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Electrification of Cement Clinker Production: A Case Study on Variable Renewable Energy Integration

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Abstract: This study integrates variable renewable energy (VRE) and energy storage (ES) into a process simulation of an electrified cement clinker production plant to evaluate the minimum levelised cost of production. Using a combined Aspen Plus and mixed-integer linear programming (MILP) framework, the analysis identified an optimal levelised cost of clinker (LCOC) of 92.98 USD per tonne at a minimum operational threshold (MOT) of 55%, achieved using a VRE-ES system with hybrid photovoltaic (PV) and wind generation. The results indicate that the feasibility of electrifying cement production is significantly influenced by the operational threshold and the diversification of energy sources, both of which enhance buffering capacity against VRE variability and improve process flexibility.

Keywords: *Variable Renewable Energy (VRE), Energy Storage, Techno-Economic Optimisation, Aspen Plus Simulation, Calcination,*

1. INTRODUCTION

Electrification of the cement clinker production process, specifically during the pre-calcination stage, has been the subject of much research interest in the recent years due to the increasing urgency of industrial decarbonisation. However, the viability of this approach is strongly dependant on the ability of the production plant to operate reliability under variable electrical energy supply. This study aims to identify the optimised operation strategy and system design that would minimise levelized cost of production, specifically in the context of a retrofitted clinker production plant integrated with an electrified calciner that is powered by VRE.

2. METHODOLOGY AND RESULTS

The process simulation of the clinker production plant was completed using Aspen Plus, was first modelled using traditional calciner as a reference plant. This simulation was used as a baseline wherein the technical and operational parameters of this model were validated against industry data and published reports to ensure the simulation's accuracy. This plant was then modified to retrofit an electrified calciner and heat recovery system, as seen in Figure 1. The influence of a variable electrical energy supply on the performance of this plant and each of its sections was then evaluated through a series of sensitivity analyses.

Once completed, the findings were then incorporated in a techno-economic performance analysis that was conducted using a MILP model. Combined with the solar and wind resource data from the Spencer Gulf region, the model optimises the cost objective function of clinker production to evaluate the optimal operation strategy and system design that would allow for a minimal LCOC

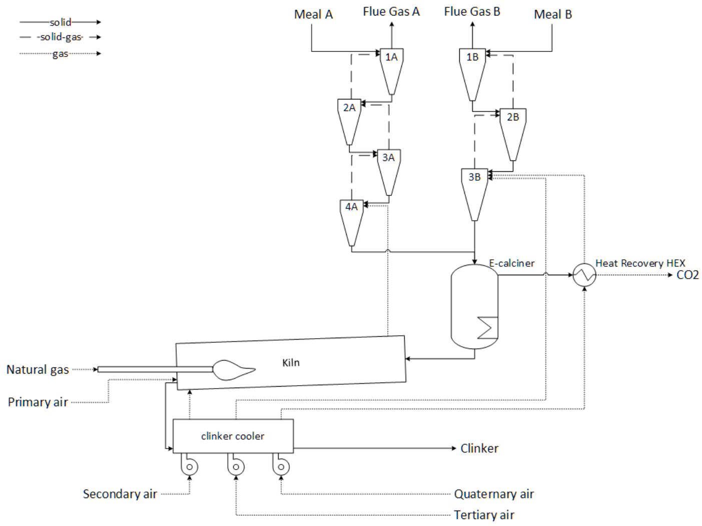

Figure 1. Schematic of the retrofitted clinker production plant with the electrified drop-tube calciner (e-calciner).

Results from the Aspen Plus simulation found that with the incorporation of an electrified calciner, carbon emissions can be reduced by 74%, assuming that the CO_2 release from the calcination process is properly sequestered or stored instead of released to the atmosphere. Investigation of the minimum operational threshold of the e-calciner found that the clinker production plant operates down to an absolute minimum of 54% normalised meal throughput, producing. Production rates lower than this point would have to completely bypass the calciner with the meals sent directly to the kiln instead.

Through the MILP techno-economic performance analysis, it was found that a larger process flexibility, as measured by the minimum operational threshold, resulted in a 5% decrease in the LCOC when the MOT is set at 55% as compared to 75%. This strategy balances the cost by recommending a longer operation period at MOT during period of low electrical energy generation, to lower the storage capacity requirements whilst avoiding full plant shutdowns which incur a large penalty cost. Additionally, it was observed that a hybrid system of PV and wind performed significantly better, with a LCOC of approximately 93 USD/tonne at 55% MOT, comparated to a system with only PV, which resulted in a LCOC of 127 USD/tonne.

3. CONCLUSIONS

The combination of Aspen Plus simulation and MILP-optimisation confirms that renewable energy generation variability could be overcome by designing cost-optimised VRE-ES strategies without incorporating an excessive reliance on stored energy. The lowest LCOC of 92.98 USD/tonne can be achieved by a MOT of 55%, using a hybrid PV-wind system configuration (capacity factor of 97%). Results have shown that a more flexible operation threshold, combined with a more diversified energy system, allows for more resilient and cost-effective approach that would be able to overcome period of low VRE supply by maintaining a lower production throughput without the need for plant shutdowns. Overall, the integration of VRES and electrified calciner approach proposed in the study serves as a clear framework that would minimise risk and enable large-scale decarbonatization of the cement clicker production.

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