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Novel multistep physical/chemical and biological integrated system for coking wastewater treatment: Technical and economic feasibility

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ABSTRACT

Harmless disposal of coking wastewater (CWW) has become a tough issue due to its complexity, heterogeneity and toxicity. In order to improve contaminant removal efficiency, a novel treatment system, taking into accounts the compositions and toxic characteristics of CWW, was deliberately developed and applied in a full-scale coking wastewater treatment plant. This system integrated a physical/chemical pre-treatment, a biological treatment and a physical/chemical advanced treatment. The pre-treatment, including the degreasing and air floatation, contributed to a significant reduction of oil (removal efficiency > 85%). The bio-treatment was a pre-aeration/aerobic$_1$/hydrolysis/aerobic$_2$ fluidized bed process, which removed 84.1% free cyanide, 93.5% thiocyanate and 86.2% total phenols, indicating an efficient biological detoxification. The successful degreasing and detoxification was conductive to the high removal efficiencies of COD (98.6%) and NH_3-N (95.4%). The removal efficiency of total nitrogen reached 90%. Furthermore, the removal efficiencies of 18 polycyclic aromatic hydrocarbons were in the range of 80–99%, while the removal efficiencies of 5 benzene derivatives were in the range of 88–96%. The total concentrations of these trace toxic contaminants were maintained lower than 50 $\mu g\,L^{-1}$ in the final effluent. The overall cost of this system was equal to 9.67 RMB m^{-3} (<2 US dollars) of CWW. The satisfactory performance of contaminants removal and the low cost implied that this integrated system was a feasible and reliable option for CWW treatment.

1. Introduction

Millions of tons of coke are produced to cater to the growing demand for steel along with rapid urbanization in the developing world. Coking wastewater (CWW) is one of the harmful by-products from coke production, which contains enormous amount of carcinogenic compounds. As the largest producer of coke, China experienced increasing pressure to alleviate the environmental consequences of CWW [4,15,16]. It was estimated that ~2.4×10^4 t of phenols, ~700 t of cyanide and ~1.6×10^3 t of benzo[*a*]pyrene were generated along with CWW in China in 2005 [19]. Additionally, other countries, such as India, Korea, etc., are also producer of coke and endure similar pollution of CWW [10,12,22], suggesting that it is a worldwide problem. Recently, the Chinese government issued stricter new discharge standard (Table SM-1) for CWW treatment plants (CWWTPs) [18]. There are more than 1000 coke factories in China, most of which are still using outdated CWW treatment systems since 1990s. Thus, it is urgent to develop more efficient and steady treatment technique for these factories.

It is well known that harmless disposal of CWW is a great challenge due to its complexity, heterogeneity and toxicity. Two groups of specific contaminants, including oil and toxic compounds, were the dominating inhibitors to biological treatments of CWW. First, oil formed a suspending layer which interfered with the aeration in bio-treatment [20]. Second, typical toxic compounds in CWW, including free cyanide (CN^-), phenols and thiocyanate (SCN^-), had inhibition on many functional bacteria, such as ammonia oxidizing bacteria (AOB) and nitrite-oxidizing bacteria (NOB) [2]. In view of these facts, a prepositive degreasing/detoxification process should be established as the pretreatment method for CWW.

Recently, researchers are making efforts to develop cost-effective treatment methods to dispose CWW. Most literatures

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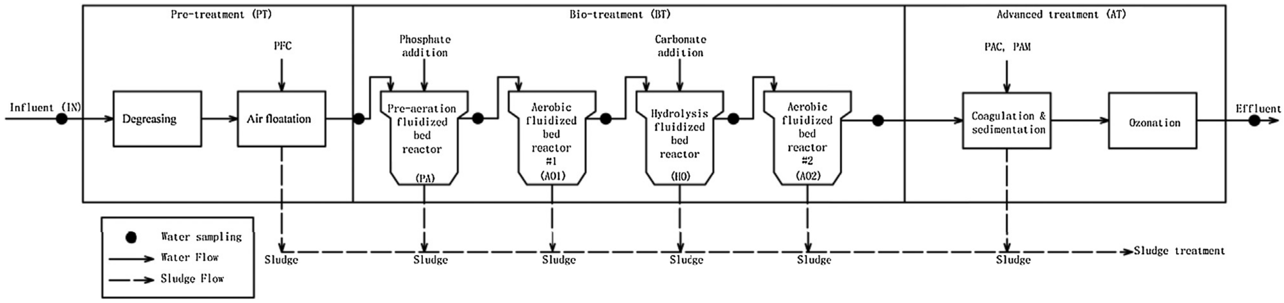

Fig. 1. Schematic diagram of No.2 Songshan coking wastewater treatment plant and sampling sites. Water samples were collected from seven sited, including the total influent, the infiuent of bio-treatment, the effluent of each stage in PA/AO_1/HO/AO_2,and the total effluent from April 1, 2011 to March 31, 2013.

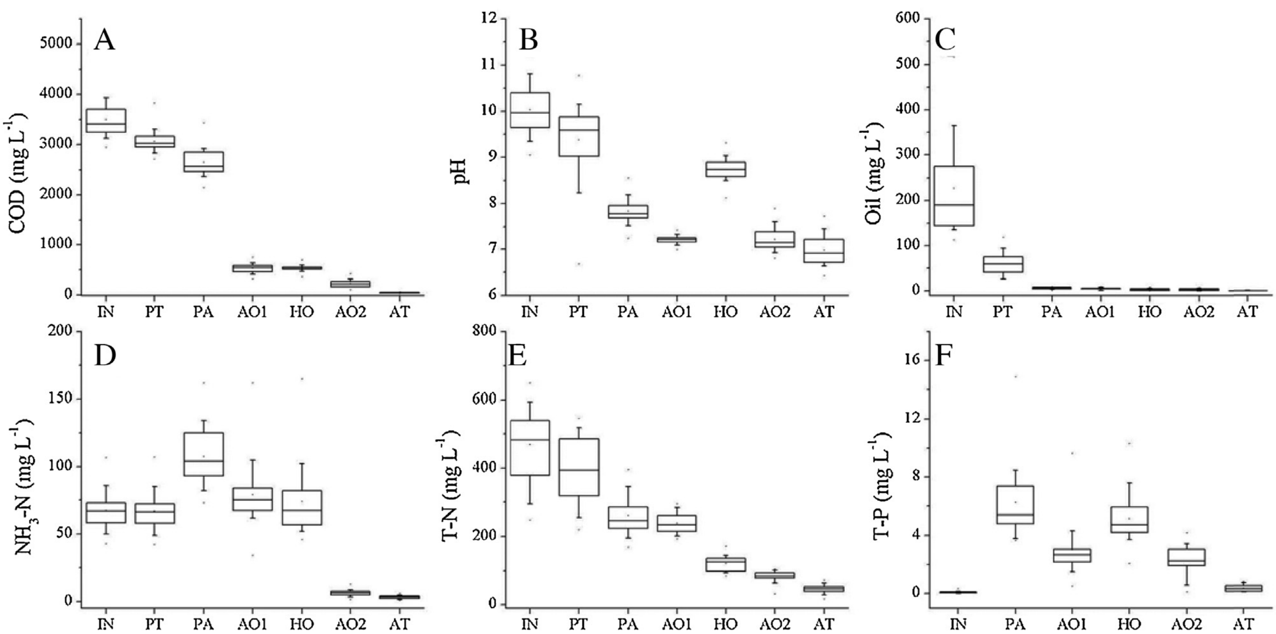

Fig. 2. Statistical variations of conventional parameters. (A) COD, (B) pH, (C) oil, (D) NH_3-N, (E) T-N, (F) T-P. Box range 25–75%, whisker range: 10–90%. IN—influent; PT—pre-treatment; BT—bio-treatment; PA—pre-aeration; AO_1—aerobic$_1$; HO—hydrolysis; AO_2—aerobic$_2$; AT—advanced treatment. Sampling was conducted daily form April 1, 2011 to March 31, 2013 with a total of 712 data.

focused on specific physical/chemical methods, including sedimentation [23], ozonation [5], Fenton [9] and membrane separation [13], etc. These methods were technically feasible to reduce the suspended solids, colloidal particles, floating matters, colors and toxic compounds, but they had several drawbacks, such as high cost (ozonation), additional contaminants generation (Fenton), membrane fouling, etc. Therefore, these techniques were only used as affiliated treatment stage in some full-scale CWWTP.

To the contrary, biological treatment consumed lower energy and fewer additions, thus it became the most common technique for full-scale wastewater treatment plants. Individual biodegradation methods for the phenols, CN^-, SCN^- and ammonia-nitrogen (NH_3-N) were reported [8,14,17], but successful biological treatment of CWW turned to be very difficult as these contaminants often oppose each other's effective degradation. For instance, high concentration of cyanide inhibited phenols depredating bacteria [1], and high concentration of phenols inhibited SCN^- degradation [7]. Furthermore, cyanide and phenol inhibited AOB and NOB activity [2]. These inhibitions will be enhanced when the composition of influent changes suddenly.

In view of these facts, the establishment of a system for CWW treatment should take into accounts the compositions and toxic characteristics of contaminants, and then deliberately integrate a series of treatment methods aiming at the purifications of different contaminants. To the best of our knowledge, only a few successful full-scale integrated systems were reported [11]. Over the past decade, our research group attempted to develop several integrated systems for CWW [21,26,28]. Based on the operational experience and drawbacks of the previous works, a novel integrated treatment system, which included: (1) pre-treatment (PT) using degreasing and flotation, (2) bio-treatment (BT) using pre-aeration/aerobic$_1$/hydrolysis/aerobic$_2$ (PA/AO_1/HO/AO_2) fluidized-bed process, and (3) advanced treatment (AT) using sedimentation and ozonation, was developed and applied in a full-scale CWWTP.

However, the detailed information regarding to the contaminants removal efficiency of this system was yet not reported. The objective of the current study was to demonstrate the technical and economic performance of this system. Based on the long-term monitoring data, the contaminant removal efficiency was analyzed. The monitoring data included: (1) conventional parameters, (2) predominant toxic contaminants, and (3) trace toxic contaminants. Furthermore, the economic evaluation was conducted based on the