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# Multi-product carbon footprint assessment for low-rank coal-based acetylene manufacturing process

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ABSTRACT

The coal to acetylene process is still commonly used nowadays in some countries like China of which their energy structure relies deeply on coal. Compared with the coal to acetylene process using electro-thermal method in tradition, the oxygen-thermal method consumes less electricity and produces furnace gas with higher carbon monoxide (CO) purity. However, the potential to reduce carbon emission of the oxygen-thermal method is unclear which makes it necessary to evaluate the carbon footprint of oxygen-thermal coal to acetylene process. To accurately define the process is the first challenge in this research. Given that the coal to acetylene process generates acetylene and CO simultaneously, it is safe to regard this process as a multi-product process. Another challenge in this study is the shortage of relevant literatures on multi-product chemical processes, especially for the coal to acetylene process. In fact, a large majority of the current literatures try to use a general way to solve the ecological problems, which is not suitable for assessing the coal to acetylene process. Therefore, in this research, more attentions have been paid to adapting the traditional carbon footprint assessment to the coal to acetylene process, including selecting a proper boundary, collecting reasonable data and adopting appropriate allocation rules. The study examined the case based on the differences between the global warming potential (GWP) factors, the greenhouse gases (GHG) emission factors and the activity data of the systems, and noted that the GWP and GHG emission factors are usually regarded as given values while the activity data depends on characteristic parameters of the system. Thus, the activity data of the system should be verified repeatedly through the mass balance, carbon accounting and energy balance of the system. Moreover, individual contribution to the carbon footprint from each product should be considered in the aggregate carbon footprint, since the coal to acetylene process features multi-product outputs. Finally, recommendations for minimizing carbon emission of the system were presented.



## 1. Introduction

China is rich in coal resources, such as lignite, soft coal, and anthracite. Compared with other candidates, lignite (a kind of low-rank coal) constitutes the largest proportion of China's coal reserves, which is able to supply the world for 227 years (Diercks et al., 2008). However, the inefficient and unclean use of coal has caused a series of environmental problems, like the greenhouse gas emission problem (Hao et al., 2010). Thus, the clean use of lignite is of great significance to the clean coal utilization of China. The process of coal to acetylene in an electro-thermal method is a typical and widely used technology to utilize coals, but the process consumes a large sum of energy and the large amount of GHG emissions caused by this technology cannot be neglected. Emissions results from not only the process itself, but also from the great amount of electricity consumed. To deal with the problems of high energy consumption and GHG emissions in electro-thermal process, some scholars turn to oxygen-thermal acetylene process (Liu et al., 2011). Different from the electro-thermal process, in oxygen-thermal process extra coke is added as fuel to replace power consumption and the substitution will tremendously reduce the consumption of electricity. The combustion of extra coke provides heat to drive the conversion reaction, and the combustion products contain high purity of CO which increases the complexity

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of this process. To tackle this problem, CO is treated as a by-product from the oxygen-thermal process. Thus, the oxygen-thermal acetylene process should be treated as a multi-product system (Liu et al., 2011).

To study the carbon emission problem of the oxygen-thermal process, a carbon footprint method specific to multi-product chemical processes is necessary. However, there are few elaborate methods or related literatures to evaluate the carbon footprint of a multi-product chemical process (ISO, 2012; Rugrungruang et al., 2009). Thus, appropriate adjustments on the traditional methods are expected to assess the process legitimately (Xie et al., 2006). Some researchers used linear programming or other models to analyze multi-product systems (Azapagic. and Clift., 1999; Alireza Tehrani Nejad, 2007; Muttil and Chau, 2007). Even so, comprehensive tools should be applied to effectively assess carbon footprint in poly-generation systems. A previous research has compared the carbon emissions of two calcium carbide processes with a multi-product thought and the results showed that in calcium carbide process the oxygen-thermal method has the advantage of reducing GHG emissions (Mi et al., 2014). However, calcium carbide process is only a subsystem of the entire oxygen-thermal coal to acetylene process. As for the entire coal to acetylene process, it is still unclear whether the entire process could be beneficial for the reduction of GHG emission. Thus, a detailed research is expected to objectively assess the oxygen-thermal acetylene process. Besides, an integral carbon footprint assessment was not introduced into the calcium carbide process research. Carbon emission of two different calcium carbide processes was compared in a simpler way. Therefore, the entire oxygen-thermal coal to acetylene process requires to be assessed from the respect of carbon footprint.

On the other hand, an increase of GHG in the atmosphere has caused most of the global warming issues. Aiming at relieving the greenhouse effect, governments and organizations have established series of regulations and guidelines to urge enterprises to seek techniques that will reduce emissions (ISO, 2012). In these regulations and guidelines, carbon footprint assessment, as a scientific approach to evaluate climate changes, has drawn significant attention in recent years (Pang et al., 2014). Thereafter several carbon footprint assessment techniques have been suggested successively by different countries and organizations.

Currently, three methods for carbon footprint assessment are widely used, i.e., process analysis, input–output analysis and hybrid life cycle analysis (Rugani et al., 2013). Process analysis tracks the climate impact throughout the entire process of product manufacture. The major limitation of this method lies in the large deviations that occur when the object system is a large entity, such as governments, organization and industrial departments. The input–output method implements the carbon footprint assessment in a macroscopic scale based on an economic analysis of departments or a certain enterprise. The defects include the excessive requirements of detailed data, and uniform prices for products are impractical (Wiedmann and Minx, 2007). Based on a life cycle assessment (LCA), the hybrid life cycle analysis, which combines process analysis and input–output analysis, was proposed to assess the carbon footprint sectional (Weidema et al., 2008). In 2007, the World Resources Institution and the World Business Council for Sustainable Development proposed the GHG protocol (WRI/WBCSD, 2007). The British Standards Institution collaborated with the Carbon Trust and Department of Environment Food and Rural Affairs and proposed a publicly available specification (PAS) – PAS 2050 to regulate the evaluation methods of life cycle GHG emissions from products and services (BSI, 2008). International Standards Organization (ISO) 14044 illustrates some requirements and guidance about environment based on LCA, including allocation rules for multi inputs and outputs (ISO, 2006). Under the guidance of the standards mentioned, a few agencies and organizations have developed compliant carbon footprint calculation criteria. Additionally, ISO 14067 specifically describes methods to calculate the product carbon footprint, which provides a standard basis for the application of the carbon footprint assessment. In the meantime, industrial sectors become hot fields in carbon footprint research because they are the primary sources of GHG emissions (Tjan et al., 2010; Quinteiro et al., 2012). The Carbon Trust proposed the concept of carbon labeling to help consumers make better choices according to the different carbon footprints of various products (Carbon Trust, 2006). All the mentioned regulations and standards have attempted to provide a comprehensive carbon footprint assessment index and rules. However, problems still exist (Yoshida et al., 2002; Johnson, 2008). Data inventory for raw materials from upstream is established based on industry average statistics that requires investigations of numerous enterprises, which increases the difficulty of assessing the carbon footprint. For example, to obtain detailed inventory data that satisfied the requirements in PAS 2050, a large amount of human and material resources needs to be invested. The data needed for the assessment of PAS 2050 exhibit various features, and additional attention should be given to activity data impacted by system (ISO, 2012; Wiedmann and Minx, 2007). For another example, in ISO14044 the allocation rules are given in such a simple way that users cannot learn a detailed calculation process. By adopting multi-product carbon footprint assessment specifically, the users are able to allocate carbon emissions to each product, so the results are more credible and objective. Therefore, an improvement in the accounting methods used for carbon footprints should be made, and the improvement will also increase confidence in the assessment.

In this research, a more simple and explicit method is used to assess multi-product carbon footprint (MPCF) of the low-rank coal-based acetylene manufacturing process. System boundary selection, activity data confirmation, and mass, carbon and energy balances have been discussed in detail to present a complete assessment. An allocation principle for this process has also been explicitly illustrated. Finally, the MPCF of the oxygen-thermal coal to acetylene manufacturing process has been calculated and analyzed.

## 2. Process system boundary selection

The carbon footprint of a product is the carbon emissions calculated from the mass balance and energy balance combined with GWP and GHG emission factors, and the amount of emissions is quantified in the mass of carbon dioxide equivalent ($CO_2$e) (ISO, 2012). The system boundary should be selected to perform the product carbon footprint assessment. According to the utilization of sources, a full life cycle can be theoretically divided into three successive stages, i.e. raw material conversions, manufacturing processes and waste disposals. A system can be also divided into two parts in an assessment approach. One part is the product manufacture and the supporting utilities. The other part is the raw material conversion and the waste disposal. Carbon emissions from both parts should be considered in the system boundary. Moreover, a schematic diagram of the manufacturing process and energy consumption should be depicted, and each unit should be illustrated in detail.

In manufacturing processes where coal is used as raw material, a classifying-grade conversion of coal can greatly improve the utilization efficiency of raw materials and significantly reduce pollutions (Xie et al., 2010), especially the lignite which has an abundant reserve in China. Compared with the processes of coking and coal gasification, the coal-based acetylene route has the potential to become a clean coal conversion technology due to its simple process, high value-added products and great economic benefits (Miller, 1965).