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Review article

Coke oven gas: Availability, properties, purification, and utilization in China

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ABSTRACT

The global demand for energy is constantly on the rise because of population explosion, rapid urbanization, and industrial growth. Existing energy resources are struggling to cope with the current energy requirements. Aside from exploring renewable energy alternatives, available energy resources must be utilized to their maximum potential. Coke oven gas (COG) is highly rated as a valuable by-product of coal carbonization to produce coke in the steel industry. Typically, a single ton of coke generates approximately 360 m^3 COG. China annually produces 70 billion N m^3 COG; however, only 20% of the gas produced is utilized as fuel. Disposing COG without an effective recovery and efficient utilization is a serious waste of an energy resource and results in environmental pollution. COG is regarded as a potential feedstock for hydrogen separation, methane enrichment, and syn-gas and methanol production. It can also be effectively utilized to produce electricity and liquefied natural gas. The availability, properties, purification, and utilization of COG are reviewed in the current study. COG utilization routes are summarized in detail, with focus on some major industrial projects in China and other countries that are based on COG utilization technology.

Contents

Abbreviations: COG, coke oven gas; GDP, gross domestic product; BF, blast furnace; Syn-gas, synthesis gas; CV, calorific value; BFG, blast furnace gas; BTX, benzene, toluene and xylene; HCs, hydrocarbons; CHP, combined heat and power; SO_x, sulfur oxide; DRI, direct reduction iron; EAF, electric arc furnace; PSA, pressure swing adsorption; WGSR, water–gas shift reaction; PO, partial oxidation; FTS, fischer tropsch synthesis; CPO, catalytic partial oxidation; S/C, steam/carbon; RWGSR, reverse water–gas shift reaction; CO_x, CO and CO_2; GHGs, green house gases; GHG, green house gas; SNG, synthetic natural gas; CNGCL, China Natural Gas Corporation Limited; LNG, liquefied natural gas; CCPP, combined cycle power plant.

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1. Introduction

The threat of the world's energy supply by depletion of fossil fuel reserves, along with rapid industrialization and urban growth, has not only encouraged the search for alternative energy sources, but it has also pushed for an effective and efficient utilization of available ones. Fossil fuels have predominantly been the major energy source for industrial, transportation, and domestic use over the centuries. Approximately 90% of the global energy requirements are covered by these sources alone [1]. Global primary energy usage rose by approximately 2.4% in 2007 and is likely to increase further in the future, with developing Asian countries continuously improving their standard of living. The energy demand in China rose by 7.7%, followed by 6.8% and 1.6% in India and US respectively [2]. For the past decade or so, China has enjoyed the most drastic economic growth, with a 10% increase in the gross domestic product (GDP). This growth allowed China to recover quickly from the 2007–2008 financial crisis. With such economic and population boom, the energy consumption in China is also on the rise and, more importantly, strongly affects the global energy balance [3].

The energy structure of China has traditionally been dominated by coal. Although other fuel options have also entered the energy setup in the past few decades, coal still plays a leading role in China's energy scenario. Model forecasts predicted an annual increase in coal demand by almost 2% for 2010 [4]. With a coal reserve of an estimated 5570 billion tons, the third largest in the world, China is regarded as the world's largest coal producer and consumer [5].

For the past few decades, steel has become an icon of modern urbanization and industrial development, with coal serving as the backbone of the iron and steel industries. According to the World Coal Association, approximately 70% of the total global steel production relies on coal [6]. The steel industry has played an important role in the economy of China because of its rich coal reserves, with a rapid growth overtaking that of Japan to become the largest steel producer in the world. Despite such achievements, the energy efficiency of China's steel industry is the lowest among the major steel-producing countries around the globe. However, research and development are continuously improving the energy efficiency to achieve a sustainable development [7]. In 2004, the average net energy usage for the coking process in China was 4.3 GJ/t, whereas the international average was 3.8 GJ/t [8].

Coke oven gas (COG), sometimes simply called "coke gas," is a by-product of the coke-making process, where volatile coal matter is generated as COG, leaving carbon intensive coke behind. Coke is a very strong macro-porous carbonaceous material produced by the carbonization of a specific coal grade or of different coal blends at temperatures $\geqslant 1400$ K. Approximately 90% of coke produced from blends of coking coals is used to maintain the iron production process in a blast furnace (BF) [9]. Typically, 1.25–1.65 tonnes of coal produces a single tonne of coke, while generating approximately 300–360 m^3 of COG (6–8 GJ/t coke) [8]. Table 1 shows the energy balance for a typical coke-making plant along with different raw materials and product distribution [10]. In China, the annual coke output in 2007 was about 335 million tons, or approximately 60% of the total global coke production. The annual COG production in China for 2007 was estimated at around 70 billion N m^3. However, only 20% of the produced COG is utilized as fuel; most of the gas is directly discharged into the atmosphere, with serious environmental consequences and considerable energy waste. Developing new technologies to recover and utilize COG from the steel industry is therefore urgently needed [11,12]. In China, the coking enterprises located near coal mines only recover 24% of the COG by-product, losing a high percentage of potential energy as well as generating 25 Mt of carbon dioxide (CO_2) [8]. Moreover, converting COG into more energy-valued products can significantly enhance the energy efficiency of the steel industry in China.

COG has been highly investigated as an important source of hydrogen (H_2), with Japan making some early developments in establishing a sustainable H_2 production technology from COG [12]. Purwanto and Akiyama [13] proposed a simple method of H_2 production from COG. Onozaki et al. [14] performed the partial oxidation and steam reforming of tar from hot COG to produce H_2 at low cost and high efficiency without using any catalyst. H_2 enrichment in COG can also be achieved through catalytic methane CH_4 reforming via catalytic partial oxidation [15]. The use of membrane technology can also lead to synthesis gas (syn-gas) production through the partial oxidation of COG [12]. The syn-gas ($CO + H_2$) produced from COG via various routes, such as partial oxidation, steam reforming, or dry reforming, can be utilized to produce important organic products, such as methanol [16]. Catalytic co-methanation of CO and CO_2 in COG can also be used for CH_4 enrichment. The choice and nature of a catalyst can significantly affect both the activity and selectivity in CH_4 production. The use of both transition and noble active metal supported catalysts with different oxide supports have been previously reported for CO and CO_2 hydrogenation to produce CH_4 [17–21].

In the current review, we discuss the availability of COG with respect to the steel industry and coke gas production, focusing on China's perspective. The purification and utilization of COG is largely discussed, and current utilization routes and future technological research and developments in the said field are considered. COG utilization facilities in China are highlighted, with key

Table 1
Mass and energy flow of a typical coke-making plant [10].

Energy input (42.7 GJ/t coke)	
Coal	91.44%
Electric power	0.37%
Fuel gas (firing gas)	7.61%
Steam	0.58%
Energy output (42.7 GJ/t coke)	
Coke	69.63%
COG	17.92%
Tar	2.77%
BTX	0.98%
Sulfur	0.05%
Energy loss	8.65%