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Research review paper

State of the art of biological processes for coal gasification wastewater treatment

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ABSTRACT

The treatment of coal gasification wastewater (CGW) poses a serious challenge on the sustainable development of the global coal industry. The CGW contains a broad spectrum of high-strength recalcitrant substances, including phenolic, monocyclic and polycyclic aromatic hydrocarbons, heterocyclic nitrogenous compounds and long chain aliphatic hydrocarbon. So far, biological treatment of CGW has been considered as an environment-friendly and cost-effective method compared to physiochemical approaches. Thus, this reviews aims to provide a comprehensive picture of state of the art of biological processes for treating CGW wastewater, while the possible biodegradation mechanisms of toxic and refractory organic substances were also elaborated together with microbial community involved. Discussion was further extended to advanced bioprocesses to tackle high-concentration ammonia and possible options towards in-plant zero liquid discharge.

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1. Introduction

Nowadays, coal as an important raw material has been used for producing a variety of high-value chemicals via coal gasification, liquefaction, coking etc. The coal-derived alternative fuels have become a main energy source in addition to traditional oil and gas (Pan et al., 2012; Zhou et al., 2012). As a consequence of such rapid growth of this new business, a large quantity of wastewater has been generated from various processes, e.g. gasification, purification, water-gas shift, synthesis and distillation. The wastewater, known as coal gasification wastewater (CGW), especially the one discharged from the low/medium temperature lignite gasification unit, contains extremely complex

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high-concentration aromatic hazardous, toxic and refractory compounds including phenolics, polycyclic aromatic hydrocarbons (PAHs), nitrogen heterocyclic compounds (NHCs) and long chain n-alkanes.

The U. S. had dedicated extensive effort to the treatment of CGW due to rapid growth of coal chemical industry in the period of 1970s to 1990s. Since then, the battlefield of CGW has gradually shifted to China with increasing capacity of its new coal-to-chemical plants. Nowadays, CGW has been considered as a emerging challenge to the sustainable development of Chinese coal chemical industry. As such, extensive effort has been devoted to developing various biological processes for enhancing the removal of hazardous and refractory organics in CGW with the ultimate target of zero liquid discharge (ZLD) (Tong et al., 2010). Compared to physical and chemical/electrochemical methods, biological processes for CGW treatment appear to be more cost-effective and environmentally friendly. However, due to its highly recalcitrant nature, CGW has become a primary barrier that hampers further development of new coal-to-chemical industry in China. Therefore, this review attempts to offer a comprehensive picture about CGW generated from Lurgi or BGL gasifiers and possible biological treatment processes including anaerobic and aerobic degradation of hazardous and refractory organics in CGW.

2. Characteristics of CGW

2.1. Overview

Fig. 1 illustrates various water flows in a coal-to-gas demo-plant, including supply water (light blue), saline water (dark blue), wastewater (brown), saline wastewater (grey) and brine (black). Furthermore, Fig. 2 displays the wastewater streams from the slag flushing, ammonia stripping & phenol extraction and low temperature methanol-washing processes which have been known as the main contributors to CGW.

The characteristics of CGW are mainly determined by coal quality and gasifier types. For instance, in cases where lignite and bituminous coal are used as raw materials in the Lurgi or British Gas/Lurgi (BGL) gasification process, highly recalcitrant CGW with complex composition is often expected due to low grade of coal metamorphism and incomplete combustion within the gasifier. In contrast, gasification of high-grade anthracite generates relatively low-strength wastewater in Shell or Texaco gasifiers. It should be noted that Lurgi and BGL gasification processes currently have a broad market due to their high production capacity and gas calorific value. So far, the conventional biological processes, e.g. sequencing batch reactor (SBR), Anaerobic/Anoxic/Oxic (A2O) have been employed for treating CGW (Chen et al., 2012). In the literature, CGW usually refers to as the effluent produced after phenol and ammonia recovery by extraction and striping respectively.

In order to achieve ZLD of CGW, integrated physiochemical and biological treatment processes have been employed, which are the combination of flotation, anaerobic and aerobic, advanced oxidation, ultrafiltration, high efficiency reverse osmosis (HERO), evaporation and crystallization (Fig. 3). Although biological processes have been believed to be essential towards ZLD, the recalcitrant or toxic nature of CGW has posed the serious challenges to biodegradation of CGW (Ji et al., 2015). Ammonia striping as a pretreatment is helpful for recovering or removing a large portion of organic substances (Gai et al., 2008), but the concentrations of residual recalcitrant organics are still too high, seriously affecting the performance of subsequent biological treatment.

2.2. Hazardous and refractory substances in CGW

The chemical oxygen demand (COD) and total phenols (TPh) in raw CGW are often in the range of 5000 to 20,000 mg/L (Gai et al., 2007; Yang et al., 2006). Even after effective ammonia-stripping and phenol extraction, the concentration of residual recalcitrant organic compounds in the influent into CGW treatment plant (CGWTP) still remains at high side (Table 1). In fact, >28 kinds of organic compounds had been detected in CGW, among which phenol, cresol isomers, 5-methyl, 5-ethylhydantoin and 5,5-dimethyl-hydantoin were identified as the

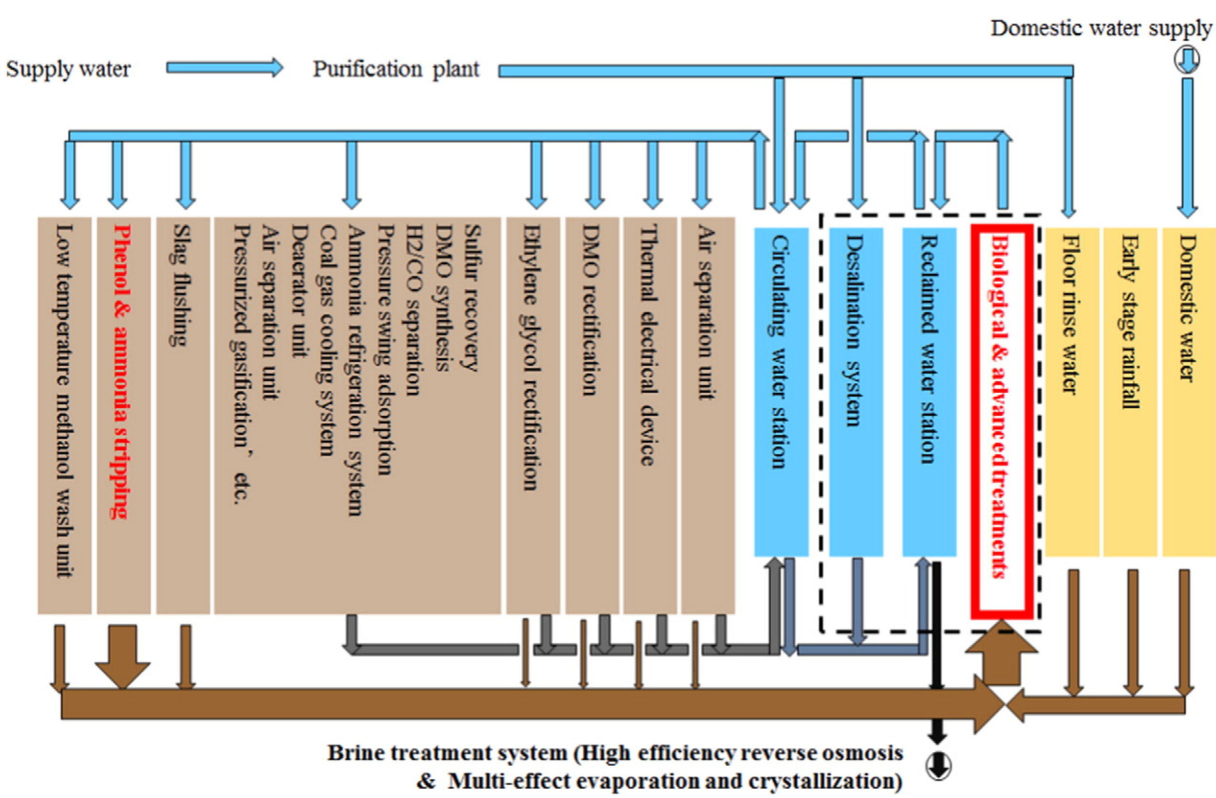

Fig. 1. Flowchart of supply water and wastewater in a coal-to-gas demo-plant (data not published).