ARCHITECTURE CIVIL ENGINEERING ENVIRONMENT
The Silesian University of Technology
No. 2/2012

CO-TREATMENT OF LANDFILL LEACHATE WITH MUNICIPAL WASTEWATER IN MSBR: LAB-SCALE AND SIMULATION STUDY

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Received: 23.05.2012; Revised: 28.05.2012; Accepted: 29.05.2012

Abstract
The first step of the study consisted in determination of the efficiency of municipal landfill leachate co-treatment with the synthetic wastewater in a lab-scale membrane sequencing batch bioreactor. The proportion of the leachate volume in the feed was equal to 5%. The concentration of mixed liquor suspended solids in the membrane bioreactor was roughly 3.5 g·L^{-1}, the dissolved oxygen concentration in the aeration chamber was 4.0 mg·L^{-1}, and the sludge load 0.1 gCOD·(gMLSS·d)$^{-1}$. The system was operating in two cycles per day. The efficiency of the treatment process was based on the comparison between the influent and effluent quality. The main objective of the presented study was to develop a mathematical description of the investigated treatment processes. To this end, the biokinetic ASM2d model coupled with submodels were implemented in the WEST® Software version 3.7.6. The results of the modelling study allow conclusion that the applied model was invalid. The discussion of the possible underlying causes and perspectives of a future development of a valid model are presented.

Streszczenie
W pierwszym etapie badań podjęto próbę określenia efektywności współoczyszczania w membranowym reaktorze SBR odcieków ze składowiska odpadów komunalnych ze ściekami syntetycznymi. Udział odcieków w mieszaninie ścieków oczyszczanych wynosił 5% objętości. Stężenie osadu czynnego w bioreaktorze membranowym wynosiło 3.5 g·L^{-1}, natomiast stężenie tlenurozpuszczonego 4.0 mg·L^{-1}, a obciążenie osadu czynnego 0.1 gChZT·(gs.m.·d)$^{-1}$. Układ pracował w systemie dwóch cykli na dobę. Kryterium oceny stopnia oczyszczenia ścieków była zmiana wartości wskaźników zanieczyszczeń charakteryzujących ścieki poddawane procesowi oczyszczania i odprowadzane z bioreaktora.
Celem przestawionych badań było opracowanie matematycznego modelu procesów zachodzących w układzie doświadczalnym. Wykorzystano biokinetyczny model ASM2d wraz z modelami procesów towarzyszących i zaimplementowano je w oprogramowaniu symulacyjnym WEST ® w wersji 3.7.6. Uzyskane wyniki symulacji pozwalają wnioskować, że zastosowany model w niewłaściwy sposob opisywał działanie membranowego reaktora SBR, czego przyczyny omówiono w artykule. Przedstawiono rownież perspektywy dalszych prac mających na celu uzyskanie właściwego opisu matematycznego badanego reaktora.

Keywords: **Activated sludge; ASM2d; Computer simulation; Landfill leachate; MSBR; Modelling; Wastewater treatment.**

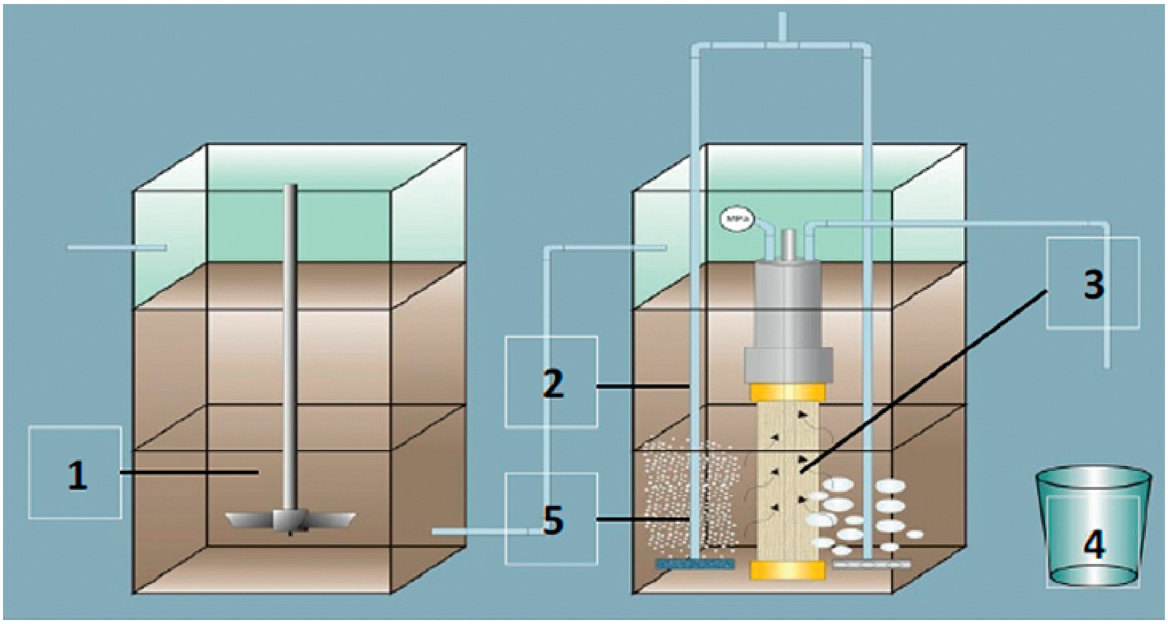

Figure 1.
Experimental set-up: (1) feed tank, (2) aerated MSBR, (3) capillary membrane module, (4) effluent tank, (5) fine-bubbles aerator.

1. INTRODUCTION

Landfill leachate is a significant environmental threat because of its load of contaminants, high concentrations of toxic organic substances, variable composition and variable volume. Therefore, the treatment of this type of wastewater is more challenging compared to municipal wastewater treatment and often requires the use of combined physicochemical and biological methods [1, 2]. A solution which falls into this category is the application of membrane sequencing batch reactor (MSBR). This technology combines the activated sludge method with pressure membrane techniques. The presence of membrane modules in the system eliminates the need for secondary settling tanks, ensures a longer retention time of slowly biodegradable macromolecular substances in the bioreactor, and enables operation with low sludge loads due to elevated MLSS content [3, 4, 5]. In Europe, there are more than 100 wastewater treatment plants (WWTPs) fitted with membrane bioreactors (MBRs), and in the US the number of such plants was reported to be higher than 200 [6, 7]. The aim of this study was to develop a mathematical model of a lab-scale membrane sequencing batch reactor (MSBR) co-treating landfill leachate with synthetic wastewater. The applied model was based on the Activated Sludge Model No. 2d (ASM2d) [8]. It is a common practice that full-scale implementations are preceded by experiments on a smaller scale. The time and cost of research can be markedly reduced by combining lab-scale experiments with computer simulation studies using mathematical models. A calibrated model can be a useful tool in the designing and optimisation of the experimental and technical systems, but can also be conducive to understanding the underpinnings of the process [9].

2. MATERIALS AND METHODS

2.1. Construction and operation of the lab-scale MSBR

The process was carried out in an MSBR fitted with an inner capillary microfiltration PVDF membrane. The feed was pumped from a storage tank into the MSBR. The volume of the MSBR was 15 L. The treated effluent was sucked into the capillaries and pumped to an effluent storage tank. The MSBR and feed tank were equipped with sensors of water level, dissolved oxygen (DO) concentration and temperature. The schematic of the unit is depicted in Fig. 1.

The applied membrane module had a filtration area of 0.45 m^2 and was characterized by high mechanical strength and chemical resistance [10]. The operation of the membrane bioreactor was based on the assumption that the activated sludge would adsorb and oxidize the contaminants present in the wastewater while the membrane would act as a filter separating biomass and refractory macromolecular compounds. The 12-h operational cycle of the bioreactor

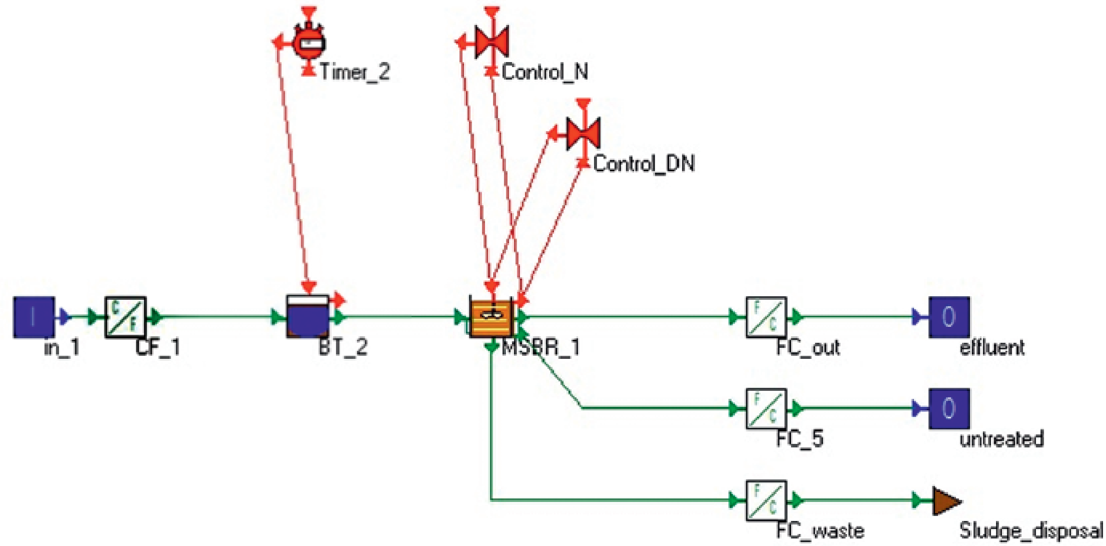

Figure 2.
The setup of the MSBR model in WEST® 3.7.6

comprises the following phases: filling and mixing (denitrification) – 4 h, aeration (nitrification) – 7 h, settling and withdrawal of treated wastewater – 1 h. The concentration of MLSS was maintained at the level of 3.5 $g \cdot L^{-1}$, the concentration of DO during the aeration phase was 4 $mg \cdot L^{-1}$, and the COD sludge load was equal to 0.1 $gCOD \cdot (gMLSS \cdot d)^{-1}$.

2.2. Reactor feed

The feed of the reactor was composed of synthetic wastewater and 5% (by volume) of landfill leachate. The optimal proportion of leachate was determined during preliminary experiments (unpublished data).

The landfill leachate was collected at a municipal landfill in Tychy-Urbanowice, Poland. The inoculum of the MSBR was MLSS from the Central WWTP in Gliwice, Poland. The synthetic wastewater was prepared according to [11]

2.3. Analytical methods

The DO concentration was measured by a DO meter (model CO – 411). The concentration of phosphate and nitrate was analysed by ionic chromatography (DIONEX DX-120). The TOC, TIC and TC were analysed by a TOC analyser (Multi N/C, Jena Analytik). Total nitrogen, ammonia nitrogen and COD were determined spectrometrically (MERCK NOVA 400). The BOD5 was determined by respirometry (OXI Top, WTW).

2.4. Modelling the MSBR

The model of the MSBR was implemented in the WEST® (World Wide Engine for Simulation, Training and Automation) Software Package version 3.7.6 [12]. This model consisted of several submodels, which were used to mimic different aspects of the lab-scale system (Fig. 2). The activated sludge process was modelled with ASM2d, which allows the simulation of processes of organic matter, nitrogen and phosphorus removal. The hydrodynamics of the MSBR was modelled by the use of a SBRPointSettler2PhaseReact model [13]. In Fig. 2 the coupled biokinetic and hydrodynamic models are represented by the box tagged “MSBR_1”. This model emulates also separation capacity of the membrane, however, in a simplified manner. The non-setteable fraction of suspended solids coefficient (fns) describes the efficiency of membrane in removing solids. The value of this parameter was set to 0 during the simulations. The particulate fraction of the ASM2d components retained in the reactor was withdrawn from the MSRB model during the idle phase (“Sludge disposal”, Fig. 2). To control the DO concentration in the model two on-off controllers were used (“Control_N” and “Control_DN”, for nitrification and denitrification, respectively, Fig. 2). The applied model included also a submodel of a buffer tank (“BT_2”, Fig. 2), which was used for the correct representation of the actual conditions of feeding wastewater to the reactor. Any excess water was bypassed. (“untreated”, Fig. 2). The “Timer_2” model was to sync the fill phase of MSRB with the drain phase of the buffer tank.

2.5. Influent fractionation

The components of ASM2d differed from the set of data that characterized the lab-scale MSRB. Thus, the set of model fractions, which mimics the real influent, was determined based on the laboratory assays described in [14] and influent fractionation procedure reported in [8, 15].

3. RESULTS AND DISCUSSION

The model output obtained during the simulation presented in this work describes the quality of the MSBR effluent. The 100-day operation of the reactor was simulated in a steady state.

The data were averaged and elaborated to represent a steady state. In order to assess the accuracy of the mathematical description of the MSBR the obtained simulation results were compared with the measured parameters (Fig. 3). It was observed that the simulation results deviate significantly from the real data.

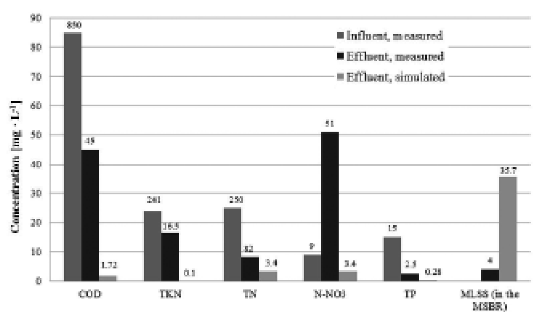

Figure 3.
Comparison of the measured and simulated effluent concentrations, and the influent and effluent concentrations in the lab-scale system. The graph bars for COD, TKN, TN in the influent and TN in the effluent, measured, were reduced by a factor of 10. The real values are shown as data labels

The application of the mathematical model often necessitates adjustment of the parameters, which markedly affect the model output. This procedure is termed "model calibration". The goal of calibration is to obtain acceptable fit between the real and simulated data for most of the variables of interest. The calibrated model should describe a given process with an acceptable accuracy for different data sets. That capacity of a model is tested during model verification. The initial simulation is often performed with default parameters of a model, as was the case in this work. The default parameters of the ASM2d, which is a core of the presented model, were based on the parameters suggested in [8]. Due to the large discrepancies observed between the measured and simulated data the model parameters were not subjected to any adjustment. Noteworthy, the calibrated model would probably permit to obtain results fitting the real data with more accuracy, but its applicability would be questionable. The authors of [16] suggest that if the calibration results indicate that a major adjustment of the model parameters is necessary, it is most likely that a structural error is present in the model. In this case, the revaluation of the model is advised. To this end, the mass balances should be checked again and extra verification measurements be made. Interestingly, the authors of [17] stated that models of full-scale systems are more sensitive towards operational data than to most of the model parameters. However, it appears to be easier to describe a lab-scale system, the data used for modelling purposes should be screened for errors and consistency, since fitting a model to erroneous or unbalanced data will inevitably lead to laborious and unjustifiable model calibrations [17]. The quality of modelling study can be markedly increased when it is performed according to the guidelines presented in the literature, termed as "calibration protocols", e.g. [9, 18]. These protocols describe, amongst others, the methodology of model-specific determination of influent fractions and kinetic and stoichiometric parameters.

The authors of [9] observed that that the degradation of organic nitrogen (i.e. hydrolysis and ammonification) is the rate limiting-step in the overall nitrogen turnover in a pilot-scale SBR. This was caused probably by the high fraction of organic nitrogen present in the influent, which was approximately 95% (75% in this study) of TN. Since the ASM2d is valid only for municipal wastewater, modelling of the treatment of wastewater high in organic nitrogen may give unreliable results [8]. In order to adequately describe the dynamic nitrogen trends in an SBR the authors of [9] proposed the ASM2d model extended with a hydrolysis process for the entrapped organic nitrogen. This extension was based on the concept used in the ASM1, where the particulate nitrogen is first hydrolysed to soluble organic nitrogenand then ammonified to $N\text{-}NH_4$ by heterotrophic biomass [9]

The findings reported in [9, 19, 20, 21] permit to conclude that the application of the ASM2d is not as straightforward as for conventional activated sludge systems treating municipal wastewater. One of the reasons for invalidity of the model is changes in the microbial community under quite different operational conditions, which cannot be accounted for by the model [22]. This was corroborated by the study presented in [21] whose findings revealed that an ASM-type mechanistic model was unable to take into account all aspects of the SBR system under study, particularly regarding the settling properties as well as the change in the microbial community structure. In [20] further extension of the ASM2d was proposed. In addition to the limited hydrolysis of organic nitrogen, this model allowed modelling of 2-step nitrification and 2-step denitrification. The authors of [20] stated that the ASM2d model structure has to be adapted in response to changes in the behaviour of a given system.

4. CONCLUSIONS

The observed large discrepancies between the real data and the simulation results allow a conclusion that the model based on the ASM2d is inadequate to simulate the behaviour of the investigated lab-scale MSBR. The fact that the ASM2d cannot be directly applied to model the investigated MSBR may follow from: the lack of detailed model-specific data, specific properties of the MSBR, and the invalidity of the ASM2d. To enhance the applicability of the model of the MSBR it is necessary to determine the model fractions and kinetic and stoichiometric parameters according to the calibration protocols. In addition, the long-term behaviour of the MSBR should be studied in more detail to single out specific periods of its operation. It may be assumed that the application of the averaged data from a 100-day period of the MSBR operation is inappropriate from the modelling perspective. These data does not describe the changes of the system behaviour over this period, which leads to erroneous mathematical description of the system based on the mechanistic ASM2d.

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