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Life cycle analysis of coal based methanol-to-olefins processes in China

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ABSTRACT

In the present paper, life cycle analysis of coal based methanol-to-olefins processes in China is performed based on the detailed information of the china's largest project of its kind. The purpose of our analysis is to identify the reduction potentials of the project for the energy/water saving and the emission control. The details of the project are given together with the involved techniques. In our analysis, the water and energy consumptions, CO_2/SO_2/NO_x emissions are all demonstrated in terms of six sub-processes with both the direct and indirect contributions. Based on the analysis, we identify that the coal-to-methanol process consumes a vast amount of water and energy with significant CO_2/SO_2/NO_x emissions. For water/energy savings, methanol-to-olefins process is of litter potential because its consumptions are mainly the indirect ones. The negative effects of CCS should be noticed for the implement in the large-scale coal based chemical engineering due to its significant consumptions of the water and energy.

1. Introduction

In China, there exists rich resource of coal over a wide range of areas of China (e.g. Shanxi, Inner Mongolia). The efficient, clean and low-carbon utilization of coal are quite important for China's energy development (Musa et al., 2018; Huang and Huang, 2018). Traditionally, the coal is intensively employed for electricity generation through steam turbines. However, in recent years, renewable energy (e.g. wind (Zhang et al., 2016a; Sahu, 2018) and hydro (Zhang et al., 2018; Zhang et al., 2017a; Zhang et al., 2016b; Li et al., 2017) energies) and energy storage facilities (Zhang et al., 2017b; Zhang et al., 2017c) are developing very fast in China, leading to great challenges on the electricity consumption problems. Hence, for the purpose of the coal utilization, the chemical potential of the coal are being released through a large amount of coal chemical engineering projects (Yi et al., 2015) (e.g. coal based methanol-to-olefins processes, CMTO). Therefore, life cycle analysis of the coal chemical engineering projects is quite essential to evaluate the various kinds of impacts of the above chemical usage of coal (e.g. energy efficiency, water consumption, and carbon release). The present paper fits the above target through a detailed life cycle analysis of the largest coal chemical engineering project in China.

In the literature, life cycle analysis has been widely employed for various kinds of chemical engineering (e.g. catalyst evaluation (Benavides et al., 2017; von der Assen and Bardow, 2014)) and energy industries (e.g. wind (Huang et al., 2017), alternative fuels (Ou et al., 2012; Ou et al., 2010), biofuels (Varanda et al., 2011; Altamirano et al., 2016; Wang et al., 2017), hydrocarbon biorefinery (Wang et al., 2013; Gebreslassie et al., 2013; Gao and You, 2017)). Specifically, for the coal-related technologies (e.g. coal-to-methanol (Qin et al., 2016; Li et al., 2010), coal-based SNG (Li et al., 2016; Gao et al., 2017a), coal-to-liquid (Gao et al., 2017b) and solar aided coal-fired power system (Zhai et al., 2016), life cycle analysis also provides a power tool to evaluate the energy consumption and greenhouse gas emissions during the whole life cycle of the targets (Ou et al., 2011). Specifically, Wang et al. (2013) integrated the life cycle assessment with the multiple-objective, mixed-integer nonlinear programming (MINLP) model with the superstructure. They applied those integrated LCA methods into the hydrocarbon biorefinery (Wang et al., 2013; Gebreslassie et al., 2013). Gao and You (2017) further proposed a functional-unit-based life cycle method to a county-level hydrocarbon biofuel supply chain. Gao et al. (2017b) performed life cycle analysis of several typical direct and indirect coal liquefaction technical routes for providing vehicle power in China with full considerations of environmen-

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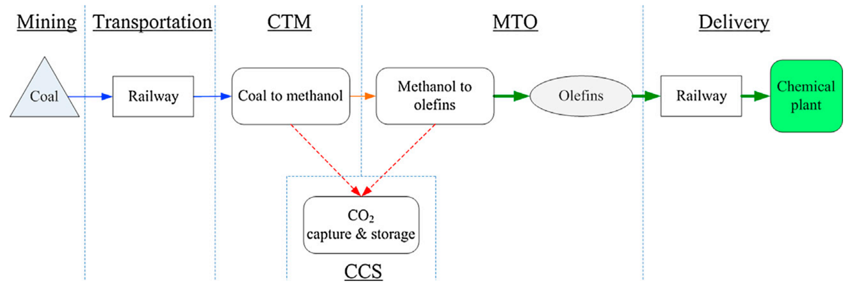

Fig. 1. A detailed description of the boundary of the life cycle analysis of the coal based methanol-to-olefins processes. The "CTM" and "MTO" in the figure refer to the coal-to-methanol and methanol-to-olefins processes respectively.

tal pollutants. Zhao et al. (2017) compared the coal-to-olefins and coal-to-propylene processes on the energy consumption and greenhouse gas emissions of the propylene production. They also reviewed the other propylene production routes including catalytic cracking and stream-cracking.

In the present paper, life cycle analysis of the largest coal based methanol-to-olefins project in China is performed based on the detailed operational data. The water and energy consumptions, $CO_2/SO_2/NO_x$ emissions are all calculated in our analysis in order to establish a comprehensive evaluation of the project. In the literature, LCA for coal chemical engineering was mainly achieved based on the available data of chemical process simulation and optimization. However, for a large-scale industrial project, the data (e.g. emission coefficients) could be very different with the aforementioned data. In China, recently, several large projects of coal based methanol-to-olefins have commissioned and have also been stably operated for several years. Those data provide us a good opportunity to perform LCA of this technique in great detail. In the present paper, the actual operation data of a large industrial-scale project was adopted for LCA of coal based methanol-to-olefins process. Energy consumption and hazards emissions are all considered together with greenhouse gas emissions and water consumption. To be emphasized, water is currently a critical factor for the development of China's coal chemical industry.

The contents of each sections of the present paper are briefly given as follows. The second section describes the details of the project information and techniques involved together with the modelling methods of life cycle analysis. The third section shows the general characteristics of the consumptions/emissions of the project through our life cycle analysis. The fourth section further illustrates the contributions of the direct and indirect ones on the total emissions/consumptions. The fifth section summarizes the key findings of the present paper together with perspectives.

2. Life cycle analysis methodology

2.1. Brief introduction of coal based methanol-to-olefins project

The project locates at the industrial base of Jiuyuan District, Baotou, Inner Mongolia Autonomous Region. The project was mainly invested by the Shenhua Group Cooperation Limited (now merged with other company in Aug 2017 with the new name as "National Energy Investment Group").

For the coal based methanol-to-olefins (MTO) process, the Baotou project adopted the DMTO technique, which was mainly developed by the Dalian Institute of Chemical Physics, Chinese Academy of Sciences. The main features of the DMTO is the high conversion rate of the methanol (about 99.8%) and high selectivity of the ethylene and propylene (about 80%). Furthermore, the C_4 could be further converted to the ethylene and propylene based on the same catalyst.

Table 1
Parameters of the primary facilities of the coal based methanol-to-olefins project.

Primary facilities	Value	Unit
Air separation	240,000	m^3/h
Coal-to-methanol	1800,000	ton/year
Methanol-to-olefins	600,000	ton/year
Polypropylene	300,000 [a]	ton/year
Polyethylene	300,000 [a]	ton/year
High pressure steam boiler	410 [b]	ton/hour/unit
Condensing turbine with extraction	100	MW

[a] After the expansion, according to the current plan, the annual productions of polypropylene and polyethylene will be 400,000 ton and 350,000 ton respectively.
[b] There are three units in the whole project.

Table 2
Main products of the coal based methanol-to-olefins project.

Main product	wt.%	Lower heating value (MJ/Nm^3)
Polyethylene	38.5	59.44
Polypropylene	39.8	87.61
C_4	12.7	117.61
Amylene	5.3	148.73
Propane	2.0	93.18
Sulphur	1.7	59.44

DMTO could be divided into two steps: generations of dimethyl ether (DME) through dehydration of methanol; generations of olefins (e.g. ethylene and propylene) through dehydration of DME. The overall chemical reaction for DMTO could be simplified as

$$2CH_3OH \rightarrow C_2H_4 + 2H_2O \quad (1)$$

$$3CH_3OH \rightarrow C_3H_6 + 3H_2O \quad (2)$$

Hence, water could be produced during the DMTO. It should be also noticed that during DMTO, the steam will be consumed to ensure the target chemical reactions.

In Table 1, parameters of the primary facilities of the project are given together with the future plan. According to Table 2, the main products of the project consist of the polyethylene (38.5 wt.%) and polypropylene (39.8 wt.%). In Table 2, the lower heating values of each product are also given for the further energy efficiency analysis following the China's national standard.

2.2. Boundary of LCA

Fig. 1 shows a detailed description of the boundary of the life cycle analysis of the coal based methanol-to-olefins processes. For the convenience, the full process involved in this project are divided into six sub-processes: mining, transportation, coal-to-methanol (CTM), methanol-to-olefins (MTO), olefins delivery and CO_2 capture and storage (CCS). In the following discussions, the life cycle analysis will be performed for each process.