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Energy gases and related carbon emissions in China

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ABSTRACT

With increasing energy demand and environmental problems in China, energy gases, such as natural gas(NG), coalbed methane(CBM) and coke-oven gas(COG) are alternatives of coal with great potential due to abundant reserves and remarkable environmental superiority for carbon reduction. Based on a large number of sampling data derived from comprehensive field investigations, energy gases used in China are researched on their compositions, net calorific values(NCVs), resources distributions and annual productions firstly in this paper, and then the Chinese-specific carbon contents by gas type and consuming sector are calculated to establish basic data for accurate estimation of carbon emissions. Results show that Chinese-specific carbon contents for NG, CBM and COG are 15.19 kg/GJ [15.15–15.37 kg/GJ], 15.13 kg/GJ [14.72–15.39 kg/GJ] and 11.41 kg/GJ [9.95–12.34 kg/GJ], respectively. Compared to IPCC, both carbon contents of NG and CBM are in close proximity to the default value, while COG has an obviously lower carbon content. Little difference exists among carbon contents of NG utilized in four main sectors including industry, power generation, households and vehicles, while a relatively obvious difference exists among those of COG. Carbon emissions would be greatly reduced by increasing the share of gas consumption in each sector. The market circumstances, application technologies, development bottlenecks as well as emission reduction potentials are studied respectively for the four utilization sectors with bright prospects. Finally, effective policy recommendations are given on the development of energy gases for the purpose of achieving a win-win of economy and environment.

1. Introduction

As the population as well as the economy grows, China needs more and more energy supply now and in the future. At the same time, carbon dioxide emission increasingly attracts the world's attention because of global climate warming. China now is facing a dilemma of 3H, high-volume-of resource inputs, high-volume-of GDP outputs and high-volume-of pollutant emission (Wu et al., 2014), which causes great pressure on the sustainable development. Energy structure adjustment is an effective way to ease the tensions. China's current energy consumption is still dominated by fossil fuels, including coal (69%), oil (18%) and natural gas (4.9%) (EIA, 2014a). Over-consumption of coal warns Chinese government to seek more energy resources to reduce reliance on coal. China has to experience a transition period of transferring from relying on fossil energy to clean energy. Energy Gases are not renewable but clean energy, which could provide a buffer during this long transition (Liu et al., 2013). Natural gas (NG), coalbed methane (CBM) and coke-oven gas(COG), are considered as the most potential alternative gases, with abundant total resources and remarkable environmental superiority.

NG, usually referring to conventional natural gas, plays an extremely important role as the dominant energy in many developed countries. The world's total proved natural gas reserve is 187.1 trillion m^3 at end 2014, while China has 3.5 trillion m^3 accounting for only 1.8% of the total. China's natural gas production grew at an average rate of about 6.71% from 1980 to 2010 (Lin and Wang, 2012), and the production increased by 7.7% in 2014 over 2013 (BP, 2014). China's consumption increased by 8.6% in 2014 over 2013, accounting for 5.4% of the world's gas consumption (BP, 2014), and China's dependency on foreign NG import has been more than 30% in the year of 2014. By 2016, China is projected to account for 7.0% of global gas consumption. Under a resource constraint scenario, Na Li et al. has predicted that natural gas consumption would peak in 2050, accounting for nearly 14.7% of total consumption (Li et al., 2016). Compared to the developed countries, NG in China is in low reserve, difficult production and low efficiency to some extent. However, the Chinese government anticipates that the share of energy gases in total energy consumption could increase to around 10% by 2020 (EIA, 2014a).

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CBM is one kind of unconventional natural gas that is rapidly developing in China. CBM production in the U.S. was 42.5 billion m^3, nearly 5% of U.S. gas production in 2013. In Canada CBM is abundantly found in Alberta, estimated to be approximate 56.6 billion m^3 (Alberta Canada, 2013). Abundant CBM resources are concentrated in 15 major coal-bearing basins in China (Meng et al., 2014). In 2012, the national total proven CBM reserves were up to 551.8 billion m^3, and the CBM production reached 12.6 billion m^3 (Sun et al., 2013). Although China is abundant in CBM reserves, its utilization rate is only about 40% (Gao et al., 2010). If CBM is made accessible to markets, it would offer an alternative to coal, diesel and liquefied petroleum gas which are still largely consumed in many factories. The 12th Five-year Plan (NEA, 2011) has detailed the goals of CBM production and consumption, which will definitely promote the prosperity of CBM within the next several years.

COG is a by-product of coal carbonization to coke. China has rather abundant reserves of coal and ranks top in coke production, consumption and exportation (Man et al., 2014). China's coke production increased dramatically from 122 million tons in 2000 to 448 million tons in 2012 (NBS, 1996–2013). Today, about 64% of the world's coke is from China (Liu et al., 2013). There is about 430 m^3 COG produced from every one ton of coke production. Annual COG production from Chinese independent coking enterprises exceeds 90 billion m^3. Raw COG can be burned on-site in blast furnaces and in coke batteries during the coking process. Otherwise, the gas can be used to generate electricity (Razzaq et al., 2013) and for some other use.

NG, CBM and COG are together in huge quantity with great potential to share the pressure of coal reliance. And they are all considered as good alternative energy in industry, power generation, residential heating or cooking and transport applications.

Since reform and opening up, China's economy has been developing rapidly. However, this came at the expense of excessive energy consumption resulting in serious environmental problems (Zhang et al., 2015). China now has surpassed America as the world's largest energy-related CO_2 emitter. The growing energy consumption, low energy efficiency, coal-based energy structure and carbon-intensive economic structure were considered as the driving factors (Liu et al., 2016). In 2011, China emitted about 8715 million tons of CO_2 (EIA, 2014a), of which only 257.3 million tons were emitted by natural gas consumption (EIA, 2014b). The government has committed that China's CO_2 emission intensity of its gross domestic product (GDP) would be reduced by 40–45% by 2020 compared to the 2005-level (Kang et al., 2014; Xu et al., 2014). Carbon emissions are highly correlated with energy application, so hopes have been placed on energy gases to achieve this goal during China's energy transition period. However, to realize the carbon reduction goal by this way, we should firstly get clear on several issues like how the potential of energy gases in carbon emission reduction is, whether it will actually result in economic and environmental sustainability by booming the consumption of energy gases and what opportunity and challenge are faced by energy gases. Answers of these questions come from objective and quantitative evaluation of the consumption, carbon emission and prospect of energy gases in China. This is very crucial and it will help the Chinese government effectively guide the development of energy gases.

In this paper, comprehensive field investigations and a large number of sampling experiments are first conducted, based on which energy gases in China are researched on their compositions, net calorific values(NCVs), resource distributions and annual productions. Then Chinese-specific carbon contents by gas type and by consuming sector are calculated according to a statistical analysis method, which will provide the premise of accurate estimation of carbon emissions. Energy gases consumed in industry, power generation, households and vehicles are studied respectively on the market circumstances, application technologies, development bottlenecks and emission reduction potential. Finally, feasible suggestions for the development of energy gases are given to maximize the economic and environmental efficiency.

2. Methodology

2.1. Sampling and analysis method

The sampling plan was designed according to regionally-weighted stratified sampling method which gave more consideration to areas with large gas production to demonstrate the representativeness of the samples. Each sample data was the average of three groups of sample data in the same sampling point under the same conditions. Gas samples were collected in plastic gas sample bags or gas cylinders at each sampling spot. Sampling and testing processes were in strict conformance with approved standards GB/T13610 (GB/T13610, 2003) and GB/T11062 (GB/T11062, 1998). An instrument of Agilent 7890 GC equipped with refinery gas analysis columns, FID and TCD detectors was used to analyze the compositions of the samples.

2.2. Carbon contents calculation method

Based on the measured gas compositions, calorific values(CVs) per cubic meter can be calculated following Eqs. (1)–(3) under the reference condition of 293.15 K and 101.325 KPa (GB/T11062, 1998).

$$Z_{mix} = 1 - [\sum_{i=1}^{N} x_i \bullet \sqrt{b_i}]^2 \quad (1)$$

$$H^0 = \sum_{i=1}^{N} x_i \bullet H_i^0 \quad (2)$$

$$H = H^0 / Z_{mix} \quad (3)$$

Where, Z_{mix} is compression factor which is used to adjust the CV of ideal gas to that of real gas; x_i means the molar fraction of component i; H_i^0 is the CV of component i in ideal gas, kJ/m^3; H^0 is the total volume CV of ideal gas, kJ/m^3; H means the total volume CV of real gas, kJ/m^3. There are two kinds of CV, the gross calorific value (GCV) and the net calorific value (NCV). H_2O existing in liquid phase after combustion releases a GCV while H_2O existing in gaseous phase after combustion releases a NCV. The NCV is on average 10% less than the GCV for natural gas (IEA, 2004). In this paper, NCV is applied to calculate carbon content to keep consistent with default values of IPCC. Parameters of ideal gas are derived from the Chinese National standards of GB/T11062-1998 (GB/T11062, 1998).

Dividing volumetric carbon content (kJ/m^3) by CV (MJ/m^3) yields the carbon content (kg/GJ) calculated by Eqs. (4) and (5). For consistency, NCV is applied as H to calculate carbon content in this paper (Eggleston et al., 2006).

$$m_c = \sum_{i=1}^{N} x_i \bullet M_c \bullet N_{ci} \bullet 1000/24.06 \quad (4)$$

$$C_c = m_c / H \bullet 1000 \quad (5)$$

Where, m_c is volumetric carbon content, meaning carbon content per unit volume, kg/m^3; M_c is the atomic weight of carbon, here taking the value of 12 g/mol; N_{ci} means the number of carbon atoms in carbonaceous component i; C_c represents the carbon content in one unit of heat, kg/GJ.