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Analysis of CO_2 Emission for the cement manufacturing with alternative raw materials: A LCA-based framework

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Abstract

The cement industry is a significant CO_2 emitter mainly due to the calcinations of raw materials and the combustions of fuels. Some measures have been considered to reduce the CO_2 emissions in cement industry, of which alternative raw materials are the most efficient practicing way. In this study, a LCA-based CO_2 accounting framework with alternative raw materials was constructed to analyze the CO_2 emissions from concrete with different kinds of low carbon substitution, within which cement production process was divided into six stages associated with the environmental impacts. A better routine is expected to understand the environmental hazards of cement products and to optimize the design to reduce adverse environmental impacts.

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Keywords: Low carbon cement; Alternative raw materials; Life cycle analysis; CO_2 emission.

1. Introduction

The cement industry is one of the major contributors for greenhouse gases (GHG) emissions, specifically CO_2 emissions [1]. This is due to the calcinations of raw materials for the production of cement and burning fuels needed to maintain high temperatures in a kiln [2]. In 2000, the cement industry sector in the world released 2.37 Gt air pollutants to the environment [3]. Regarding CO_2 emissions, the global emissions of CO_2 reached approximately 28.3 Gt in 2005, of which the cement industry generated approximately 1.8 Gt CO_2 [4-5], indicating that the cement industry contributed approximately 6% of the total global CO_2 emissions. Some measures have been considered in order to reduce the CO_2 emissions of cement industry, e.g., use of carbide slag as an alternative raw material for low carbon cement may lead to a drastic reduction. The low carbon substitutions provide significant opportunities for symbiotically utilizing large quantities of byproducts of other industrial processes [6]. However, indirect energy use and extra emissions (including fly ash) of alternatives have not yet been fully considered during the CO_2

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accounting. Therefore, This paper aims to calculate the potential reduction of CO_2 emissions via alternative materials for cement manufacturing.

Life cycle assessment (LCA) has been widely used to compare the relative environmental performance of competing processes, by analysing the environmental impacts generated by the processes within defined categories and boundaries. The inclusion of each process or product's stage life cycle is fundamental for this analysis. In some cases, however, a full life cycle (cradle to grave) analysis is not pertinent, and the analysis has to end at an intermediate stage (cradle to gate) [7]. As a suitable tool for assessing environmental impacts, LCA has been successfully applied to the cement manufacturing and the clinker production and its associated supply chains [8], including direct impacts from the production site as well as indirect impacts, e.g. from resources mining and electricity production [8, 9, 10]. It can be used to optimize the manufacturing process by reducing adverse environmental impacts [9].

In this study, a framework was proposed to account the life cycle CO_2 emissions of cement industry, both direct emissions and indirect emissions, with carbide slag as alternative raw materials. In addition, environmental impact, especially global warming potential, was also incorporated in the framework.

2. Methodology

2.1 Cement Manufacturing Process with Alternative Raw Materials

The process for manufacturing cement with alternative raw materials is divided into six stages, i.e., raw material collecting stage, transportation stage, grinding/mixing stage, calcination stage, fuel combustion stage, and storage and packaging stage, as shown in Fig. 1. Here, we take carbide slag as an example.

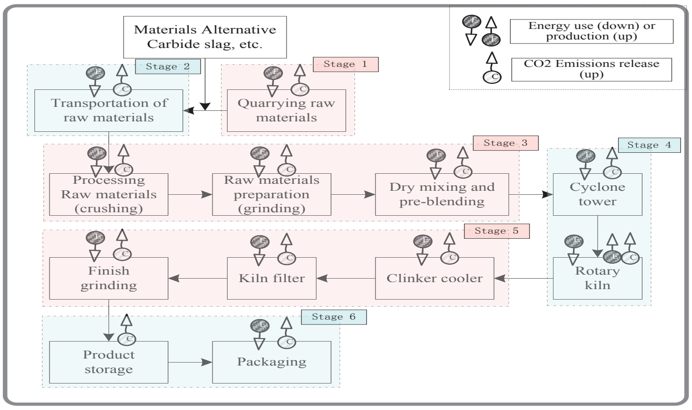

Fig.1 Flow diagram of the cement manufacturing process (energy use & conversion, CO_2 emissions)

2.2 LCA-based CO_2 Accounting Methods for Baseline and Alternative Scenarios

The amount of CO_2 emitted from concrete manufacturing process with alternative raw materials was calculated using the existing methods for evaluating CO_2 emission throughout the process. *IPCC Guidelines for National Greenhouse Gas Inventories* (2006) [11] provides emission factors and default values for all sectors including cement industry. Here we use IPCC data to conduct the CO_2 emissions accounting. The cement production is divided into six stages as mentioned above. In order to compare the differences between traditional cement production and alternative materials cement production, we considered both the baseline (without any alternative raw materials) and alternative scenarios.

In the clinkering stage, the amount of CO_2 emissions of each scenario was different and calculated as shown in Table 1.

Table 1 Accounting of baseline scenario and alternative raw materials scenario

Baseline scenario	CO_2 emissions from decomposing of carbonate because of the calcinations of raw materials for the cement production: $$BE_1 = C_c \cdot \frac{44}{56} + C_m \cdot \frac{44}{40} \quad (1)$$ in which: BE_1——CO_2emissions per unit clinker production in baseline scenario, kg; C_c——CaO content in clinker, %; C_m——MgO content in clinker, %; 44/56——The molecular weight conversion between CO_2 and CaO; 44/40——The molecular weight conversion between CO_2 and MgO.
Alternative raw material scenario	CO2 emissions from the calcinations of raw materials for the cement production: $$PE_1 = \frac{R_C}{(1-L_C)\cdot F_C} + \delta_1 \quad (2)$$ in which: PE_1——CO_2 emissions per unit clinker production in alternative raw material scenario, kg; R_c——CO_2 content in alternative raw materials, %; L_C ——Raw ignition loss, %; F_c——Coal ash content in clinker; the default value is 1.04; δ_1——Direct CO_2 emission caused by the increase consumption of human power, equipments and electricity, kg.
QA/QC(Quality assessment/Quality control) process	Measuring instruments should be regularly maintained/ calibrated to achieve the corresponding standard. Records of measuring instruments should guarantee the data consistency. Calibrating measuring instruments to meet national standards.

In the transportation stage, CO_2 emissions can be estimated from two aspects, fuel consumption and transportation behaviour (including vehicle type and distance):

$$E^t{}_{CO_2} = \sum_i (Q^t{}_i \times EF^t{}_{CO_2,i}) \quad (3)$$

in which, $E^t{}_{CO_2}$ is the CO_2 emissions of certain mode of transportation, unit: kg; $Q^t{}_i$ is the consumption of fuels in the corresponding mode, unit: TJ; $EF^t{}_{CO_2,i}$ is the emission factors of corresponding fuels, unit: kg/TJ.

In the stage of fossil fuel combustion, CO_2 emissions of stationary source combustion can be calculated as follows:

$$E^c{}_{GHG,i} = Q^c{}_i \times EF^c{}_{GHG,i} \quad (4)$$

in which, $E^c{}_{GHG,i}$ is the CO_2 emissions of certain fossil fuel, unit: kg; $Q^c{}_i$ is the amount of the corresponding fossil fuel, unit: TJ; $EF^c{}_{GHG,i}$ is the emission factors of corresponding fuels, unit: kg/TJ.

In the stage of energy use, we use total electricity consumption of whole production process to estimate the indirect CO_2 emissions. One thing should be noted that total electricity consumption did not include the amount of waste heat power generation:

$$\sum P_{ei} = \sum E_i \times F_e \quad (5)$$

in which, P_{ei} is the CO_2 emissions of total electricity consumption, unit: kg; E_i is the electricity consumption of each production process, unit: kW•h; F_e is emission factor of electricity, unit: kg/kW•h; and i is the number of each process.

3. LCA-based CO_2 Accounting Framework with Alternative Raw Materials

A LCA-based CO_2 accounting framework with alternative raw materials is proposed. We define the accounting boundary as the life cycle process of cement production, which contains raw materials quarrying, transportation, crushing, grinding, calcinations, fuels combustion, products storage, packaging and transportation. During the whole process, both direct and indirect CO_2 emissions are considered in the accounting framework. Various alternative raw materials, including carbide slag, coal gangue, sand stone, construction and demolition waste, etc, are also listed in the framework, one of them or more combination scenarios can be chosen in the low carbon cement manufacturing to make better solutions for different situations. Except for CO_2 emissions accounting, other gas or ash emissions are accounted in this framework as well, which are used to evaluate the environmental impact of cement production, including climate change, acidification, eutrophication, abiotic depletion, ozone layer depletion, fresh water aquatic ecotoxicity, photochemical oxidation and terrestrial ecotoxicity [12].

4. Conclusion

In this study, a CO_2 accounting method of the low carbon cement manufacturing process with alternative raw materials was constructed to analyze the CO_2 emissions from concrete with low carbon substitutions. A LCA-based CO_2 accounting framework was also built to provide a better way to understand the environmental hazards of cement products and to optimize the cement manufacturing process in order to reduce adverse environmental impacts.

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Biography

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