Wastewater management approach in an industrial park

J. Liu and M. Tang

ABSTRACT

Many industrial parks adopt a two-tier wastewater management framework whereby tenants and the park are required to build satellite and centralized wastewater treatment facilities, respectively. Due to the diversity of industrial wastewaters, the treatment process scheme in the public centralized wastewater treatment plant (WWTP) may not suit the characteristics of all effluents discharged from the tenants. In consideration of varying wastewater biodegradability, the treatment scheme in a centralized WWTP is advised to install two series of treatment processes. In detail, various effluents from the tenants shall be commingled according to their levels of biodegradability. For the non-biodegradable streams, advanced oxidation processes shall be applied in addition to biological treatments. To facilitate the grouping of effluents, each effluent will be evaluated for its biodegradability. An analytical protocol derived from OECD standard (TG302B) was developed and found effective for biodegradability assessment. A case study is described in this paper to showcase the methodology.

Key words | advanced oxidation processes, biodegradability, industrial parks, wastewater management

J. Liu
M. Tang (corresponding author)
Technology and Application Centre,
CITIC Envirotech Ltd,
10 Science Park Road #01-01 The Alpha,
Singapore
117684
E-mail: *melvintang@citicenvirotech.com*

INTRODUCTION

With rapid global industrialization, there is an increasing pressure to handle the higher levels of wastewater production so as to reduce adverse ecological and anthropogenic impacts. Particularly in China, elevated environmental safety enforcement has led to a projected increase in capital expenditures for industrial wastewater treatment capacities, a necessity for sustainable growth. In the monetary sense, this trend translates into an estimated 25% growth over the next 5 years (from 2015), reaching an astronomical value of $6.8 billion by 2020 for the industrial water and wastewater treatment market (GWI 2015). Making things worse, not only are the volumes of wastewater to be treated increasing dramatically, rapid innovations leading to wider product ranges that are based on new materials and novel chemicals have also led to an increased complexity in the chemical composition of industrial wastewaters, increasing treatment difficulties for wastewater plants.

With most of these manufacturing industries located within industrial parks, industrial water pollution control has to start from the satellite and/or centralized wastewater treatment plants (WWTPs) in these parks. The environmental discharge standards are increasingly stringent, placing rigorous controls not only on the discharge of hazardous materials, but also on nutrients (nitrogen and phosphorus contents) and chemical oxygen demand (COD). The COD parameter measures the oxygen equivalent of organic materials present in the wastewater that can be chemically oxidized using acidified dichromate (Metcalf & Eddy 2003). Therefore, as used in many countries (refer to Table 1), COD is a surrogate parameter that directly reflects the amount of organics present in the water sample, serving as an important index that assesses the impacts of the discharged wastewater stream on the receiving bodies in terms of oxygen level reductions and the subsequent detrimental impacts on aquatic life.

While superficially similar, industrial park wastewater management is quite different from municipal sewage treatment. An industrial park (also known as industrial estate, trading estate) is an area zoned and planned for industrial development. One of the motivations to establish an industrial park is to concentrate dedicated infrastructures in a demarcated area and reduce the per-business expense of amenities such as WWTPs (Peddle 1993; Tian *et al.* 2014). While such industrial agglomeration improves economies of scale for economic development and pollution control, it is common to see industrial parks falter when the

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Table 1 | Effluent discharge standards for the COD parameter in some countries

	Singapore		China		Japan
Effluent discharge standard for COD (mg/L)	Watercourse 100	Controlled watercourse 60	Class 1A 50[a]	Class 1B 60[a]	160

[a]Extracted from GB18918-2002. Please refer to Table 3 for more details (China Ministry of Environmental Protection 2007).

pollution is too severe and overloads the waste management systems (Shi *et al.* 2010; Piadeh *et al.* 2014). This paper discusses the challenges of wastewater treatment in a typical industrial park and approaches to tackle such challenges.

CHALLENGES IN INDUSTRIAL PARK WASTEWATER MANAGEMENT

Diversity of industrial wastewater

Table 2 lists some of the pre-treated wastewater sources and characteristics for an industrial park in Jiangsu Province, China. Occupying a land area of 12.89 km^2, the said industrial park is host to 73 precision chemical companies, manufacturing a wide range of chemical, pharmaceutical and herbicidal products. As these companies are generating streams that are high in concentration, toxicity and recalcitrant compounds (slowly biodegradable or non-biodegradable compounds), sustainable growth of the region can be adversely affected if handled poorly. Hence, Chinese authorities have made it mandatory for the centralized WWTP within the industrial park to adhere to Class 1A discharge standards (please refer to Table 3), the most stringent requirement for wastewater treatment. The trade effluent consents for wastewater discharges to public centralized WWTPs are shown in Table 4.

Why does the sewage treatment plant not work well for industrial wastewater?

Unlike a municipal sewage treatment plant (STP) that primarily receives domestic wastewater, an industrial park WWTP accepts a variety of pre-treated effluents from industries. The treatment processes adopted by an STP are therefore ineffective to treat streams described in Table 2

Table 2 | Examples of trade effluent characteristics in an industrial park in Jiangsu Province, China

Tenant	Products	Flowrate (m^3/d)	COD (mg/L)	NH_3-N (mg/L)
A	Glyphosate, phenmedipham, desmedipham	4,200–5,500	400–800	20–50
B	Mycophenolate, dihydroxyandrostenolone	140	3,000–7,000	200–300
C	UV absorbers: aniline, chloroaniline, methyl phenol, toluene	600	300–500	7–80
D	Textile dyes and additives: cyanuric chloride, sodium nitrite, amino acids	600	300–500	7–50

Table 3 | Chinese discharge standards stipulated (extracted from GB18918-2002 (China Ministry of Environmental Protection 2007))

		Class 1 standards			
Parameters	Units	Class 1A	Class 1B	Class 2 standards	Class 3 standards
COD	mg/L	50	60	100	120
BOD	mg/L	10	20	30	60
Suspended solids	mg/L	10	20	30	50
Total nitrogen	mg/L	15	20	–	–
Ammonia	mg/L	5	8	25	–
pH	–	6–9			
CFU		10^3	10^4	10^4	–

Table 4 | The targeted trade effluent consents

COD (mg/L)	BOD_5 (mg/L)	Suspended solids (mg/L)	NH_3-N (mg/L)	Total phosphorus (mg/L)	Oil & grease (mg/L)	pH
1,200	300	100	80	3	15	6–9

Table 5 | Environmental water discharge standards imposed on the said industrial WWTP

COD (mg/L)	BOD_5 (mg/L)	Suspended solids (mg/L)	NH_3-N (mg/L)	Total nitrogen (mg/L)	pH
50	10	10	5	15	6–9

and meet legal environmental standards as laid out in Table 5.

Thus, a common practice is to adopt a two-tier wastewater management framework that requires both tenants and the park management to treat the wastewater. That is, all tenants are required to build their own satellite wastewater treatment facilities and pre-treat the wastewater generated from their factories to meet the trade effluent consents. These pre-treated effluents are then further treated in the centralized WWTP within the park to comply with the national environmental discharge standards (Das 1994; Yao *et al.* 2017). Although the trade effluent consents specify several typical water quality parameters, they are usually inadequate to evaluate effluent treatability inside the centralized WWTP. The remaining effluent biodegradability after the first tier of treatment is of an important concern, as the likely presence of substantial recalcitrants and low levels of biodegradable compounds will cause treatment difficulties in the second tier centralized WWTP, especially if only biological processes are installed. In view of such a problem, treatment processes for a new public centralized WWTP are recommended to adopt a two-series treatment train scheme, treating various effluents that have been blended according to their biodegradability. For the group of recalcitrant streams, advanced oxidation processes (AOPs) should be adopted in one of the two series, additional to biological treatment.

AOPs are applied for the oxidation of complex organic contaminants that are challenging for biodegradation into simpler end products. Complete oxidation of such compounds is generally unnecessary and partial oxidation in most cases will suffice to destroy chemical structures causing the recalcitrant nature (such as cyclic and ring structures) and make the wastewater streams more amenable for biological treatment downstream. Table 6 summarizes the pros and cons of several mainstream AOP technologies.

To facilitate the grouping of effluents, each effluent will be evaluated for its biodegradability using an analytical protocol derived from the OECD standard. The biodegradability assessment protocol was found to be effective and a case study on this management methodology is described in the following sections of this paper.

RESULTS AND DISCUSSION

Protocol of wastewater segregation

The grouping and characterization of trade effluents according to their biodegradability is not easy. While the biochemical oxygen demand (BOD) parameter has been relied on traditionally, it is not representative of reality as activated sludge acclimatization was ignored. It is therefore difficult to predict the final effluent COD based on the

Table 6 | Summary of advantages and disadvantages of mainstream AOPs (Kommineni *et al.* 2000; Oturan & Aaron 2014)

AOP technology	Advantages	Disadvantages
H_2O_2/O_3	• Established technology • Disinfection supplement	• Potential for bromate formation • O_3 off-gas treatment • Inefficient O_3 utilization
H_2O_2/UV	• Established technology • No bromate formation • No off-gas treatment	• Turbidity and interfering compounds (like NO_3^-) interferes with UV penetration
Fenton Oxidation	• No bromate formation • No off-gas treatment • Less energy intensive (compared to O_3 and UV based processes)	• Low pH requirements increase operation and maintenance costs from pH adjustments • Iron sludge production increases handling and disposal costs

influent BOD or BOD/COD ratio. To overcome such limitations, a biodegradability assessment protocol adapted from the OECD inherent biodegradability test (OECD TG302B) was developed (OECD 1992).

OECD TG 302B is also known as the Zahn-Wellens/EMPA test and the basic methodology has been adopted since 1981, with improvement modifications finalized in 1992. The test essentially follows the biodegradation of test samples by a relatively large concentration of activated sludge under conditions of continuous aeration up to 28 days. With sampling done at regular intervals, the amount of COD eliminated can be plotted against time to trace the biodegradation.

It was found that the protocol is effective and reliable in predicting the biodegradability and residual COD within the final effluent. Figure 1 illustrates the experiment results that quantified the biodegradability of two different trade effluents. By fitting the biodegradation curve to a logarithmic equation, the gradient of the curve provided a quantitative evaluation of the associated biodegradability, allowing a biodegradability database to be built for future references. For the recalcitrant stream with a mere 40% biodegradation at the end of the assessment, AOPs can be applied to break down chemical structures causing the recalcitrance, enhancing biodegradation for downstream biological processes.

'One company, one inlet pipe' scheme

To allow for stream grouping of various types of wastewaters, each company discharging effluents to the centralized public WWTP in the industrial park has installed dedicated wastewater transmission pipelines before connecting to a common wastewater collection pool. Necessary control devices and instrumentation such as an on-line flow meter and water quality analysers (e.g. pH, COD or total organic carbon, conductivity, etc.) has been be installed for control and monitoring purposes. The instruments can also be used for billing (i.e. for commercial purposes). Such a management scheme is termed 'one company, one inlet pipe'. The photograph in Figure 2 shows the multiple inlet pipelines from a variety of companies in the said industrial park.

Proposed treatment train for an industrial park centralized public WWTP

After the grouping of trade effluents into the categories of 'recalcitrant streams' and 'fairly biodegradable streams' based on their results from the biodegradability assessment

Figure 2 | Photo of the common wastewater collection pool at the centralized WWTP, with the tailpipes of individual wastewater transmission pipelines from different companies.

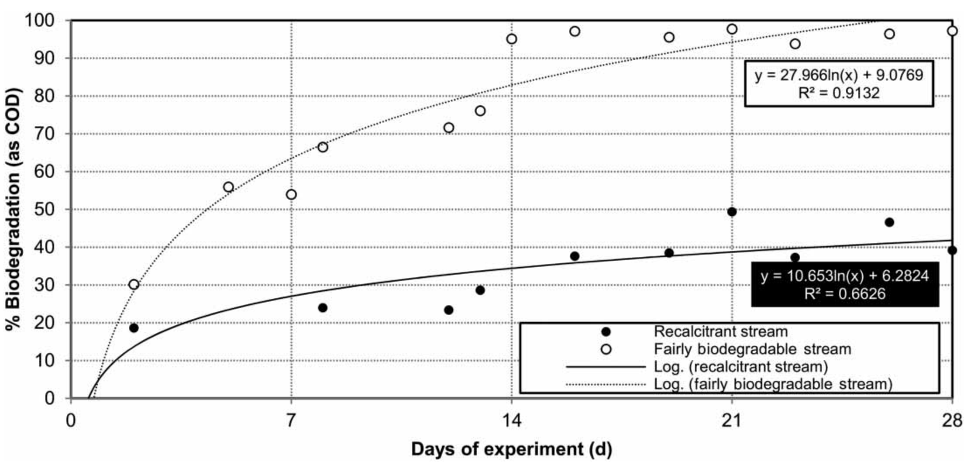

Figure 1 | Streams of different biodegradability fitted to logarithmic curves.

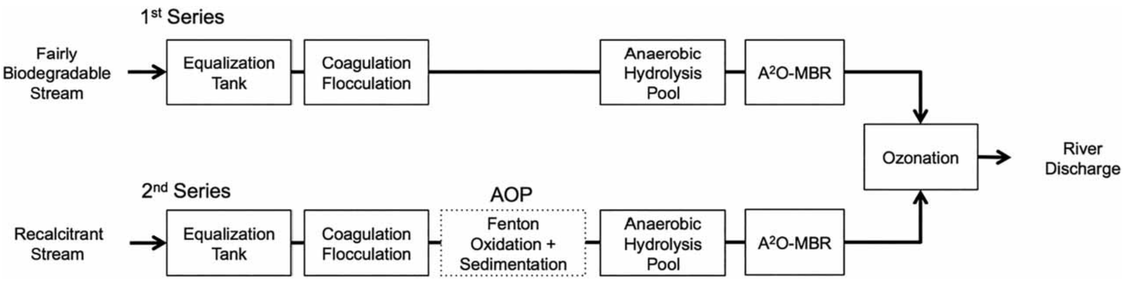

Figure 3 | Two-series centralized WWTP treatment train design (A_2O: anaerobic–anoxic–oxic; MBR: membrane bioreactor).

Table 7 | Summary of the functions and technologies of the various proposed processes (Metcalf & Eddy 2003)

				Removal efficiencies	
Process	**Function**	**Technology**	**Removal mechanisms**	**COD**	**Suspended solids (SS)**
Equalization tank	To damp the flowrate variations and achieve a (nearly) constant flowrate for downstream processes	Mixing via agitator, recirculation flow or basic aeration with draining sump	N.A.	N.A.	N.A.
Coagulation–flocculation and primary sedimentation	To destabilize colloidal particles and allow for particle growth through controlled collisions, and then removal through settling	• Coagulants can be alum, ferric chloride and calcium hydroxide • Flocculation mixers can be static mixers, paddles and propeller type • Sedimentation	• Double layer compression • Charge neutralization • Sweep coagulation • Interparticle bridging	Variable, especially if COD is contributed to by SS	Up to >90%
Fenton oxidation	To break down complex organics into simpler, more amenable products through hydroxyl radical oxidations that are catalyzed by Fe^{2+}	Mainstream AOP utilizing H_2O_2 and Fe^{2+} catalysts for hydroxyl radical production	Free radical oxidation	Up to 60%	Effluent SS <30 mg/L
Anaerobic hydrolysis pool	To break down complex organics through anaerobic metabolism and increase biodegradability of waste streams	Wastewaters are filtered through media containing attached growth of anaerobic bacteria and biofilms, allowing consumption and subsequent breakdown of complex organics	• Anaerobic respiration • Ammonification	10–20%	Effluent SS <30 mg/L
A^2O-MBR	A hybrid between the A^2O process for biological carbon, nitrogen and phosphorus removals, and the MBR process to replace gravitational settling for better solid–liquid separation (and better effluent qualities)	• Anoxic denitrification • Phosphorus removal by phosphate-accumulating organisms • Oxic carbonaceous removal	• Anaerobic respiration • Anoxic respiration • Oxic respiration	Up to >90%	100% (due to MBR)
Ozonation	The final barrier of effluent discharge standards control, providing disinfection and polishing of MBR permeates to ensure discharge compliance	Ozone is a highly reactive oxidant that disinfects water streams through direct bacterial cell wall disintegration	Free radical oxidation	Up to 6-log removals	

N.A.: not applicable; A^2O: anaerobic–anoxic–oxic; MBR: membrane bioreactor.

adapted from the OECD standard TG302B (OECD 1992), they will enter one of the two series of treatment trains that cater to different levels of biodegradability. The concept is as illustrated in Figure 3 and the functions of each process are detailed in Table 7.

CONCLUSIONS

The treatment processes in a centralized industrial park WWTP is advised to be designed according to the biodegradability of the wastewater streams discharged by the tenants so as to achieve effective treatment. For fairly biodegradable streams, the biological treatment processes for nutrients removal should suffice to meet the treatment objectives. On the other hand, for recalcitrant wastewater streams, AOPs such as Fenton oxidation or ozonation should be applied in addition to biological treatment to enhance treatability. For the purpose of grouping and categorizing different streams according to their biodegradability quantitatively, a biodegradability assessment protocol derived from OECD standards was successfully developed to evaluate treatability and guide the centralized WWTP treatment train design process.

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