ENVIRONMENT AND ENVIRONMENTAL EFFECTS

HIGH STRENGTH WASTEWATER TREATMENT PROCESS SIMULATION

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ABSTRACT

Researchers and engineers are continuously striving to enable quicker and more individualized wastewater treatment processes control solutions for the development of process models, which is a long procedure with calibration and validation, and online data supply as they are dynamic systems introducing another level of sophistication (Sen and Randall, 2008). The existing mathematical wastewater treatment models give a forecast for treatment results under various flow and pollutant circumstances, but results still are dissatisfactory due to the changeable dynamics of pollutants, which affects the treatment systems directly. The investigation was done for an existing pharmaceutical factory wastewater treatment plant with a moving bed biofilm reactor(MBBR) process, which offers the specific advantages of the biofilm system in the treatment of high strength wastewater. The basic research was undertaken to verify a model and investigate the biodegradable and slowly biodegradable COD fraction variations influence on the model’s results.

Key words: Wastewater treatment, process simulation and control, biofilm, fungi.

INTRODUCTION

The objectives of this research were to simulate the existing pharmaceutical factory (JSC “Grindeks”) wastewater treatment process using *BioWin ASM 2D* model, where important process scenarios are possible to investigate.

The simulation period was 1 year for all the given scenarios, but the feasibility of the scenarios was investigated through the impact of high strength organic loading rates, COD fraction component conversation and maximum specific substrate removal rate at temperatures ranging from 28 to 32 °C and flow rates ranging from 10 to 30 m^3/h, which correspond to existing WWTP performances.

Many of the waste streams resulting from the pharmaceutical factory have high pollutant strengths and thus are of concern to the environmental pollution issue. However, this research concentrated on the wastewater from the process line (buffer tank) and treated wastewater effluent to the existing Riga town sewer system, where they must apply the limits given from local municipality. The wastewater from the factory is of particular concern because it contains BOD_5 ranging from 1000 to 4 500 mg/l, COD concentration from 1000 to 10 000 mg/l, and in the effluent they must reach the 600 mg/l for COD and 500 mg/l for suspended solids, also a limitation for total nitrogen, phosphorus and another pollutants exist as well, which time by time create difficulties for the process stability resulting in the pollutant concentration limit exceeding in the effluent.

MATERIALS AND METHODS

WWT plant description

The wastewater treatment process consists of the following main components: buffer tank, five in series moving bed biofilm reactors (MBBR) with plastic suspended carriers and finally a flocculation and flotation unit for suspended solid removal. In a MBBR process, the biofilm grows on small carrier elements suspended throughout the liquid in the reactor.

At the end of the 1980's MBBR biofilm technology was developed at the Norwegian University of Science and Technology in Trondheim by professor Odegaard and coworkers (Odegaard, 2006).

Biofilm carrier elements type $K3^{TM}$ (*AnoxKaldnes*) made of polyethylene, which has a density slightly less than water and size of 12×25 mm, with a surface area of 500 m^2/m^3. The wastewater from the factory process line is moved to a buffer tank with a wet volume of 200 m^3. The wastewater is pumped with frequency controlled pumps to the first biological reactor. The wet volume of each reactor is also 200 m^3 and all five biological reactors contain 50% carrier material $K3^{TM}$. The flow rates, temperature, pH and oxygen concentration are monitored in each reactor separately. The air flow rate in the reactors can be between 250 – 1000

Nm^3/h. In the first reactor MBBR1 most of the easily degradable organic content will be removed. In reactor MBBR2 the reduction of larger molecules and in the third reactor MBBR3 more organic biological degradation takes place. In the fourth reactor MBBR4 the nitrification process takes place, but in the fifth reactor MBBR5 the denitrification process takes place. The reactor MBBR5 is equipped with both an aeration system and a gentle mixer for mixing the suspended carriers. In the case when the MBBR5 is used as nitrification stage, the reactor is aerated (Lind et al., 2009).

BioWin 3.0 simulator model ASM 2D

BioWin is a Microsoft Windows-based wastewater treatment process simulator used world-wide in the analysis and design of wastewater treatment plants.
Fig. 1 shows a pharmaceutical factory wastewater treatment plant system configuration set up in *BioWin* accordingly to the existing WWTP (Lind et al., 2009; Gujer et al., 1995).

Substrate transformation and utilization in the biofilm processes is more complex than in activated sludge, therefore a more complex *ASM 2D* model was used for the modeling of the MBBR process (Gujer et al., 1995; Gjunsburgs et al., 2006). This is principally because of the introduction of diffusion within the biofilm and also a parallel suspended growth bacterial activity is taking place (Sen and Randall, 2008).
To perform the comparative analysis, the model was mainly aimed at the biological step, where organic matter and nitrogen removal were incorporated. Using the *BioWin 3.0* simulator model *ASM 2D,* the model step in various scenarios, and COD for high and low load range are presented in the article. Simulations were performed using the data from the existing WWTP from the year 2011, and influent data are presented in Figures 2-3, effluent data are presented in Fig. 4.

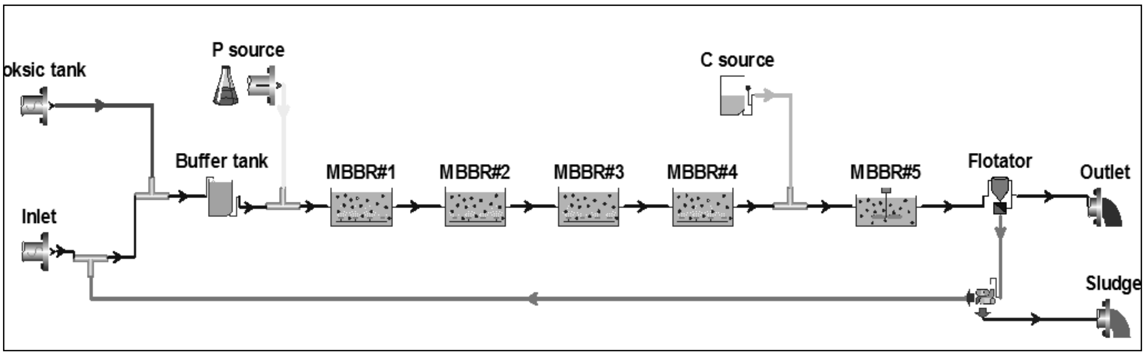

Figure 1. BioWin model WWTP layout

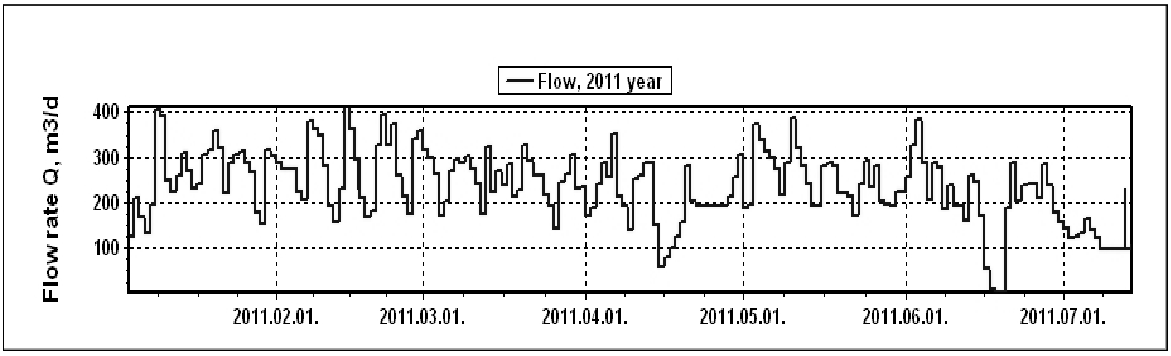

Figure 2. The incoming wastewater flow rate for year 2011 (7 month period)

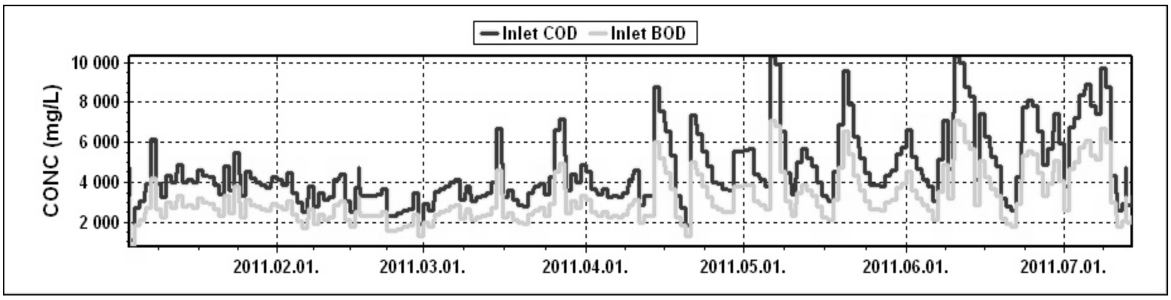

Figure 3. The inlet wastewater COD and BOD_5 for year 2011 (7 month period)

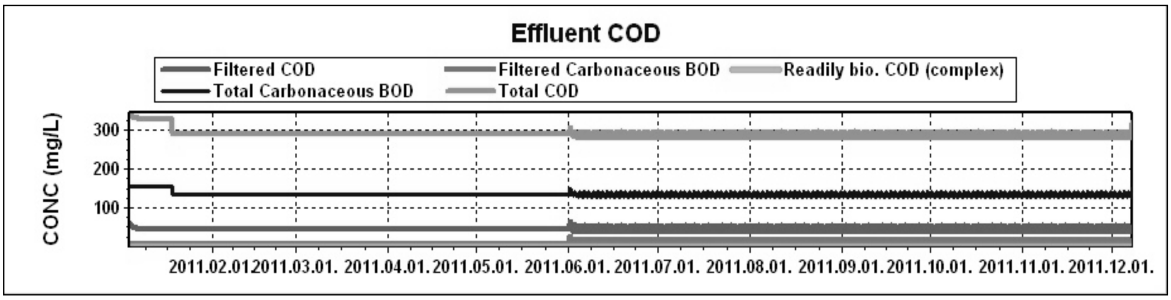

Figure 4. The effluent COD and BOD for year 2011

Calibration

In order to evaluate the quality of the BioWin ASM 2D model under the dynamic conditions, it was proposed to check, if the simulated value of an output variable was included in the confidence interval estimated for its measured value of the effluent (Jeppsson, 1996). The simulation was successful because there was no significant statistical difference between the simulated and measured values of the investigated variable COD, see Fig. 6. The calibration of the COD fractions were investigated using the existing wastewater COD components, such as - readily biodegradable, un-biodegradable, slowly biodegradable soluble and particulate. Table 1 shows the incoming wastewater fractions from buffer tank. The total COD is assumed to be composed of different particulate and soluble components and represented by relative fractions. As a start up input value of the COD soluble fraction was 3604 mg/l. The total soluble COD fraction is about 90% from the total COD.

Each of the simulated variables was included in the confidence interval and according to the Table 1 data and the inlet wastewater COD fraction was estimated for the respective measured variable and is given in Fig. 5.

Table 1

Wastewater COD fractions from buffer tank

Parameter	Description	23.03.2012.		Measurement methods
		Value, mg/l (± 5%)	Percentage from total COD (± 5%)	
COD	Total COD	3976	100	The standard COD measurement
S	Total soluble COD	3604	91	Determine for example pH>9 and coagulation $ZnSO_4$, filtration 0.45 μm
S_S	COD readily biodegradable	~ 80	2	BOD measurement after 2 h
S_I	COD un-biodegradable soluble	321	8	The difference between soluble COD and BOD
X	COD particulate	372	9	$X = COD_{total} - S$
X_S	COD slowly biodegradable	3433.6	86	$X_S = BSP_{total} - S_S$
X_I	COD un-biodegradable particulate	28.6	0.7	The difference between COD and soluble fractions of COD and BOD

The comparison between measured and model obtained data for COD and BOD_5 values is given in Fig. 6. The kinetic parameters and biofilm diffusivity coefficients of the soluble components, for the first stage of investigation were taken from references (Gjunsburgs et al., 2006; Lapara, 1998; Sen and Randall, 2008) for the *ASM 2D* model and used for the process simulation in the MBBR for the existing wastewater treatment plant. The calibration and validation of the current *BioWin* model must be based upon laboratory scale experiments for the coming investigation stages, but for the start of investigation, the model behavior has been verified with available resources from literature (Tchobanoglous and Burton, 1991; Guisasola et al., 2003).

Biodegradation with Fungi

The slowly biodegradable COD fraction consists of different ingredients, where phenol components are present. The phenol from the biodegradability point of view can be classified as a slowly biodegradable fraction of COD (Guisasola et al., 2003; Kekisheva et al., 2007). Biodegradation of the particular fraction was also investigated in this model. The laboratory investigations were performed with the aim to replace bacteria in one of the MBBR with fungi.

The slowly biodegradable colloidal and particulate variation profile is given in Fig. 7.

For determination of treatment efficiency of slowly degradable substance with fungi (Rancano et al., 2003; Wesenberg et al., 2003; Majeau et al., 2010), batch tests of degradation of phenol containing wastewater was elaborated. Initially 4 fungi stock cultures were tested, from which Trametes Versicolor showed most degradation pattern. Batch tests were performed in a culture medium by adding phenol wastewater, with a final concentration of 400 mg/l, and stock culture (T.versicolor). Experiments were done in 250 ml flasks containing 100 ml culture medium, 50 ml citric – phosphate buffer for maintaining a pH of 5.0, 7.5 ml phenol wastewater and 10 ml (OD=0.700 Abs) stock culture. The stock culture was inoculated from a liquid medium. Flasks were placed in an incubator with an orbital shaker at 30 °C temperature and 150 rpm rotation and the pH (5.0) was controlled manually. Experiments were done in sterile conditions by autoclaving all cultures.

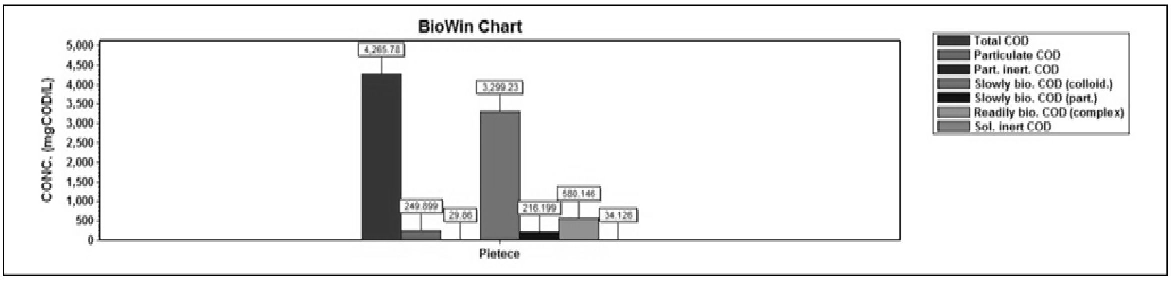

Figure 5. The incoming wastewater fractions for BioWin model

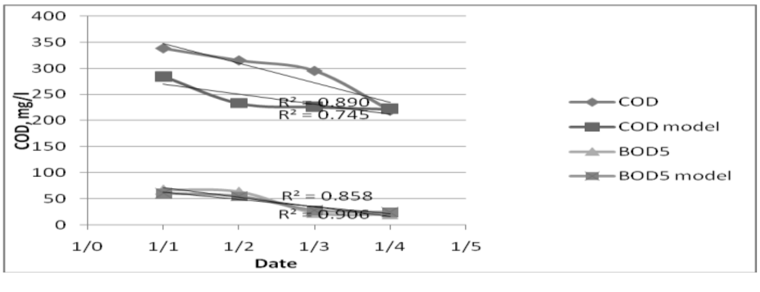

Figure 6. The effluent COD and BOD_5 value comparison for model and measured data

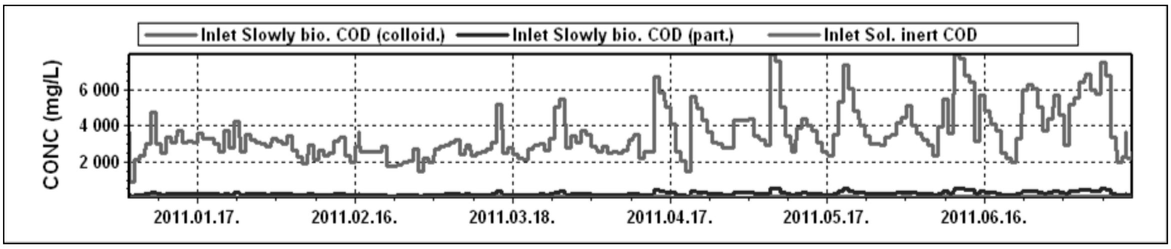

Figure 7. The slowly biodegradable COD fraction profile for average load scenarios

medium, buffers, and flasks prior to adding the stock culture. Flasks were covered with cotton corks for aerobic conditions. The duration of the experiment was 7 days, where samples were taken on days 0, 1, 2, 3, 5 and 7. All experiments were performed in 3 repetitions. The culture medium in experiment, per 100 ml contained: 0.08g KH_2PO_4, 0.02g K_2HPO_4, 0.05g $MgSO_4$, 0.50g yeast extract and 0.03g NH_4NO_3. Before the experiment, a stock culture was inoculated from an agar plate in a growing liquid medium for 7 days. On the final day all media with formed fungi were homogenized and added to the experiment flasks. The phenol concentration was determined with a spectrophotometer.

RESULTS AND DISCUSSION

Biodegradation with Bacteria

The *BioWin* model was prepared for twelve wastewater treatment scenarios, and the simulation was performed for the following hydraulic load variations from an average of 10 - 16 m^3/h up to extremely high 21 - 30 m^3/h, also the scenarios for COD load variation was perform for average from 3000 - 6000 mg/l up to extremely high over 9000 mg/l and also for low load range < 1000 mg/l. The temperature for all simulations was in average range from 28 to 32 °C, but also the additional scenarios for extremely high temperature range till 45 °C was investigated. In this article due to the limits only the hydraulic flow rate, COD and the biodegradable and slowly biodegradable COD fraction variation simulations are presented. For the scenarios with hydraulic loads increases, there was no significant influence to the variations on treated wastewater effluent for COD and BOD values. In this scenario the temperature was 30 °C and MBBRs process was capable of producing stable COD removal, still the oxygen supply rate was in the design range till 1000 Nm^3/h, see Figs. 8 and 9.

The decreasing stability was recognized for temperature 45 °C possible due to high oxygen uptake rate imposed by high COD consumption rate, see Figs. 10 and 11.

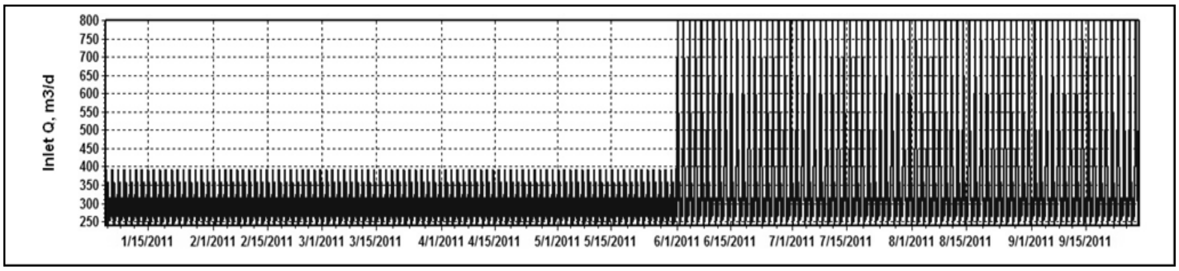

Figure 8. The Inlet hydraulic flow profile with sharp flow rate increase

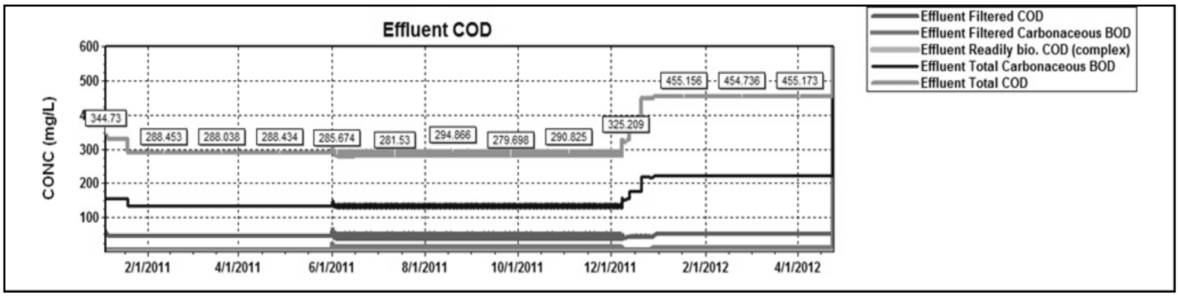

Figure 9. The effluent COD variation profile for the scenarios with flowrate increase, for temperature 30 °C

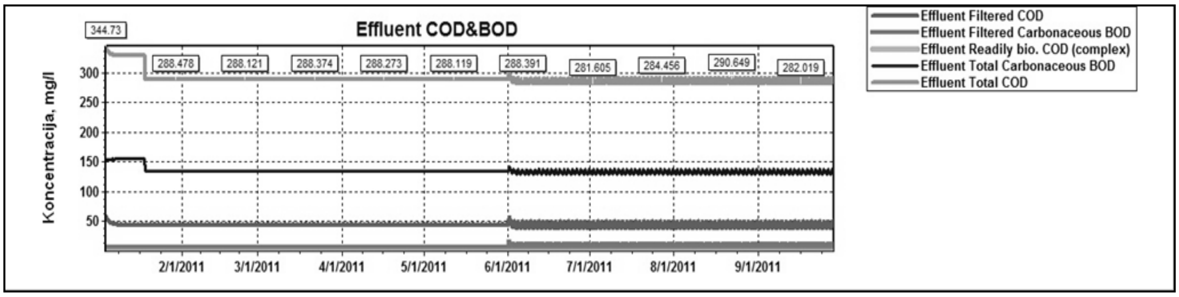

Figure 10. The effluent COD and BOD variation profile for scenarios with flow rate increase, temperature of 45 °C

The effect of varying COD and BOD on the MBBR performance was simulated by changing the values between 1000 mg/l and 10 000 mg/l for temperature 30 °C and also under the different flow rates from low to high, which corresponded to the simulation scenarios. The MBBRs process was also capable of producing stable COD removal for average and high load region, but COD in effluent exceeded the limits for extremely high load range (> 9000 mg/l), for these particular scenarios. The comparison between COD and BOD values of process parameters in influent and effluent per day within the year 2011 (7 month) period under the dynamic conditions are presented in Figures 12, 13, and 14.

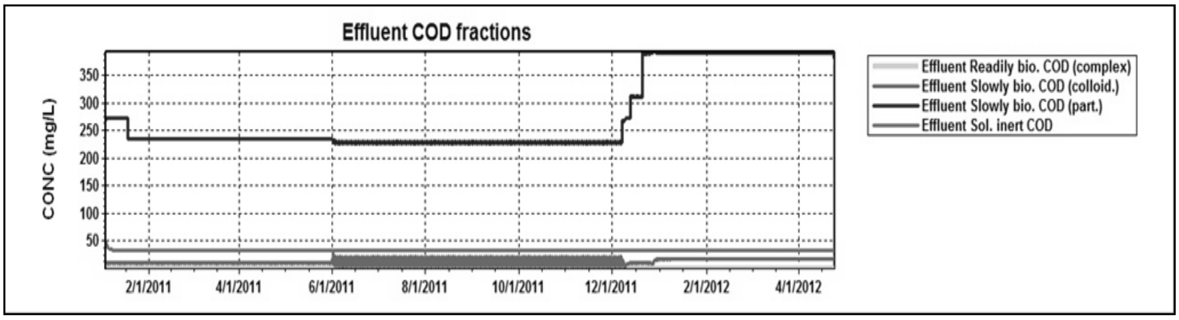

Figure 11. The effluent COD fraction variation profiles for scenarios with flow rate increase, at the temperature of 45 °C

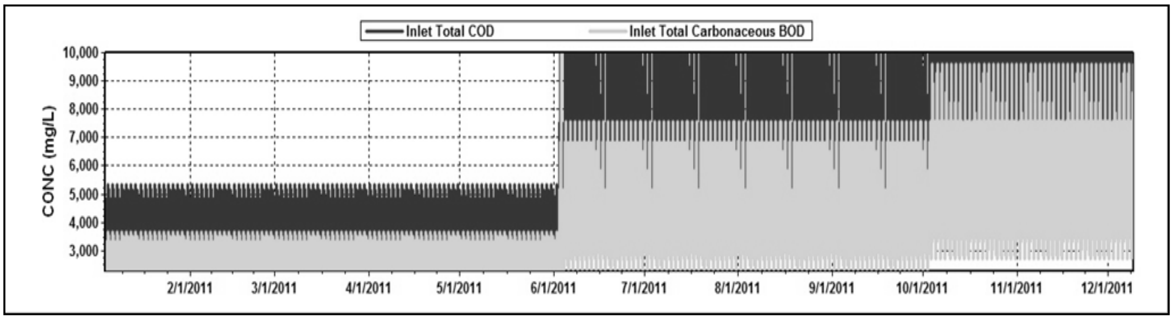

Figure 12. The COD and BOD inlet values for high load scenarios

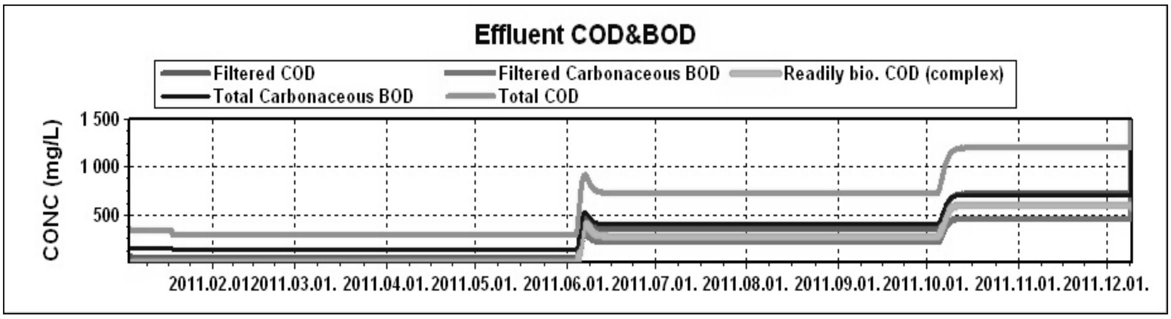

Figure 13. The effluent COD and BOD variation profile for high load scenarios

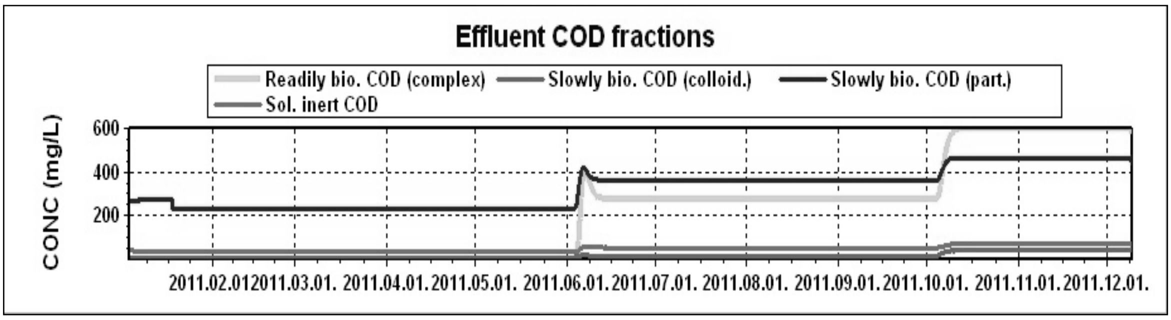

Figure 14. The effluent COD fraction composition for high load scenarios

The model also shows, that because of a higher biodegradable COD value the biofilm thickness in MBBR 1 and MBBR2 had a higher value of 0.87 mm and 1.1 mm comparing to 0.73 mm in MBBR3, MBBR4 and MBBR5. To compare with municipal wastewater where more difference between the biofilm thicknesses is recognized (Sen and Randall, 2008), see Fig. 15.

The effect of COD fraction influence on the model results was investigated by varying the COD biodegradable and slowly biodegradable components from 3976 mg/l to 1000 mg/l. The total COD values in the inlet was 6000 mg/l, the temperature was 30 °C which corresponds to the average values simulation scenarios. There the MBBR's process was capable of producing stable COD removal, but exceeds the limits when the biodegradable COD fraction has a sharp concentration drop and the slowly biodegradable fraction increases. This always was accompanied by the filtrated COD values increase in effluent, and also the model results show a sharp oxygen decreases till 0.97 mg/l in the last two MBBRs. The inlet COD and fractions profiles are given in Fig. 16 and the values of effluent are presented in Fig. 17.

Biodegradation with Fungi

The achieved degradation of phenol containing wastewater was 68% within 7 days, decreasing from 410 mg/l to 130 mg/l concentration of total phenol. It was found that the degradation process of phenol wastewater can be approximated to a linear line, with a rate of 40 mg/l/day, e.g. degradation of phenol mg per litre per day. While for various bacteria mixtures in literature, the degradation rate of phenol is reported between 120 – 300 mg/l/day for phenol concentration of 400 mg/l (Vasiliadou et al., 2008; Tziotzios et al., 2005). The phenol removal rate can be used for the wastewater

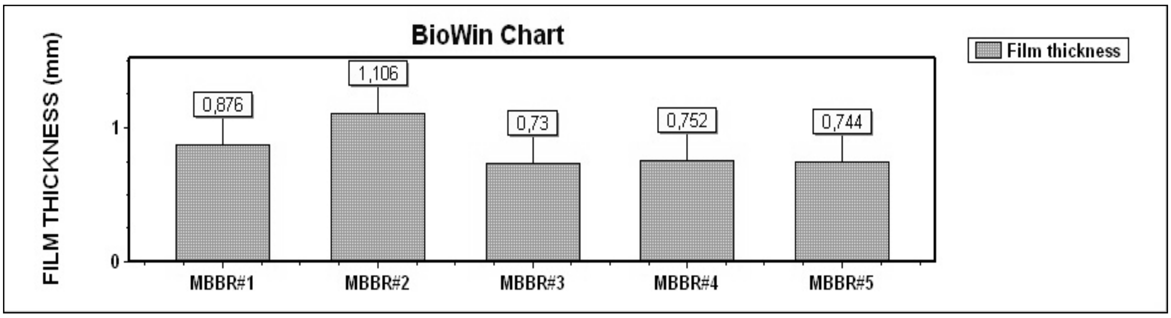

Figure 15. The biofilm thicknesses variation per each MBBR for high COD scenarios

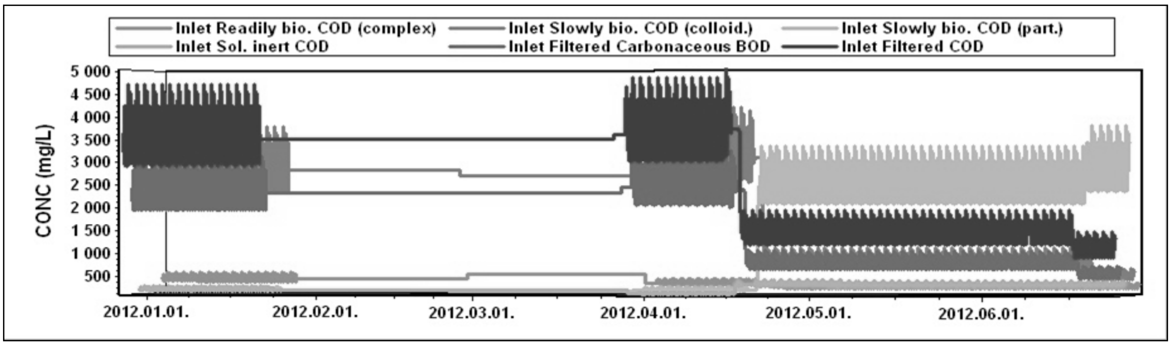

Figure 16. The inlet COD fraction variation profiles

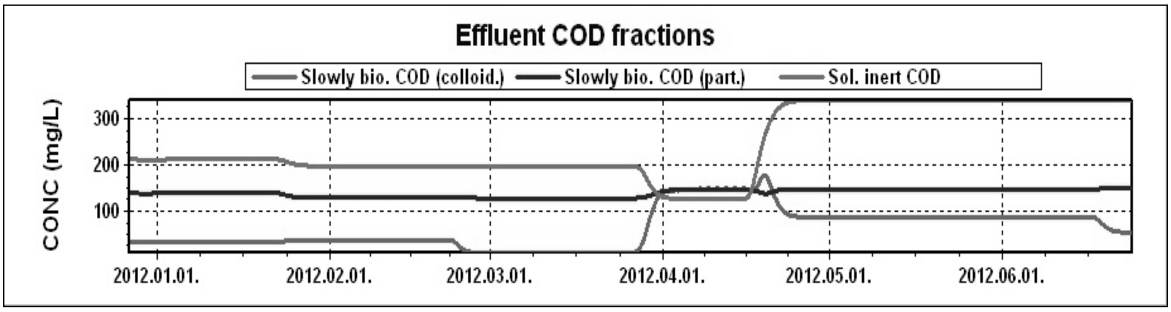

Figure 17. The effluent COD fraction variation profiles

treatment process modelling for bioreactors with fungi in suspension, at a fixed operational state of pH 5.0 and a temperature of 30 °C. However the synthetic medium impact on resulted rates should be noted, since the carbon and minerals source was not limited during the experiments.

CONCLUSIONS

This research focused on performance of the MBBR simulation for high strength wastewater treatment of a pharmaceutical factory, with different COD fractions, from biodegradable to slowly biodegradable. Evaluation of the treatment process simulation results and the author's difficulties encountered in performing the simulation are presented in this paper.

The *BioWin ASM 2D* model can be used to simulate the high strength wastewater treatment process, but proper calibration of the model's parameters can be a difficult task without involving respirometric procedures as experimental tools.

A respirometric batch tests must be conveniently used further in this study in order to estimate the main kinetic and stoichiometric model coefficients and they must be determined for aerobic and anaerobic conditions.

The simulation of the MBBR process showed that the technology is capable of producing a stable COD removal for average and high load (up to 9000 mg/l), and meets the limits in effluent for these particular scenarios with the exception when the biodegradable COD fraction has a sharp concentration drop and slow biodegradable fraction increases.

The difference in biofilm thickness must also be taken into consideration and further the diffusion mechanism into biofilm investigated, as well as the role of the activated sludge particles, which are in suspended form, must be taken into consideration.

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