experiments were conducted with the modified process of sewage water in one line (treatment line (TL)) and the existing process in another line (reference line (RL)) of the pilot plant. The physical (such as Temperature, Suspended solids and Sludge volume) and chemical (ammonium-nitrate (NH_4^+-N), nitrate-nitrogen (NO_3^--N) and total-nitrogen (TN)) parameters were analyzed. The results concluded that the NH_4^+-N, NO_3^--N and TN concentrations of treated waste water were satisfactory with a concentration of <10 mg/l as per the European Directives 98/15/EEC at treatment line as compared to influent and reference lines. The average nitrogenous-compounds' removal efficiencies were 84% and 76% of NH_4^+, 80% and 65% of NO_3^-, 78% and 62% of TN for TL and RL, respectively.

Keywords: Eutrophication; Pre-anaerobic; NH_4^+; NO_3^-; TN

Abbreviations: ITEST, Increased Technology and Efficiency in Sewage Treatment; BMEPC, Baltic Marine Environment Protection Commission; STP, Sewage Treatment Process; TN, Total Nitrogen; HELCOM, Helsinki Commission; HRT, Hydraulic Retention Time; ASP, Activated Sludge Processes; COD, Chemical Oxygen Demand; BOD, Biological Oxygen Demand; DO, Dissolved Oxygen; NH_4^+-N, Ammonium Nitrate; NO_3^- - N, Nitrogen Nitrates; EWM, Electronic Weighing Machine; SV, Sludge Volume; SVI, Sludge Volume Index; AN, Ammonium Nitrate; RL, Reference Line; NN, Nitrogen Nitrate; TL, Treatment Line.

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1. Introduction

The Eutrophication problem punctuated specially in the Baltic Sea is mainly caused due to different man made anthropogenic activities and discharging highly concentrated nitrogenous compounds via agricultural runoff and inadequately treated wastewater in its catchment area into sea (Dupas et al., 2015; Fleming-Lehtinen et al., 2015; HELCOM, 2010). Overloading of nutrients such as nitrogenous and phosphorus compounds to fresh water bodies induces severe problems such as water pollution, eutrophication and development of toxic cyanobacterial blooms, hypoxia and toxic aquatic species (Zhao et al., 2015; Wen et al., 2015; Keidrzynska et al., 2014). Baltic Marine Environment Protection Commission (BMEPC) called ‘Helsinki Commission/HELCOM’ (formed by Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland, Russia and Sweden) aimed to protect marine environment of Baltic Sea, which is an active organization since last four decades. The self purification of sea was very slow and it was not enough to meet present loading rates of pollutants due to long water retention time to take movement from south to north. This problem was recognized at its implementation level during 1950 (Elmgren, 2001; Lehtinen et al., 2015). Generally, the sewage treatment plants of inter Baltic Sea territory continents as a point source contribute above 30% of nitrogenous compounds’ accumulation due to inefficient treatment (HELCOM, 2010).

Biological sewage treatment by activated sludge process has been utilized to resolve problems associated with the water pollution (such as organic materials, nitrogen and phosphorous) for more than one hundred years and still emphasizes that domestic wastewater is the prominent source behind agricultural runoff contribution for eutrophication around the globe (Matuska et al., 2010). Biologically, activated sewage treatment processes (STPs) without pre-anoxic zone were poor in mean total nitrogen (TN) and phosphorus removal rates of 47% and 0%, respectively. However, pre-anoxic zone had better removal rates of TN and phosphorus of 75% and 98%, respectively (Zeng et al., 2011). HELCOM, 2005 (2005) reported that the weekly loading rates of ammonia had decreasing trends but Nitrate has high variation in trends with small changes in temperatures.

Nitrogen removal from activated biological STPs with pre-anaerobic and post-aerobic treatment is the most cost-effective, less sludge production, efficient nutrient removal, high operational flexible and less operational complex process. This process mainly involves anoxic denitrification and aerobic nitrification to convert ammonium to nitrogen gas as compared to other STPs (Kassab et al., 2010; Yao et al., 2013a,b; Zhang et al., 2014; Ruiz et al., 2006). The implementation of biological treatment process temperature is an important factor because enzyme’s activity and growth rate are affected in cold countries’ environment due to the low temperature (Yao et al., 2013a,b; Sen et al., 1992). It is a challenging and most difficult process especially in winter seasons due to the fall of temperatures less than 5 °C, where nitrification process ceases (Gerardi, 2002). Denitrification stage is not so affected by temperature (Obaja et al., 2003) as compared with nitrification, which is very sensitive to small changes in temperatures between 10 and 17 °C (Randall et al., 1990). For the effective biological treatment and optimum nutrients’ removal, the suitable temperatures are 20 ± 2 °C (Yang et al., 2014).

Integrated continuous anaerobic and aerobic treatments at ambient temperature were highly beneficial with reduced hydraulic retention time (HRT) for treating and eliminating sludge through organic degradation. The absence of oxygen environment with limited carbon source (0.3–0.5 mg/l) was sufficient and more efficient, which removes chemical oxygen demand (COD) and biological oxygen demand (BOD) (Hussein et al., 2014; Zeng et al., 2011). Conventional and traditional treatment processes can be replaced by employing combination of activated STPs and ASR for efficient removal of pollutants in sewage water (Zeng et al., 2010).

2. Materials and methods

2.1. Pilot plant location

The ITEST pilot plant, a pilot test facility (www.sjostadsverket.se) center for municipal wastewater purification was located at Hammarby Sjöstadsverk, Stockholm, Sweden. The sewage received by the pilot plant was same as main full scale municipal wastewater treatment plant. The pilot plant shared the pre-clarification (grid and sand trap), pre-sedimentation and phosphorous precipitation with the full scale main treatment plant. The layout and schematic view of ITEST pilot plant with treated line is shown in Fig. 1. It is worth to mention that the layout of reference line was the same as treated line except for the absence of heat exchangers (Fig. 1)

2.2. Description pilot plant and parameters

The pilot plant was equipped with two identically activated sludge recycling (ASR) processes. One with modified treatment temperature and another is same as main water treatment plant (i.e. reference line temperature). Bacteriological nitrification and denitrification are recognized as feasible processes for removal of nitrogen from wastewater. The relationship between treatment temperature and reaction rate is an important parameter for the design consideration particularly in cold climate (Dawson and Murphy, 1972). One of the test lines was run at sludge concentration, sludge age and temperature similar to the main Activated Sludge Processes (ASP) treatment plant, which is named as reference line (RL). Another line was run at same sludge concentration and sludge age with a desired temperature of about 20 °C, named as treatment line (TL). Heat exchanger was used for treatment line after the primary

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