Water Research 84 (2015) 8–17

Contents lists available at ScienceDirect

Water Research

journal homepage: www.elsevier.com/locate/watres

Long-term study on the impact of temperature on enhanced biological phosphorus and nitrogen removal in membrane bioreactor

N. Sayi-Ucar [a], M. Sarioglu [b], G. Insel [a, *], E.U. Cokgor [a], D. Orhon [c], M.C.M. van Loosdrecht [d]

[a] Istanbul Technical University, Environmental Engineering Department, Istanbul, Turkey
[b] MWH Global, Istanbul, Turkey
[c] ENVIS Energy and Environmental Systems Ltd., Istanbul, Turkey
[d] Delft University of Technology (TUD), Department of Biotechnology, Delft, The Netherlands

ARTICLE INFO

Article history:
Received 10 March 2015
Received in revised form
22 June 2015
Accepted 23 June 2015
Available online 9 July 2015

Keywords:
EBPR
GAO
PAO
Simultaneous nitrification and denitrification
Temperature

ABSTRACT

The study involved experimental observation and performance evaluation of a membrane bioreactor system treating municipal wastewater for nutrient removal for a period 500 days, emphasizing the impact of high temperature on enhanced biological phosphorus removal (EBPR). The MBR system was operated at relatively high temperatures (24–41 °C). During the operational period, the total phosphorus (TP) removal gradually increased from 50% up to 95% while the temperature descended from 41 to 24 °C. At high temperatures, anaerobic volatile fatty acid (VFA) uptake occurred with low phosphorus release implying the competition of glycogen accumulating organisms (GAOs) with polyphosphate accumulating organisms (PAOs). Low dissolved oxygen conditions associated with high wastewater temperatures did not appreciable affected nitrification but enhanced nitrogen removal. Dissolved oxygen levels around 1.0 mgO_2/L in membrane tank provided additional denitrification capacity of 6–7 mgN/L by activating simultaneous nitrification and denitrification. As a result, nearly complete removal of nitrogen could be achieved in the MBR system, generating a permeate with no appreciable nitrogen content. The gross membrane flux was 43 LMH corresponding to the specific permeability (K) of 413 LMH/bar at 39 °C in the MBR tank. The specific permeability increased by the factor of 43% at 39 °C compared to that of 25 °C during long-term operation.

1. Introduction

The wastewater temperature is of great importance in biological treatment since it influences not only the physical state of certain substances (i.e. solubility of oxygen, ammonia) but also the reaction rates of biochemical processes for nutrient removal. There is a limited literature body on nutrient removal processes in countries in the tropical climate zones, especially with respect to the impact of the high temperature on enhanced biological phosphorus removal (EBPR).

In general, the rate of biological processes increase at higher temperatures. This was tested by Krishna and Van Loosdrecht (1999), specifically for substrate storage and settleability, in a temperature range also including the tropical level above 30 °C; the accumulation of storage polymers was found to increase with temperature, together with observable rates of related biochemical reactions. Temperature dependency of EBPR was also explored by Brdjanovic et al. (1997) using an anaerobic-aerobic, acetate-fed, sequencing batch reactor sustained at 20 °C. Conversion of relevant compounds for biological phosphorous removal was investigated at 5, 10, 20 and 30 °C in separate batch tests; while a continuous increase was observed in the interval of 5–30 °C for the conversion rates under aerobic conditions, the rate of anaerobic phosphorous-release (or acetate-uptake) mechanism reached a maximum at 20 °C with a steady increase between 5 and 20 °C that could be defined in terms of a temperature coefficient, θ of 1.078. This was not in agreement with earlier studies (Barnard et al., 1985; Ekama et al., 1984) reporting that EBPR efficiency was higher at lower temperatures in the range from 5 to 24 °C.

Only a few studies, mostly carried out at laboratory-scale with synthetic substrates, were devoted to the fate of the EBPR process in the tropical temperature range. Baetens (2001) reported declining rates of phosphate release and uptake at temperatures of 35 °C and higher, with a significant inhibition at 42.5 °C and above,

* Corresponding author.
E-mail address: inselhay@itu.edu.tr (G. Insel).

http://dx.doi.org/10.1016/j.watres.2015.06.054
0043-1354/

while no phosphate release or uptake was observed at 45 °C. Undoubtedly, temperature dependency of EBPR efficiency closely depends upon the metabolic competition between phosphorus accumulating organisms (PAOs) and glycogen accumulating organisms (GAOs). In this context, Lopez-Vazquez et al. (2008) investigated the short-term temperature effects on the aerobic metabolism of glycogen-accumulating organisms within a temperature range from 10 to 40 °C, concluding that GAOs were not observed to have metabolic advantages over PAOs concerning the effects of temperature on their aerobic metabolism; At high temperatures, competitive advantages favoring GAOs were associated with anaerobic processes (Lopez-Vazquez et al., 2009a) also evaluated the influence of temperature together with different carbon sources and pH on the competition between PAOs and GAOs in pure culture studies; they found that at low and moderate temperatures PAOs remained dominant and sustained effective EBPR, whereas at high temperature (30 °C), GAOs tended to be the dominant species. While these studies provided valuable clues, the impact of tropical temperature still needs to be assessed, based on long-term observations of treatment systems operating with real sewage.

Aside from direct metabolic impact, high temperature may also impair and reduce in the reactor the level of dissolved oxygen in systems where aeration cannot be adjusted. The effect of low dissolved oxygen conditions induced by high temperature is definitely worth investigating for all aerobic processes related to nutrient removal, especially on nitrogen removal mechanisms involving simultaneous nitrification-denitrification (SNdN) process (Hocaoglu et al., 2011; Insel et al., 2011; Münch et al., 1996). The filtered COD experiments showed that nearly all soluble biodegradable COD fractions were consumed. However, remaining slowly biodegradable COD together with endogenous heterotrophic biomass could serve as carbon source for SNdN in the aerobic and MBR tanks.

In this study, the effect of long-term temperature variation on enhanced biological phosphorus removal process was investigated for a membrane bioreactor system treating a high strength municipal wastewater in Saudi Arabia. The EBPR performance of a pilot MBR was evaluated together with biological nitrogen removal under varying process temperatures ranging from 25 to 40 °C during 500 days of operation. It should be noted that the pilot MBR selected for the study also served for testing the feasibility of effluent recovery and reuse, which was defined as the other major objective of the study. The MBR system proved to be useful in the sense that it eliminated all settling problems enabling uninterrupted survey and evaluation of the nutrient removal performance under different operating conditions.

2. Material and methods

2.1. Pilot plant information

The experimental study was carried out using a pilot-scale membrane bioreactor, which was installed at the head works of a sewage treatment plant to enable easy intake of raw wastewater of Dubai Municipality at Al Aweer (Fig. 1). Degritted sewage was fed to the MBR pilot plant having a 1 mm fine screen prior to the bioreactors. The pilot plant used in this study was a flat-sheet membrane bioreactor with a cut-off size of 0.2 μm based on microfiltration. The membrane module (total area of 18 m^2) was supplied from Hitachi, Japan. It included a pumping station, anaerobic (selector) tank (0.9 m^3), anoxic tank (1.26 m^3), aerobic (1.80 m^3) and a membrane tank (2.5 m^3) where the membrane cassettes were immersed. Treated effluent was collected in a permeate tank (0.3 m^3). The process flow diagram of the MBR pilot was illustrated in Fig. 2.

Fig. 1. Pilot-scale membrane bioreactor at Dubai Municipality at Al-Aweer.

The pilot plant was setup in a very flexible way to test the system under all biological nutrients removal (BNR) options that are commonly applied in full scale systems (University of Cape Town (UCT), Virginia initiative plant (VIP), Bardenpho, Anaerobic-Anoxic-Oxic (A^2O) etc.). This also enabled to investigate the effect of high dissolved oxygen (DO) on EBPR and denitrification in case membrane return activated sludge (RAS) is returned directly to the head of the plant without being initially returned to the aeration tank. The pilot plant was equipped with online oxidation reduction potential (ORP), pH, DO measurement for controlling the process together with differential pressure (PIT) and flow controllers (FIT) for membrane filtration (Fig. 2). The membrane tank also enables sludge wastage (WAS) for sludge retention time (SRT) control.

In this study, the airflow rate was set to a constant level to investigate the impact of DO variability on the system performance under dynamic loadings. It was possible to observe the direct and indirect effects of temperature on the physical and bioprocesses. In this regard, the combined effect of GAO-PAO competition together with DO oscillations in aeration and MBR tank were experimented. It is important to note that the aeration intensity of MBR module had been limited by the membrane producer.

2.2. MBR operation

During this study, the MBR operation was carried out based on UCT configuration. The average influent flow rate (Q) was adjusted to 25.3 ± 4.2 m^3/day. The "A" and "S" flow rates were set to 4·Q and Q, respectively. The return activated sludge was adjusted to 45 m^3/day to convey activated sludge back to the aerobic reactor. The hydraulic retention time of the system was 9 h. The hydraulic retention time for anaerobic, anoxic and aerobic tanks corresponds to 1.1, 1.8 and 2.5 h, respectively. The average mixed liquor suspended solids (MLSS) concentration in MBR tank was maintained in the range of 11,000–13,000 mg/L together with a scouring airflow rate of 8 Nm^3 per hour. The aerobic reactor was bubbled with blower/diffuser system having 30 Nm^3/hour airflow rate. The filtration was provided with external peristaltic permeate pumps. The filtration and relaxation periods of the membranes were adjusted to 20 and 2 min, respectively by programmable logic controller (PLC) system. The prolonged air scouring was applied and it continued during relaxation period. The excess sludge was wasted from RAS stream in order to adjust sludge age. Average daily sludge wastage rates were 550, 440 and 320 L/day for the corresponding temperatures of 25, 30 and 37 °C, respectively. Based on mass balance over TP, the actual total SRTs corresponding to those temperatures can be calculated as 10, 11 and 13 days. The SRT of the