Original Research

Two-Stage Aerobic Treatment of Wastewater: a Case Study from Potato Chips Industry

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Abstract

A two-stage aerobic treatment consisting of conventional active sludge treatment followed by membrane bio reactor has been tested for 100 days. The overall pollutant removal efficiencies (97.1% COD, 99.5% BOD_5, 94.7% total nitrogen and 72.9% total phosphorous) are high enough to produce effluent that meets criteria for discharge to surface water with a relatively low amount of surplus sludge: 0.34 gSS $(gCOD_{removed})^{-1}$. The only exception is total phosphorous concentration. The analysis of biodegradable COD in the effluent shows that only 14% is still biodegradable. Although the high quality effluent may be reused in preliminary soiled potato washing, the limiting criteria may be an increased concentration of chlorides.

Keywords: aerobic wastewater treatment, potato chips industry, CAS, MBR, effluent recycle

Introduction

The food and beverage industry is one of the drivers of economic development in Bosnia and Herzegovina (B&H). However, at the same time, due to a large number of small and medium sized companies which do not treat their wastewater, it is also one of the largest polluters of the environment.

The potato chip-producing sector is constantly growing and in the last 4 years has almost doubled their quantity of products sold (1,557 tons in 2004 and 2,880 tons in 2007) [1].

Wastewater from the potato processing industry should be first treated to recover valuable by-products such as starch, oil and grease [2], and then treated usually using biological methods, including mesophilic or thermophilic anaerobic treatment [3, 4], conventional active sludge, thermophilic aerobic treatment [5, 6], combination of anaerobic and aerobic processes [7], and treatment using fungi cultures [8].

Membrane Bio Reactor (MBR) treatment technology is already well defined and has been applied successfully in treatment of wastewater from different origins. Cicek [9] gives a review of applications of this technology in the field of agricultural wastewater treatment and, due to its capacity to treat a high-strength stream and resilience in the face of shock loads, it is deemed especially suitable for the food processing industry.

On the other hand, membranes may suffer from the presence of high quantities of colloidal substances that will reduce permeability and requires more frequent membrane cleaning [10]. The abrasion of membranes by inorganic particles is another important issue [11] that can lead to premature failure of the system or deterioration of results. The MBR process alone already achieves low specific sludge production due to the high sludge age. However, for wastewater containing a high quantity of organic material, further investigations have been done using a two-stage membrane reactor to further decrease the need for surplus sludge disposal [12] or to achieve more stringent effluent characteristics [13].

The scope of this work is to test the performances of a two-stage treatment consisting of a conventional active sludge system and membrane bio reactor to treat high strength wastewater from the chip industry in B&H.

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Company Description

Annual potato chip production of the company in this study is 700 tons, requiring processing of 3,200 tons of raw potatoes. The factory operates five days a week, and work is organized into two shifts. Basic products are different types of potato chips. Production is carried out on one production line, and it is uniform throughout the year. The production process starts with placement of potatoes into a container that is continuously dosued into a washing machine with rotating brushes. Washed potatoes are mechanically transported to a potato peeling machine that performs the peeling along with separation of waste material. From the abrasive peeling machine, the potatoes are transported to the centrifugal cutting machine. The cut pieces then go to the blancher and then to the deep fryer. Afterwards, the fried chips are transported to the flavour doser, and then to the packaging machine. The packaged chips are then transported to the storehouse for finished products, and from there to the market.

The factory uses process water from the city water supply system. Total annual consumption measured by one inlet water meter amounts to 8,071 m^3/year, or approximately 32 m^3/day. The quantity of wastewater generated amounts to approximately 31.4 m^3/day [14].

Materials and Methods

Experimental Setup

The tested wastewater treatment process is composed of three main stages (Fig. 1): existing full-scale pre-treatment (PT), a conventional activated sludge basin (CAS) and a membrane bioreactor (MBR), all connected in series as explained below.

Wastewater generated in the production line flows through a gravity channel to a small basin (around 1 m^3) with manual screen (1 cm bars space) that separates pieces of potato and peeled skin. A submerged centrifuge pump transports water to a parabolic screen (0.75 mm bars space) and then another pump forces it to a small hydrocyclone for starch recovery. The outlet from the cyclone is stored in a small basin (around 1 m^3) in order to provide water for intermittent flushing of the wastewater gravity channel. Wastewater is then discharged to the final recipient.

For the purpose of this experiment, a CAS system was placed after hydrocyclone and fed by a variable speed peristaltic pump. The CAS system has a total useful volume of 25 l and a small settling trap at the exit to enable partial sludge retention. The CAS effluent was used to feed the MBR pilot plant having total useful volume of 25 l. Microfiltration is accomplished by one submerged Kubota flat membrane (203 type) with 0.4 μm pore size and 0.11 m^2 filtering surface. Aeration, mixing and membrane air scouring (in the MBR unit only) were provided using coarse bubble diffusers located at the bottom of the two basins.

The filtrate is extracted from the membrane by means of variable speed peristaltic pump. A level controller located in the MBR basin sent on/off signals to an AS inlet pump. The difference between maximum and minimum level was set to approximately 2 l.

Sampling and Analytical Methods

The biological basins were initially inoculated with active sludge taken from a small municipal wastewater treatment plant. Although the experimental plant was monitored weekly for more than six months, this paper presents only results obtained under stable conditions achieved after the start-up and adaptation period (total of 100 days). Grab samples were collected regularly at locations 1, 2 and 3, as shown in Fig. 1. Additional samples were collected inside the biological basin in order to monitor MLSS concentrations in the reactors. Dissolved oxygen level (Hach – SensIon 6 field instrument), membrane cross pressure and flow rate through the system were also controlled and recorded weekly.

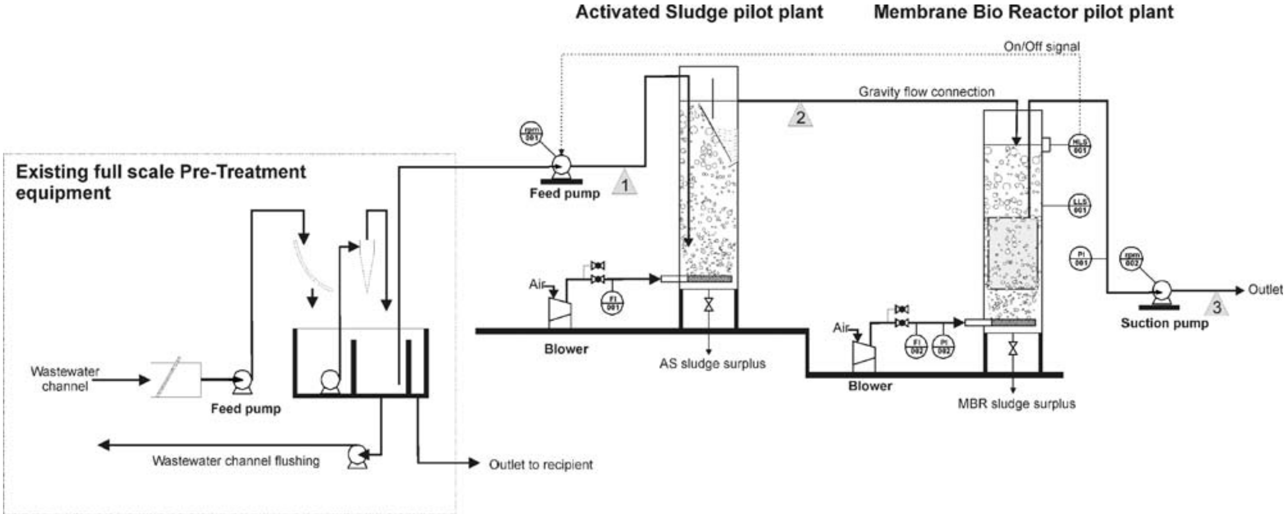

Fig. 1. Pilot plant scheme showing existing pre-treatment facilities and sampling point locations.

Laboratory analyses were performed following the American Standard Methods [15]. The first order rate constant of BOD degradation in time (kBOD) and the biodegradable COD (BCOD) were calculated following methodology described by Roeleveld and Loosdrecht [16].

Results and Discussion

Operational Conditions

The first biological basin (AS) was operated at MLSS around 5 g/l and HRT of slightly less than two days (Fig. 2d). It should be highlighted that no direct control by means of surplus sludge extraction was performed in this basin (the surplus sludge extraction valve shown in Fig. 1 for CAS reactor has not been used). Under this condition the MLSS concentration was set by the balance of incoming suspended solids, biomass growth and suspended matter escaping from the small settling trap and ending up in the MBR basin (which in turn depend on the sludge characteristics in term of settleability). Laboratory chemical analyses on the effluent from this basin were performed on the clarified liquid after one hour settling (inclusive of suspended solids not settleable). Analysis of settleable solids were performed inregularly and averaged results are used only for balance purposes.

The MBR reactor was maintained during the first 45 days at MLSS around 10 g/l, after which the sludge concentration was raised up to 20 g/l and maintained at this value until the end of the experimental period (Fig. 2d). Surplus sludge was removed weekly from the bottom valve. Since no significant differences between two modes of operation (MLSS of 10 g/l and 20 g/l) were noticed, the results are presented as an average for the whole period without making distinction between these two operational conditions. Since the two treatment stages were connected in series, HRT was the same. Around 650 g of SS have been removed during the testing period in addition to approximately 400 g of MLSS increased in the basins. The final specific surplus sludge production has been calculated as 0.34 gSS $(gCOD_{removed})^{-1}$.

Influent and Effluent Quality

Average results and operational conditions are presented in Table 1. Wastewater from chip production is slightly acidic and characterized by large amounts of organic material, nutrients and suspended solids. Comparable results are reported in previous work [2, 6], while other literature, probably referring to raw wastewater containing starch, shows even 5 times higher concentrations [7, 17]. All works show very strong fluctuations in inlet water quality. This variability may pose a serious problem for biological process stability.

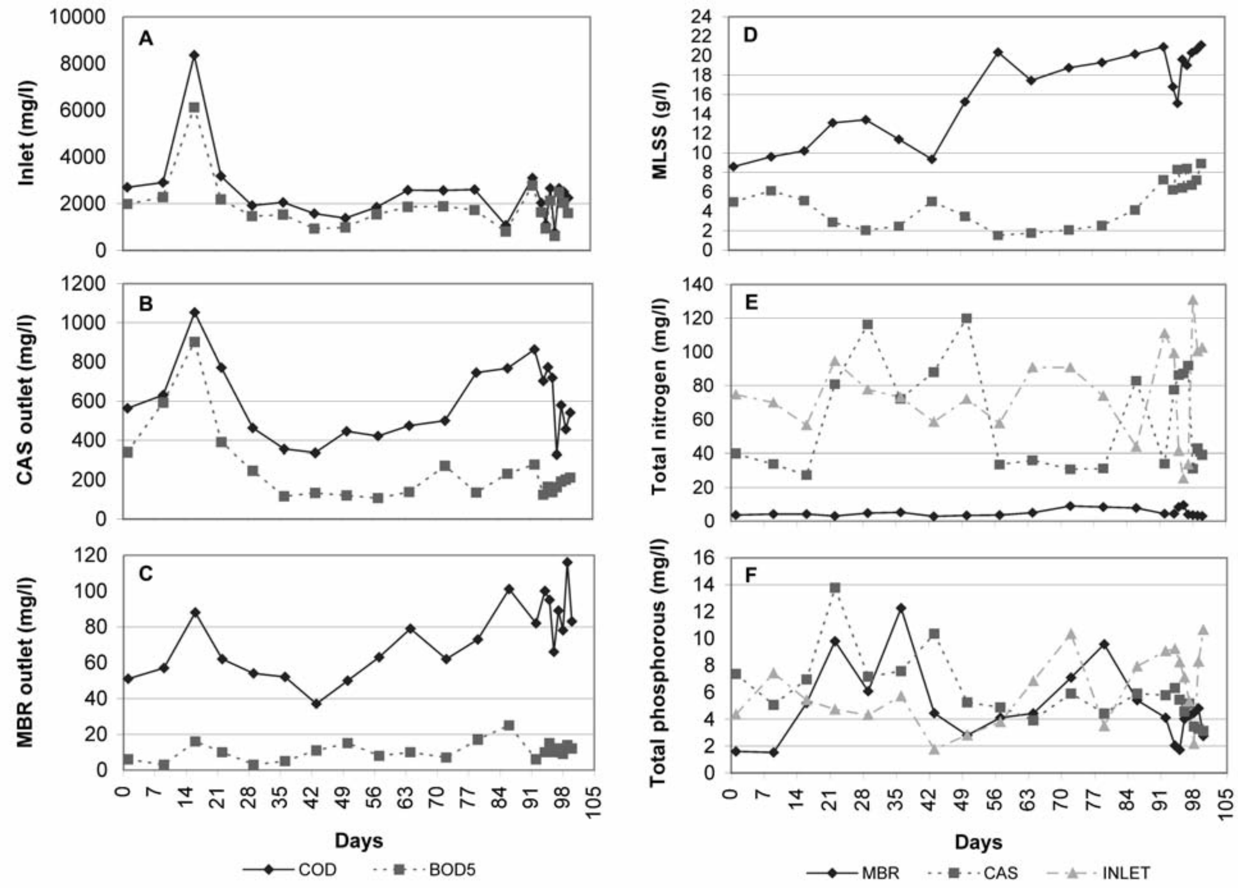

Fig. 2. Evolution of the system during the investigated period. a) COD and BOD_5 in the influent after filtration and cyclone; b) COD and BOD_5 in the CAS effluent (only clarified part); c) COD and BOD_5 in the MBR effluent; d) MLSS in the CAS and MBR basins; e) total nitrogen in CAS and MBR effluents; f) total phosphorous in CAS and MBR effluents.

Table 1. Wastewater composition (average and standard deviation) at three sampling points and operational conditions of the pilot plant.

		After filtration (0.75mm) and cyclone		After filtration, cyclone, CAS		After filtration, cyclone, CAS, MBR	
Number of available samples		21		21		21	
		Average	Std dev.	Average	Std dev.	Average	Std dev.
Turbidity	NTU	516	273	402	213	1.2	0.7
pH	/	5.8	0.7	7.5	0.5	7.9	0.3
Electroconductibility	uS/cm	2,177	889	1,722	651	1,294	315
Alkalinity	mg/l	830	246	838	329	487	124
COD	mg/l	2,471	1,512	595	192	73	20
BOD_5	mg/l	1,882	1,129	247	189	11	5
Ammonium-N	mg/l	38.9	16.9	17.0	20.0	1.0	0.9
Nitrate-N	mg/l	4.7	4.6	7.5	16.0	1.2	0.7
Total nitrogen	mg/l	75.2	27.0	61.1	30.6	5.0	2.2
Total phosphorous	mg/l	6.1	2.6	6.0	2.5	4.9	2.8
Chlorides	mg/l	114	54	89	24	74	20
Active surfactants *	mg/l DBS	1.1	1.2	-	-	0.2	0.1
Hydraulic Residence Time	h	-	-	45.7	3.4	45.7	3.4
MLSS	g/l	-	-	4.9	2.4	16.2	4.4
Temperature	C	-	-	18.2	3.8	17.7	3.9
Dissolved oxygen	mg/l	-	-	5.9	1.9	6.6	1.6
F/M	1/d	-	-	0.0296	0.0201	0.0004	0.0002

* Only 14 samples available.

In addition, suspended matter is often in colloidal form and represents a challenge for a classical wastewater treatment plant based on conventional gravity secondary clarifier technology.

The experimental pilot plant achieved an overall reduction of 97.1% of COD and 99.5% of BOD_5. The final effluent concentration was always under 125 mg/l for COD and 25 mg/l for BOD5 (Figs. 2a, b, c). The conventional system alone achieved a reduction of 76.3% of COD and 87.2% of BOD5. During day 97, samples of influent, CAS and MBR effluents were investigated to determine the biodegradable fraction changes (as BCOD/COD) and its nature (in terms of kBOD) along the treatment process. Results show a net decrease of biodegradable fraction from 0.93 (raw wastewater) to 0.46 (CAS effluent) and then to 0.14 (MBR effluent). This indicates that almost all of the biodegradable COD has been removed. A similar conclusion for a single-stage MBR system based on removal efficiency BOD_{20} has been reported by Sayed S.K.I. et al. [17]. The calculated values of kBOD were in the range of 0.24-0.33 d^{-1}, with highest value for the influent. Roeleveld and Loosdrecht [16] reported a range of kBOD of 0.15-0.8 d^{-1} for municipal wastewater in Netherland.

Regarding nutrients, the overall pilot plant achieved 94.7% removal efficiency for nitrogen (Fig. 2e) with low concentration of ammonia and nitrates in the effluent. Since it was not expected that the denitrification process will occur to such an extent, the mechanism of nitrogen removal has been investigated in more detail. The CAS basin appears to have a minor effect on final nitrogen concentration (low sludge age: around 4.6 days) so that most of the ammonia is converted, resulting in slight increase in nitrates and a transfer of nitrogen to the organic form, most probably due to biomass uptake. Unfortunately, no analyses were performed to validate the share of nitrogen between dissolved and suspended form but most likely the nitrogen is carried inside the suspended solid fraction and is not dissolved. It should be noted that the total nitrogen concentration given in Table 1 for CAS effluent must be increased by the quantity of nitrogen passing to the MBR system in the form of settleable solids (as already mentioned in the methodology, the analyses of CAS effluent were performed on the clarified liquor after one hour of settling).

However, few analyses performed on settleable solids (shown as average in Table 2) shows that these solids have a relatively poor quantity of nitrogen and based on normal nitrogen contents in bacteria cells (around 12% of dry matter on weight basis) only 10-20% of these solids can be assumed as active sludge (the main fraction is most probably starch).

Table 2. Mass balances based on averaged concentrations for SS, BOD_5, TN and TP.

Averaged values during monitored period	SS (mg/l)	BOD_5 (mg/l)	TN (mg/l)	TP (mg/l)
CAS				
INLET	471	1,882	75.2	6.1
ACCUMULATION AS S.S. IN THE REACTOR	75	92	1.3	0.2
OUTLET SETTLEABLE	582	716	61.1	1.5
OUTLET NOT SETTLEABLE	406	247	9.8	6.0
BALANCE (INLETS-OUTLETS-ACCUMULATION)	-592	827	3.0	-1.7
MBR				
INLET	988	963	70.9	7.5
ACCUMULATION AS S.S. IN THE REACTOR	239	302	8.3	1.3
REMOVED AS SLUDGE	497	629	17.3	2.7
OUTLET	16	11	5.0	4.9
BALANCE (INLETS-OUTLETS-ACCUMULATION)	236	22	40.2	-1.4
TOTAL				
INLET	471	1,882	75.2	6.1
ACCUMULATION AS S.S. IN THE CAS REACTOR	75	92	1.3	0.2
ACCUMULATION AS S.S. IN THE MBR REACTOR	239	302	8.3	1.3
REMOVED AS SLUDGE	497	629	17.3	2.7
OUTLET	16	11	5.0	4.9
BALANCE (INLETS-OUTLETS-ACCUMULATION)	-356	848	43.2	-3.1

Nitrogen is thus almost completely eliminated in the MBR system where higher sludge age was achieved (around 21.5 days).

Usually, biomass in the MBR is rapidly mixed by the aeration system. Since air is introduced in the central part of the reactor (where the filtration membrane is located) there is an uplift of biomass in this section followed by its descent in the lateral part.

However, during the experimental period, it was noticed that due to the high MLSS and probably due to the presence of colloid matter, the biomass in the MBR reactor was recirculating very slowly while the water was flowing through the biomass slightly faster. Wastewater from the CAS basin was entering MBR on the lateral section of the reactor. This situation allowed the formation of two distinct zones:

(i) the lateral part where the wastewater with high organic carbon concentration was in contact with biomass but not with the aeration system, and

(ii) the central part where biomass and water were strongly aerated and filtered by the membrane.

In the lateral section of the channel, anoxic conditions have been established and scattered presence of newly formed bubbles of nitrogen noticed.

Similar to nitrogen, phosphorus was taken up by microorganisms in the process of sludge growth in the CAS basin transferred to the MBR basin from where it was removed as surplus sludge. The overall phosphorus removal efficiency achieved by the system in the experimental period was 72.9% (Fig. 2f). This relatively poor removal efficiency is to be related to the fact that the whole experimental setup was run with the aim to minimize sludge production. The low sludge production negatively influenced biological phosphorus removal capacity. The mass balances based on average concentration of suspended solids, BOD_5, nitrogen and phosphorus are summarized in Table 2. The balance for phosphorus shows a general inlet deficit of this nutrient during the examined period. A possible explanation for this is a not stationary situation with high phosphor levels in the initial reactor biomass slowly released during the progress of the experiment.

Water Recycling Options

Effluent from second stage MBR treatment may be reused in for preliminary potato washing or general cleaning purposes in the “dirty” part of the process line.

Much more extensive use of recycled wastewater was analyzed in Aantrekker et al. [18], who investigated the water loop closure possibility. Following basic treatment, recycled wastewater was further treated by microfiltration, active carbon and UV disinfection. Under these conditions the accumulation of chlorides in the loop and in the potato was reported to be a limiting factor.

Catarino et al. [2] presented achievements from the Portuguese potato chip industry where around 10% of water that was subject to starch and grease recovery and subsequent treatment was recirculated in the production process for soiled potato washing. Other minor water quantities were reused for outside washing, and the watering system and fire network.

Results from experimental setup show that the combination of CAS and MBR reactor has little effect on chloride concentrations (average reduction of 35%) probably due to the uptake in sludge biomass. Theoretically, considering as a worst case no effect in the WWTP, up to 40% recycling could be achieved without compromise due to chloride accumulation the possibility of discharging surplus water in a surface body based on Bosnian current legislation (chlorides limit set to 200 mg/l).

Conclusions

A two-stage aerobic treatment consisting of conventional active sludge treatment followed by membrane bio reactor has been tested for 100 days in stable conditions at HRT of two days for each stage. The conventional active sludge pre-treatment succeeded protecting membranes from inorganic particles, colloids and large load oscillation. The overall pollutant removal efficiencies (97.1% COD, 99.5% BOD_5, 94.7% total nitrogen and 72.9% total phosphorous) are high enough to produce effluent that meets criteria for discharge to surface water. The only exception is concentration of total phosphorous. The analysis of biodegradable COD in the effluent shows that only 14% is still biodegradable and that further improvement of biological step would hardly achieve higher removal efficiency. Despite high level of organic matter and suspended solids in the wastewater, the sludge production has been relatively low amounting to 0.32 gSS $(gCOD_{removed})^{-1}$. Although the high quality effluent may be reused in preliminary soiled potato washing, the limiting criteria may be increased concentration of chlorides.

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