Electrification's promising path

Electrification of kilns, encompassing both direct and indirect methods, offers a promising pathway towards eliminating greenhouse gas emissions and transitioning to more sustainable industrial processes. The electric arc calciner (EAC) technology, developed by SaltX Technology, leverages plasma technology to convert electricity directly into high-temperature heat, and emerges as a cost-effective and scalable solution.

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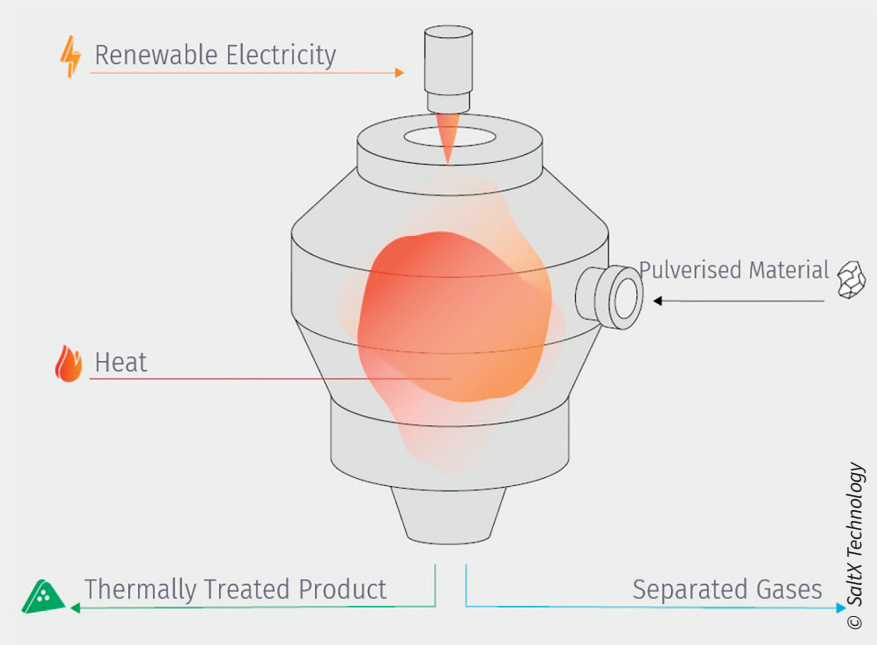
Climate goals are unlikely to be achieved if the carbon emissions from the cement and quicklime industries are not substantially curtailed. This calls for actionable roadmaps and commitments to meet real-world needs for decarbonisation via comprehensive net-zero pathways, deploying economically viable and effective technologies, alongside the swift expansion of renewable energy solutions. Such initiatives are crucial to encourage the minimisation of CO_2 emissions inherent in cement production processes.

This article explores the developments of SaltX Technology, a Swedish green technology company that develops and delivers sustainable technology with the mission of eliminating heavy industries' dependency on fossil fuels using its plasma-driven electrified kilns.

Figure 1: diagram of the SaltX electric arc calciner (EAC)



Electrification of industrial heat

Electrification of the cement industry is one of a set of global initiatives to reduce greenhouse gas emissions and transition towards more sustainable industrial processes. The premise is to replace the traditional fossil fuel-based heating systems used in kilns with electrically-powered alternatives. Instead of combusting fuels like coal or natural gas to generate heat, electric kilns employ various methods to convert electrical energy into high-temperature heat.

Electrification of industrial heating can be divided into two broad categories: direct electrification and indirect electrification.[1] Direct electrification involves the conversion of (ideally low-carbon) electricity directly into usable high-temperature heat on an industrial scale. This includes induction, resistance, microwave and electric arc (ie, plasma) heating systems. Direct electrification typically involves fewer conversions, which according to the laws of thermodynamics means that they hold the greatest promise for overall high efficiency.[2,3] However, on the other hand, they require the greatest disruption to existing cement plant designs and systems since most arrangements are currently based on fuel combustion, which do not lend themselves to simple conversions to become electrically driven.

Indirect electrification is often carried out by converting electrical energy into a carrier fuel such as hydrogen or ammonia or by converting CO_2 and water into synthetic carbon fuels like methane or methanol (also known as e-fuels).[4,5] This approach has the benefit of being able to utilise (for the most part) existing system designs, namely fuel handling and combustion systems. However, the process of converting electricity into a combustible fuel has inherent losses, limiting the overall efficiency and increasing the operating cost of cement clinker production.

Nonetheless, electrically-heated kilns are in line with other sectors' drive towards electrification, and the desire to converge to a robust and sustainable energy system standard. Directly-electrified kilns have the potential to be easily integrated into modern automated production processes, which can lead to further efficiency improvements.

However, there are also challenges to the electrification of cement production. The cost of electricity, especially from low-carbon sources, can be prohibitively high compared to traditional fossil fuels and the capital costs for new electric kilns can also be significant. Despite these challenges, the trend towards electrification in the cement industry and other heavy industries is likely to continue as part of broader efforts to reduce greenhouse gas emissions and mitigate climate change.[6] This is especially important as high carbon emitters incur increasing economic penalties.

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Figure 2: 2MW test facility commissioned by SaltX in 2023

The electric arc calciner

Over the last two years SaltX Technology has leveraged its developments in the industrial energy storage space, employing them for calcination processes. SaltX Technology has developed a cost-effective route towards electrification of kilns with its electric arc calciner (EAC) technology. The EAC converts electricity directly into high-temperature heat (>1600˚C) with a plasma generator. The SaltX EAC is designed to replace or complement existing fuel-fired kilns while meeting the needs of the cement industry in terms of quality and scale. The only inputs of the EAC are raw meal and (low-carbon) electricity so a stream of pure CO_2 is recovered during pre-calcination. This contrasts with fossil fuel-driven pre-calciners that produce a mixture of CO_2 and other combustion gases that need to be separated in a complementary energy intensive carbon capture process.

The EAC features a cylindrical chamber, much like the cyclones found in a preheater but with a plasma generator positioned at its heart (see Figure 1). This design allows for the cement raw meal to be introduced into the chamber, where it undergoes rapid calcination thanks to both radiative and convective heat transfer within this confined space. A distinctive aspect of this technology is its efficient heat transfer mechanism, which effectively reduces the required volume and temperature of the gas in the calciner minimising blower power and thermal losses. The plasma generator delivers power densities in the order of 600kW/m^3 and is designed for both compactness and scalability. The calcined material and the CO_2 generated are both fed out of the unit where they are separated using standard cyclone separation techniques. This separation of the solid material from the CO_2 gas requires a fraction of the energy that would be needed for capturing diluted CO_2 from flue gases.[7,8]

Similar to other direct electrification technologies, the SaltX EAC also allows for precision control of calcination. By manipulating the time and view factor of the radiative heat transfer to the material, calcination properties can be fine-tuned. High capacity can be achieved per unit volume of the kiln since full calcination can be achieved in 5-45s, depending on operating parameters. This opens the possibility to a new operational paradigm of demand management of cement production. The low effective thermal mass of the calciner and the responsiveness of the plasma system, as well as the high rate at which calcination occurs, makes more flexible operation possible. The operator (or automated control system) could potentially throttle or conversely maximise production throughput based on the availability and/or cost of low-carbon electricity.

Technology developments

The EAC was born from SaltX's energy storage systems based on dehydrating slaked lime to produce quicklime in a reversible thermochemical energy storage process. Tweaking the temperature level and operation profile meant that the calcination of limestone became feasible. For SaltX these developments open up two large markets: heater (ie, chargers) for thermal energy storage solutions, and electric kilns for electrification of the quicklime and cement industries. Development efforts intensified in 2022 with a 300kW electric kiln pilot installation. The focus was to demonstrate that unlike

other electrification efforts using plasma technology,[9] thermal energy could be transferred directly to the cement raw meal rather than via a large volume of hot gas.

The results from the pilot plant were then integrated into the design of an industrial-scale test facility that started operation in November 2023 (see Figure 2). The new 2MW facility has a 10-fold increase in throughput compared to the previous pilot plant. In addition to scaling of the kiln technology, other subsystems, including preheating, filtration and aftercooling, have been added to provide a test environment where the complete calcination process is evaluated and optimised. The installation is being used as a design test facility to verify calcination properties of different types and qualities of limestone, cement raw meal and potentially other raw materials. The tests carried out are a precursor to electric kiln designs for a given project or application where the SaltX EAC is designed for electrifying the (pre-)calciner of cement plants.

Zero Emission QuickLime (ZEQL) initiative

SaltX has also teamed up with Swedish quicklime producer SMA in an initiative called ZEQL (Zero Emission QuickLime), an electrified manufacturing method and factory concept. The first ZEQL plant is scheduled to start operations in 2025. The ZEQL concept seeks to eliminate CO_2 emissions by switching from fossil fuels to renewable electricity and by separating out the CO_2 released from the limestone calcination. ZEQL aims to rapidly replace existing kilns with new electrified ones, where SMA Mineral has the goal of lowering its carbon footprint by 50 per cent by the end of 2027.

Costs and CO_2 reduction

Key to any disruptive project are analyses of costs and environmental impact. However, these are highly case specific. Several studies have looked into the cost of production of cement clinker through comprehensive evaluations that consider various factors such as raw material inputs, energy consumption, labour costs and overhead expenses.[10] When evaluating decarbonisation methods such as electrification, utilisation of alternative fuels and carbon capture technologies, a fair comparison of yearly and/or lifecycle costs, including capital, operating, maintenance and fuel expenses is necessary on a case-by-case basis. Additionally, the concept of the cost of avoided carbon is an integral metric in this analysis. It refers to the additional expenses incurred by adopting decarbonisation measures to reduce carbon emissions during cement clinker production. Understanding the cost of avoided carbon enables companies to assess the economic feasibility of investing in sustainable technologies and quantify the financial considerations associated with emissions reduction. Based on SaltX's case studies an expected cost of cement clinker production is in line with studies carried out by Quevedo Parra et al,[10] Mokhtar et al[11] and Daehn et al.[12] An expected production cost of clinker is between -5 to +30 per cent compared to a reference coal-driven cement plant with corresponding emissions reductions between 30-70 per cent. Key parameters in the studies are electricity prices, the cost of CO_2 handling for utilisation and/or sequestration as well as the scope of the decarbonisation measures.

Additionally, as part of the overall decarbonisation roadmap for the cement industry it should be noted that the EAC is also compatible with various other low-carbon levers.[13] This could lead to hybridised solutions to balance the cost of avoided carbon for a given project.[10] This might include hybrid technology and method implementations including biofuels, recycled materials and supplementary cementitious materials (SCM) and novel approaches such as the integration of mineralisation techniques along with clinker production.

Conclusion

The advent of electric kiln technologies, particularly the EAC by SaltX Technology, could play a major role in the sustainable transformation of the cement industry. This article has highlighted:

- The critical need for decarbonisation within the cement and quicklime industries due to their significant carbon footprint.
- The potential of electrification, especially direct electrification methods like the EAC, to replace or augment existing fossil fuel-driven kilns, thereby substantially reducing CO_2 emissions.
- The EAC's innovative design enables efficient heat transfer, rapid calcination, and the production of a stream of pure design, facilitating easier carbon capture compared to traditional methods.

In summary, the electrification of cement production, through technologies such as the EAC, offers a viable and impactful pathway towards achieving global decarbonisation targets. ■

REFERENCES

[1] RUHNAU, O, BANNIK, S, OTTEN, S, PRAKTIKNJO, A AND ROBINIUS, M (2019) 'Direct or indirect electrification? A review of heat generation and road transport decarbonisation scenarios for Germany 2050' in: *Energy*, 166, 1 January 1, p989-99.

[2] RECHARGE (2021) 'Electrify everything directly or indirectly: the five policy steps needed to decarbonise Europe' *https://www.rechargenews.com/energy-transition/electrify-everything-directly-or-indirectly-the-five-policy-steps-needed-to-decarbonise-europe/2-1-1014899* [Accessed 2 March 2024].

[3] IRENA (2023)'Innovation Can Pave the Way to Decarbonise High-temperature Heat in Industries' *https://www.irena.org/News/articles/2023/Sep/Innovation-can-pave-the-way-to-decarbonise-high-temperature-heat-in-industries* [Accessed 2 March 2024].

[4] SCHMIDT, PR (2022) *E-Fuels: A techno-economic assessment of European domestic production and imports towards 2050. Concawe report 17/22*. Brussels, Belgium, 334p.

[5] MARTIN, J, NEUMANN, A AND ØDEGÅRD, A (2023) 'Renewable hydrogen and synthetic fuels versus fossil fuels for trucking, shipping and aviation: A holistic cost model' in: Renewable and Sustainble Energy Reviews, 186, Oct, 113637.

[6] CZIGLER, T, REITER, S, SCHULZE, P AND SOMERS, K(sd) 'Laying the foundation for a zero-carbon cement industry' *https://www.mckinsey.com/industries/chemicals/our-insights/laying-the-foundation-for-zero-carbon-cement* [Accessed 2 March 2024].

[7] GHADIRI, M AND CLIFT, R (2011) 'Gas-solids separation, overview. A-to-Z Guide to Thermodyn Heat Mass Transfer Fluids Engineering' *https://www.thermopedia.com/content/48/* [Accessed 2 March 2024].

[8] CARTA, M (2015) 'Gas Separation' in: Encyclopedia of Membranes. *https://link.springer.com/ referenceworkentry/10.1007/ 978-3-642-40872-4_261-1* [Accessed 2 March 2024].

[9] VATTENFAL AND CEMENTA (2018) CemZero: A feasibility study evaluating to reach sustainable cement production via the use of electricity. Technical Report. *https://www.cement.heidelbergmaterials.se/sites/default/files/assets/document/65/de/final_cemzero_2018_public_version_2.0.pdf.pdf*

[10] QUEVEDO PARRA, S AND ROMANO, MC (2023) 'Decarbonization of cement production by electrification' in: *Journal of Cleaner Production*, 425, 1 November, 138913.

[11] MOKHTAR, A AND NASOOTI, M (2020) 'A decision support tool for cement industry to select energy efficiency measures' in: *Energy Strategy Reviews*, 28, 1 Mar, 100458.

[12] DAEHN, K, BASUHI, R, GREGORY, J, BERLINGER, M, SOMJIT, V AND OLIVETTI, EA (2021) 'Innovations to decarbonize materials industries' in: Nature Reviews Materials, 7 (4), 12 October, p275-294. *https://www.nature.com/articles/s41578-021-00376-y* [Accessed 2 March 2024].

[13] GAILANI, A, COOPER, S, ALLEN, S, PIMM, A, TAYLOR, P AND GROSS, R (2024) 'Assessing the potential of decarbonization options for industrial sectors' in: *Joule*, 8, 20 March, p1-28. https:// doi.org/10.1016/j.joule.2024.01.00