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Application of industrial ecology in water utilization of coal chemical industry: A case study in Erdos, China

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ABSTRACT

China has been accelerating coal chemical development, more and more industries have focused on the highly efficient water utilization. The water utilization in coal chemical industry was evaluated in Erdos, China. According to the industrial ecology principles, the processes in sectors of pretreatment, desalination, wastewater treatment plant, reuse, recirculation and brine have been fully discussed. The water balance was investigated to evaluate water reuse, reaching efficiencies of 70–81%. Two major cleaner production measures based on industrial ecology have been transformed: 1, the production water of pretreatment has been mainly pumped to recirculation sector as supplement; 2, production water of reuse sector has been transferred to desalination sector. Results indicated that if the production water from reuse sector to desalination sector was sufficient, 15,000 tons of pretreatment production water scheduled for desalination sector and cost of 730 United States Dollars have been saved daily. The driving forces for industrial ecology implementation in the industry mainly included the requirements of resource and environment, industrial policy, technical support and enterprise culture. And the present technologies of water utilization in this industry provided scientific guidance for the designs and operation of water utilization for the coal chemical industry.

1. Introduction

In recent years, Chinese energy industries have been focusing on accelerating the development of new coal chemical technologies mainly taking up productions of clean energy such as liquefied natural gas, synthetic methanol, ammonia, olefin and urea to reduce the resource consumption by coal-fired power generation (Chen and Xu, 2010; Yoon and Lee, 2011). Numerous coal chemical industries were building and starting operations in arid regions of China's Northwest, such as Shaanxi, Inner Mongolia and Ningxia, these provinces were characterized by abundant coal resource but less water resource, what's worse, huge water consumption of the coal chemical industries aggravated the existing fresh water scarcity. Besides, the coal chemical industries were characterized as pollution-intensive industries for high strength wastewater with huge quantity; thus many attentions should be paid on the balance of the energy development and water consumption and environment protection. According to the national energy development strategy, new coal chemical industries must develop and promote the high-efficiency and cleaner coal utilizing technology to realize the energy sustainable development (Xie et al., 2010). And industrial ecology (IE) as the promising strategy can provide efficient approaches for water utilization to reduce the environmental impact and realize the coordinated development with the environment.

The concept of IE was popularized by using the analogy between natural ecosystems and industrial systems (Boix et al., 2015), and indeed a more recent definition for IE has been expressed as "a systems-based, multidisciplinary discourse that seeks to understand emergent behavior of complex integrated human/natural systems" (Allenby, 2004, 2006). The key feature of IE relied on the integration of various components of a system to reduce the net resource input as well as pollutant and waste outputs (Despeisse et al., 2012). The main goal of implication of IE can improve the

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industries' environmental performance, preserve environment while increase business success.

Robèrt et al. (2002) evaluated the IE concept by considering its application in terms of the strategic sustainable development and indicated that the applications of IE contributed five levels in the hierarchical model (Table 1). Baas and Boons (2004) suggested that IE was a label under which many linkages between production and consumption processes were grouped, and they provided an analytical framework to investigate regional IE through three phases including regional efficiency, regional learning and sustainable industrial district. There were many studies concerning IE applications in various word-wide industries. According to IE principles, more environment-friendly reagents for copper sulphide ore flotation and environmental managements for granite slab production were proposed (Mendoza et al., 2014; Reyes-Bozo et al., 2014). For the coal chemical industries, application of more advanced technologies with high efficiencies of water use and wastewater reuse was the key to reduce the water consumption and wastewater discharge (Pan et al., 2012). Liu and Zhang (2013) have demonstrated that IE provided principles for water utilization for marine chemical industry and it has achieved effective utilization of underground brine, seawater and freshwater, besides, economic and environmental benefits have been achieved. IE activities were also implemented in sugar refining industry and it has achieved the successful transition from a traditional corporation to a sustainable corporation (Yang and Feng, 2008).

In addition to separated industry, planning and construction of port cities and eco-industrial parks have also been guided by IE principles and studies indicated the IE could provide significant guidance with less influences on the environment (Cerceau et al., 2014; Gibbs and Deutz, 2007). The concept of eco-industrial park, which was defined as "a system of planned materials and energy exchanges that seeks to minimize energy and raw materials use, minimize waste and build sustainable economic, ecological and social relationships" (Alexander et al., 2000), has been popularized. And Boix et al. (2012) has indicated that under the condition of an eco-industrial park, the sum of benefits achieved by working collectively was higher than working as a standalone facility. But for individual industry, the integration of tools and approaches of IE, cleaner production (CP), pollution prevention could be more practically realized at factory level (Despeisse et al., 2012). Actually, the approaches of IE and CP have been attached great importance and vigorously promoted by Chinese government (Geng et al., 2007) and IE principles on water utilization referring to this coal chemical industry were shown in Table 2, relying on the report of Liu and Zhang (2013).

Coal gasification technology was the clean use of coal resources, representing large-scale and high-efficiency characteristics, which included Lurgi, Texaco, Shell, and U-gas processes (Xie et al., 2010). This paper represented a case study on China Coal Erdos Energy & Chemical Co. Ltd, a famous coal chemical industry in China, which utilized British Gas/Lurgi (BGL) gasification technology. The BGL was derived from Lurgi and represented lower requirement for oxygen, higher gasification efficiency and less wastewater quantity than Lurgi (Zheng and Furinsky, 2005). At the industry where the study was carried out, the water utilization virtually concerned all departments and equipments especially for the gas washing, condensing, purification and synthesis processes. Result indicated that this coal chemical industry with present technologies and CP measures was characterized by high water utilization efficiency and zero liquid discharge (ZLD) which represented a symbol of the Green Engineering.

Exact descriptions of water utilization and applications of IE in a coal chemical industry were rare in the previous studies. The major goals of this paper were to show a strategy for more efficient water resource management with less water consumption and no wastewater discharge; to evaluate the effect of CP measures on the water utilization and investigate the mass balance by measurement of the water flows and calculation of water consumption; to present the driving forces of the water utilization and discuss the challenges of IE implementation and feasibility of technologies for other cases. Additionally, the reuse of salt produced from the brine in the crystallizer was discussed to reach the resources recovery and utilization. Results indicated IE and CP measures implemented in the coal chemical industry demonstrated an economy-environment win-win situation and provided scientific guidance for the designs and operation of water utilization for other coal chemical industries.

2. Methods

The water utilization at a coal chemical industry in Erdos, China was monitored for many months. The water treatment plant (WTP) included 6 sectors, and pretreatment, desalination, recirculation, wastewater treatment plant (WWTP), reuse and brine were checked in the study. Relying on the IE principles and operational experience, two major transformations have been made to improve the water utilization efficiency and save the cost. Although more efforts should be concentrated on tackling key technological problems to reach the ZLD, the driving forces for highly efficient water utilization and environment protection played the critical guiding significance to design and operate the practical engineering. Therefore, the impetus for the highly efficient water utilization has been investigated to reveal the driving forces. How to successfully achieve the purpose of cleaner production based on IE principles was still a matter, and the challenges of IE implementation in this coal chemical industry have been discussed, and the feasibility of technologies for other industries especially the coal chemical industries has also been evaluated. In addition, the key processes to realize the resource recovery and utilization of the salt produced from brine in the crystallizer were also investigated.

The technology route was outlined in Fig. 1. The evaluated parameters included suspended solid (SS), turbidity, residual chlorine, silting density index (SDI), sodium ion, pH, ammonia, conductivity, urea, chemical oxygen demand (COD), Silicon dioxide (SiO_2), total dissolved solids (TDS), total phenols (TPh), volatile phenol (VP), oils, total hardness, calcium hardness, phenolphthalein alkalinity, methyl orange alkalinity, total alkalinity, mixed liquid suspended solids, chloride ion, phosphate, total iron, zinc, sulfate and total heterotrophic bacteria count. Based on these parameters,

Table 1
Concepts of industrial ecology applied to the strategic sustainable development model (Robèrt et al., 2002).

Level	Definition
1	Principles for the constitution of the system
2	Principles for a favourable outcome of planning within the system; principles for sustainability as the desired outcome
3	Principles for the process to reach the above outcome of sustainability, e.g. principles of sustainable development to reach sustainability
4	Actions and concrete measures
5	Tools and metrics to monitor and audit