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Impact of the addition of oil-based mud on carbon dioxide emissions in a cement plant

Sabah A. Abdul-Wahab [a,*], Ghazi A. Al-Rawas [b], Sappurd Ali [c], Hilal Al-Dhamri [d]

[a] Department of Mechanical and Industrial Engineering, College of Engineering, Sultan Qaboos University, Oman
[b] Department of Civil and Architectural Engineering, College of Engineering, Sultan Qaboos University, Oman
[c] National Engineering and Scientific Commission (NESCOM), Islamabad, Pakistan
[d] University of Leeds, Civil Engineering, UK

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ABSTRACT

The general objective of the current case study was to determine the carbon dioxide (CO_2) emissions derived from a cement manufacturing plant. The specific objective of this study was to evaluate the impact of the addition of oil-based mud (OBM), an oil well drilling waste, as a partial replacement for the limestone in the kiln feed, on CO_2 emissions. To achieve this objective, the study was divided into three parts. In the first part, the CO_2 emissions associated with various production-associated areas of the cement plant (calcination, fossil fuel combustion, the power plant, and vehicle emissions) were calculated using the statistical data collected from the case study plant. In the second part of the study, limestone, the prime emitter of CO_2, was partially replaced with different percentages of OBM (1–5%) in the kiln feed. The CO_2 emissions after the addition of 1%, 2%, 3%, 4%, and 5% OBM were re-calculated for the calcination process only. In the third portion of the study, the ground level concentrations of CO_2 due to the calcination process (after the addition of OBM to the kiln feed) were investigated by means of an integrated modeling system comprised of the California PUFF-Weather Research and Forecasting model (WRF/CALPUFF). The results of the study indicate that CO_2 emissions due to the calcination of limestone dominated the other source emissions. The contribution of the calcination process to CO_2 emissions was 65.74%. The CO_2 contributions via consumption of fossil fuel in the kilns, power plant emissions, and vehicle-based emissions were 26.96%, 7.02%, and 0.29%, respectively. The total amount of CO_2 released into the atmosphere during the production of one t of cement was 673.67 kg. In conclusion, the partial replacement of limestone with OBM in the kiln feed had a positive impact on the reduction of CO_2 emissions during the calcination process. A decrease in CO_2 emissions in the calcination process was noted against the increase of every mass percentage of OBM.

1. Introduction

A remarkable increase in the atmospheric concentrations of carbon dioxide (CO_2) has been observed from 1959 (315 ppm) to a current atmospheric average of approximately 385 ppm. It is projected that the current concentrations will continue to rise to as much as 500–1000 ppm by the year 2100 (Taub, 2010). The gradually rising concentrations of CO_2 in the atmosphere may have an irreversible impact on climate change and global warming (Solomon et al., 2009). The increases in atmospheric concentrations of CO_2 could lead to a rise in temperatures which in turn could cause sea levels to rise, dry-season rainfall reductions, severe droughts in some parts of the world, extreme weather conditions, more frequent extreme rainfall events with high intensity, an increase of flood frequency, the loss of ecosystems, and potentially hazardous health effects (Gunawardhana and Al-Rawas, 2014; Mishra and Siddiqui, 2014). A study conducted by Jacobson (2008) in the USA indicated that CO_2 emissions associated with fossil fuels can increase surface ozone, carcinogens, and particulate matters, which can result in increased cases of asthma, cancers, hospitalization, and death.

The cement industry is a major contributor of CO_2 emissions globally, contributing about 7% to these emissions (Li et al., 2013a,b). The manufacture of every t of cement generates around 0.79 t of carbon dioxide (Deja et al., 2010). The massive amount of

* Corresponding author. Tel.: +968 24141360; fax: +968 244141316.
E-mail address: sabah1@squ.edu.om (S.A. Abdul-Wahab).

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CO_2 emissions associated with cement manufacturing demands consideration due to its impact on global warming and climate change.

1.1. Carbon dioxide (CO_2) emissions from the cement manufacturing process

CO_2 emissions from the cement industry are generated from two main sources: combustion of fossil fuel and the de-carbonation of limestone ($CaCO_3$) during clinker production. When homogenized raw meal undergoes the process of calcination, substantial amounts of CO_2 are released. This calcination occurs when limestone decomposes thermally in pyro-processing units to produce lime (CaO) and CO_2, a by-product, as per the calcination reaction ($CaCO_3 + heat \rightarrow CaO + CO_2$). The calcination process accounts for 50% of the total CO_2 emissions associated with the cement manufacturing process. The pyro-processing units are heated by burning fossil fuels, and the combustion of these fuels generates additional amounts of carbon dioxide (CO_2). Of the CO_2 emissions, 40% are related to the combustion of the fossil fuel used in the pyro-processing units. The remaining 10% of the CO_2 emissions can be attributed to the extraction and transportation of raw materials from quarries, the use of electricity to run other plant machinery, and the handling of cement products (Arachchige et al., 2013; Aranda-Usón et al., 2013; Shen et al., 2014).

As the majority of the cement industry's emissions can be attributed to the pyro-processing stage for clinker production (process-related emissions and combustion-related emissions), scientists and researchers are continuously trying to suggest remedial measures for the reduction of CO_2 during this stage (Chen et al., 2010). The CO_2 emissions during pyro-processing can be reduced by using alternative raw materials in clinker production, a more efficient kiln process, and the replacement of fossil fuels with carbon-neutral fuels (Benhelal et al., 2012; Hoque and Clarke, 2013; Li et al., 2014a). A reduction in calcination process-related CO_2 emissions is only possible by utilizing alternative raw materials in the kiln feed. The reuse of industrial waste such as steel slag, fly ash, and oil well-derived drilling waste is available for this purpose and will not only be beneficial for environmental hazards associated with such waste, but would be a bonus for the industries producing such waste (Houillon and Jolliet, 2005; Nakakubo et al., 2012; Valderrama et al., 2012). Researchers and engineers are focusing on the use of various types of industrial waste in the kiln feed for clinker production in the cement industry (Valderrama et al., 2013; Vatopoulos and Tzimas, 2012; Xu et al., 2014).

1.2. Literature review

Al-Dhamri and Black (2014) used oil-based mud (OBM) drilling waste as a raw meal ingredient to produce clinker for cement manufacturing. Three raw meal samples containing 0%, 1%, and 2% were considered. The experimental results of the study showed that the utilization of OBM as a part of raw meal has a positive influence on CO_2 emission reduction in cement clinker production. Li et al. (2014b) studied the effect of sugar filter mud (FM) on Portland cement clinker formation. Five samples of raw mix in which FM was substituted in various weight percentages for limestone were prepared for clinker manufacturing. The experimental work of this study suggested that the activation energy of $CaCO_3$ decomposition is reduced and there is an increase in the liquid phase amount due to the use of FM in clinker formation. The clinkers produced with different raw mixes had all of the main phases of the referenced clinker. Al-Dhamri et al. (2011) used the petroleum refinery by-products spent alumina catalyst (SAC), reduced fluid catalytic cracking catalyst (RFCC), and the natural rock kaolin as a substitute for imported bauxite in the raw meal of a clinker. Four types of clinker were produced using bauxite as the reference, kaolin as the secondary reference, SAC, and RFCC. The cement was prepared by adding gypsum with sampled clinkers. The results of the study indicate that the replacement of bauxite with kaolin, RFCC, and SAC in cement manufacturing provided the same results as bauxite and kaolin. Al-Dhamri and Melghit (2010) used SAC and RFCC waste as a substitute for bauxite in clinker manufacturing. Three types of clinker were prepared using bauxite as a reference, SAC and RFCC. The results of the study suggested that the chemical composition and physical and mechanical properties of the clinker prepared by replacing bauxite with spent catalysts were very close to the referenced clinker. However, the spent catalysts had no effect on the quality of sampled cement. Chen and Juenger (2009) prepared Portland cement clinker using minimal limestone and maximum waste material (fly ash and blast furnace slag) content. The results of the study indicate that it is possible to synthesize Portland cement clinker from a maximum of a 27.5% fly ash and 35% slag. The early age hydration behavior of the cement manufactured by using this clinker was similar to a commercial type. However, the phase formation in the clinker was affected considerably by the waste material. Tsakiridis et al. (2008) investigated the possibility of adding steel slag in the raw meal of Portland cement clinker. Two samples of clinker were produced-one by using ordinary raw materials as a reference sample and the other with 10.5% steel slag. Chemical and mineralogical analysis and a microscopic examination of the prepared clinker indicate that the use of steel slag did not affect the mineralogical characteristics of cement manufactured by using this clinker. The results of the physico-mechanical tests show that the addition of the steel slag had no negative effect on the quality of the produced cement. Bernardo et al. (2007) utilized oil well-derived drilling waste and electric arc furnace slag as alternative raw materials in clinker formation. Three raw mixes containing oil well-derived cutting wastes and electric arc furnace slag (EAF) were prepared by partial replacement of limestone percentages while a fourth one with a limestone and clay mixture was used as a reference mix. The experimental results of the study showed that oil well-derived cutting waste and EAF can replace a portion of limestone ($\leq$38%) and clay ($\leq$72%) in the formation of Portland clinker. The uses of these wastes in the clinker were able to reduce the thermal demand of the process as well as CO_2 emissions. The waste-based clinkers were environmentally friendly and the related cement exhibited the same performance as common hydraulic binders. Tsakiridis et al. (2004) added red mud, an alkaline leaching waste, in raw meal in the formation of Portland cement clinker. Two samples containing ordinary raw materials as a reference raw meal and 3.5% red mud were prepared for this study. The results of the study showed that the addition of red mud in raw meal of Portland cement clinker has no effects on its mineralogical characteristics. Furthermore, this addition did not negatively affect the sampled cement quality.

1.3. Case study

The literature review indicates that a reduction in CO_2 emissions due to the decomposition of limestone through the calcination process is only possible by replacing a certain percentage of the limestone with alternative raw materials in the formation of Portland cement clinker. The industrial waste (oil-based mud cuttings, steel slag, fly ash, etc.) are considered the best choices for such substitutions. The reuse of such waste in the cement industry cannot only act as a remedial measure against environmental hazards associated with such substances; additionally, their utilization will be fruitful for the cement industry due to the potential reduction in energy use and pollutant emissions.