Journal of Cleaner Production 112 (2016) 1292–1301

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Life cycle environmental performance of by-product coke production in China

Xin Liu, Zengwei Yuan*

State Key Laboratory of Pollution Control and Resource Reuse, School of the Environment, Nanjing University, Nanjing 210023, PR China

ARTICLE INFO

Article history:
Received 28 July 2013
Received in revised form
4 August 2014
Accepted 31 December 2014
Available online 31 January 2015

Keywords:
Life cycle assessment (LCA)
Coke wet quenching (CWQ)
Coke dry quenching (CDQ)
Environmental management
Cleaner production

ABSTRACT

The geographically representative and time-related life cycle inventory (LCI) for intermediate industrial products is critical for further life cycle assessment (LCA) of final consumer products. A cradle-to-gate LCA is presented in this study to provide a Chinese-specific LCI of coke production and to compare its environmental performance in alternative quenching modes. The LCI was compiled using site-specific investigation data from local independent coking enterprises, complemented by literature, databases, and expert judgement. The results show that coke production with the newly promoted coke dry quenching (CDQ) technology, which reduces air emissions and recovers heat during the on-site quenching process, is more environmentally friendly than that with the traditional coke wet quenching (CWQ) technology, with up to 15% decrease regarding the selected environmental impact categories. Coal preparation and on-site coke production turn out to be the determining factors of environmental performance for both scenarios. This study provides an LCI for coke production in China, which, as an important intermediate product, will improve the LCA of the steel and iron industries. The quantitative LCA will also provide a solid basis for the neutralization of international trade barriers and the successful promotion of CDQ technology in China from an environmental perspective.

1. Introduction

The analysis of the environmental impacts of final consumer products is where life cycle assessment (LCA) studies originated and are still most widely applied (Azapagic, 1999; Guinee et al., 2010). As important raw materials in the industrial chains, the life cycle inventories (LCIs) of intermediate industrial products usually play a fundamental role in evaluating the life cycle environmental impacts of final industrial products or final consumer products. However, the LCIs of intermediate industrial products are often not paid enough attention and are less geographically representative and time-related, which may result in significant inaccuracies in the LCA of the final consumer products. It is therefore necessary to improve the life cycle inventory (LCI) datasets for intermediate industrial products for future LCA research and decision support.

Coke is an intermediate fuel product derived primarily from non-renewable coal resources. It is further used in many downstream industries, especially the steel and iron industries. As the largest coke producer and consumer in the world, China plays an important role in the global coke supply chain. Chinese coke production reached 428 million tons during the year 2011, which accounted for more than 62% of the total world production. Meanwhile, China consumed 268 million tons of coke, making the country a net coke exporter (National Bureau of Statistics of China, 2013). Unlike most foreign coke plants that are collocated with iron and steel production facilities, independent coke producers that recover by-product chemicals during coke production (referred to as "by-product" coke production) account for more than 60% of the total coke production capacity in China.

The intensive energy consumption and severe pollution problems, which can cause great damage to ecosystems and human health (Bhopal et al., 1994; Parodi et al., 2005), have seriously constrained the sustainable development of the coking industry. Besides, coke export encounters green trade barriers, mainly due to the low export prices without considering environmental costs. Chinese governments as well as environmental professionals have paid attention to the environmental issues of the coking industry since the 1990s (Asia-Pacific Partnership on Clean Development and Climate, 2010; Ministry of Environmental Protection of P. R. China, 2003, 2012; Ministry of Industry and Information Technology of P.R. China, 2008; Zhu et al., 2009). In addition to conventional pollutants, more and more studies are beginning to

* Corresponding author. Tel./fax: +86 25 89680532.
E-mail address: yuanzw@nju.edu.cn (Z. Yuan).

http://dx.doi.org/10.1016/j.jclepro.2014.12.102
0959-6526/

characterise the emissions of organic compounds such as polycyclic aromatic hydrocarbons (PAHs) (Wang et al., 2010; Xu et al., 2006), polychlorinated dibenzo-*p*-dioxins and dibenzofurans (PCDD/Fs) (Liu et al., 2009) and heavy metals (Mu et al., 2012) from the coking processes. Coke dry quenching (CDQ) technology, as an energy-saving and cleaner production technology, is officially encouraged to substitute the traditional coke wet quenching (CWQ) technology by the Chinese Ministry of Industry and Information Technology (Ministry of Industry and Information Technology of P.R. China, 2010). The penetration of CDQ technology in China had reached 23% by the end of 2010 (Huo et al., 2012). However, due to technical characteristics, CDQ technology also has some environmental drawbacks compared to the traditional CWQ technology, such as inability to reuse treated wastewater in quenching stage and losses from burning off (Wang, 2011). These benefits and drawbacks should be compared from a life cycle perspective to have a holistic understanding of the environmental impacts of coke production.

LCA is a tool suitable for comparing the environmental impacts of coke production in alternative quenching modes and the associated supply chains. The LCA of coke production can be traced back to the 1990s when the World Steel Association released its first version of the Steel LCA report in 1995 (updated twice later), which took the life cycle of coke into account by using the global average values (World Steel Association, 2011). However, the underlying LCI dataset is not publicly available. The LCIs of coke production in the Ecoinvent and PE databases are both derived from Germany in the 1990s (PE International, 2010; Weidema and Hischier, 2006). The average raw material consumption and conventional pollutant emissions of the Chinese coking industry based on production technologies in the 1990s was published in 2002 (Yang et al., 2002). These datasets are too obsolete to represent the current situation of Chinese coke production. Studies on the comparative LCA results of coke production in traditional and alternative environmental control modes have not been found, except for the use of the Organic Rankine Cycle (ORC) for low grade heat recovery during the production of metallurgical coke (Walsh and Thornley, 2012).

Therefore, a cradle-to-gate LCA is presented in this study to (a) provide a Chinese-specific LCI of "by-product" coke production and (b) compare the environmental performance of "by-product" coke production using traditional CWQ (Scenario 1) and alternative CDQ (Scenario 2) modes. The outcome of this study is expected to enhance the LCI datasets of intermediate industrial products for further LCA studies and lay a quantitative basis for the neutralization of international trade barriers and the successful promotion of CDQ technology in the Chinese coking industry from an environmental perspective.

2. Materials and methods

2.1. Description of coke production processes

We explore the typical "by-product" coke production processes, which use the 4.3 m high stamp-charged machinery oven to produce first-class metallurgical coke primarily for blast furnace steelmaking. The operation procedures are shown schematically in Fig. 1.

Coals with different volatile contents (purchased) are first blended in proportion onto the conveyor belts and transferred to the coke crusher where they are pulverised to preselected sizes smaller than 3 mm. A specific volume of the prepared coal mixture is then tamped and charged into the coke oven from one side of the coke oven battery, where metallurgical coke and raw coke oven gas are produced at approximately 1200 °C during a coking cycle for approximately 25–30 h. At the end of the coking cycle, the incandescent coke is pushed from the other side of the oven by the pusher machine into the quench car. After the quenching system, coke is transported by the conveyor belt to the crushing and screening system where proper sized metallurgical coke is produced for the blast furnace operations. Raw coke oven gas, which contains water vapour, tar, benzene and other chemical compounds, leaves the coke oven chambers and enters the by-product recovery stage. This stage treats coke oven gas so efficiently that the coke oven gas can be used as a fuel gas and recovers valuable by-product chemicals such as tar, sulphur and crude benzene at the same time. Air pollutants during charging, pushing, quenching, coke screening and combustion are collected with the application of air pollution control devices (APCDs), but there are still fugitive emissions and leaks to the air. Wastewater is treated using an Anoxic/Oxic (A/O) biological denitrification processes.

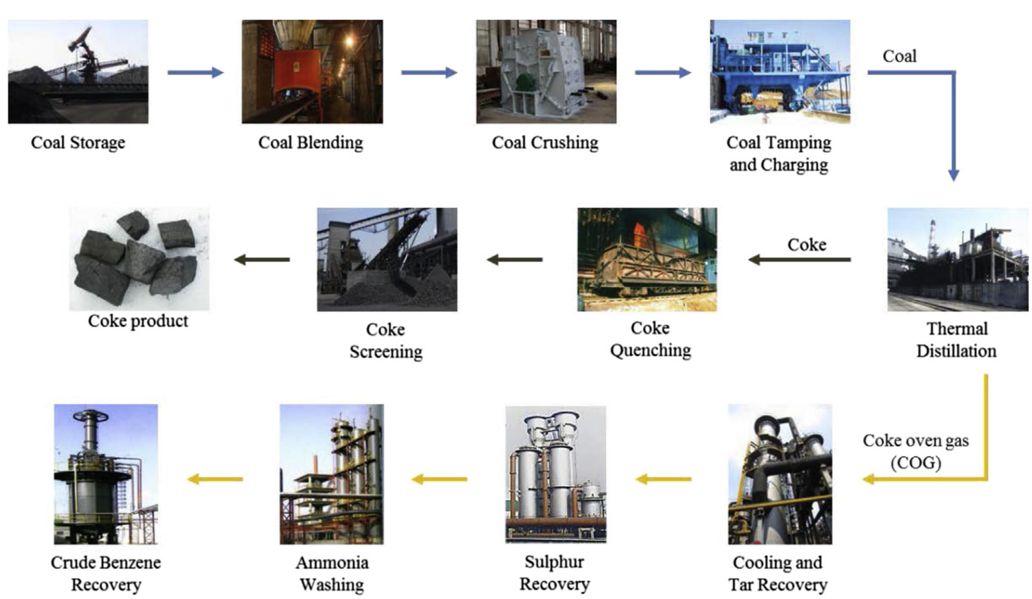

Fig. 1. Brief flow diagram of "by-product" coke production.