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Technical, economic and environmental assessment of coagulation/filtration tertiary treatment processes in full-scale wastewater treatment plants

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ABSTRACT

The technical performance, economic cost and environmental impact of six full-scale tertiary coagulation/filtration processes located in Kunming, China were evaluated. All tertiary treatment processes removed total phosphorus (TP) and total suspended solids (TSS) efficiently, with the removal percentages of 55.0%–80.0% and 50.0%–74.0%, respectively. Polyaluminium chloride (PAC) consumption for TP and TSS removal in the six tertiary treatment processes were quite different, with chemical dosages of 7.9–38.5 g PAC/g TP removed and 0.3–1.7 g PAC/g TSS removed, respectively. The multiple linear regression analysis showed that the PAC dosage closed to the optimal value benefited TP and TSS removal, and this also reduced the economic cost. For environmental impacts, the main source of greenhouse gas was electricity consumption and the coagulation/filtration process had positive effect on reducing eutrophication. The comprehensive assessment including technical, economic and environmental aspects was characterized by the composite cost index. The composite cost index showed that the tertiary treatment process of micro-flocculation with D type/cloth media filtration achieved the best comprehensive performance, while D type filter had great potential for energy saving and chemical reduction.

1. Introduction

Wastewater reuse is an effective way to alleviate the shortage of water resources. As an important approach to protect water environment, WWTPs (wastewater treatment plants) play an important role in wastewater purification and reclamation. The final effluent of WWTPs is often reused as scenic environment water, industrial water, agricultural irrigation water, etc. The secondary effluent of WWTP usually cannot meet the discharge standard and requirements for reclaimed water reuse. Therefore, it is necessary to adopt tertiary treatment for secondary effluent. The tertiary treatment processes mainly include coagulation, sedimentation, biological filter, physical/membrane filtration, ozonation, disinfection, etc. (Plakas et al., 2016; Norton-Brandão et al., 2013; Friedler et al., 2008; Ebeling et al., 2003). Coagulation/filtration processes are widely applied in tertiary treatment because of its simplicity, high removal efficiency and low cost. To the best of our knowledge, there are lots of studies on jar tests and pilot scale tests related to coagulation and flocculation (Illueca-Muñoz et al., 2008; Guida et al., 2007). However, the full-scale coagulation/filtration processes have been relatively less investigated. The performance evaluation of full-scale coagulation/filtration process would be beneficial to optimize the operation of the tertiary treatment process and to provide references for the selection of sound tertiary treatment processes.

At present, the technical performance evaluation of WWTPs or wastewater treatment processes includes qualitative and quantitative evaluation. Qualitative indicators usually refer to the reliability, simplicity and stability of the wastewater treatment systems. The removal efficiency, removal loading, effluent concentration distribution, etc., are denoted as quantitative technical performance indicators (Quadros et al., 2010; Bott et al., 2012). Nevertheless, the main drawbacks of the above mentioned technical performance indicators are that the improvement measures and suggestions to optimize the operating performance cannot be provided. To identify the key factors affecting pollutant removal

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Abbreviations

CO_2	Carbon dioxide
COD	Chemical oxygen demand
DPF	Discharge pollution fee
GHG	Greenhouse gas
HRT	Hydraulic retention time (min)
LCA	Life cycle assessment
NH_4-N	Ammonia-nitrogen
NO_3-N	Nitrate-nitrogen
PAC	Polyaluminium chloride
PAC_{TP}	Ratio of PAC consumption to the removed total phosphorus (g PAC/g TP removed)
PAC_{TSS}	Ratio of PAC consumption to the removed total suspended solids (g PAC/g TSS removed); PAM Polyacrylamide
PO_4-P	Phosphate
R_{TP}	Removal efficiency of TP (%)
R_{TSS}	Removal efficiency of TSS (%)
SPSS	Statistical Package for the Social Science
T	Temperature (°C)
TN	Total nitrogen
TP	Total phosphorus
TP_{in}	Influent total phosphorus of tertiary treatment process (mg/L)
TPS	Technology performance statistics
TSS	Total suspended solids
TSS_{in}	Influent total suspended solids of tertiary treatment process (mg/L)
V_D	Filtration rate of D type filter (m/h)
VIF	Variance inflation factor
V_V	Filtration rate of V type filter (m/h)
WWTP	Wastewater treatment plant

will benefit to achieve maximum removal of pollutants, so as to improve operating performance of wastewater treatment systems. Multiple linear regression has been widely applied to explore the influence factors of dependent variable, which is the mathematical statistical method for quantitative study of the functional relationship between a dependent variable and multiple independent variables (Hijosa-Valsero et al., 2011). However, for the full-scale coagulation/filtration processes, the application of multiple regression method to explore factors affecting the removal of pollutants is relatively less.

The performance of wastewater treatment process has a great relation with the economic cost. For example, Remy et al. (2014) evaluated the environmental impact of the five tertiary treatment processes by the life cycle assessment (LCA) method, and found that although the effluent of the membrane bioreactor was the best, the costs of electricity and chemical consumption were quite high. Therefore, it is necessary to evaluate the tertiary treatment processes combined with technical performance and economic cost.

The main purpose of the previous WWTPs was to achieve the effluent quality standards so as to protect the receiving water bodies (Mannina et al., 2016). Although the tertiary treatment process greatly improves the effluent quality, it would have a direct or indirect impact on the environment due to the consumption of energy, chemicals and other materials (Rahman et al., 2016). Nowadays, the environmental impact caused by the wastewater treatment process has been received more attention. As an effective tool for environmental impact evaluation, LCA has been widely applied in wastewater treatment processes. Various environmental impact indicators are involved in LCA, such as greenhouse gas (GHG), eutrophication, acidification, photochemical oxidation, toxicity-related aspects, ozone layer depletion and abiotic resource depletion, etc. (Corominas et al., 2013). However, GHG and effluent eutrophication have been received more attention compared with other impact categories, because of their most significant contribution to the environmental pollution (Li et al., 2013; Corominas et al., 2013; Lorenzo-Toja et al., 2016). GHG or eutrophication has been considered as the only environmental indicator in many studies related to environmental impact assessment of WWTPs, while other environmental factors have been neglected. For instance, Rodriguez-Garcia et al. (2011) mainly focused on the effluent eutrophication of WWTPs, while global warming was only considered in the study of Dong et al. (2017). For the environmental impact evaluation of tertiary treatment processes in this study, GHG and eutrophication are mainly concerned.

The limitation would exist if technical performance, economic cost and environmental impact are evaluated separately, which cannot give an overall and comprehensive evaluation results and is also unfavorable to make a comparative analysis for multiple evaluation objects (Molinos-Senante et al., 2014; Plakas et al., 2016). Therefore, a single index system needs to be integrated into a comprehensive index contained multi-dimensional information. Many methods can be used to integrate several indicators into a composite indicator (Nardo et al., 2008). The comprehensive evaluation methods used commonly include analytic hierarchy process (Molinos-Senante et al., 2014), gray relational analysis (Zeng et al., 2007), data envelopment analysis (DEA) (Molinos-Senante et al., 2016) and the combination of the above analytical methods (Pophali et al., 2011). Majority methods except the DEA method need to be assigned weights, leading to the strong subjectivity. But the defect of the DEA method is that it is not suitable for the evaluation of fewer decision units or objects. In addition, some other comprehensive evaluation methods are also proposed. For example, Molinos-Senante et al. (2014) proposed the weighted average value of economy, environment and society to evaluate the sustainability of the seven secondary treatment processes. Based on the combination of environmental and economic indicators, Lorenzo-Toja et al. (2016) segregated 22 WWTPs into A, B and C three different categories, in which the A and C rating represented the best and the worst eco-efficiency standard, respectively.

According to the monetization approach, composite cost was taken as the comprehensive index to evaluate tertiary treatment processes in the present study. The monetization approach is based on the idea that the seriousness of different categories or indicators can be measured by money (Wu et al., 2005). Namely, the influence of different pollutants emission on environment can be quantified by money. “Green tax” levied on pollutant emissions denotes the social willingness to pay for the environmental pollution (Wu et al., 2005). “Green tax” is widely used in environmental impact assessment. To promote the environmental friendly earthwork construction, Li et al. (2010) identified the most important environmental impact indicators during the construction process by the “green tax” method. Li et al. (2013) also evaluated the environmental costs of twelve environmental impact indicators of a WWTP by the “green tax” method, indicating that eutrophication and global warming are two most expensive environmental impacts.