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REVIEW ARTICLE

An obstacle to China's WWTPs: the COD and BOD standards for discharge into municipal sewers

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Abstract In 2001, a construction campaign regarding wastewater treatment plants (WWTPs) occurred in China. Unfortunately, the treatment has not yet achieved anticipated effectiveness. A critical reason for this is that the influent chemical oxygen demand (COD) and biochemical oxygen demand (BOD) concentrations in WWTPs are unacceptably low. This paper indicates that a fundamental, but commonly overlooked contributing factor to this problem is that a large portion of easily degradable COD and BOD is degraded prematurely before entering municipal sewers, and this is directly correlated to China's standards for pollutant discharging into municipal sewers. This perspective is further unfolded through retrospection of the history of Chinese wastewater treatment and the investigation of standards among developed zones and districts. This paper suggests that in China, the standards for pollutant discharging into municipal sewers should be relaxed. Meanwhile, unnecessary pretreatment of COD and BOD should cease for the purpose of ensuring that easily degradable COD and BOD can be transferred to WWTPs to improve treatment efficiency. Moreover, additional alternatives are presented to resolve this problem.

Keywords Wastewater treatment plants · Influent concentrations · Discharge · Standards · Municipal sewers

Introduction

To remedy severe water pollution resulting primarily from substantial discharge of wastewater, China launched a construction campaign of wastewater treatment plants (WWTPs) in 2001, which is mainly based on biochemical processing. The number of WWTPs is increasing rapidly. The number was 315 in 2000 (Qiu et al. 2010b). However, this number rose to 3340 by 2012 (Jin et al. 2014). The Twelfth Five-Year Plan of Energy Conservation and Emission Reduction (2011 to 2015) of China indicates that the municipal wastewater treatment rate should reach 85 % at the end of 2015. Furthermore, sufficient reduction of nitrogen (N) and phosphorus (P) is required by the government to prevent eutrophication of water bodies.

Unfortunately, the treatment efficiency (i.e., removal rate of pollutants) in many WWTPs has not achieved the anticipated effectiveness. Reasons for this are as follows: many wastewater treatment plants are off the scale when designed due to inadequate studies on influent characteristics, which leads to low performance factors of facility operations, treatment capacity issues, and an extensive rate of unutilized resources (Han 2012). The treatment processes of WWTPs are conservatively and rigidly designed with a lack of depth processing (Qiu et al. 2010b). In addition, the control level of WWTPs is stifled due to undeveloped instrumentation, control, and automation (ICA) levels generated by costly online instruments and over employment of workers (Qiu et al. 2010b). However, there is a critical, yet commonly overlooked factor, which is that the influent chemical oxygen demand (COD) and biochemical oxygen demand (BOD) concentrations in

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WWTPs cannot satisfy the requirements of efficient treatment. Taking COD as the example, the influent COD in WWTPs in developed countries is 600~800 mg/L generally, at least 300~400 mg/L. In China, however, the value is 200~300 mg/L in general, even less than 100 mg/L in some regions (Carucci et al. 1996; Cokgor et al. 1998; Fuerhacker et al. 2000; Hou et al. 2005; Mailler et al. 2014; Orhon et al. 1997). Hence, the microorganism for treatment lacks an external carbon source which is the necessary material of bacterial metabolism and source of energy, and subsequently cannot work well (Zhang et al. 2009). Particularly, the low ratio of carbon to nitrogen (C/N) leads to a low removal efficiency of nitrogen. Su (2010a) finds that the average C/N of two WWTPs in Guangdong is 6.73 and 6.38 respectively, meanwhile the removal rate of nitrogen is 64.53 and 34.97 % respectively. In general, low influent COD and BOD concentrations in WWTPs (Table 1) and the low treatment efficiency (i.e., removal rate of pollutants) directly generated by insufficient carbon sources (Su 2010a; Li et al. 2011; Liu et al. 2011; Park et al. 2005) actually have become a common contemporary problem in China.

The generating causes of low COD and BOD include differences of food consumption between the Chinese cultural structure and the Western cultural structure, as well as the infiltration of underground water, the inflow of rain water and inland water, and degradation of COD and BOD in the process of wastewater transportation in sewers (Xie et al. 2012). Table 2 outlines the differences between China and the West in terms of sewerage systems. There is another fundamental contributing factor which is also commonly overlooked, i.e., in China, a large portion of easily degradable COD and BOD is degraded prematurely before entering municipal sewers, and this is directly correlated to China's COD and BOD standards for pollutant discharging into municipal sewers. This means that because the standards have established upper limits of COD and BOD, the average influent COD and BOD concentrations decrease to an unacceptable low level due to low concentration wastewater, storm water, underground water, food habits, etc. However, if such limitations were non-existent, many systems would discharge higher COD and BOD concentration wastewater to municipal sewers which were connected to WWTPs. In addition, other contributing factors would be offset and the average COD and BOD concentrations would become acceptable which would result in the avoidance of the current problematic situation.

The history and current situation of China's standards

To explain this issue further, it is essential to retrospect the history of Chinese wastewater treatment. Decades ago, China's public finance system was inadequate which lead to the establishment of a limited number of WWTPs. For example, in 1978, there were only 35 WWTPs in China. In the 1990s, the number reached about 200. At that time, for the purpose of protecting water environment, a large number of decentralized industrial and domestic wastewater treatment facilities (including septic tanks) were constructed by enterprises and residences to eliminate COD and BOD. Currently, many WWTPs are established, and the tail water of those facilities is intercepted.

On the other hand, also for the purpose of protecting water environment as well as effectively operating WWTPs, China issued wastewater quality standards for discharge into municipal sewers in 1986. After much revision, the standards are currently composed of 46 indices including toxic indices such as metal, organic and inorganic matters, and conventional indices such as COD, BOD, total nitrogen, and total phosphorus. Also, different upper limit values have been established (except pH value) according to the discharge direction of wastewater, i.e., discharge into WWTPs, or discharge into water bodies. The COD and BOD upper limit values are shown in Table 3 (Ministry of Housing and Urban–rural Development of the People's Republic of China 2010).

The standards have been enforced from then onwards. To meet the standards, the decentralized industrial and domestic wastewater treatment facilities established years ago are still

Table 1 Influent COD concentrations in China's WWTPs

WWTPs	Influent COD_{Cr} (mg/L)[a]	City/Province	Sources
A	170.13	Guangzhou, Guangdong	Zhou and Zhou 2006
B	100.00	Guangzhou, Guangdong	Qiu et al. 2010a
C	161.63	Hubei	(Shi 2013)
D	102.89	Chongqing	(Peng 2013)
E	144.50	Daqing, Heilongjiang	Bai and Wang 2001
F	247.57	Jinan, Shandong	Su 2010b
G	40.40	Hunan	Yuan et al. 2014
H	300.20	Shanghai	(Sun et al. 2014)

[a] The influent COD_{Cr} concentration in WWTPs is a mean value

Table 2 Differences between China and the West in relation to sewage pipeline systems

Pipeline condition	China	Western countries
Pervasion of sewers[a]	64.8 % (2012)	>80 % (2004)
Infiltration of sewers	31 % (Shanghai, China)[b]	28.8 % (Germany)[c]
Illicit connections	Extremely serious and widespread related to high-speed urbanization[d]	Not serious due to the massive application of combined sewer system and strict control on illicit connections[e]
Construction of septic tanks	Throughout old towns where even WWTPs are constructed[f]	No septic tanks where centralized sewerage systems are available[g]
Detection and rehabilitation of sewers[h]	Traditional detecting techniques of sewers and lack of investment cost	Advanced detection technology with widely used trench-less rehabilitation technology

[a] (Garelli 2004; Wang 2012b)

[b] The ratio of groundwater infiltration to the total wastewater produced in dry season in Shanghai (Li et al. 2003)

[c] The ratio of external water (e.g., groundwater, stormwater, inland water, etc.) infiltration to the total wastewater produced in dry season in Germany (Tang and Zhang 2015)

[d] (Li et al. 2010)

[e] (Zhang 2010; US Environmental Protection Agency 2014)

[f] (Lu et al. 2007; Hao et al. 2006)

[g] (Gunady et al. 2015; Harrison et al. 2012; Izbicki et al. 2015)

[h] (Tang and Zhang 2015; US Environmental Protection Agency 1999; Wang 2012b; He and Sun 2010)

functioning even if their serving areas have been covered by WWTPs'. Interestingly, additional enterprises (e.g., catering industry enterprises) are required to establish pretreatment facilities to satisfy the COD and BOD standards. Therefore, easily degradable COD and BOD are degraded before entering WWTPs. The original intent of the standards was to prevent an excessive amount of COD and BOD from incapacitating WWTPs. There's an opposite aspect of this scenario: the COD and BOD are not exceedingly high, but unacceptably low. The ostensibly stringent standards directly generate and exacerbate the problem (Fig. 1).

The situation of standards worldwide

To solve the problem, it would be necessary for us to analyze this situation through global perspectives, especially to investigate the wastewater quality standards for pollutant discharging into municipal sewers or other relevant wastewater discharge standards in developed regions (Table 4).

In Australia, the COD and BOD standards for pollutant discharging into sewers are lax for various reasons. Among them, an important factor is that Australian sewage has a relatively high nitrogen concentration. Thus, nitrogen removal is an important concern for WWTPs in Australia, and it means that sufficient carbon sources and appropriate C/N should be ensured by looser COD and BOD standards. In China, the sewage has a low C/N, and nitrogen removal is also required. Thus, less strict COD and BOD standards should be considered.

In the USA, the upper BOD standard for pollutant discharging into sewers is not considerably high (300 mg/L, similar to Chinese standards), whereas the data obtained from two WWTPs in the USA show that influent BOD concentrations are 153 and 240 mg/L, and removal rates of BOD are 97.7 and 98.9 % respectively (Table 4), which are extremely high compared with China's removal rates. The influent BOD concentration ranges from 50 to 70 mg/L with an unsatisfactory removal rate in southern Chinese cities (Shao 1999). To explain this issue, the general BOD concentration of wastewater in the USA should be considered, that is to say, most of the wastewater contains a relatively high BOD concentration (but below the standard) (Pescod 1992). Thus, the integrated BOD concentration cannot be low. However, in China, the situation is significantly different. The general BOD concentration of wastewater is far below the current standard due to reasons such as severe dilution or degradation and widely used septic tanks. Therefore, it is apparent that the upper limit

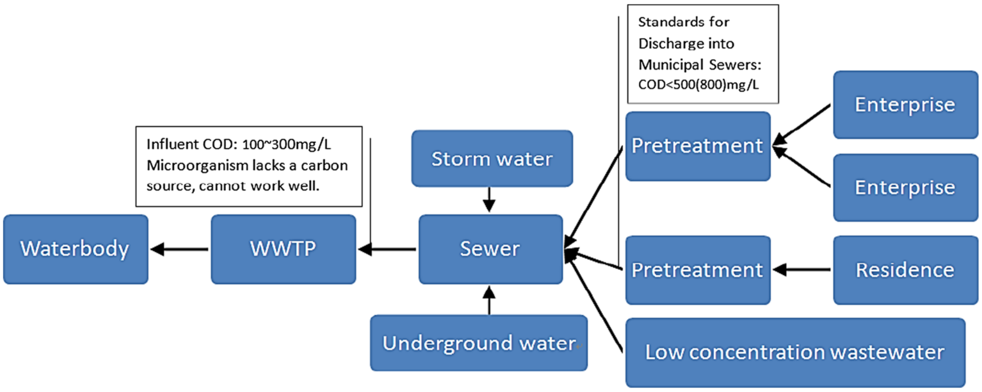
Table 3 Wastewater quality standards for discharge into municipal sewers

Standards	Levels[a]	COD_{Cr}	BOD_5
CJ343-2010	A	500 (800)[b]	350
	B	500 (800)[b]	350
	C	300	150

[a] *A*: For the serving areas of WWTPs with reclamation treatment; *B*: For the serving areas of WWTPs with secondary treatment; *C*: For the serving areas of WWTPs with primary treatment

[b] The value in the parentheses is for the serving areas of WWTPs which are constructed or expanded after 2010, and $BOD_5/COD > 0.4$

Fig. 1 Schematic of the obstacle to China's WWTPs



which is compatible with the USA is unacceptably low for China.

We have not ascertained European standards for pollutant discharging into sewers. However, in Europe, the influent COD concentration in WWTPs remains at a high level with a high removal rate of COD. The requirement for effluent COD concentration from urban WWTPs is not to exceed 125 mg/L (The Council of The European Communities 1991). Thus, we can speculate that the limiting COD and BOD values of wastewater discharging into sewers are not stringent in Europe.

Moreover, Hong Kong's standards for pollutant discharging into sewers which are incorporated with Euro-codes have been obtained (Drainage Services Department of Government of the Hong Kong Special Administrative Region 2013). We can see that COD and BOD upper limits are very high. As the raw sewage of Stonecutters WWTP in Hong Kong is primarily treated by seven WWTPs, the influent BOD concentration is still high compared with China. In fact, the situation in Hong Kong is similar to that of South and East China. Thus, it is also a good example for us to reconsider Chinese standards.

Discussion

Overall, some lessons about the standards can be drawn from worldwide experiences. It is obvious that the modification of current strict standards is essential considering the treatment efficiency and experiences of Australia and Europe. However, replicating the standards of the USA is not feasible due to contrasting conditions between China and the USA. It may be advantageous to relax the upper limit values for COD and

Table 4 The standards and running conditions of WWTPs in four developed regions

	The standards for pollutant discharging into sewers	WWTPs	Concentrations of the influent in WWTPs	Treatment efficiency of WWTPs
Australia[a]	1500 mg/L (COD)[b] 600 mg/L (BOD)	Four WWTPs[c] (average)	682 mg/L (COD) 11.76 (C/N)	94.49 % (nitrogen removal)
The United States	300 mg/L (BOD)[d]	Oak Orchard WWTP[e]	240 mg/L(BOD)	98.92 % (BOD removal)
		Snapfinger WWTP[f]	153.6 mg/L (BOD)	97.70 % (BOD removal)
Europe		Lynetten WWTP[g]	605 mg/L (COD)	95.37 % (COD removal)
Hong Kong	2000–3000 mg/L[h] (COD) 800–1200 mg/L[h] (BOD)	Stonecutters WWTP[i]	272 mg/L (BOD)	85 % (objective BOD removal)

[a] The standards here are national values. In Queensland, the values are 3000 and 2000 mg/L (Queensland Urban Utilities 2011); in Western Australia, the values are 6000 and 3000 mg/L (Sampson et al. 2015)

[b] (Agriculture and Resource Management Council of Australia and New Zealand, and Australian and New Zealand Environment and Conservation Council 1994)

[c] (Haas et al. 2008)

[d] The standard of COD concentration is not stipulated in the United States (Lu et al. 1991)

[e] (State Department of Environmental Conservation http://static.ongov.net/WEP/OakOrchard_WWTP/FactSheet_OakOrchard_06152012.pdf)

[f] (Yao et al. 2013)

[g] (Cui et al. 2007)

[h] The specific values for COD and BOD of effluents discharged into fowl sewers are determined by the flow rate of effluents (Water Policy and Science Group Environmental Protection Department 1997)

[i] Stonecutters WWTP is a large-scale treatment plant whose raw sewage is effluent from the primary treatment of seven WWTPs in Hong Kong (Sun 1997)

BOD and accurate values of the standards should be determined through more effective research works such as more thorough and detailed investigation of COD and BOD concentration of local urban sewage and critical analyses of the change of COD and BOD concentration in pipeline systems. It is essential to note that consideration of additional alternatives regarding the standards can be beneficial. WWTPs may be classified in accordance with regional characteristics and treatment scales and processes, and each type of WWTP can establish its own standards if possible (Yao et al. 2013). Pollutant loads should also be controlled based on waste load allocation of the government for the purpose of maintaining stable operations of WWTPs.

Furthermore, unnecessary pretreatment of COD and BOD should be terminated in China for the purpose of ensuring that easily degradable COD and BOD (i.e., essential carbon sources) can be transferred to WWTPs to improve treatment efficiency. For instance, septic tanks widely used in cities should be eliminated due to low processing capacity, potential environmental hazards, and adverse impacts on subsequent performances of WWTPs (Wang 2012b). At the same time, the cancellation of pretreatment of COD and BOD can lead to a decrease in expenditures, particularly in terms of avoiding costly and complex treatment processes applied to low C/N wastewater for improving nitrogen treatment efficiency of WWTPs. Nevertheless, for wastewater with hardly degradable COD such as petrochemical wastewater, differential policies should be adopted (dos Santos et al. 2014; Mustafa et al. 2014), i.e., pretreatment is necessary to prevent hardly degradable COD from entering municipal WWTPs, and ultimately from harming water bodies.

Nevertheless, thorough analyses of relevant documentation and literature, we discovered that WWTPs in Europe and the USA operate effectively under low influent concentration. It seems that the tendency in Europe and the USA is going in a different direction. Their public policies are encouraging further on-site reduction of wastewater, and the emphasis is on establishing new approaches to operate conventional wastewater treatment plants under low COD and BOD input conditions. Specifically, alternative external carbon sources such as glycerin-based chemicals, high-fructose corn syrup (HFCS), waste sugar water, and acetic acid are added to wastewater to meet biological nutrient removal carbon needs (Fiss et al. 2015). WWTPs in developed countries are optimized with advanced and flexible treatment processes on the basis of conventional processes (Han 2012), such as advanced oxidation, activated carbon filtration, membrane bioreactors, and so on (Joss et al. 2008; Nelson and Murray 2008). Control levels of WWTPs are really high in developed countries. For example, instrumentation, control, and automation (ICA) techniques have been developed and successfully applied in municipal WWTPs in Europe (Qiu et al. 2010).

However, such an ideal condition of WWTPs is difficult to achieve in China and many other developing countries. Costly treatment technologies including depth sewage processing is not compatible with China's WWTPs due to the shortage of construction and operation funds which are mainly subsidized by the government without payment from citizens (Han 2012). In addition, the application of ICA techniques in actual processes is still very limited due to costly online instruments, along with the complexities of downsizing redundant personnel. Therefore, our viewpoint is that developing countries such as China should not follow the tendency blindly in view of their totally different situations.

Considering the issue of financial shortages regarding operational costs of WWTPs in China, it is necessary to analyze the impacts of relaxing standards and terminating pretreatment on economic performances of WWTPs. In the short run, an increase of operational costs seems to be apparent due to higher influent COD and BOD in WWTPs. However, in the long run, the situation is different. Savings in the reduction of pretreatment (e.g., construction expense of septic tanks) can be put into the optimization of subsequent treatment processes of WWTPs which undoubtedly benefits the operation efficiency of WWTPs. This is a transition of operation mode from decentralization to centralization, which will increase treatment efficiency without increasing costs (Hao et al. 2006). In addition, influent loads of current WWTPs are far below the design values which cannot meet full-load requirements, and this leads to ineffective operations of facilities, high energy consumption, and waste of construction costs (Hu et al. 2000; Wang 2008; Wang et al. 2012). These adverse effects ultimately result in higher unit operation costs (Meng et al. 2013).

Meanwhile, the amount of sludge cannot meet the design requirements due to the low load wastewater which is adverse to the centralized treatment of sludge. For small- and medium-scale WWTPs accounting for 84 % of the total WWTPs in China (Jin et al. 2014), "scale effect" of wastewater treatment and sludge treatment is quite significant (Chen et al. 2006; Han 2012). If the amount of sludge cannot achieve the design scale, the treatment cost of unit sludge will increase (Meng et al. 2013). Furthermore, considering the "scale effect," a combined sludge treatment center is also an appropriate alternative for WWTPs to treat sludge more effectively (Cao 2002).

Conclusions

The reduction of easily degradable COD and BOD prior to entering municipal sewers actually stifles the treatment efficiency in many WWTPs in China. It is directly correlated to China's standards for pollutant discharging into municipal sewers. Through the retrospection of the history of Chinese wastewater treatment and the investigation of developed countries' standards, the paper suggests that in China, the standards for pollutant discharging into municipal sewers should be relaxed. Meanwhile, unnecessary pretreatment of COD and BOD should be terminated for the purpose of ensuring that easily degradable COD and BOD can be transferred to WWTPs (e.g., septic tanks should be eliminated).

There is no doubt that other solutions can be adopted to ameliorate the above phenomenon. Aimed at reducing the leakage and infiltration of sewers, it is crucial to enhance the quality of newly-constructed pipelines, vigorously promote advanced detecting techniques of existing pipelines and reduce the illicit connections of storm water sewer systems (Tang and Zhang 2015). Moreover, there are also several treatment processes developed to eradicate the shortage of carbon sources problems in WWTPs. For example, a primary treatment process enhanced by composite flocculants which combined bioflocculants Pullulan and poly-aluminum-chloride (PAC), biological contact oxidation process and biological aerated filter (BAF) process, four-stage step feeding AO process, and the utilization of short-chain fatty acids generated during waste-activated sludge fermentation in alkaline conditions (Qiu et al. 2010b). However, it will be a rough road to the realization of universal application of such depth processes in China and other developing countries due to the limited availability of funds for construction and operation.

Yang (2014) called on China to continue the momentum of green law. Wang (2012a) also called for more stringent discharge standards in China. We would like to say that green is not synonymous to stringent. If a green law is not consistent with a natural law, there would be a problematic contradiction.

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