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# Water consumption analysis of olefins production from alternative resources in China

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A B S T R A C T

Traditional olefins production is heavily dependent on oil. Due to the short supply of oil resources, there are four possible alternative feedstocks in China: (1) coal; (2) natural gas; (3) coke-oven gas; and (4) methanol, while the coal route is dominant among these processes from the perspective of Chinese fossil resources. Comparative study of the four processes is conducted in concerning of water consumption. Results show that the coal route and coke-oven gas route suffer from high water consumption: 44.2 and 55.0 t/t olefins. On the other side, the natural gas route and the oversea-imported methanol route are 27.2 and 7.3 t/t olefins, much lower than the coal route. The coal route is water intensive, but unfortunately, coal chemical plants are mainly located in the arid northern China. To address this predicament, this paper proposes three suggestions: (1) Adjusting water prices system to arouse the enthusiasm of saving water and energy; (2) Promoting olefins production from co-feeding of coal and gas in areas with rich coal and gas; (3) Encouraging to develop methanol-to-olefins plants in coastal areas.

## 1. Introduction

Olefins represented by ethylene and propylene are important platform chemicals, which lead the development of numerous organic chemical products. The olefins production capacity and demand increase rapidly in recent years. The ethylene production had reached 10 Mt in 2007 and 15 Mt in 2011 in China (Qu, 2012). Propylene is another important basic organic raw material, its yield is second to ethylene. It was estimated that equivalent olefins demand would be about 85 Mt/y in China, while the olefins capacity of oil-to-olefins (OTO) would be only about 46 Mt/y estimated from the references (Qu et al., 2012). It can be seen that the production of olefins is still lower than the market demand. The situation can only be improved by the rapid development of Chinese olefins industry.

Olefins production feedstocks are mainly oil, natural gas, coal, and biomass. Among them, China is rich in coal, while scarce in oil and natural gas. However, traditional olefins production is mainly dependent on oil. It was estimated that China had imported 330 Mt oil by the end of 2015, accounting for 61.1% of the total oil consumption. The sustainable and healthy development of olefins industry requires diversification of alternative resources.

Bioethanol-to-olefins technology is not enough mature and its scale is small. In China, there were about five bioethanol-to-olefins plants with total capacity of 0.12 Mt/y by 2011 (Liang and Jiang, 2011). Although bioethanol-to-olefins would be a development trend in future, commercial production still needs long time.

Due to the shortage of natural gas in China, it is mainly used as urban fuel gas to relieve the increasingly serious air pollution in major cities (NDRC, 2012). Natural gas based methanol-to-olefins (NGMTO) is therefore not encouraged in China. On the other hand, oversea-imported methanol produced from natural gas could be an attractive alternative to produce olefins in coastal areas of China. The methanol-to-olefins (MTO) process has been drawing the attention of the chemical processing industry for its less investment and environmental pollution. Until 2015, there had been four sets of oversea-imported MTO plants under operation in China. It was predicted that the MTO plants with a total capacity of 2.66 Mt/y will be put into production by 2020 (PDCCI, 2016).

The annual coke-oven gas production in China is about 70 billion $m^3$. However, most coke-oven gas is directly discharged into the atmosphere (Razzaq et al., 2013). The coke-oven gas can also be used for producing olefins. It was reported that a coke-oven gas

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based methanol-to-olefins (CGMTO) plant with a capacity of 0.6 Mt/y had been successfully operated in 2015 (PDCCI, 2016).

From the aspect of resource reserves, developing coal based methanol-to-olefins (CMTO) is regarded as an important direction for the sustainable development of the chemical processing industry in China. The technology had been successfully implemented in nine sets of CMTO plants by the end of 2015. The CMTO plants with a total capacity of 17.72 Mt/y will be put into production by 2020 (PDCCI, 2016).

For coal-rich countries, especially China, developing coal based olefins industry is regarded as of great important to sustainable development of olefins industry as well as national economy. The present researches of CMTO processes are mainly focused on techno-economic analysis. Han (2005) carried out a simple cost analysis of OTO, CMTO, and NGMTO. Yang and Dong (2012) conducted a review of coal based Fischer-Tropsch-to-olefins technology and a concise economic analysis, in comparison with CMTO. Ren et al. (2008) made an analysis of energy use, $CO_2$ emissions and production cost for steam cracking and methane to olefins. Ren and Patel (2009) also analysed energy use and $CO_2$ emissions of basic petrochemicals from natural gas, coal and biomass. However, literature on analysing water consumption of CMTO is rare. Yang (2013) reported that the direct water consumption of CMTO is about 30 t/t olefins, which take no account of indirect water consumption for resources extraction, transportation, as well as energy consumption. According to the direct water consumption, CMTO will consume about 550 Mt/y water by the end of 2020. However, CMTO projects are mostly located in water scare areas, such as Inner Mongolia, Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang. It is worthwhile to systematically analyse water consumption and take some water-saving measures for CMTO.

Life cycle assessment has become an important decision-making tool for systematically analysing resource consumption and environmental impacts. Kalbusch and Ghisi (2016) did a comparative analysis between ordinary and water-saving taps from the aspect of life cycle water consumption, energy consumption, GHG emissions, acidification, and human toxicity. Clark et al. (2013) calculated water consumed over the life cycle of conventional natural gas and shale gas production, as well as when they used for transportation fuel and electricity generation. Jiang et al. (2014) estimated water consumption and waste water generation impacts of a Marcellus shale gas well from the aspect of direct and indirect water consumption. Chang et al. (2015) conducted an analysis of greenhouse emissions and water consumption for coal and shale gas fired power generation in China. The life cycle water consumption was also calculated by Bakken et al. (2016) for Norwegian hydropower plants, one is a typical run-of-river plant located in southern Norway and the second is a reservoir-based plant located in mid-Norway. Deng et al. (2016) calculate regional water footprint of China in 2002 and in 2007, and analysed changing trend of water footprint on the basis of interregional input-output model. Lu et al. (2016) assessed water use efficiency and water footprint of winter wheat, summer maize, and annual double cropping system in the North China Plain by using field data collected at a fixed site from 1980 to 2014 as a case study. Morera et al. (2016) presented water footprint in wastewater treatment plants by using a life cycle method, which indicated that there is a large decrease of grey water footprint of treating wastewater scenario when compared with no-treatment scenario. The water consumption is analysed by using the life cycle method in above references, however, the study methodology used for coal chemical processes could not be found, especially for coal based olefins production.

The purpose of this paper is to conduct life cycle water consumption analysis of CMTO comparing with other olefins production processes. On the other way, the product cost of these processes is also analysed to weigh different economic advantage of different olefins routes. Finally, this paper attempts to get an alternative olefins production scheme with rational distribution geographically, lower water consumption, and higher economic benefit through scenario analysis. The novelty of this paper is to establish water consumption and cost model for olefins production processes in China, identify water consumption bottleneck and propose corresponding solutions for CMTO.

## 2. Methodology

### 2.1. System boundary and function unit

According to the reference (De Benedetto and Klemeš, 2009), the life cycle assessment involves determining the overall objectives and boundaries of olefins production, collecting data, calculating life cycle index, and evaluating each route to support policy making of studied cases. In order to calculate water consumption, the system boundary is firstly defined. Due to the limitations of direct water consumption analysis, the boundary is expanded to upstream-raw material extraction and transportation. Assuming that the competitive processes produce the same product of olefins, their downstream processes can be excluded from the boundaries, which is generally named as “from cradle-to-gate” analysis (Han et al., 2015).

The corresponding boundaries of olefins production processes are shown in Fig. 1 (Xiang et al., 2015a). The OTO boundary consists of crude oil extraction and processing, oil transportation, refining, and naphtha steam cracking. The boundary of CMTO involves coal extraction and processing, coal transportation, methanol synthesis, and methanol-to-olefins. The NGMTO boundary includes domestic natural gas extraction and processing, natural gas transportation, methanol synthesis, and methanol-to-olefins. The CGMTO boundary is coal extraction and processing, coal transportation, coke-oven gas production, methanol synthesis, and methanol-to-olefins. Function unit directly affects the meaning of the results (Liu and Ma, 2009). For this study of water consumption, one tone olefins is defined as the functional unit for normalization of results.

### 2.2. Water consumption calculation model

The system boundary includes two stages: (1) the upstream stage including resources extraction, processing, and transportation of oil, coal, and natural gas; (2) the olefins production stage including four processes of OTO, CMTO, NGMTO, and CGMTO.

Life cycle water consumption is the sum of direct and indirect water consumption, as shown in Eq. (1) (Chang et al., 2015). As its name implies, the direct water consumption refers to the water directly used in treatment processes (Jiang et al., 2014). In this work, the direct water consumption includes process water consumption and cooling water consumption of olefins production processes, which is obtained from references, as shown in the second column of Table 1.

$$LCWC = LCWC_{direct} + LCWC_{indirect} \tag{1}$$

The indirect water consumption is water used by producing process energy and raw materials (Jiang et al., 2014). Indirect water during olefins production stage is used for energy production. During upstream stage, indirect water is used for raw material mining, processing, and transportation. It is calculated by the sum of product of process energy consumption and the corresponding water consumption factor, as shown in Eq. (2).