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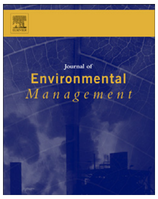

Research article

Life cycle assessment of the use of alternative fuels in cement kilns: A case study

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ABSTRACT

The benefits of using alternative fuels (AFs) in the cement industry include reduction of the use of non-renewable fossil fuels and lower emissions of greenhouse gases, since fossil fuels are replaced with materials that would otherwise be degraded or incinerated with corresponding emissions and final residues. Furthermore, the use of alternative fuels maximizes the recovery of energy. Seven different scenaria were developed for the production of 1 ton of clinker in a rotary cement kiln. Each of these scenaria includes the use of alternative fuels such as RDF (Refuse derived fuel), TDF (Tire derived fuel) and BS (Biological sludge) or a mixture of them, in partial replacement of conventional fuels such as coal and pet coke. The purpose of this study is to evaluate the environmental impacts of the use of alternative fuels in relation to conventional fuels in the kiln operation. The Life Cycle Assessment (LCA) methodology is used to quantify the potential environmental impacts in each scenario. The interpretation of the results provides the conclusion that the most environmentally friendly prospect is the scenario based on RDF while the less preferable scenario is the scenario based on BS.

1. Introduction

1.1. Cement production

Cement is an essential ingredient which fulfills basic needs such as the construction of housing and infrastructure indispensable to mankind and plays a vital part in the global construction industry. The production of cement is accompanied by high energy consumption, requires large quantities of resources and causes significant environmental impacts. It is responsible for nearly 5–7% of the global CO_2 emissions, total CO_2 anthropogenic emissions and substantial emissions of SO_2, NO_X and other pollutants (Hendricks et al., 1998; Van Oss and Padovani, 2002, 2003; Humphreys and Mahasenan, 2002; EIPPCB, 2010; Ali et al., 2011; Karagiannidis, 2012). Numerous studies have been done to evaluate CO_2 emissions, energy consumption (Capros et al., 2001; CIF, 2003; and Gartner, 2004) and SO_2 emissions (Josa et al., 2004, 2007), using Life Cycle Assessment (LCA) method. Emission of CO, NO_X and SO_2 from the cement industry contributes severely to greenhouse and acid rain effects (Zhang et al., 2011). Therefore cement production, as an energy intensive process, results in significant greenhouse gas (GHG) emissions. The reduction of emissions in this sector may lead to a significant decrease in the overall GHG releases (Boesch and Hellweg, 2010).

The cement industry consumes a significant amount of natural resources (raw materials), energy (heat and electricity) and fossil fuel sources (e.g. coal, petroleum coke). This means that the production of cement consumes an important quantity of non-renewable raw materials, which are the basic constituents of the product, as well as fossil fuels which are required in the heating processes. Moreover cement production is responsible for 5% of the global anthropogenic CO_2 emissions and 7% of industrial fuels use (Worrell et al., 2000; Chen et al., 2010a,b). Furthermore a recent study on the current status and the latest literature on the cement production indicate that there are differences in the estimation of the CO_2 emissions (5–8% of global CO_2 emissions) and the cement manufacturing sector contributes up to 8% of the total global anthropogenic CO_2 emissions (Mikulčić et al., 2016). According to this study, if one assumes that cement production generates a world-average carbon emission of 0.83 kg CO_2/kg cement produced (Teklay et al., 2015), multiplies it with the produced cement (Oh et al., 2014), and compares it to the total CO_2 emissions (IPCC, 2014) then it is found that cement production contributes up to 8% of the total global anthropogenic CO_2 emissions, a percentage

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that is in correlation to the latest report on global CO_2 emission trends by Olivier et al. (2015).

Cement contains a material called clinker which is formed when the raw material limestone is burned at high temperatures in a cement kiln (Van Oss and Padovani, 2002). In this process (called calcination) calcium carbonate decomposes and CO and CO_2 emissions are produced (Chen et al., 2010a,b). Calcination is highly important from a climate perspective, since carbon bound in minerals is transformed to CO_2 (Huntzinger and Eatmon, 2009). Furthermore, it typically causes about 50% of the total CO_2 emissions stemming from cement production. A large portion of the remaining emissions originates from combustion of the fuels in the kiln (Nadal et al., 2009; GTZ-Holcim, 2006). The clinker is then ground to a fine powder and blended with some additives. According to the calcination reaction, the production of one ton of clinker requires an average of 1.5–1.6 tons of raw materials and most of the material is emitted from the process as CO_2 emissions into the air (Gäbel et al., 2004). Consequently, during the heating process in the kiln, CO_2 emissions are generated through the chemical reaction of the materials and by burning the fossil fuels, which are necessary to heat the kiln. The emissions of CO_2 depend mainly on both the type of process and the fuel used (European Commission, BREF, 2010). For instance, in a typical dry process with five stages preheater, precalciner and 100% use of petroleum coke as a fuel, CO_2 emissions derived from the chemical reactions are around 0.53 tons of CO_2 per ton of clinker, while CO_2 emissions derived from the fuel consumption are about 0.31 tons of clinker (European Commission, BAT, 2013; Moya et al., 2010; Phair, 2006). In addition to CO_2, atmospheric emissions from cement plants include other pollutants such as particles, nitrogen oxides (NOx), sulphur dioxide (SO_2) and some minor pollutants (Schneider et al., 2011).

The clinker production process has large environmental impacts compared to raw material preparation and the final cement production process. These environmental impacts are attributed to the direct kiln emissions and to the production of the primary fuels. Moreover, direct kiln emissions are the principal contributor to five main impact categories: global warming, terrestrial ecotoxicity, photochemical oxidation, acidification and eutrophication (Chen et al., 2010a,b).

Other environmental issues associated with cement include the energy required for production and transportation of raw materials, fuels, clinker and cement and the impact of mining, resource depletion and waste generation (Schneider et al., 2011; European Commission, BREF, 2010). The emission quantities also depend on the temperature level and the oxygen content during the combustion stages. In addition, kiln emissions can be influenced by flame shape and temperature, combustion chamber geometry, the reactivity of the fuel, the presence of moisture, the available reaction time and the burner design (Gäbel et al., 2004).

1.2. Alternative fuels (AFs)

Traditionally, coal has been used as the basic fuel for clinker production. Nevertheless, a wide range of other fuels are also used, including petroleum coke (petcoke), natural gas and oil. The use of alternative fuels (AFs) in calciner lines began in the mid-1980s and was very quickly incorporated in the precalciner stage (Schneider et al., 2011). In 2004 in Europe, 6.1 million ton of different types of wastes were used as fuels in cement kilns and one million tons of these wastes were hazardous. Waste fuels with adequate calorific values can replace fossil fuels and allow fossil fuel savings. However, kilns have to be suitable for burning wastes and conditions have to be optimized, in order to secure high energy efficiency (European Commission, BAT, 2013).

The clinker-burning process offers good conditions for using different types of waste materials, replacing parts of the conventional fuels. The typical types of waste fuels (hazardous and non-hazardous) that may be used include wood, paper and cardboard, textiles, plastics, processed fractions (e.g. RDF), rubber and tires, industrial sludge, municipal sewage sludge, animal meal and fats, coal and carbon waste, agricultural waste, solid waste (impregnated sawdust), solvents and related waste, oil waste and oily waste (Cembureau, 1997, 1999).

According to the European cement industry, the substitution of conventional fossil fuels with alternative fuels based on waste can make an important contribution to sustainable development, through the reduction of the global burden of greenhouse gases such as CO_2 emissions. Taking into consideration that during the cement processes a total of 0.83 tons of CO_2 are emitted per ton of product (80% of the finished product is clinker) and the fact that this amount is derived from decarbonation (0.45 ton/ton product), combustion of coal (0.28 ton/ton product) and electricity production in coal-fired power plants (0.1 ton/ton product), the use of alternative fuels for cement clinker production is certainly of high importance and an attractive alternative, comparative to non-renewable fossil fuels. Thus, one of the main strategies through which the cement industry may contribute to a reduction in CO_2 emissions is to substitute fossil fuels used in cement kilns with fuels derived from waste (Cembureau, 1997, 1999). Furthermore according to Best Available Techniques (BAT), a Reference Document for the Production of Cement (European Commission, BAT, 2013), the main emissions from the production of cement are emissions to air from the kiln system, which derive from the chemical reactions involving the raw materials and the combustion of fuels. The main constituents of the exit gases from a cement kiln are nitrogen from the combustion of air, CO_2 from calcination of $CaCO_3$ and the combustion of fuel, water vapor from the combustion process and from the raw materials and excess oxygen. The utilisation of waste in the cement industry, principally as alternative fuels, is compatible with the general principles of waste management and the principles of sustainable development set by the European Union and with existing EU policies on energy efficiency, climate change and waste management (Cembureau, 2009). Also it will help in achieving the targets set in Agenda 21 of the Earth Summit in Rio de Janeiro (1992), the Johannesburg Declaration on Sustainable Development (2002) and the Millennium Development Goals.

The re-use of waste as alternative fuels can make a waste reusable or recoverable. Therefore, replacement of some conventional fossil fuels with alternative fuels brings both ecological and economic benefits (Mokrzycki et al., 2003). The benefits of using alternative fuels in the cement industry include reduction of the use of non-renewable, conventional fossil fuels, such as coal and petcoke, as well as the environmental impacts associated with coal mining. In addition the use of alternative fuels maximizes the recovery of energy, contributes towards a decrease of emissions such as greenhouse gases by replacing the use of fossil fuels with materials that would otherwise have to be managed as waste, with corresponding emissions and final residues. Furthermore, the use of alternative fuels maximizes the recovery of the non-combustible part of the alternative fuel material and eliminates the need for disposal of slag or ash, as the inorganic part of them is incorporated and substitutes raw materials in the cement (Environmental Protection Agency, 2008).

The term Alternative Fuels (AFs) refers to waste materials used for co-processing. Such waste typically includes plastics and paper/card from commercial and industrial activities, waste tires, waste oils, biomass waste, waste textiles, residues from dismantling operations, hazardous industrial waste (e.g. certain industrial sludges, impregnated sawdust and spent solvents). Because some materials

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