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The life cycle inventory study of cement manufacture in China

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ABSTRACT

To make clear the environmental damages and potential improvements of Chinese cement industry, the detailed life cycle inventory (LCI) of cement manufacture with direct input and output in the boundary of cement plant as well as corresponded transport is conducted. The functional units are 1 t of Portland Ordinary cement and 1 t of clinker. The input data contain not only the traditional items such as raw materials (limestone, sandstone, ferrous tailings and gypsums), energy (coal and electricity), and admixtures (fly ash and furnace slag), but also fresh water which is not paid attention in other literature. The output data contain not only greenhouse gas (CO_2) and primary pollution (NO_x, PM, SO_2), but also the hazardous air pollutants (HCl, NMVOC, PCDD/Fs, PAHs and fluoride) as well as noise and heavy metal emissions (As, Cd, Cr, Hg, Ni, Pb, Zn, Cu) which are usually neglected by others. The data were measured on-site. The applications of reducing pollutants and waste heat recovery technologies, and AFRs usage in cement industry are evaluated. The three steps of developments of LCI study for China cement industry are discussed.

1. Introduction

As the biggest cement production and consumption country in the world for more than 20 years, China has witnessed its cement production in 2012 to hit 2, 180 Mt according to China Cement Association (CCA, 2013). The pollutants emissions due to cement manufacturing would probably make irreversible environmental damages, and depleted natural resources cannot support the sharp increases of Chinese cement production, warned by the Ministry of Environmental Protection of China (MEPC, 2013). China would like to change its traditional cement manufacture way to reduce pollutants emissions and to save energy and natural resources. The roadmap of sustainable development for China cement industry has been made by central government and concerned parties. The first thing is to know exactly the input and output, in other words, the consumptions of natural resources and fossil fuels, and the amounts of pollutants emissions of cement production. The life cycle inventory (LCI) and life cycle assessment (LCA) study nowadays are not only the tools to interpret the environmental damages from product manufacturing, to evaluate possible improvements and to recognize the hotspot in environmental behavior (Heijungs et al., 1992; Guinée et al., 2002), but also the approaches to support the decision making process (Benedetto and Klemeš, 2009a, 2009b; Jeswani et al., 2010).

There are some valuable studies on the sustainability of cement manufacturing. Sustainability requires redesigning of production, consumption and waste management (Čuček et al., 2012a). The sustainability of cement manufacturing means using less natural resources including water and energy, more renewable resources and emitting less pollution when produce cement. Huntzinger and Eatmon (2009) have conducted a life-cycle assessment of Portland cement manufacturing to compare the traditional process with alternative technologies in USA. They have indicated that approximately 5% of global CO_2 emissions originate from the manufacturing of cement, the third largest source of carbon

Abbreviations: AFRs, Alternative Fuels and Raw materials; CNMLCA, Centre of National Material Life Cycle Assessment; CKD, Cement Kiln Dust; DCS, Distributed Control System; ESP, Electro-static Precipitator; LCA, Life cycle assessment; LCI, Life Cycle Inventory; LCIA, Life Cycle Impact Assessment; LNB, Low-NO_x Burner; MSC, Multi-stage Combustion; NSP, New Suspended Preheater; SCR, Selective Catalytic Reduction; SNCR, Selective Non-catalytic Reduction.

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emission in the United States. Analysis using SimaPro 6.0 software shows that the recycling of cement kiln dust (CKD) was found to have little environmental savings over the traditional process. Benhelal et al. (2012) have presented a novel design for green and economical cement manufacturing. Decomposition reactions take place in calciner without fuel consumption by utilizing a hot CO_2 stream as heat carrier and exhaust gases have been employed to produce steam and power. Moya et al. (2011) study the potential for improvements in energy efficiency and CO_2 emissions in the European Union's (EU27) cement industry and the relationship with the capital budgeting decision criteria. The possible thermal energy improvement in the clinker production, if all these BATs were implemented, has been quantified to be around 10%. This achievement would place the cement industry in the upper bound of the benchmark range for clinker manufacture. Considering the delays observed nowadays in terms of diffusion of BATs, it requires a conductive policy environment that combines support for both technology development and to their deployment. Habert et al. (2010) study the effects of potential technological improvements in cement industry compared to global goals of sustainability. The factor 4 concept, being twice as productive with half the resources (materials and energy), leading to a factor 4 improvement in efficiency, aims at reducing the CO_2 emissions in developed countries in 2050 by a factor of four from their 1990 levels, after they have first been reduced by a factor of 2 by 2020. They have found that the technological shift will require not only changes in concrete raw materials and mix designs, but also new building techniques, using less materials for the same final structure. However, they focus on CO_2 emissions. For developing countries, the air pollution of NO_x, PM and SOx are paid more attentions. Josa et al. (2004, 2007) have conducted comparative analysis of LCI and life cycle impact assessment (LCIA) of cement in the EU. They have classified the main environmental interventions related to cement manufacture and characterized and their effect on different impact categories in Europe. But only the four main emissions (CO_2, NO_x, SO_2 and dust) and the raw materials and energy are considered. Strazza et al. (2011) use the resource productivity enhancement as means for promoting cleaner production and analyze co-incineration in cement plants through a life cycle approach assess in Italy. The improvement on the investigated process has been quantitatively measured as a way for cleaner production, first in terms of gross energy requirement, and then through an environmental performance comparison with a sector benchmark. The analysis has highlighted the benefits on the global environmental balance for the practice of co-incineration in the cement production process. Chen et al. (2010) assessed environmental impact of cement production with the different processes scenarios and cement plant variability evaluation. For the kiln emission data, a European pollutant emission register for French intensive industries is used to quantify the variability of indicators between cement plants. Now there is a lack of LCI study on cement manufacture for developing countries such as China. In China, the manufacture plant even the local government often whitewash emissions data, which result in the unreliability of data from yearbooks and official statistics when collected without careful review. Thus, it is very important and necessary to conduct an LCI study of cement manufacture in China and the input and output data measured on-site are more accurate. In this paper, an LCI study on China cement industry is conducted to evaluate the environmental damages and to identify potential improvements from the applications of reducing pollutants emissions and saving energy technologies. The detailed LCI data collection and quantification system is established. The LCI of transport of catalogs the related flows in the transportation of raw materials, admixtures and fossil fuels crossing the boundary of cement plant. The input and output data of cement production in the boundary of cement plant are measured on-site. The input data contain not only the traditional items such as raw materials (limestone, sandstone, ferrous tailings and gypsums), energy (coal and electricity), and admixtures (fly ash and furnace slag), but also fresh water which is not paid attention in other literature. The output data contain not only greenhouse gas (CO_2) and primary pollution (NO_x, PM, SO_2), but also the hazardous air pollutants (HCl, NMVOC, PCDD/Fs, PAHs and fluoride) as well as noise and heavy metal emissions (As, Cd, Cr, Hg, Ni, Pb, Zn, Cu) which are usually neglected by others. The applications of reducing pollutants and waste heat recovery technologies, and AFRs usage in cement industry are also evaluated in the interpretation.

2. Materials and methods

This LCI study follows the guides of ISO Environmental Management–Life Cycle Assessment (ISO 14040, 2006; ISO 14044, 2006; Heijungs et al., 1992; Guinée et al., 2002).

2.1. The LCI study

LCI study is one of the fundamental parts of life cycle assessment (LCA) study. This methodology is used to evaluate the impact of processes or products on the environment, and all significant environment impacts in their life cycle that can be addressed. Every stage from the production of the raw materials to the end of their usage lives should be included with the concept of "from cradle to grave". As the main components of LCA study, LCI study is to identify and quantify the energy and raw materials used and wastes in solid, liquid or gas form emitted during the manufacture of a product. An LCI study contains the goal and scope of the study, the input resources and energy and output pollutants data collection, and the interpretations. The life cycle inventory analysis is defined the phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle. Inventory analysis involves data collection and calculation procedures to quantify relevant inputs and outputs of a product system. The LCI result is the outcome of a life cycle inventory analysis that catalogs the flows crossing the system boundary. The environmental damages due to the flows from cement manufacturing can be assessed by environmental footprints such as carbon footprint (CF), water footprint (WF), energy footprint (ENF), and emission footprint (EMF) Also, those environmental footprints as defined indicators can be used to measure sustainability (Čuček et al., 2012a, 2012b; Van Blottnitz and Curran, 2007; Ahlroth et al., 2011). Huntzinger and Eatmon (2009) have conducted a life-cycle assessment of Portland cement manufacturing to compare the traditional process with alternative technologies in USA. Josa et al. (2004, 2007) have conducted LCI and life cycle assessment (LCA) study of cement in the EU.

2.2. The data collection

Fig. 1 shows the system of cement production. The preparation process includes the raw materials and coal transportation, transfer from yard to mill, grinding, homogenizing, and storage in the silo. In the burning or incineration process, the raw meal is fed from feed inlet to the preheater, and then falls into the calciner to decompose with coal combustion at 950 °C. Afterward, this decomposed materials fall into the kiln to be incinerated to form a new intermediate product–clinker over 1400 °C. This is NSP (New Suspended Preheater) technology. In 2012, there are more than 80% cement plants in China applying NSP technology (CCA, 2013). In the final finishing process, cement is produced by granulating