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Energy-saving optimization of coking wastewater treated by aerobic bio-treatment integrating two-stage activated carbon adsorption

Hongtao Zhou [a], Chaohai Wei [a, *], Fengzhen Zhang [a], Jianbo Liao [a], Yun Hu [a], Haizhen Wu [b, **]

[a] The Key Lab of Pollution Control and Ecosystem Restoration in Industry Clusters, Ministry of Education, School of Environment and Energy, South China University of Technology, Guangzhou, 510006, PR China

[b] School of Biology and Biological Engineering, South China University of Technology, Guangzhou, 510006, PR China

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ABSTRACT

Contaminants removal efficiency and energy consumption are of practical importance in wastewater treatment. Herein, an energy saving system including aerobic bio-treatment combined with a two-stage adsorption (AB-2A) was proposed and applied to the treatment of coking wastewater. The adsorption before bio-treatment partially extracts energy and organic constituents from the wastewater, making the subsequent bio-treatment more effective. The adsorption after bio-treatment brings the effluent to the discharge requirements. In comparison with the biological treatment combined with subsequent ozonation (M0 mode), the proposed system rationalizes the material flows in the wastewater treatment by optimized activated carbon utilization targeting higher adsorption and energy extraction efficiencies. The combined system AB-2A aimed at reducing the chemical oxygen demand (COD) to the national discharge standard at maximized net energy benefit (NEB) and benefit cost ratio (BCR). The modified cost benefit analysis was applied to energy balance evaluation of the system. Two combustible adsorbents, a commercial activated carbon (CAC) and a sludge-derived activated carbon (SAC), were used for pollutants adsorption. The results showed that the average effluent COD of the combined system AB-2A reached 78.8 mg/L when subjected to the activated carbon adsorption after biodegradation, with 7.0 g/L CAC added sequentially to the biologically treated and then to the raw coking wastewater (M2(CAC) mode). COD removal efficiency of M2(CAC) mode exceeded 96% being equal to the reference result of M0 mode. Additionally, the NEB and BCR reached −11.81 kWh/m^3 and 0.80 in M2(CAC) mode, respectively. Moreover, the M2 mode applying SAC (M2(SAC) mode) in amount of 7.0 g/L demonstrated the highest energy recovery compared to M0 and the separate adsorbent application to the raw influent and the bio-treated effluent (M1 mode). The difference values of NEB and BCR in M2(SAC) compared to M0 were shown as big as 28.87 kWh/m^3 and 0.07, respectively. The excess sludge recycling in the wastewater treatment resulted in the positive benefit in energy saving. Summarizing, the AB-2A system using SAC appears to be high COD removal efficiency and energy saving in the future sustainable wastewater treatment.

1. Introduction

Coking wastewater is produced in the coal thermal treatment process including high temperature carbonation, town gas purification and by-products recovery (Huang et al., 2016; Zhang et al., 2015). The wastewater is characterized with high organic pollutant load, complex composition, and strong bio-inhibitive and carcinogenic properties, making it refractory for conventional biological treatment (Chu et al., 2012; Yu et al., 2015). The organic pollutants typically include phenolic compounds, benzene derivatives, amines, organic nitriles, polycyclic aromatic hydrocarbons (PAHs) and heterocyclic compounds (Bai et al., 2011). From the aspect of energy consumption, the treatment of coking wastewater presents a substantial article of expense: the electric energy consumed in 2014 for the wastewater treatment in China comprised 11,240 GWh spent for the treatment of 71.6 billion tons

* Corresponding author.
** Corresponding author.
E-mail addresses: cechwei@scut.edu.cn (C. Wei), hzhwu2@scut.edu.cn (H. Wu).

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Nomenclature

AB-2A	aerobic bio-treatment combined with two-stage adsorption
AC	activated carbon
BCR	benefit cost ratio
BEA	bio-treatment effluent adsorption
BOD_5	five-day biochemical oxygen demand
CBA	cost benefit analysis
CAC	commercial activated carbon
COD	chemical oxygen demand
DO	dissolved oxygen
D_{av}	average pore diameter
GHGs	greenhouse gases
HRT	hydraulic retention time
KH_2PO_4	potassium dihydrogen phosphate
LCA	life cycle analysis
MLSS	mixed liquor suspended solids
M0	aerobic biological treatment combined with subsequent ozonation
M1	aerobic biological treatment combined with adsorption applied independently to the raw and to the biologically treated wastewater
M2	aerobic biological treatment combined with adsorption applied in a sequence countercurrent to the wastewater flow - the adsorbent applied to the biologically treated wastewater is used subsequently for the adsorption in raw wastewater treatment
$NaHCO_3$	sodium bicarbonate
NEB	net energy benefit
OLR	organic load rate
PAHs	polycyclic aromatic hydrocarbons
RCWA	raw coking wastewater adsorption
SAC	sludge-derived activated carbon
SV30	30-min sludge settled volume test
SVI	sludge volume index
S_{BET}	specific surface area
V_t	total pore volume
WWTP	wastewater treatment plant
ΔBCR	the difference of BCR in M2 compared to M1
ΔNEB1	the difference of NEB in M1 compared to M0
ΔNEB2	the difference of NEB in M2 compared to M0

of disposed wastewater. Surprisingly, the combustion heat of raw coking wastewater is estimated at the range of 69.5–72.4 MJ/m^3 (Heidrich et al., 2010), suggesting that the wastewater contains a substantial energy able to offset the energy consumption in its treatment. Thus, a treatment technology providing effective removal of contaminants at a low energy consumption is needed to reduce the energy expense and environmental pollution.

Biological treatment is a relatively economical secondary wastewater treatment (Boldrin et al., 2011). However, several pollutants remain in the bio-treated coking effluent including PAHs, halogenated organics and long-chain hydrocarbons (Ren et al., 2013), making the discharge of treated wastewater inappropriate and the additional advanced treatment necessary. Additionally, adsorption is an effective physico-chemical method extensively used at the wastewater polishing stage subsequent to the biological treatment. To meet the discharge standard, biological treatment combined with adsorption was commonly used in wastewater treatment. Vázquez et al. (2007) used granular activated carbon to remove phenols from coking wastewater subjected to bio-treatment, observing the adsorption capacity of 1.48 mg/g. Rafatullah et al. (2010) published a review on adsorption of methylene blue, a non-biodegradable pollutant in the textile and printing wastewaters. Commercial activated carbon is a common adsorbent applied in treatment of petrochemical (Parthasarathy et al., 2016) and dye (Ribas et al., 2014) wastewaters, being, however, expensive for the energy consumption in its production (Cardoso et al., 2012). Even though variable activated carbon materials are available, a few contaminants of coking wastewater may only be adsorbed by specific adsorbent materials due to their molecular weight and the functional groups, making introduction of activated carbon materials to coking wastewater treatment useless, thus requiring additional measures (Du et al., 2014). A few studies reported the energy recovery from spent activated carbon mostly focusing at the energy consumption by the regeneration of activated carbon (Schmitt et al., 2017). This approach results in high energy consumption by adsorption in wastewater treatment. Therefore, an improved technology such as biological treatment combined double adsorption, should be proposed to decrease the energy consumption and increase the pollutants removal efficiency simultaneously in wastewater treatment.

To assess the energy saving efficiency of a wastewater treatment plant or a reactor unit, multiple energy evaluation methods have been proposed in recent years. Life cycle analysis (LCA) is applied to energy evaluation in wastewater treatment process since 1995, becoming a relatively mature and common approach nowadays (Meneses et al., 2015). However, the LCA database is established for the European environment conditions, which may not be used directly in other geographical regions (Beylot et al., 2015). Also, most of the studies using the LCA method focus on the climate change impact and ignore other effect factors, such as cost of materials (Da Costa et al., 2018). The cost benefit analysis (CBA) is another conventional methodology for economic assessment, widely accepted as a rational and systematic decision-making support tool (Yaqob et al., 2016). During the analysis, a large number of factors including financial, economic, social and other aspects should be considered in order to assess the financial and economic viability of projects (Miller et al., 2014). The determination of research boundaries and the appraisal method are the bottleneck problems for accurate evaluating of the energy transformation in wastewater treatment.

Here, a novel wastewater treatment system integrating aerobic bio-treatment and two-stage adsorption has been proposed combining advantages of both treatment technologies and the energy recovery from contaminants contained in the coking wastewater. The adsorption prior to bio-treatment extracts energy and partial organic constituents from the wastewater, improving the effectiveness of subsequent bio-treatment. The adsorption applied to the bio-treated wastewater brings the effluent to the discharge standard. The newly proposed combined system allows rationalizing the material flows in the wastewater treatment: the activated carbon is used twice thus optimizing the extraction of pollutants, providing the required wastewater discharge standards and saturating the adsorbent with the recoverable energy. This combination allows higher adsorption and energy extraction efficiencies at improved performance of biological oxidation, thus surpassing the combination of biological treatment with subsequent ozonation.