Biochemical Engineering Journal 88 (2014) 42–49

Contents lists available at ScienceDirect

Biochemical Engineering Journal

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

Regular Article

Effect of temperature on membrane bioreactor performance working with high hydraulic and sludge retention time

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ARTICLE INFO

Article history:
Received 5 November 2012
Received in revised form 24 February 2014
Accepted 15 March 2014
Available online 24 March 2014

Keywords:
Wastewater treatment
Membrane bioreactors
Biokinetics
Biodegradation
Temperature
Membrane flux resistance

ABSTRACT

This study analysed the effect of temperature on MBR performance. For this purpose, a full-scale pre-denitrification MBR system was used. This system operated at a constant flow of urban wastewater (0.42 m^3/h) with continuous monitoring of mixed liquor temperature (9–31 °C). Its sludge retention time (SRT) was 35 days and its hydraulic retention time (HRT) was 35 h. Variations in temperature did not affect the effluent COD concentration. Permeability was reduced both by the increase in membrane flux resistance (R_t) at temperatures <15 °C and by viscosity. A lower temperature produced a decrease both in the endogenous respiration rate (b_H) and the observable biomass yield coefficient for heterotrophs. This effect was particularly evident in the b_H and led to an upward trend in the concentration of the TSS and the VSS/TSS ratio. The system was found to have a high nitrification and denitrification potential regardless of temperature. However, residual dissolved oxygen due to membrane aeration or recirculation reduced nitrate removal at low temperatures.

1. Introduction

A membrane bioreactor (MBR) is an advanced water treatment technology, widely recognised as a key treatment process in wastewater reclamation and reuse [1]. As a result, its application in urban wastewater treatment has increased dramatically in recent years. MBR systems are based on a combination of an activated sludge process and membrane technology that separates the particulate materials from the wastewater. This eliminates the need for a secondary clarifier [1]. The most important operational factors in the MBR process are trans-membrane pressure (TMP), sludge retention time (SRT), hydraulic retention time (HRT), dissolved oxygen (DO), food to microorganism ratio (F/M), and temperature [2]. All these factors have an impact on the total suspended solids concentration in mixed liquor (TSS), biokinetic and stoichiometric parameters [3] as well as effluent quality and membrane fouling [4].

Currently, SRT and HRT values are constrained in MBRs by technical and economic factors [2]. A high HRT means high bioreactor volumes, and a high SRT signifies high concentrations of TSS [3], which affect oxygen transfer [5] and membrane cake development [6]. Recommended values for real MBR installations range from 5 to 10 h for HRT and from 10 to 20 d for SRT [2]. Nevertheless, recent advances in membrane fouling reveal that higher SRT values improve membrane permeation [2,4,6]. Research has also found that a high HRT reduces membrane-fouling problems [4] and improves effluent quality [7]. Therefore, optimised SRT and HRT values with an automated control of DO concentrations in the mixed liquor can minimise the risk of fouling in the MBR and ensure the production of a high-quality effluent [6]. In real bioreactors, most of the MBR operational factors can easily be modified. However, this is not the case for the mixed liquor temperature, which fluctuates because of seasonal and diurnal temperature variations. The high specific heat of water means that this factor is extremely difficult to adjust.

Temperature conditions significantly affect microbial growth and activity, solubility, as well as other physicochemical properties of organic matter [8]. As a result, temperature variability has been linked to deterioration in bulk water quality parameters and to MBR system instability [9]. MBR stability depends on the magnitude of the fluctuations caused by temperature variations, which have been linked to sludge deflocculation and decreased sludge metabolic activity. According to Mulder [10], a low temperature increased permeate fluid viscosity, which reduced flux and affected the TMP. Nonetheless, this was not the only phenomenon related to low temperature that might explain the greater hydraulic resistance to filtration. Other contributing factors include intensified

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http://dx.doi.org/10.1016/j.bej.2014.03.006
1369-703X/

deflocculation with a reduction of floc size and the release of extracellular polymeric substances, lower particle back-transport velocity, and a lower degradation of COD [6].

The various phenomena affected by temperature variations could have consequences not only for membrane permeability, but also for other aspects of MBR systems. Accordingly, the objective of this research study was to investigate the effects of seasonal temperature transients on the performance of a full-scale MBR working at SRT and HRT values higher than the usual values for real installations. The effects of temperature shifts were assessed in terms of effluent quality, biomass evolution, evolution of the TMP, and total membrane resistance to flow (R_t).

2. Materials and methods

2.1. Experimental installation and operating conditions

This study used a full-scale membrane bioreactor installation with pre-denitrification conformation equipped with microfiltration membranes (Fig. 1). The system was composed of an anoxic tank (1.2 m Ø, 3.2 m h), an aerobic tank (1.5 m Ø, 5 m h), and a membrane tank (1.5 m Ø, 2 m h) equipped with hydrophilicised, submerged, flat microfiltration-membranes (0.4 μm nominal pore size) made of chlorine polyethylene (PE). The system operated at a constant permeate flow rate of $Q = 0.42\ m^3/h$ and a flow rate between the tanks of 4Q. The TMP varied, depending on membrane permeability.

The experimental installation was located at the wastewater treatment plant (WWTP) in Granada (Spain) and received the wastewater from the plant's pretreatment system composed of a 3 mm brush screen and an aerated grid chamber. The raw wastewater flowed through a brush screen (1 mm), which removed large suspended particles. The sludge was purged from the aerobic reactor, and aeration was applied to remove solids from the membrane and to control fouling. Membranes were chemically cleaned with NaClO (100 mg Cl_2/L) in scheduled procedures when the TMP exceeded 250 mbar. The SRT and HRT were constant over the period of study with values of 35 d and 35 h, respectively. The level of dissolved oxygen (DO) was maintained within a range of 0.5–1.6 mg O_2/L in the aerobic and membrane tanks. The F/M ratio was kept at 0.146 kg COD/kg VSS d.

Influent, effluent, and purge flow rates were continuously monitored, as were operational parameters such as the DO, pH, temperature, TMP, and the level of the tanks. Readings of all these parameters were taken each second and recorded in a database. The software application, ActiveFactory 9.2, was used for data analysis.

2.2. Physical and chemical analysis

During a one-day period, a peristaltic pump was used to collect a total of 5 L composite samples from both the influent and effluent. The storage system was maintained under refrigeration (4 °C). All samples were analysed for total (TSS) and volatile (VSS) suspended solids, total and filterable (0.45 μm) BOD_5, COD, NH_4^+, NO_3^-, NO_2^- and total nitrogen. Accordingly, 1 L samples of mixed liquor were collected daily from each tank to determine the TSS and VSS. The supernatant samples of mixed liquor were obtained by centrifuging it at 4000 rpm for 15 min at 20 °C. The TSS were analysed by vacuum filtration, drying at 105 °C, and gravimetric determination by using 0.45 μm filters. This was done while the VSS were analysed by incineration at 550 °C. The COD was calculated by means of the COD closed reflux micro method. Absorbance of the digestate was measured colorimetrically at 600 nm. The BOD_5 was determined with the manometric method by incubating the sample in darkness at 20 °C for five days. Allylthiourea was added to inhibit nitrification. NH_4^+, NO_3^- and NO_2^- were measured by means of ion selective electrodes (Orion 9307BNWP, 9512BNWP and Crisson 96-64 nitrite Electrode). Electrode slopes were automatically determined using a standard of known concentration. To quantify the total nitrogen, 50 mL of an unfiltered diluted sample (1/10) was oxidised at 120 °C for 30 min in the presence of boric acid, sodium hydroxide, and potassium peroxodisulphate. The result of the oxidation was analysed with Merck-Spectroquant analytical kits for NO_3^- (Kit No.: 1.14773.0001). All measurements were carried out according to standard methods for the examination of water and wastewater [11].

2.3. Respirometer

Fresh sludge samples were taken from the aerobic tank of the experimental installation. These samples were aerated for 24 h before respirometric analysis to ensure an endogenous state. After large particles were removed from the biomass by passing the mixed liquor through a 3 mm sieve, it was fed into the respirometer. Here the biomass yield coefficient for heterotrophs (Y_H) and the endogenous respiration rate constant for heterotrophs (b_H) were calculated by determining the oxygen consumption rate. The instrument used for this purpose was a perfectly stirred 1 L batch respirometer (SURCIS BM-T).

Two sets of experiments were carried out with the respirometer. The first set focused on the oxygen uptake rate (OUR). Endogenous biomass as well as inhibiting nitrification (allylthiourea) were used to determine the b_H, based on Henze et al. [12]. The second set of experiments calculated the Y_H according to the procedure adopted by Strotmann et al. [13]. These experiments used an easily biodegradable organic compound such as sodium acetate. In addition, the biodegradable COD concentration in the effluents was determined with this same procedure in order to verify the efficiency of the MBR processes. For b_H calculations, the non-biodegradable endogenous residue fraction, f_p, was assumed to be 0.08, and $C_5H_7NO_2$ was the stoichiometric formula of the biomass. In order to evaluate differences in the process parameters but not in the respirometer conditions, the amount of sodium acetate added was constant in all of the Y_H experiments (50 mL of a solution with a concentration of 213 mg/L).

The dissolved oxygen (DO) concentration and temperature were continuously measured inside the reactor and recorded online every 2 s. All experiments were conducted under controlled temperature conditions using a water cooler connected to the respirometer. In this way, the temperature inside the respirometer remained similar to the temperature inside the biological reactors in the experimental installation. The pH was also kept within a range of 7.0–8.0.

2.4. Statistical analysis

The data obtained were analysed with the statistical program STATGRAPHICS Plus 3.0 for Windows. The least significant differences test (LSD-test) was used to measure the homogeneity of the data during the different temperature periods. An ANOVA test assessed the homogeneity of the variance with a significance level of 5% ($p < 0.05$). The values obtained for mixed liquor supernatant COD and Y_H and b_H were fit to the best possible mathematical regression with respect to temperature.

3. Results and discussion

The full-scale MBR system in the study was in continuous operation for 170 days from 23 August to 9 February. During this time it was subject to seasonal variations. The system had previously