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Original Research

Greenhouse Gas Emissions by the Chinese Coking Industry

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Abstract

The Chinese coking industry (CCI) is currently facing a great challenge on reducing greenhouse gas (GHG) emissions. Our study was set up to assess the GHG emission characteristics of 10 representative coke enterprises and analyse the factors of fuel type, production scale, loading method, oven model, loading rate, etc. The research results showed that fuel gas type, oven model, and loading rate had obvious impacts on the carbon emission intensity of coking plants, while the production scale and the loading method had little effects. The carbon emission intensity of the coking plant using mixed fuel gas was much higher than the plant using coke oven gas as fuel. The carbon emission intensity of the 6.0 m coke oven was 0.7 times higher than that of the 4.3 m coke oven. And the emission intensity of the clean heat recovery coke oven was the highest. An infrequent low loading rate would increase the direct carbon emission intensity significantly. The research results will help the government to compare the emission intensity of the coking industry and make policies about carbon emission intensity reduction.

Keywords: greenhouse gas, carbon emissions, Chinese coking industry

Introduction

China is now the world's biggest carbon dioxide emission country due to burning fossil fuels and human activities [1-3]. China is also the world's largest coke-producing and -exporting country, accounting for more than 60% of global coke production in 2010 [4]. The coking industry shares about 13% of total coal consumption in China. With rapid growth, the Chinese coking industry (CCI) has become one of the major contributors to total GHG emissions in China.

Thus, China is increasingly becoming concerned with GHG emission reduction issues [5-11], particularly interests in the CCI. Currently, China has made a series of policies and procedures for energy conservation and emission reduction in the coking industry, including most noticeably the "National Industrial Structure Adjustment Directory (for coke)'' and the "Clean Production Standard for Cook Industry." The main feature of these policies is to

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encourage the application of energy-efficient technologies and management in CCI companies. Generally, the implementation has brought positive effects. Studies regarding GHG emissions have been vigorously conducted in many developed countries [12-26]. However, research on GHG emissions of CCI remain insufficient. Hence, the study fills such a gap by assessing GHG emissions of CCI in China. The main objective of this paper is to identify major influencing factors of GHG emissions in Chinese CCI so that more efficient policies and measures for mitigating GHG emissions can be raised. This paper collected production data of 10 coke enterprises and analyzed the influence of fuel gas type, production scale, loading method, oven model, and loading rate, etc, on carbon emission intensity of the coking plants.

Method

System Boundary

This work provides a full chain analysis of GHG emission implications of coking industries in China. Fig. 1 shows an integrated diagram of the accounting inventory, including producing processes of coke, gas purification, coke quenching, and coke screening. The amount of CO_2 emissions was calculated using the carbon mass balance method, studying the carbon flow that enters and leaves the system. All carbon release for the whole process is accounted for as CO_2, containing combustion emissions and the carbon contained in the waste gases, which may eventually be emitted as CO_2. Indirect emissions like the consumption of electricity is not considered.

Calculation Method

The carbon footprint methodology was proposed for the coking industry by the guidelines for the monitoring and reporting of greenhouse gas emissions (2007/589/EG). The figure shows the mass balance concept schematically. The mass balance should consider all carbon-containing inputs, stocks, products, and other exports to determine the level of emissions of greenhouse gases using the equation:

– CO_2 emissions [tCO_2] = (input – products – export) * conversion factor CO_2/C (1).
– Input [tC]: carbon entering the boundaries of the entity.
– Products [tC]: carbon in products and materials (including by-products and waste) leaving the boundaries of the entity.
– Export [tC]: carbon exported from the boundaries of the entity, e.g. discharged to sewer, deposited into landfill, or through other losses. Export does not include the release of greenhouse gases into the atmosphere.

Using the equation, the mass and C-content should be known for calculating CO_2 emissions. C-containing feedstocks, products, and exported materials for CCI also should be considered:

– Feedstocks: coal, petrol coke, oil for coal oiling, blast furnace gas/BOF-gas for under firing of coke oven, fuel gases for steam/electricity production, materials for cleaning the coke oven gas and purification of wastewater.
– Products: coke, tar, raw benzene (light oil).
– Exported materials: excess coke oven gas, wastewater, (solid waste, if any).

The C-content of coke oven gas, blast furnace gas, BOF-gas, and other fuel gases can be obtained with the help of GC-analysis. The unclear and secondary data for C-content and DMT was employed to measure the C-content of tar and raw benzene C_{total} = 91.2 + 0.078 volatiles $_{(daf)}$ – 0.00739 volatiles:

– Volatiles of coke: < 1 % (daf).
– Total carbon content of coke 97.5 – 97.8 % (daf).
– Tar: 0.883 t C/t.
– Raw: benzene 0.923 t C/t.

Selecting Coking Plants

Ten coke plants of Shanxi Province were selected as samples, and relevant data were collected from 2012 to 2013 (Table 1). Two of these coking plants are iron and steel enterprises, the others were independent coking

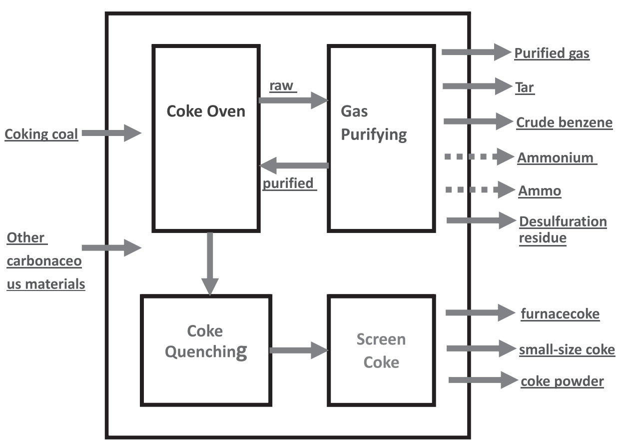

Fig. 1. An integrated diagram for the accounting inventory of a coking plant.

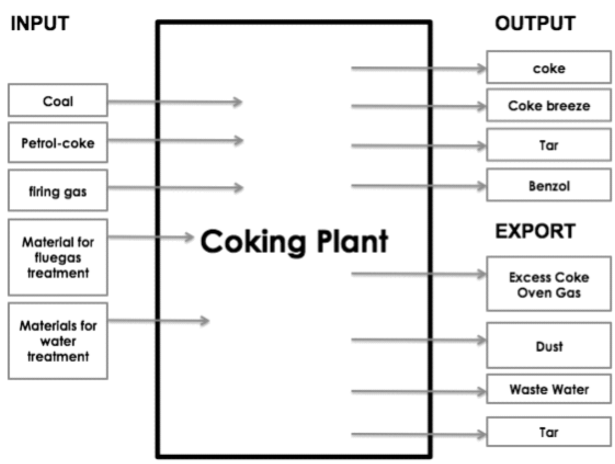

Fig. 2. The mass balance concept scheme.

Table 1. Cook enterprise basic information.

Name	Category	Scale of production (million tons/year)	Types of coke oven	Product load rate
TH	Independent coking	0.9	4.3 m tamping coke oven	71%
LY	Independent coking	0.6	4.3 m tamping coke oven	42%
LB	Independent coking	2.1	4.3 m tamping coke oven	100%
YG	Iron and steel	0.8	4.3 m tamping coke oven	90%
LYJ	Independent coking	1.5	5.5 m tamping coke oven	40%
HA	Independent coking	1.3	5.5 m tamping coke oven	15%
MQH	Independent coking	1.0	6.0 m top-charging coke oven	67%
SJ	Independent coking	3.0	6.0 m top-charging coke oven	92%
TG	Iron and steel	2.2	7.63 m top-charging coke oven	100%
XG	Independent coking	0.4	cleaning type heat recovery stamping coke oven	100%

enterprises. Four adopted a 4.3 m tamping coke oven, two were 5.5 m tamping coke ovens, two had 6.0 m top-charging coke ovens, and one was a 7.63 m top-charging coke oven. The loading rates were 15% and 100%.

Results and Discussions

Carbon Emission Intensity Calculation

The calculated results of the carbon emission intensity by 10 coking enterprises are shown in Fig. 3. The results showed that the carbon emission intensity of 10 coking enterprises were 128 and 904 kgCO_2/t-coke in comparison to 150 and 300 kg CO_2/t-coke for most plants. This implies that coking plants were influenced by such factors as fuel gas type, production scale, loading method, oven model, and loading rate, etc.

Carbon Emission Intensity Affected by Fuel Gas Type

Coke oven heating of independent coking enterprises usually uses coke oven gas, and in the accessary coking plant of iron and steel enterprises the mixed gas of coke oven gas, blast-furnace gas, and converter gas are usually used for heating. The CO_2 emissions of independent coking plants were compared with auxiliary coking plants of iron and steel companies, and the results are illustrated in Fig. 4. The results showed that the fuel gas type was a key role in carbon emission intensity. The emissions of a coking plant using mixed gas was four times more than that using coke oven gas, and the components and heating values of coke oven gas were studied to explain this result (Table 2).

The carbon content per 7,000 calories of blast-furnace gas is seven times more than that of coke oven gas, while the carbon content per 7,000 calories of converter gas is five times. Thus, it seems reasonable that the carbon emission intensity using mixed gas was higher than that adopting coke oven gas.

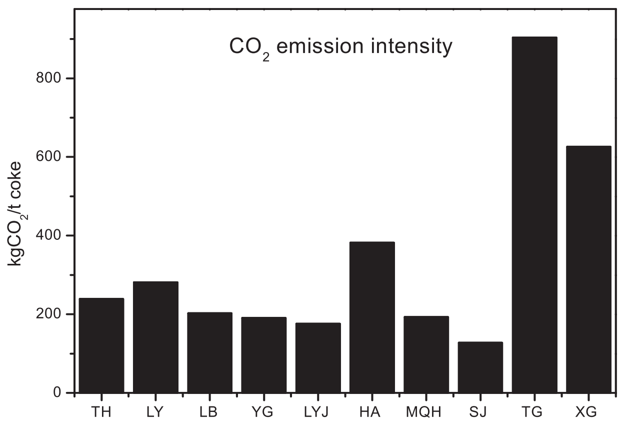

Fig. 3. Direct carbon dioxide emissions of coking enterprises.

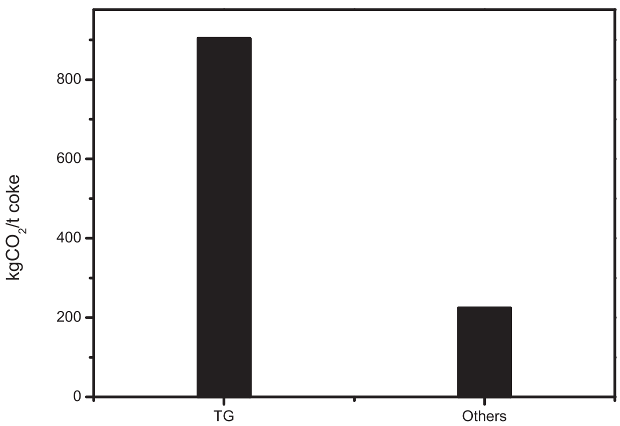

Fig. 4. The comparison of carbon emission intensity affected by fuel gas type.

Table 2. The characteristics of different fuel types.

	H_2 Vol.%	CH_4 Vol.%	CO Vol.%	CO_2 Vol.%	C_nH_m Vol.%	N_2 Vol.%	O_2 Vol.%	Caloric value (MJ/Nm^3)	Carbon content (gC/MJ)
Blast-furnace gas	~4	~0	~25	~15	~0	~55	~1	~3.5	70
Converter gas	~2	~0	~60	~17	~0	~20	~1	~8	50
Coke oven gas	~60	~25	~6	~1.5	~2	~5	~0.5	~18	10

Carbon Emission Intensity Affected by the Production Scale

To examine the effect of production scale for carbon dioxide emissions, four companies (TH, LB, SJ, and MQH) were studied. The production scales of TH and LB (both with 4.3 m side-charging tamping coke ovens) was 900,000 tons/a and 700,000 tons/a, respectively. The production scales of SJ and MQH with 6.0 m top-charging coke ovens were 3 million tons/a and 1 million tons/a, respectively (Fig. 5). The results showed that the production scale of TH was 1.29 times more than that of LB, and the carbon emission intensity of TH was 1.18 times more than that of LB, which indicated that a larger scale would cause more carbon emission intensity. Correspondingly, the production scale of SJ was 1.29 times more than that of MQH, and the carbon emission intensity of MQH is 1.18 times more than that of LB. It turned out that there were no direct relationships between production scale and carbon emission intensity.

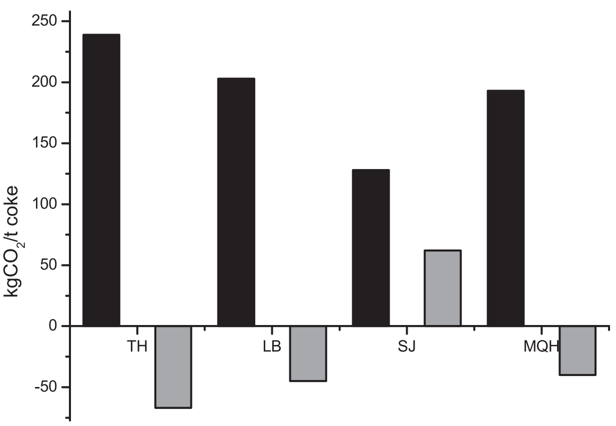

Fig. 5. Direct carbon dioxide emission intensity of coking enterprises with different production scales.

Analyzing Carbon Emission Intensity as Affected by Loading Method

To examine the effect of loading method on the direct carbon dioxide emission intensity of different coking plants, four companies (LB, YG, LYJ, and MQH) were studied. LB with a 4.3 m tamping coke oven was one of the most common coke oven models in Shanxi, while YG, LYG, and MQH adopted a 4.3 m top-charging coke oven, a 5.5 m tamping coke oven, and a 6.0 m top-charging coke oven, respectively (Fig. 6). The results showed that the carbon emission intensity of LB was 1.06 times more than that of TG, and LYJ was 0.91 times that of MQH. It was demonstrated that it had no obvious relationship between loading method and carbon emission intensity.

Analysis of Carbon Emission Intensity Affected by Different Coke Oven Models

At present, 4.3 m coke ovens are widely used and account for 70% in Shanxi province. 6.0 m coke ovens account for 10%, and the clean type heat recovery coke oven was 10%. So, 4.3 m coke ovens, 6.0 m coke ovens,

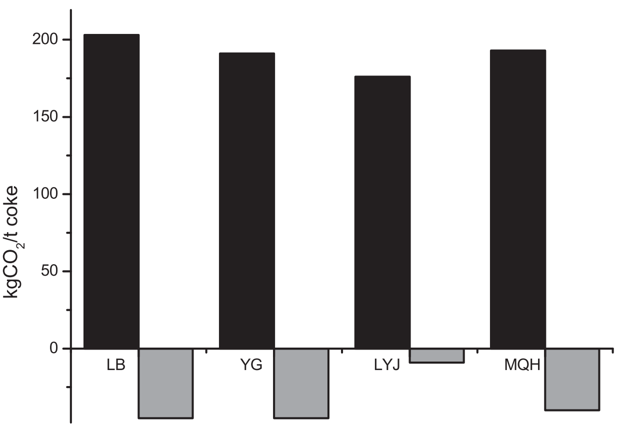

Fig. 6. Direct carbon dioxide emissions of coking enterprises using different loading methods.

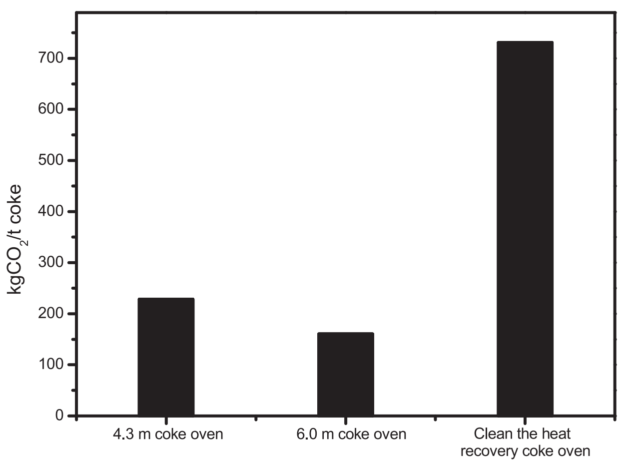

Fig. 7. Direct carbon dioxide emissions of coking enterprises with different oven types.

Table 3. Single coal quantity and pushing times with different oven models.

Types of coke ovens	Single coal quantity	Pushing times (assuming that production is 2 million t/year)
4.3 m coke oven	About 24 tons	228
6.0 m coke oven	About 32 tons	171

and clean type heat recovery coke ovens were selected to investigate the effects of different coke oven models on carbon emission intensity. The average values of direct carbon emission intensity are shown in Fig. 7. The results showed that the carbon emission intensity of a 6.0 m coke oven was 0.7 times more than that of a 4.3 m oven, and the clean type heat recovery coke oven's emissions were the highest, which was about 3.2 times more than that of a 4.3 m oven and 4.5 times more than that of 6.0 m oven. These proved that the carbon emission intensity of the 6.0 m oven was serious. It can be explained that the pushing times of 4.3 m oven are 1.3 times more than that of 6.0 m coke oven (Table 3). That's why the oven door would be opened and the heat inside the oven would lost during the coke-pushing process, which means more fuel gas was needed to make up the loss. The coke pushing time of a 4.3 m oven is more than that of a 6.0 m oven or a 7.1 m oven. So, it would demand more fuel gas to make up for the loss of heat, resulting in more carbon emission intensity. In addition, the modern large-scale ovens equipped with advanced and efficient combustion systems would also reduce carbon emission intensity. Meanwhile, the large-scale coke ovens were superior to the reduction of emissions and consumption, increasing labor productivity, saving energy, etc. Therefore, the large coke oven would be the most promising technology of the coking industry.

The clean type heat recovery coke oven is different than an ordinary vertical oven, mainly in the horizontal carbonization chamber operated using the high-temperature exhaust gas under negative pressure without coke oven gas recovery. With no coke oven gas recovery, the formation of the raw coke oven gas and other chemical products in the carbonization chamber are all burned and the outputting carbonaceous product is only coke. As a result, the balance gap for inputting carbon and outputting carbon would account for direct carbon emission intensity.

On the other hand, the carbon output of the clean type heat recovery coke oven is far less than the common vertical ovens, so its direct carbon dioxide emissions are much higher than the ordinary vertical ovens. The clean-type coke oven under negative pressure has a great advantage for reducing harmful emissions while avoiding dioxide reduction.

Carbon Emission Intensity as Affected by Loading Rate

Due to the impact of the global financial crisis, many coking enterprises have reduced their production. Only a small number of coking plants that are needed by iron and steel companies or using coke oven gas to produce advanced products are still running at full capacity. Four independent companies were selected and compared. Their loading rates were 13.6% (HA), 42.2% (LY), 66.5% (MQH), and 91.5% (SJ) (Fig. 8).

Fig. 8 shows that loading rates are decreasing with an increase of direct carbon dioxide emissions. The carbon emission intensity of an independent coking plant under normal operation is usually 150 ~ 250 $kgCO_2$ / t, and it rises to nearly 300 $kgCO_2$ / t as the loading rate is reduced to about 40%. It came up to nearly 400 $kgCO_2$ / t when the loading rate was reduced to about 10%. It was clear that the reduction of loading rate significantly increases direct carbon dioxide emissions.

The reduction of loading rate of a coking plant is exploited by coking time. When the coke finishes instead of pushing, the heat process continues, and is responsible for reducing coke production and maintaining oven temperature. The coking time under normal operating conditions is usually about 20 hours. The coking time will be more than 30 hours with the reduction of 40% for the loading rate. It will reach up to more than 80 hours with the reduction of 10% for the loading rate. The longer coking time resulted in more consumption of coke oven gas to maintain oven temperature.

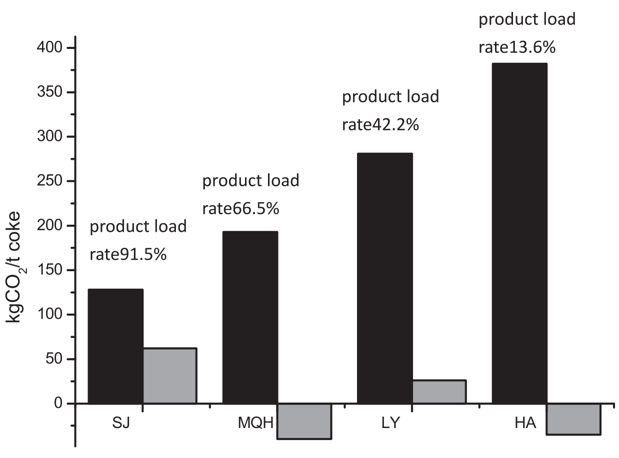

Fig. 8. Direct carbon dioxide emissions of coking enterprises at different loading rates.

Conclusion

The carbon emission intensity of 10 different types of coking enterprises in China calculated and discussed the carbon emission intensity characteristics and levels of the different coking plants. The results showed that the fuel gas type, coke oven model, and loading rate had different impacts on carbon emission intensity, while the production scale and the loading method didn't have any obvious influence. The results could help the government learn more about coking enterprises and make carbon emission intensity reduction policies.

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