Journal of Environmental Management 165 (2016) 235–242

Contents lists available at ScienceDirect

Journal of Environmental Management

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

Research article

Simulation and optimization of a coking wastewater biological treatment process by activated sludge models (ASM)

Xiaohui Wu [a, **], Yang Yang [a, c], Gaoming Wu [b], Juan Mao [a], Tao Zhou [a, *]

[a] School of Environmental Science and Engineering, Huazhong University of Science and Technology, Wuhan, 430074, PR China
[b] Wuhan Iron and Steel Co. Ltd., Wuhan, 430080, PR China
[c] Nuclear Power Institute of China, Chengdu, 610041, PR China

ARTICLE INFO

Article history:
Received 22 July 2015
Received in revised form
24 September 2015
Accepted 27 September 2015
Available online 2 October 2015

Keywords:
Activated sludge model no. 3 (ASM3)
Industrial wastewater treatment plants
Coking wastewater
Parameter estimation
Sensitivity analysis

ABSTRACT

Applications of activated sludge models (ASM) in simulating industrial biological wastewater treatment plants (WWTPs) are still difficult due to refractory and complex components in influents as well as diversity in activated sludges. In this study, an ASM3 modeling study was conducted to simulate and optimize a practical coking wastewater treatment plant (CWTP). First, respirometric characterizations of the coking wastewater and CWTP biomasses were conducted to determine the specific kinetic and stoichiometric model parameters for the consecutive aeration-anoxic-aeration (O-A/O) biological process. All ASM3 parameters have been further estimated and calibrated, through cross validation by the model dynamic simulation procedure. Consequently, an ASM3 model was successfully established to accurately simulate the CWTP performances in removing COD and NH_4–N. An optimized CWTP operation condition could be proposed reducing the operation cost from 6.2 to 5.5 €/m^3 wastewater. This study is expected to provide a useful reference for mathematic simulations of practical industrial WWTPs.

1. Introduction

In the past decades, activated sludge process has been becoming the most worldwide popular biological process in treating different types of wastewaters. In order to evaluate and predict the process efficiencies of various WWTPs during the biological nutrient removal, many advanced dynamic mathematical models have been developed. Modeling is considered to be an inherent part of the design and operation of a wastewater treatment system. These models allow us to understand preferably the biological wastewater treatment process and response to influence of variable wastewater quality and process parameters in a more feasible and cost-effective way.

Developed by IWA (International water association), a series of activated sludge models (i.e. ASM1, ASM2, ASM2d, ASM3) have been considered as good solutions in correlating the complexity of the activated sludge processes and the prediction of biological treatment efficiency under dynamic conditions (Henze et al., 1987, 1995, 2000; Gujer et al., 1999). ASM1 were the primary developed model (Henze et al., 1987). Using facultative consumption of oxygen or nitrate as the elector acceptor, the model could successfully describe the removal of organic carbon compounds and ammonium within municipal activated sludge. After several years, it was developed to ASM2 (Henze et al., 1999) for addressing the biological nitrogen and phosphorus removal processes in WWTPs and late to ASM2d considering the denitrifying process of phosphorus accumulating organisms (PAOs) (Henze et al., 1999). Thereafter, a more complex ASM3 has also occurred to describe the biological nitrogen removal processes considering the storage of biopolymers under transient condition (Gujer et al., 1999). The series of ASM models could provide researchers and practitioners with a standardized set of basic models in successfully evaluating WWTPs. Today, ASM series are widely accepted in the scientific community and the sanitary engineering profession (Ujang et al., 2004), especially in numerous cases of municipal WWTPs.

Nevertheless, the related researches or applications of ASMs in industrial WWTPs are still very limited. There are a few published ASM modeling attempts, including the cases of pulp mill wastewater (Barañao and Hall, 2004), tannery wastewater (Munz et al., 2008) and palm oil wastewater (Damayanti et al., 2010). The

---

[*] Corresponding author.
[**] Corresponding author.
E-mail addresses: xhwoo@hust.edu.cn (X. Wu), zhoutao@hust.edu.cn (T. Zhou).

http://dx.doi.org/10.1016/j.jenvman.2015.09.041

Symbols

$b_{A, O}$	Aerobic endogenous respiration of nitrifiers
$b_{A, NO}$	Anoxic endogenous respiration of nitrifiers
$b_{H, O2}$	Aerobic endogenous respiration rate of X_H
$b_{H, NO}$	Anoxic endogenous respiration rate of X_H
$b_{sto, NO}$	Anoxic respiration rate of X_{STO}
$b_{sto, O2}$	Aerobic respiration rate of X_{STO}
f_{SI}	Production of S_I in hydrolysis
f_{XI}	Production of X_I in endogenous biomass respiration
k_h	Hydrolysis rate constant
$K_{A, NH}$	Ammonium substrate saturation constant for nitrifiers
$K_{A, O}$	Oxygen substrate saturation constant for nitrifiers
$K_{A,HCO}$	Saturation constant for alkalinity for autotrophs
K_{HCO}	Saturation constant for alkalinity for X_H
K_{NH}	Saturation constant for S_{NH}
K_{NO}	Saturation constant for S_{NO}
K_O	Saturation/inhibition constant for oxygen S_O
K_S	Saturation constant for substrate S_S
k_{sto}	Aerobic storage rate constant
K_{sto}	Saturation constant for XSTO
K_X	Hydrolysis saturation constant
S_I	Soluble inert organics
S_{NH}	Ammonium
S_{NO}	Total oxidized nitrogen
S_S	Readily biodegradable substrates
X_H	Heterotrophic biomass
X_I	Inert particulate organics
X_S	Slowly biodegradable substrates
X_{STO}	Organics stored by heterotrophs
μ_A	Autotrophic maximum growth rate
μ_H	Heterotrophic max. growth rate of X_H
Y_A	Aerobic yield of X_A
$Y_{H, NO}$	Anoxic yield of heterotrophic biomass
$Y_{H, O2}$	Aerobic yield of heterotrophic biomass
$Y_{STO, NO}$	Anoxic yield of stored product for S_S
$Y_{STO, O2}$	Aerobic yield of stored product for S_S

results revealed that the classic ASM models (Gujer et al., 1999) could not be applied in industrial WWTPs due to the different characteristics of either the activated sludge or the influent wastewater as compared to municipal WWTPs. In addition, these researches were in lab-scale and have not been really applied in industry-scale engineered WWTPs.

Cooking wastewater is a typical industrial wastewater generated from the coal chemistry industry. It generally contains not only concentrated biodegradable components but also refractory organic pollutants such as phenols, polycyclic aromatic hydrocarbons (PAHs), pyridines, indoles, and quinolines (Guo et al., 2011; Chu et al., 2012). The particular characteristics of the wastewater should make the CWTP possess of very complicated biological processes to obtain good treatment efficiency. It is suggested that mathematical ASM models would be a very useful and cost-effective tool during the design, operation and optimization of such a wastewater treatment system. However, to our best knowledge, a referenceable ASM modeling example applying in complex industrial WWTP is still scarce.

In this study, a mathematical modeling work for a real case of CWTP in operation was conducted. The ASM3 was selected as the model environment, since the assumptions of model that storage of readily biodegradable substrates inside the cell would be the dominant process is appropriate to describe biological processes with high load of influent substrates (Gujer et al., 1999; Goel et al., 1998; Koch et al., 2000; van Loosdrecht and Heijnen, 2002). Our objectives were to: (i) determine the essential kinetic and stoichiometric model parameters, through experimentally evaluating the characteristics of the influent coking wastewater and the CWTP activated sludges; (ii) build, calibrate and validate an ASM model for the CWTP biological system by means of the simulation software WEST 2012®, and (iii) use the ASM3 model to successfully simulate the effluent pollutants (COD and NH_4–N) and optimize the key operation conditions of the CWTP.

2. Materials and methods

2.1. The biological process of the coking wastewater treatment plant

The CWTP locates in Wuhan city, P. R. China and treats 12,000 m^3/d (8400 m^3/d raw wastewater + 3600 m^3/d of dilution water) average of coking wastewater discharged from a steel mill. Table 1 summarizes the common wastewater physical–chemical parameters and their daily average values of the CWTP influent. Collected from summer of the year 2013, the related process data of the CWTP were used for the ASM3 simulations in this study.

Fig. 1 briefs a flowchart of the biological process in the CWTP. The main process is consist of aeration unit—anoxic unit—aeration unit in sequence of wastewater flow, namely O/A/O process. The process is operating in parallel. Each includes 4000 m^3 and 8600 m^3 aeration tanks (called O_1 and O_2 respectively), a 5000 m^3 anoxic tank, a primary sedimentation tank (380 m^3) and a secondary sedimentation tank (500 m^3). It should be noticed that the O/A/O process is actual an O_1-A/O_2 process, since only the water effluent of O_1 enters the anoxic tank whereas the sludge in the primary sedimentation tank is returned to O_1 at a ratio of 1. The underflow from the secondary sedimentation tank flows back to the anoxic tank at a ratio of 1.5 in order to supply the nutrient requirements of the bacteria and maintain sufficient solids concentration. During the process operation, the concentration of dissolved oxygen (DO) is 2.3 mg/L in O_1 and 5.2 mg/L in O_2, respectively.

To simulate the CWTP process correctly, a digitizing schematic of the biological process drawn by the software WEST 2012® (Worldwide engine for simulation, training and automation) is also given in the bottom of Fig. 1. Therein, the biological process would be divided into two individual processes, i.e. the "O_1" process and the "A/O_2" process.

Table 1
The wastewater characteristics of the CWTP influent.

Parameter	Value[a]
Influent flow (m^3/h)	500
Raw wastewater (m^3/h)	350
Dilution water (m^3/h)	150
Temperature (°C)	28–35
pH	8.3
COD (mg/L)	2000
NH_4–N (mg/L)	135
TKN (mg/L)	270
TSS (mg/L)	40

[a] Average values, collected from the summer, year 2013.