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Simulation and optimization of ammonia removal at low temperature for a double channel oxidation ditch based on fully coupled activated sludge model (FCASM): A full-scale study

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HIGHLIGHTS

- A novel model was proposed to simulate and optimize the poor ammonia removal efficiency of a full-scale WWTP at low temperature.
- Several important kinetic parameters were determined by respirometer test.
- The optimal operating condition was DO of 3.5 mg L^{-1}, SRT of 15 d, HRT of 14 h.
- Ammonia removal efficiency would improve 19.14% under the optimal operating condition.

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ABSTRACT

An optimal operating condition for ammonia removal at low temperature, based on fully coupled activated sludge model (FCASM), was determined in a full-scale oxidation ditch process wastewater treatment plant (WWTP). The FCASM-based mechanisms model was calibrated and validated with the data measured on site. Several important kinetic parameters of the modified model were tested through respirometry experiment. Validated model was used to evaluate the relationship between ammonia removal and operating parameters, such as temperature (*T*), dissolved oxygen (DO), solid retention time (SRT) and hydraulic retention time of oxidation ditch (HRT). The simulated results showed that low temperature have a negative effect on the ammonia removal. Through orthogonal simulation tests of the last three factors and combination with the analysis of variance, the optimal operating mode acquired of DO, SRT, HRT for the WWTP at low temperature were 3.5 mg L^{-1}, 15 d and 14 h, respectively.

1. Introduction

Activated sludge process was regarded as one of the most effective and economical way in treating wastewater. Various functional microorganisms and other matter made up of the activated sludge. Nitrification bacteria and denitrification bacteria were two kinds of the functional microorganism which contributed to the nitrogen removal. In recent years, an increasing number of studies showed that temperature played an important role in nitrification and denitrification process. Ammonia oxidation was not only the main way of nitrogen removal, but also the foundation of other nitrogen removal reaction, such as nitrification, partial nitrification, and anammox (Kumar and Lin, 2010; Lan et al., 2011; Waki et al., 2010). The optimum growth temperature of majorities of the nitrifying bacteria was 30–35 °C. when temperature was below 15 °C, the activity of nitrifying bacteria reduced and as a result, the nitrification rates dropped significantly (Sudarno et al., 2011; Sun et al., 2010). However, in many places of the world temperature difference varied greatly between summer and winter. It led to that many wastewater treatment plant (WWTP) had satisfying nitrogen removal efficiency in summer, whereas very poor in winter. And so was in China. Moreover, the effluent quality of wastewater treatment was becoming more and more stringent. So it was necessary to figure out a cost-effective way to optimize the process of WWTP at different seasons.

It was well known that the biochemical reaction processes in activated sludge system were complicated, nonlinear and difficult

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Table 1
Definition of modified FCASM components.

No.	Symbol	Definition	Units
1	S_{O_2}	Dissolved oxygen	$g(O_2)\ m^{-3}$
2	S_A	Acetate	$g(COD)\ m^{-3}$
3	S_{PRO}	Propionate	$g(COD)\ m^{-3}$
4	S_F	Fermentable, readily biodegradable organic substrates	$g(COD)\ m^{-3}$
5	S_I	Soluble inert organic matters	$g(COD)\ m^{-3}$
6	S_{NH_4}	Ammonium plus ammonia nitrogen	$g(N)\ m^{-3}$
7	S_{NO_3}	Nitrate nitrogen	$g(N)\ m^{-3}$
8	S_{NO_2}	Nitrite nitrogen	$g(N)\ m^{-3}$
9	S_{NO}	Nitric oxide	$g(N)\ m^{-3}$
10	S_{N_2O}	Nitrous oxide	$g(N)\ m^{-3}$
11	S_{N_2}	Nitrogen	$g(N)\ m^{-3}$
12	S_{PO_4}	Inorganic soluble phosphorus, primarily orthophosphates	$g(P)\ m^{-3}$
13	S_{ALK}	Bicarbonate alkalinity	$mol(HCO_3^-)\ m^{-3}$
14	S_{IC}	Inorganic carbon	$g(COD)\ m^{-3}$
15	S_{H_2}	Hydrogen	$g(COD)\ m^{-3}$
16	S_{CH_4}	Methane	$g(COD)\ m^{-3}$
17	X_I	Inert particulate organic material	$g(COD)\ m^{-3}$
18	X_S	Slowly biodegradable substrates	$g(COD)\ m^{-3}$
19	X_{OH}	Aerobic heterotrophic organisms	$g(COD)\ m^{-3}$
20	$X_{STO,OH}$	A cell internal storage product of aerobic heterotrophic organisms	$g(COD)\ m^{-3}$
21	X_{DNZ}	Nitric oxide-reducing bacteria	$g(COD)\ m^{-3}$
22	$X_{STO,DNZ}$	A cell internal storage product of nitric oxide-reducing bacteria	$g(COD)\ m^{-3}$
23	X_{DNQ}	Nitrous oxide-reducing bacteria	$g(COD)\ m^{-3}$
24	$X_{STO,DNQ}$	A cell internal storage product of nitrous oxide-reducing bacteria	$g(COD)\ m^{-3}$
25	X_{DNS}	Nitrite reducing organisms	$g(COD)\ m^{-3}$
26	$X_{STO,DNS}$	A cell internal storage product of nitrite reducing organisms	$g(COD)\ m^{-3}$
27	X_{DNB}	Nitrate reducing organisms	$g(COD)\ m^{-3}$
28	$X_{STO,DNB}$	A cell internal storage product of nitrate reducing organisms	$g(COD)\ m^{-3}$
29	X_{NS}	Ammonium oxidizing autotrophs	$g(COD)\ m^{-3}$
30	X_{NB}	Nitrite oxidizing autotrophs	$g(COD)\ m^{-3}$
31	X_{ACID}	Acid-producing bacteria	$g(COD)\ m^{-3}$
32	X_{ACET}	Hydrogen production of acetic acid bacteria	$g(COD)\ m^{-3}$
33	X_{MAC}	Turn acetic acid methane-producing bacteria	$g(COD)\ m^{-3}$
34	X_{MH_2}	Turn hydrogen methane-producing bacteria	$g(COD)\ m^{-3}$
35	X_{PAO}	Non-denitrifying phosphorus-accumulating organisms	$g(COD)\ m^{-3}$
36	$X_{PP,PAO}$	Polyphosphate of non-denitrifying phosphorus-accumulating organisms	$g(P)\ m^{-3}$
37	$X_{PHA,PAO}$	A cell internal storage product of non-denitrifying phosphorus-accumulating organisms	$g(COD)\ m^{-3}$
38	$X_{GLY,PAO}$	A cell internal storage product of non-denitrifying phosphorus-accumulating organisms	$g(COD)\ m^{-3}$
39	X_{DPB}	Denitrifying phosphorus-accumulating bacteria	$g(COD)\ m^{-3}$
40	$X_{PP,DPB}$	Polyphosphate of denitrifying phosphorus-accumulating bacteria	$g(P)\ m^{-3}$
41	$X_{PHA,DPB}$	A cell internal storage product of denitrifying phosphorus-accumulating bacteria	$g(COD)\ m^{-3}$
42	$X_{GLY,DPB}$	A cell internal storage product of denitrifying phosphorus-accumulating bacteria	$g(COD)\ m^{-3}$
43	X_{GAO}	Glycogen-accumulating organisms	$g(COD)\ m^{-3}$
44	$X_{PHA,GAO}$	A cell internal storage product of glycogen-accumulating organisms	$g(COD)\ m^{-3}$
45	$X_{GLY,GAO}$	A cell internal storage product of glycogen-accumulating organisms	$g(COD)\ m^{-3}$
46	X_{TSS}	Total suspended solids	$g(TSS)\ m^{-3}$
47	X_{MeOH}	Metal hydrolyzate	$g(TSS)\ m^{-3}$
48	X_{MeP}	Chemical phosphorus	$g(TSS)\ m^{-3}$

to describe. Activated sludge models proposed in 1980s and 1990s by the International Water Association (IWA) (Gujer et al., 1999, 1995; Henze et al., 1987, 1999), were proved to be useful and powerful tools to simulate and optimize activated sludge system (Souza et al., 2008; Xie et al., 2011). Varieties software containing a number of activated sludge models were developed to simulate and optimize the biochemical reaction process, which provided an important platform for process optimization (Ferrer et al., 2008; Muschalla et al., 2009). Nevertheless, most of the models could not directly reflect the effect of temperature on biochemical reaction processes. As a result, the optimized conclusion was not convincing.

Fully coupled activated sludge model (FCASM) put forward a new concept of interaction between different microorganism communities and ambient conditions (Sun et al., 2009). Temperature was coupled into the kinetic reaction equation directly. Hence, FCASM could intuitively reflex the effect of temperature on reaction rate of biochemical processes without changing the kinetic parameters. This would be more convenient to calibrate and validate the model. Considering majority of wastewater were made up of the domestic sewage and industrial wastewater in China, the negative effect of inhibitory factors on biochemical reactions was also included in FCASM. Moreover, floras were divided into eight categories in FCASM, which described the metabolic process of microorganism more detailedly. It was already proved that FCASM could be used to instruct the operation of municipal WWTP, in which the wastewater contained about thirty percent industrial wastewater (Lou et al., 2008). In order to describe the activated sludge system more comprehensively, FCASM also should contain some physical and chemical process, anaerobic digestion process, the full process of hydrolysis. Because these processes would also affect the accuracy of the predicted results (Seco et al., 2004).

In this study, the mechanistic model was used to optimize a double channel oxidation ditch WWTP with poor ammonia removal efficiency at low temperature. Through developing and extending a mechanistic model based on FCASM, a numerical model about the double channel oxidation ditch WWTP (Shengxin WWTP) was established. The data tested in field were used to calibrate and validate the modified model. Then the validated model