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An innovative Methodology to Convert CO2 into Methanol, to Increase Sustainability of Clinker Production

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1. Introduction

Climate change and pollution are very severe problems that affect Earth and must definitely addressed [1]. Sustainability is a main topic and a need that any sector must achieve, especially those characterized by high levels of emissions. One of them is the cement production sector, clinker in particular [2]. This field is highly polluting based on carbon emissions. This led European Union to take this into account with specifical laws to reduce this greenhouse gas production [3]. However, a clear solution to meet the requirements is still missing. That is why this research aims to study how to solve this problem in a fully innovative way. In particular, the focus is on the utilization of the CO_2 produced to create methanol. In this way, in full optic of Circular Economy [4], the waste produced is reused and the carbon footprint is utterly reduced, enabling this sector to achieve a new level of sustainability in production.

2. Problem Statement and Research Questions

Sustainability is one the most important topics of nowadays as the climate change is a very severe condition that is affecting Earth. One of the main causes of this problem is the Carbon emissions. Many sectors contribute to the human carbon footprint, one of them is the production of clinker and cement. This process is highly polluting and European Union has taken into account this problem. However, no solution is still available to face this.

The previous problem has been translated into the following 3 Research Questions:

- What are the emissions of CO2 of Cement and Clinker in particular?
- What are the current solutions to reduce those emissions and maybe re-use them?
- Is it possible to turn the CO2 emissions of this process into methanol? In case, how should the plant be designed?

3. Methodology

Aiming to the maximum quality of this paper, a deep insight into the existing literature has been carried out using the database Scopus. The used strings of keywords are: ("clinker" OR "cement") AND ("co2 emissions" OR "carbon emissions" OR "carbon footprint" OR "co2") AND ("co2 emissions reduction" OR "co2 reduction" OR "methanol"). The choice of these strings of keywords follows a logical path. The first one is selected to limit the research to only cement industry domain, as this is the focus of this paper. The second one is established to investigate the relationship between cement industry and CO_2 emissions. Finally, the third string focuses on emissions reduction and the conversion of CO2 into usable methanol for an efficient production of cement.

A total of 376 papers have been found. To initially reduce this number, the filter "keywords" was applied to all the strings, resulting in 52 papers. Additionally, as objective filters only documents in English were considered (50), of which 36 available for reading. No other filters are utilized, so the set of documents includes articles, conference papers, reviews and book chapters. However, one document was irrelevant to the study's scope. Furthermore, despite the language filter, one document was written in Japanese and two others presented the same content, ultimately reducing the final number of articles to 34.

After conducting a thorough analysis of the existing literature has been carefully analyzed, the authors examined methods for converting waste in CSS EOW and explored its utilization in the cement industry to mitigate CO2 emissions and reduce energy costs.

4. Literature Review

Cement manufacture has an important CO_2 footprint due to the enormous use of cement around the world [2] [5] and the fact that the cement industry has been recognized as important in the construction sector [6], which has been considered the biggest waste producer in the European Union [7]. Furthermore, worldwide cement production is expected to almost double by 2050 [8]. The share of global CO_2 emissions deriving from the cement industry is about 5% [9] [3] while in China, the largest cement producer in the world with a share of 60%, the cement industry contributes to the whole country's CO_2 emission with a share of 15% [1]. Therefore, the cement industry is considered the second largest source of CO_2 emission after the electric power industry [10]. Such a huge mass of CO_2 in the cement plant is originated from three different sources: the decomposition of limestone ($CaCO_3$), the fuel combustion as well as electricity consumption and transportation, with approximate share of 50%, 40% and 10% respectively [11]. However, the decarbonization of cement manufacturing is currently challenging due to the limited CO_2 mitigation strategies available and the lack of economic incentives [12]. Nevertheless, many cement companies are exploring ways to achieve CO_2 reductions [2]. The most widely applied solution is the CO_2 capture and storage, which includes integrated CO_2 treating process from the original gas separation to the final long term isolation from the atmosphere [13] [14] [15]. For example, the implementation of a controlled sequestration of the CO2 in the solar calciner shows that an emission reductions from 8% to 28% can be achieved [16]. However, CO_2 sequestration is applied where CO_2 recycling technologies are emerging by implementing a carbon recycling plant based on the electrochemical reduction of CO_2 to produce methanol (MeOH) [12] [4] [17].In fact, a potential future market output could be based on the utilization of CO_2 for three promising fuel options: methanol, methane and fuel based on the Fischer-Tropsch process. However, in order to achieve CO_2 capture, CO_2 must be separated directly from the flue gas, and the difficulty and cost of standard capture technology are significant [10]. Thus, other strategies are developed. The first one is the reduction of emissions by improving the energy efficiency of the cement process. Examples are the use of coal ash as a partial replacement for cement in concrete and mortar formulations [18], as coal combustion is a widely adopted process to release and subsequently recover energy in coal for electricity generation and for heating [19], the use of sustainable alternative to replace ordinary Portland cement [20] [21] [22] [23] [24] and the use of municipal solid waste gasification to save energy and reduce carbon emissions in the cement industry [25] [26]. Technologies currently available for the recovery of waste heat offer significant energy savings and substantial reductions in greenhouse gas emissions. Furthermore, the massive accumulation of solid wastes is becoming a huge problem in the environment [27], in particular in the developing countries in the world that are facing waste-related issues due to the population [28], so the use of waste in cement industries can help to solve this problem. The second one is the switch to lower carbon fuels and the promotion of material efficiency by reducing the clinker-to cement ratio. An example is the geopolymerisation of mineral wool waste that offers an attractive route for waste valorization [29], since clinkerisation accounts for most of the thermal energy expenditure of a cement plant [30] [31] [32], minimization of clinker consumption in cement concretes is one of the most important challenges to reduce CO_2 emission [33].

5. Content

The authors of the document propose an innovative approach to make cement plants a positive element for the environment, integrating them into the concept of the Circular Economy. This intervention occurs in two phases:

PHASE A: Involves setting up a plant for the production of Secondary Solid Fuel (CSS) and the recovery of unused materials directly within the cement plant, reducing the length of the supply chain and addressing issues related to the disposal of Municipal Solid Waste (MSW).

PHASE B: Introduces a second plant for transforming CO_2 into methanol, which can be used as fuel in clinker kilns. In the full perspective of Circular Economy, the cycle is completed in the following way: 1. It begins with the treatment of undifferentiated waste to recover reusable materials with guaranteed economic and environmental benefits, 2. Proceeding to the production of CSS, a regulated fuel with low levels of pollution, 3. The CO_2 produced during the clinkerization phase is recovered and transformed into methanol, a fuel from which further methanol is generated. Moreover, even if the Lower Heating Value (LHV) is increased using fossil fuels, the CO_2 produced during combustion is captured and not released into the atmosphere, thanks to the same process. This plant, without aiming to be the only system, represents a possible, credible solution already successfully tested by the Authors in some combustion plants. It also responds to the European Union's call for declinkerization of cement [31]. Currently, negotiations are underway with major cement plants to implement the plant, especially for the specific treatment of clinker. It should be noted that the CO_2 production from combustion is significantly lower than that generated by fossil fuels [3]. Many cement plants are adopting CSS also because of cement's ability to capture other pollutants. However, the use of CSS only partially resolves the issue of CO_2 produced by cement plants, as clinker decarbonization still produces significant amounts of CO_2 that directly enter the atmosphere. Based on these considerations, the Authors have developed an innovative plant strategy to address this important issue, as described in the cited paper. A thorough make or buy analysis led the Authors to prefer adopting machinery already existing on the market for the realization of individual plant components, to be assembled appropriately considering the production process. A monitoring, management, and control system has been designed to evaluate the performance evolution over time. In order to improve emissions forecasts and understand the benefits brought by the proposed plant, artificial intelligence models can be used, as they have already been successfully applied in other sectors [34]. Cement production is a critical point in the relationship between humans and the ecosystem, especially considering the previous estimate of 3 million tons of CO_2 produced globally each year. For this reason, in this particular historical moment, also under the strong push from the European Union [9], systems for clinker decarbonization are being examined, which will need to be operational within a few years [12]. The Authors of the paper, who have been studying this issue for years, are ready to intervene using a methodology 4.0 which can provide a contribution by leveraging technologies and models already used in other works, such as in warehouse [35] and in medical sector [36], as already tested with excellent technological and economic results.

6. Results & discussion

From the literature review, it emerges that the cement industry has a significant impact on CO_2 emissions due to transportation, electricity consumption and the phase of clinker decarbonization. Moreover, decarbonization of this industry is challenging due to a lack of economic incentives. Therefore, cement industries are exploring strategies such as improving energy efficiency, capturing CO_2, the using lower carbon fuels and reducing the clinker-cement ratio.

The identified methodology is capable of transforming CO2 into pure oxygen and methanol (CH3OH), both reusable within the framework of Circular Economy at acceptable production costs, especially with the use of eco-compatible energy sources. Having solved the CO2 issue, the Authors have developed the idea of transforming cement plants into high-impact environmentally positive facilities through further eco-friendly interventions. They have therefore studied and developed a plant capable of transforming undifferentiated municipal solid waste (MSW) into a raw material recovery and EOW CSS, an excellent low-CO2 fuel. Additionally, the residual CO2 is transformed into methanol and pure oxygen for industrial and medical purposes. In the hypothesis of being able to install the MSW treatment plant directly in the cement plant, damaging intermediate waste storage can be avoided, transforming the cement plant from a CO2 producer to an ally of environmental sustainability. It is also possible to create consortia plants to collect the most common waste and treat them together. After treatment, EOW billets can be transported to combustion plants and recovered raw materials to their final destination.

7. Conclusions

The paper demonstrates how, starting from the calorific value of coal and the calorific requirement needed to produce one ton of clinker currently in use, significant reduction in the average amount of coal required for this process can be achieved by applying the described methodologies.

8. Future Work Agenda

In order to fully study and analyse this innovative solution, future studies will involve Industry 4.0 controls in the production plant. A full plant will be then evaluated and embedded with the digital technologies, allowing for the control of production parameters, increasing the implementation of Industry 4.0, leveraging what has already been developed in other sectors, such as in warehouse[37]. Particular attention will be devoted to the implementation of Artificial Intelligence, as has already been studied in other sectors, such as the public sector [38], can contribute in improving the sustainability of the plant.

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