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Techno-economic performance of the coal-to-olefins process with CCS

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HIGHLIGHTS

- Conduct a techno-economic analysis of the coal-to-olefins (CTO) with CCS.
- Analyze effects of key factors on the CTO with appropriate capture rate 80%.
- Present strengths and weaknesses of the CTO compared to the methanol-to-olefins.

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ABSTRACT

Coal-to-olefins (CTO) has been attracting more attention of the chemical process industry, in the light of the scarcity of oil resources and richness of coal in China. However, it is inherently accompanied with the problem of severe greenhouse gas emissions. CTO processes therefore face increasing challenges from other alternative processes, especially methanol-to-olefins (MTO) process. This paper conducts a detailed techno-economic analysis of the CTO process with CCS. The effect of carbon capture is studied. The CTO process with 80% carbon capture is slightly less thermodynamically efficient than the conventional CTO process. The corresponding mitigation cost of the process is 150 RMB/t, which is roughly equivalent to the current carbon price. Thus, the effect of energetic and economic penalties on this carbon capture configuration is negligible. In comparison to the MTO process, the CTO process with CCS is competitive in product cost even considering carbon tax and it is capable of resisting to market risk. CTO processes with appropriate CO_2 reduction are more applicable to olefins industry in China.

1. Introduction

As the backbone of the petrochemical industry, olefins production scale is critical to development of national economy. As more and more oil-to-olefins projects launched in China, the production grows quickly, and the self-sufficient rate of ethylene and propylene will increases up to 53% and 74% by 2015 [1]. However, there is still a big gap between the domestic supply and demand, which is in urgently needed to be filled by olefins based on alternative resources. From 2005 to 2011, coal accounted for 75.1% of the total energy production of China, oil for 15.2%, and natural gas for 2.8%, as shown in Fig. 1. The oil import dependence was approached to 57% in 2012. Thus, development of the coal-based olefins industry is favorable in the context of increasingly severe oil supply shortage. There are now three coal-to-olefins (CTO) projects under operation and other two CTO projects in plan in the next there years in China. These installations are going to approach a capacity of 3 Mt/y [3].

However, CTO is facing the problem of high CO_2 emissions. There have been a number of techniques of CO_2 mitigation developed from chemical and physical methods [4]. For chemical methods, CO_2 is reused mostly as feedstock to produce valued chemical products. Although these methods enable us to exploit CO_2 as a valuable feedstock in many different applications such as the production of urea and methanol, their contribution to CO_2 mitigation is finite. Physical methods are generally regarded as geologically storing CO_2 underneath. In recent years, carbon capture and storage (CCS) technology has received increasing attention because of its large capacity of reducing CO_2 emissions. It is a more economical and efficient method compared to developing renewable energy, retrofitting major equipments, and improving energy integration for resource and energy saving [5].

A CCS process in general involves three stages: separating CO_2 from flue gas, compressing CO_2 for pipeline transport, and injecting CO_2 into geologic reservoirs. For carbon capture, there are mainly three technologies developed, including post-combustion capture, oxy-fuel combustion capture, and pre-combustion

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Nomenclature

Abbreviations

AGR	acid gas removal
ASU	air separation unit
CCS	carbon capture and storage
CG	coal gasification
CTO	coal-to-olefins
LHV	lower heating value
MS	methanol synthesis
MTO	methanol-to-olefins
RMB	ren min bi
WGS	water gas shift

Notations in formulation

θ	domestic-made factor
C_{AC}	administrative cost (RMB/t)
CCF	cumulative cash flow (RMB)
CCR	carbon capture rate (%)
C_D	depreciation cost (RMB/t)
C_{DSC}	distribution and selling cost (RMB/t)
CF_i	cash flow of year *i* (RMB)
$C_{O\&M}$	operating & maintenance cost (RMB/t)
C_{POC}	plant overhead cost (RMB/t)
C_R	raw material cost (RMB/t)
$C_{TS\&M}$	cost of CO_2 transportation, sequestration and monitoring (RMB/t)
C_U	utilities cost (RMB/t)
EI	equipment investment (RMB)
EI_j^r	reference equipment investment of unit *j* (RMB)
E_{wCCS}	quantity of CO_2 emitted from the CTO plant with CCS (Mt/y)
$E_{w/oCCS}$	quantity of CO_2 emitted from the CTO plant without CCS (Mt/y)
MC	mitigation cost (RMB/t)
OP	olefins price (RMB/t)
OY_i	olefins yield (Mt/y)
PC	product cost (RMB/t)
$PC_{w\ CCS}$	product cost of the CTO plant with CCS (RMB/t)
$PC_{w/o\ CCS}$	product cost of the CTO plant without CCS (RMB/t)
RF_i	ratio factor of component *i* (%)
S_j	practical scale of unit *j*
S_j^r	reference scale of unit *j*
sf	scale factor
TCI	total capital investment (RMB/t/y)

capture [6]. These technologies are usually applied in pulverized-coal power plants and some chemical plants [7]. Introducing a CCS will bring penalties on both energetic and economic performance [8–10]. For example, in most coal-based power plants, the CO_2 avoidance cost is about 250–330 RMB/t, which is much higher than the current carbon price. The penalties brought by the CCS on chemical processes is, however, lower than those on power generation processes [11,12]. It demonstrates that it is necessary to assess the impact of CCS on the whole performance of CTO processes.

Planning a sound development roadmap for alternative olefins production requires a broad and comprehensive assessment. Techno-economic analysis is an essential part of this process. More importantly, the role of CCS in CTO development is needed to be analyzed to find the trade-off among environmental protection, energy penalty, and economic performance. There have been some studies on techno-economic analysis of CTO processes [13–18]. However, the literatures on analyzing CTO processes with CCS from techno-economic point of view could not be found. Besides, some views back up developing methanol-to-olefins (MTO) processes since they have the advantages of low capital investment and environmental impact. There are now 1 MTO project under operation and other 10 MTO projects in plan in the next three years in China, which will approach to a capacity of 6.8 Mt/y [3]. With the potential challenge of the MTO process, how should people configure CCS on the CTO process? We answer this question by the techno-economic comparison of the CTO process with CCS and the MTO process in this paper.

2. Process modeling

As a base of techno-economic analysis, major units of a CTO process are modeled, including an air separation unit (ASU), a coal gasification unit (CG), an acid gas removal unit (AGR), a carbon capture and storage unit (CCS), a water gas shift unit (WGS), a methanol synthesis unit (MS), and a methanol-to-olefins unit (MTO). For a plant with given capacity and specified operating conditions, the model calculates all mass and energy flows. The details of the modeling are described in the following sections.

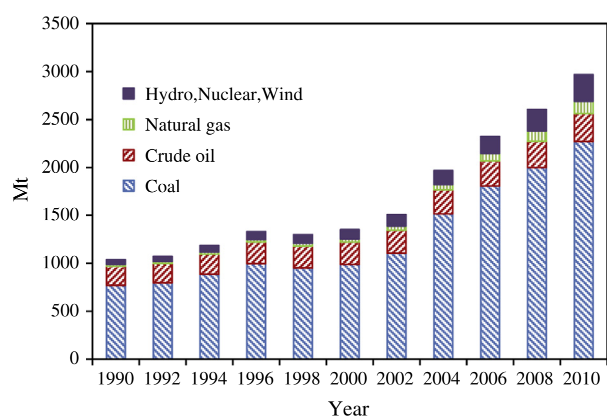

Fig. 1. Profile of major energy production in China [2].

2.1. Coal-to-olefins process

The flow diagram of the CTO process, including the MTO process, is shown in Fig. 2. Coal and water are gasified with the oxygen agent from the ASU, to produce syngas in the CG. The hot syngas is quenched in a radiant cooler and a convection condenser, where heat is recovered to generate steam. The syngas is then fed into the WGS to increase the ratio of H_2/CO for the methanol synthesis. Before methanol synthesis, the syngas is cleaned in the AGR to remove H_2S and CO_2. The clean syngas is then sent to the MS to produce methanol. The crude methanol solution is concentrated to 90% (moral fraction) before fed into the MTO. Prior to olefins separation, there are a serial of steps: quenching, washing, drying, and compression. The front-end depropanization separation technique is applied to separate olefins into ethylene and propylene [18].

2.1.1. Coal gasification unit

In the CG, Texaco gasification technique was adopted. For modeling, coal is firstly divided into three kinds of nonconventional matter as coke, ash, and unburned carbon. Then nonconventional matter is decomposed in RYield model in Aspen Plus by element