Green Cement Production: Potentials and Achievements

Emad Benhelal, Alireza Rafiei, and Ezzatollah Shamsaei

***Abstract*—In this work, three strategies of CO2 reduction including energy saving, carbon separation, and storage as well as utilizing alternative materials in detail have been reviewed. In case of energy saving approaches, shifting to more efficient process shows the best results since potentially mitigates almost 20% of CO2 emissions in the process. Carbon capture and storage (CCS) is also considered as an effective way to avoid release of CO2. However economical and technical challenges still play as remarkable obstacles against implementing such processes in cement plant. As far as alternative materials are the case, utilizing waste-derived fuel (WDF) and industrial by-products instead of conventional fuels and materials result in significant emission mitigation.**

***Index Terms*—Alternative materials, cement plant, CO_2 emissions, CO_2 mitigation, global warming**

I. Introduction

Carbon dioxide is the most important and abundant gas among all GHGs which have the highest contribution in global warming phenomenon. Thus, finding promising approaches to mitigate CO_2 emissions is the priority of studies to subside the threat of climate change.

In following, emissions in industrial sector are explained in section 2 while a comprehensive description of the sources of carbon dioxide emissions in cement process is included in section 3. Finally in section 4, technical approaches and studies toward emission mitigation in cement plant are discussed, and the most promising strategies are introduced.

II. Industrial CO_2 Emissions

Almost 61% of global CO_2 emissions are induced by industrial activities (electricity and heat generation and other industries) [1] showing the significant impact of such processes on climate change. Although the urgent request for energy and emission reduction is globally admitted, global industrial GHGs emissions are being rapidly increased; it is expected to be 14 Gt CO_2 by 2030 [2]. This emission is mostly due to combusting huge quantity of carbon intensive fossil fuels to generate required power in the process. In addition, some industrial processes have reactions which chemically change raw materials to waste gases such as CO_2. The list of such processes can be found in Draft Inventory of U.S., 2011 [3].

Considering USA as the second largest carbon producer country, in 2009, three major emitting industrial productions are steel and iron production, cement production, and ammonia production, with the emissions of 42.6 Tg CO_2 Eq, 29.4 Tg CO_2 Eq and 11.8 Tg CO_2 Eq respectively[3]. The sources of CO_2 emissions in cement plant in detail will be discussed in section 3.

III. Sources of CO_2 Generation in Cement Process

Cement manufacturing is considered to be one of the highest carbon dioxide emitting industries in the world. The process emits around 900 kg of CO_2 for every ton of cement produced [4] which constitutes approximately 5-7% of the global anthropogenic carbon dioxide emission [5]. During the cement production process, CO_2 is emitted by four different sources. Combustion of fossil fuel in pyro-processing unit produces 40% of total emissions, while another 10% is in result of raw materials transportation and electricity generating consumed by electrical motors and facilities. The rest which contributes the highest proportion of emissions (almost 50%) is released during decomposition of $CaCO_3$ and $MgCO_3$ to produce CaO and MgO as the elementary chemical reactions in the process [4].

Additionally, there are many major and minor technical and management problems which can influence plant performance requiring additional fuel and electricity consumption. These additional consumptions can lead to significant thermal waste and, in consequence, remarkable extra CO_2 emissions. These indirect causes of extra emission could be due to following reasons:

- Implementing low energy efficient process (e.g. wet or semi wet) [6];
- Lack of proper and regular maintenance and utilizing obsolete and low energy efficient machines in the process [7];
- Feeding low burnable raw meal to the preheater [8];
- Utilizing environmentally improper and carbon intensive fuels [9];
- Losses of large quantity of thermal heat through flue gas and hot air streams [10];
- Heat losses through facilities and instruments such as cooler stack, kiln, calciner, cyclones, and ducts' shell [11; 12];
- Generating large amount of carbon dioxide mixed with flue gases which requires further energy to implement capture process [4].

IV. Strategies and Potentials to Curb CO_2 Emissions in Cement Plant

In general three main strategic approaches toward carbon mitigation have been mostly studied during recent decades including:

- Strategy 1: fuel and energy saving
- Strategy 2: carbon capture and storage

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Emad Benhelal is with the Department of Chemical and Material Engineering, University of Auckland (e-mail: emad_benhelal_ce@yahoo.com).

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- Strategy 3: utilizing alternative materials

A. Strategy 1: Fuel and Energy Saving

Reduction in fuel consumption especially fossil fuels as the most air polluting sources can significantly contribute in abating global emissions of pollutant gases, greenhouse gases, and solid particles. Fuel and energy saving is also an effective strategy to slow down depletion of fossil fuels and letting the next generations to utilize such valuable resources as we do. This target has been achieved by different approaches including process modification, process integration, maintenance, insulation, energy recovery, and so on.

1) Employing more energy efficient processes (e.g. from wet to semi wet or dry process

While in a dry process, the raw meal is firstly pre-dried and even pre-calcinated before entering the rotary kiln, in the case of a wet process, raw meal is fed with high moisture content directly into a long rotary kiln. Therefore, part of total energy is consumed to evaporate the moisture content and to prepare materials for calcination reactions. That is the reason of remarkable difference between energy consumption in these two processes. It is possible to save up to 50% of required energy [13] and to reduce 20% of CO_2 emissions by shifting to dry process with calciner from wet process.

2) Reduction of thermal heat losses in pyro-processing unit

In cement plant, 90% of total input energy is consumed in the pyro-processing unit including pre-heater tower, calciner, kiln, and coolers [4]. Energy is wasted in preheater tower through pipes, cyclones' shell, and leaking air [14]. Noticeable amount of thermal energy is also lost in calciner and the kiln through shell, surface and leakages. In addition to heat losses in heating part, heat is also wasted in cooling part (air coolers). These losses can be due to leaking air as well as coolers' surface. In general, heat losses in pyro-processing unit can lead to wasting up to 20% of initial energy[11], and it results in the release of 8% extra CO_2 from cement plant.

In case of losses through shell and surface, secondary shell as well as insulation layers have been applied. While, in case of air leakages, proper sealing methods and regulars monitoring and maintenance have been proposed and implemented. These approaches have significantly reduced energy losses in the process.

3) Energy recovery from exhaust streams

Other remarkable sources of thermal heat losses in pyro-processing unit are flue gas and hot air streams. To recover and reuse these sources of thermal energy which waste up to 35% of total energy [10], different technologies can be implemented depending on the volume and temperature level of exhaust streams as well as location and the need of the process [15].

In some works waste, heat recovery systems have been proposed to generate electricity from these two streams [11], [12].These systems potentially able to produce 30-45 kWh/t-clinker electricity in the big kilns [15]. In the other cases, exhaust streams have been used to produce steam or hot water using used in the process [16], and in some else, these sources of energy are sent to the vicinity demand side in order to provide a part of required thermal energy especially for heating space [14].

4) Electrical energy savings

Electricity consumption contributes to almost 5% of carbon dioxide emissions in the cement plant [16]. Approximately 100 kWh/t-cement electricity is required in an efficient cement plant. By considering coal as the main fuel, we can see that this electricity demand results in production of up to 100 kg of CO_2 per ton of cement [17]. An example of strategies toward electricity saving is utilizing adjustable speed drivers instead of typical drivers. This substitution can lead to electricity savings from 7 to 60% depending on the application and the load applied to the motors as well as application in the process [18].

5) New preheater tower and kiln burners

Utilizing new and optimized types of cyclones is estimated to save 0.6-1.1 kWh/t-clinker electricity by reducing pressure drop [19]. Using new and optimized models of burners can also result in fuel saving. Employing these burners can lead to a stable kiln operation, maximizing combustion effectiveness, and reducing fuel consumption in the process [20].

6) Maintenance

Regular maintenance can significantly contribute to energy saving and consequently in curbing CO_2 emissions. Actions such as regular leaking monitoring and control, corrosion control, and reduction as well as periodical replacement of old motors and machines can significantly increase the plant thermo efficiency. It is evaluated that a simple air leakage at the kiln hood could lead to approximately 46 kJ/kg-clinker energy losses [7].

B. Strategy 2: Post-combustion CO2 Capture and Storage

Against all approaches described above, post combustion CO_2 capture and storage (CCS) never actually reduces the generation of CO_2. The aim of this treatment is to separate, capture, and to prevent CO_2 from being released. CCS is a set of technologies which can considerably mitigate CO_2 emissions from industrial processes and other stationary sources of CO_2. It is a three-step process which includes capture and compression of CO_2 from flue gas stream, transport of the captured CO_2 (usually by pipeline system), and storage of CO_2 in appropriate geologic formations. However, up to now and due to various technical and economic barriers, no post-combustion capture and storage process has been applied in cement plant, and a wide deployment CCS in the cement industry is not foreseen before 2020 [15].

C. Strategy 3: Utilizing Alternative Materials

Utilizing alternative materials in cement production process is not a new approach. Starting from past decade, utilizing alternative materials has rapidly extended, and due to prospect of the energy and environmental challenges, it is expected to increase even at the faster rate in the future.

1) Alternative fuels utilization

Plenty of alternative fuels, in different phases, are being used in global cement plants aiming to obtain economic and environmental achievements. These fuels generally include: 1) Agricultural biomass residues; 2) Non-Agricultural biomass residues; 3) Petroleum-based wastes and miscellaneous wastes; and 4) Chemical and hazardous wastes.

Fig. 1 shows the changes in CO_2 emissions by utilizing various alternative fuels instead of coal (carbon emissions factor = 0.68 t C/t coal and LHV = 26.3 GJ/t).

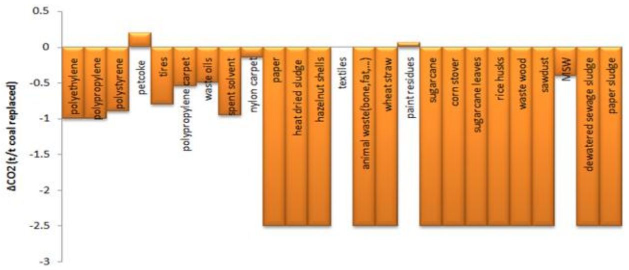

Fig. 1. Differences of CO_2 emissions by utilizing alternative fuels compare to coal (adapted from [6]).

Among all alternative fuels, utilizing waste-derived fuel (WDF) in cement plant seems to be more environmentally friendly since it simultaneously reduces emissions from both cement plants and landfills. In addition to generating fewer pollutants by using this alternative fuel as a source of energy in cement industry; CO_2 generation is considerably reduced as a result of waste reduction in landfills (Fig. 2).

2) Reusing industrial by-products as raw material and clinker substitute

Reusing industrial by-products is considered as the most promising and practical solution to reduce accumulation of by-products unintentionally produced by industries. Commonly, industries treat by-products as the waste and send them to the landfills or incinerators. Alternatively, these by-products can be mixed with raw materials and fed to cement process. Moreover, these wastes can be substituted with clinker and compose a portion of final cement.

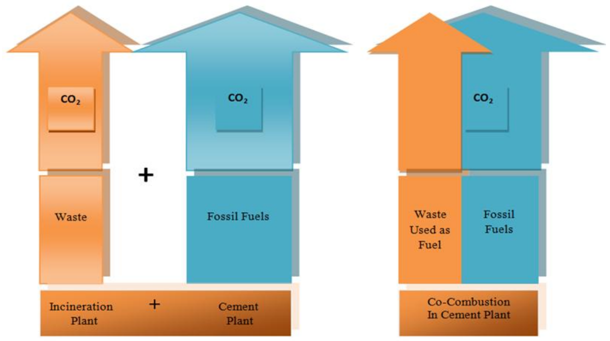

Fig. 2. CO_2 reduction by utilizing WDF in cement plant (adapted from [6]).

V. Conclusion

In this work, global strategies and potentials toward CO_2 emissions reduction in cement plant were firstly discussed compared, and then the most promising approaches were introduced. In case of energy saving, shifting to more efficient processes, for example from wet to dry process having calciner, was the best option, since it potentially reduced up to 50% of required energy and mitigated almost 20% of CO_2 emissions in the process. CCS is also considered as an effective way which is potentially able to separate and store major proportion of CO_2 produced in the plant. However, up to now, and due to various barriers and challenges, no post-combustion capture and storage process has been applied in the cement industry. As far as utilizing alternative materials is concerned, reusing industrial by-products and WDF resulted in the greatest contribution to abate CO_2 emissions. Industrial wastes utilized as fuels, raw materials, and clinker substitutes significantly contribute in emission reduction since they simultaneously curb CO_2 emissions from two sources, cement plants and landfills.

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