Effectiveness of moving bed biofilm reactor (MBBR) technology for industrial wastewater treatment and impact of sodium chloride on the biomass in MBBR

Summary of Project BEST output (WP2.2)
Riga Technical University

Introduction

Food - including milk, fish, and meat- processing industries generate high-strength wastewaters with highly variable salt concentration. The short-term loading of high concentration salts results from the disinfection of equipment or food processing at the factories. Shock loads of high salinity may disturb biological treatment processes due to osmotic pressure shock and cell lysis (Shi et al., 2014), thus compromise effluent water quality. This effect is frequently observed also in wastewater plans (WWTP) that are receiving wastewater from a combined (municipal and storm) sewerage systems. For example, NaCl concentration results from de-icing salt-sand mixtures from the roads infiltrated into the sewage system during the spring floods after the snow melting. In this case, sand-salt mixture road wastewaters are acidic (Henrikson & Brodin, 2012)

Sometimes wastewater treatment plants in the food industry in addition to physical pre-treatment are introducing biological wastewater treatment processes (for example, Orkla Latvija Ltd, Latvia). Thus, there is a need to know if the biological process can withstand short-term discard of high salts solution.
Moving Bed Biofilm Reactor (MBBR) is a highly effective biological treatment process based on a combination of the conventional activated sludge process and biofilm media. that is quite flexible and can be used as an effective pre-treatment stage at the dairy factory, that is characterised by high concentrations and fluctuations of organic matter (including fats) and nutrient loads.
The applicability of an MBBR filled with plastic media to the treatment of dairy wastewater was evaluated in a pilot-plant the dairy production “Latvijas Piens” Ltd, Latvia.

The aim of the pilot experiments was (1) to evaluate the effectiveness of moving bed biofilm reactor (MBBR) technology for industrial wastewater treatment and (2) to test the effect of short-term discard of high concentration of the sodium chloride on the biomass in MBBR.

Description of pilot-scale tests

A pilot-scale MBBR was located at the dairy production “Latvijas Piens” Ltd for industrial wastewater treatment without pretreatment. The reactor had a working volume (or wet volume) of 1,17 m^3 with an internal diameter of 1 m and a height of 2 m (Fig. 1). The operating flow rate – 500 L/h. Feeding and discharge of wastewater were conducted simultaneously. The procedures of the reactor operation, including feeding, aerating, setting, and discharging, were controlled automatically by a digital process controller.
MBBR was fed with industrial wastewater from dairy factory and microorganisms grew in the reactor under natural conditions on a protected surface of carriers. This stage allowed us to obtain a highly adapted microflora and to ensure the degradation of a high organic load from the dairy factory.

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Figure 1. Picture of the pilot-scale MBBR at the territory of "Latvijas Piens" Ltd (A); carriers for biomass in MBBR (B).

Influent wastewater used in this study can be characterized as a typical industrial wastewater after dairy production with following parameters: pH 7.7 ± 0,1, COD 3036 ± 30 mg/l, BOD_5 1761 ± 18 mg/l, total phosphorus 36.7 ± 7.0 mg/l (including PO_4-P 20.5±4.0 mg/l) and total nitrogen 128 ± 4 mg/l (including NH_4-N 65±11 mg/l, NO_3-N 4.1±2.0 mg/l and NO_2-N 0.63±0.10 mg/l) and Fat 1542 ± 16 mg/l. Electrical conductivity (EC) increased from 1.5±0.2 mS/cm up to 62±0.6 mS/cm after introduction of NaCl.

Analysis of wastewater samples

Wastewater (influent and effluent) samples were collected from a pilot and full-scale systems in plastic carboys (2 L) stored in a refrigerator (2ºC to 5ºC) after transportation and analyzed within 24 h for their chemical characteristics.

All analyses were conducted according to the standard methods (Table 1) in an accredited laboratory.

Table 1. Water quality analytical methods

Parameter	Reference
Chemical Oxygen Demand	ISO 15705:2002
Biological Oxygen Demand	LVS EN 1899–1:1998
pH	LVS EN ISO 10523:2012
Conductivity	LVS EN 27888:1993
Elements	LVS EN ISO 17294–2:2016
Chloride	LVS EN ISO 10304-1:2009
Suspended solids	LVS EN 872:2005
Total phosphorus	LVS EN ISO 15681-1:2005
Orthophosphate	LVS EN ISO 15681-1:2005
Total nitrogen	LVS EN ISO 11905-1:1998
Ammonia nitrogen	LVS ISO 5664:2004
Nitrate nitrogen	LVS EN ISO 13395:1996
Nitrite nitrogen	LVS EN ISO 13395:1996
Fat	US EPA Meth. 1664B:2010

Electrical conductivity (EC) and pH level were determined using Multi 340i SET B (WTW, Germany) at the sampling site.
The sludge microfauna species groups were determined using light microscopy (Leica 6000B, Germany).

Results

A pilot-study at the "Latvijas Piens" Ltd was performed to evaluate the effectiveness of MBBR technology for industrial wastewater treatment (Table 2) and (2) to test effect short-term effect of discard of high concentration of the sodium chloride on the biomass in MBBR.

Table 2 shows that the values of effluent COD concentrations, and its removal efficiency in MBBR systems during 4 months of operation was 50% and for BOD_5 48%. The results showed that the removal efficiency of fats was high (98%). The average values of TP of 38±34 mg/l in the influent, and 34±27 mg/l in the effluent, respectively. The removal efficiency of TP in the MBBR system without pre-treatment was low, only 11%. During the study, the average achieved removal efficiency of TN was 46% and 80% for $N\text{-}NH_4$, 87% for $N\text{-}NO_3$, and 92% $N\text{-}NO_2$.
At the same time, it should be noted that the diversity of quality parameters of influent wastewater was extremely high, which is the main reason for the high standard deviation for all quality parameters (Table 2.). As well as, the pilot tests were performed during the autumn-winter period when environmental temperature changes were also high -the temperature of wastewater in MBBR decreased from 22 °C in September 2019 to 8,2 °C in December 2019.

Table 2. The efficiency of pilot MBBR during the study.

	Parameter	Range of values		Influent quality (n=32)		Effluent quality (n=32)		Treatment efficiency
		min	*max*	*average*	*± sd*	*average*	*± sd*	*%*
1	**pH**	5.8	10.1	7.6	1.3	7.6	1.1	0
2	**EVS, mS/cm**	1.6	61.9	11.0	16.5	9.1	8.6	18
3	**COD, mg/l**	400	7463	3723	1619	1853	1302	50
4	**BOD_5, mg/l**	225	4257	2034	943	1050	755	48
5	**Suspended solids, mg/l**	26	2660	956	746	645	515	33
6	**Tot P, mg/l**	5.2	109	38	34	34	27	11
7	**P-PO_4, mg/l**	3.8	66.1	22.6	17.2	18.5	9.6	18
8	**Tot N, mg/l**	13	399	178	123	95	91	46
9	**N-NH_4, mg/l**	1.12	367.9	124	155	25	22	80
10	**N-NO_3, mg/l**	0.07	63	0.84	2.24	0.11	0.11	87
11	**N-NO_2, mg/l**	0.015	8.1	0.84	2.55	0.064	0.107	92
12	**Fats, mg/l**	12	12920	3810	3756	158	128	96

Experiment with short-term discard of the wastewater with a high concentration of NaCl was arranged. WWTP in Jelgava city of Latvia periodically receives 20 m^3 of 20% NaCl industrial wastewater solution and in total (calculated for the total WWTP influent) NaCl concentration is 3.3 g/l in the influent at WWTP. While electrical conductivity is approximately 6900 ± 100 µS/cm. Lab-scale experiment as pretesting for pilot-experiments was made using sequencing batch reactors (SBR) – one of them was a control reactor without inhibition process, second was used for the NaCl inhibitor influence examination. Results showed, that short discard of the concentrated industrial wastewater into a sewage system (one SBR cycle was with 3.3 g NaCl/l wastewater) may lead to a decrease of the effluent quality at WWTP. NaCl partly inhibits nitrification and denitrification bacteria and therefore, nitrogen removal quality decreases. Also, the high electrical conductivity of the effluent remains for the first 24 hours after NaCl discard, sludge washing out from the reactor can be observed, and thereafter, chemical oxygen demand increase in the effluent. Sludge microfauna partly degrades and many dried microfauna organisms can be observed for the first 24 hours after NaCl discard (Figure 2).

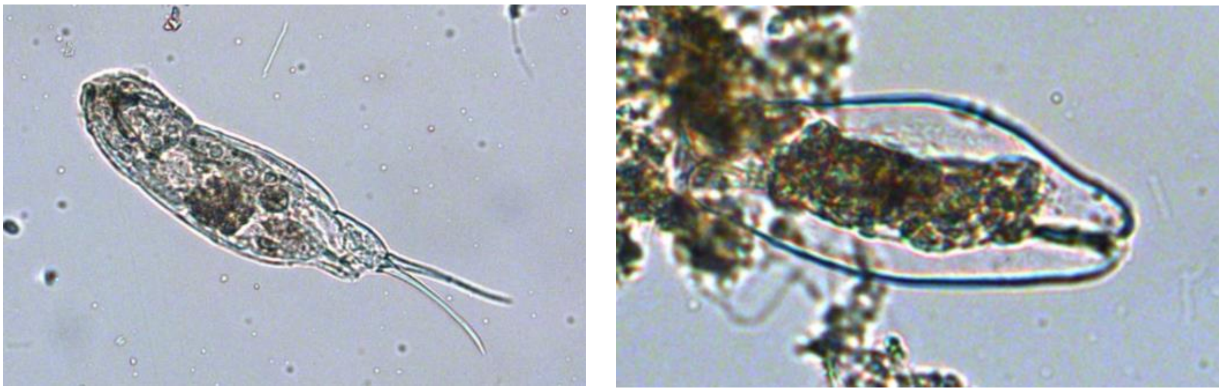

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Figure 2. Effect of short-term discard of the sodium chloride (3.3 g/l one SBR-cycle) microfauna osmotic shock: *Cephalodella* before NaCl addition (A), *Cephalodella* after NaCl addition (B). *Experiments with SBR were performed as pre-testing stage before pilot-scale tests.*

It was observed that it is possible to obtain a highly adapted microflora and to ensure degradation of the high organic load from a dairy factory. Unfortunately, it was impossible to determine the amount of biomass grown on MBBR media chips directly due to the high robustness of material and high concentration of fats in influent water. The increase of MBBR media chip mass was very low (from 0,3822 g to 0,41996 g), but enough to confirm the presence of biomass together with the visualization analysis (Figure 3).

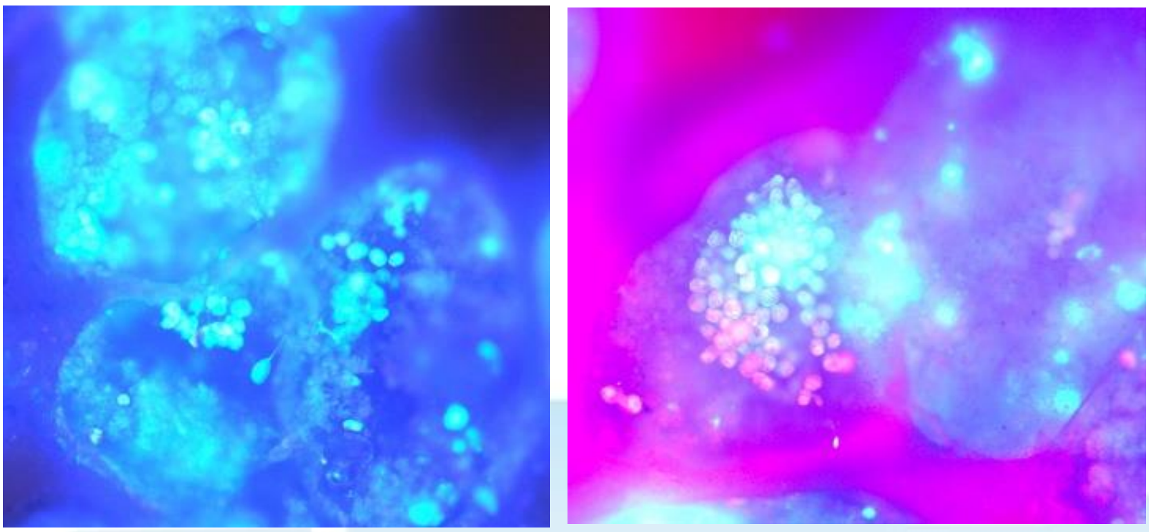

Figure 3. MBBR media chip with microfauna (Stalked ciliates in media chip pores)

The shock load of a concentrated NaCl solution was performed at 05.11.2020. As a result of the discharge, some of the media chip samples were degraded, as well as biomass was completely destroyed. Recovery of the system was insufficient, it interfered with fats, low environmental temperature, and contamination with fungi (Figure 4).

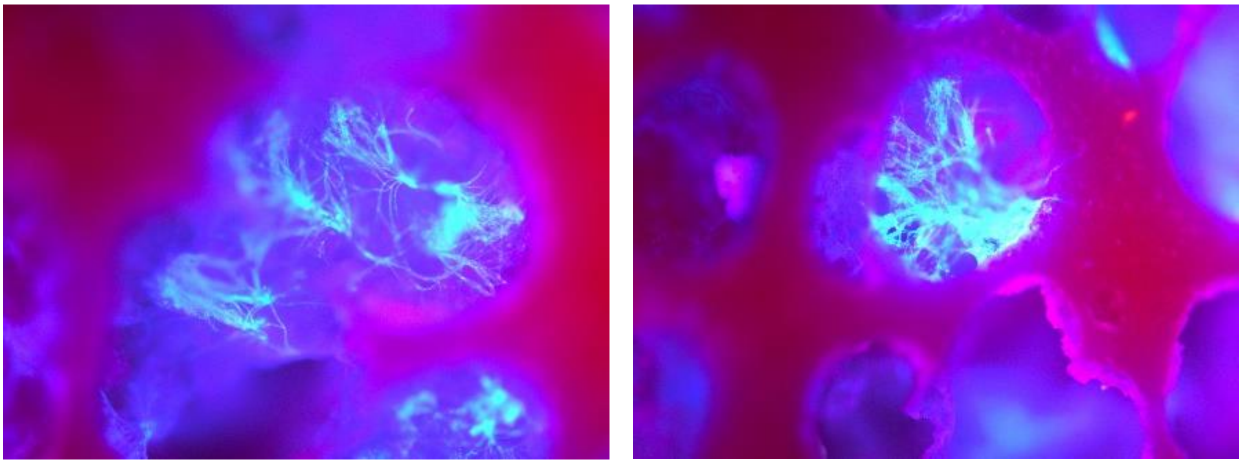

Figure 4. Contamination of MBBR media chip with fungi after shortcut discard of the sodium chloride.

The experimental period for pilot testing was short (10th September 2019 until 06th December 2019). During this period efficiency of MBBR didn't change. Thus, it can be concluded that the aeration process was the main mechanism of dairy wastewater treatment. It was observed that it is possible to obtain a highly adapted microflora, but the time was too short to obtain biomass for efficient biodegradation process. As well as biomass was completely destroyed after the shock load of a concentrated NaCl solution.

Discussion

Different groups of microorganisms are involved in the biological wastewater treatment reactors. Biological nitrogen removal (BNR) is accomplished by nitrifying organisms, which are very sensitive to toxic substances and have a low specific growth rate. Low specific growth rate delays nitrogen removal process recovery after inhibition. According to (Moussa et al., 2006), at 40 g Cl-/L, both AOB (ammonium oxidizing bacteria) and NOB (nitrite-oxidizing bacteria) was almost completely inhibited. Also, AOBs are more sensitive to salt stress (short and long-term) comparing to NOBs. Salt inhibition decreases microbial diversity, and only *Nitrosomonas europaea* and *Nitrobacter* sp. were observed at high salt concentration.

Sludge microfauna is a useful indicator of activated sludge process monitoring.

Wastewater salinity affects sludge characteristics such as sludge settleability, composition, volume indices, flocs structure. Under low salt concentration, sludge flocs are large and loose due to filamentous microorganisms and zooglea abundance. *Zoogloea* sp. abundance increases at a high F/M ratio and high concentrations of specific acids according to Richard (2003). Extracellular and intercellular material secretion by microbial cells is high in low salinity, which enhances large floc formation. Gradual salinity increase leads to settleability improvement as sludge flocs become

small and dense, and the high salt concentration suppresses filamentous microorganisms. However, high salinity (> 2 wt% salinity) reduces sludge settleability due to the cell plasmolysis and microorganisms activity decrease.
Gradual acclimatization to the higher salinity not always reach full biological nutrient removal. According to (Zhao et al., 2016), salinity higher than 2 wt% leads to COD and BOD removal efficiency decrease from 97% and 98%, respectively, to 80% for both. Ammonium and phosphorus removal decreases to 56% and 70% at 3 wt% salinity comparing to 95% at 2 wt%. Biological nutrient removal is inhibited when salinity is higher than 2 wt% (Shi et al., 2014; Zhao et al., 2016).

Conclusions

Our study showed the effect of the shock load of NaCl on biomass in MBBR without pre-treatment. The purpose of the research was to investigate a potential risk of short-term discard of high salinity wastewater from the industry to the municipal WWTP.

1. Short discard of the sodium chloride (3.3 g/l one SBR-cycle) leads to nitrification and denitrification bacteria inhibition.
2. The most valuable indicator of the NaCl inhibitor influence is electrical conductivity in the effluent, as it increases after NaCl addition.
3. Sludge microfauna has osmotic shock and dewatering after NaCl addition.
4. The most NaCl resistant microfauna genus/species are: testate amoebae *Arcella*, crawling ciliate *Aspidisca*, stalked ciliate *Epistylis*.
5. After discharge of NaCl, some of the media chip samples were degraded in the MBBR, as well as biomass was completely destroyed. Recovery of the system interfered with fats, low environmental temperature, and contamination with fungi.

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