

Impact of Advanced Technology in Qualitative Production of Cement in Cement Industry

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ABSTRACT

Technology has been playing a crucial role in transforming the operations of cement plants. It has paved the way for data-driven decision-making, which is now a hallmark of modern cement plants. The vast amount of data collected through automation systems is analyzed to uncover operational inefficiencies and opportunities for process improvements. This data-driven approach enables plant personnel to optimize production schedules, increase productivity, and stay ahead in a competitive market. Technological evolution has also enabled the implementation of predictive maintenance solutions, which help identify potential equipment failures before they occur.

The emergence of predictive maintenance solutions has revolutionized maintenance practices in cement plants. With real-time data from IoT sensors and AI-powered algorithms, these systems can predict faults in equipment well in advance, thereby preventing any unplanned down or catastrophic failure. This proactive approach optimizes maintenance schedules, minimizes downtime, and ultimately reduces maintenance costs. Moreover, automation and technology help maintenance teams to identify the energy consumption patterns of equipment sets, allowing them to implement energy-saving measures, leading to cost reductions and environmental benefits.

Keywords: AI, automation, benefits, cement, digitalization, energy, measures, technology

INTRODUCTION

Advanced technology enhances cement quality by enabling real-time process monitoring and control, optimizing raw material use, and reducing defects through AI and automation. Digitalization, IoT sensors, and machine learning allow for detailed data analysis to identify optimal operating parameters, improve equipment reliability, and predict potential issues like overheating, leading to a more consistent, higher-quality product. This shift from manual processes to connected, intelligent systems ensures better quality control, increased energy efficiency, and a more sustainable, cost-effective production cycle.

Digitalization in Cement Plants

Embracing digitalization is a key focus for a range of cement manufacturers across the country. Nanoprecise has been helping cement manufacturers incorporate state-of-the-art digital technologies to transform traditional cement plants into smart and connected facilities, for more than 4 years. One of our main efforts involves the deployment of Internet of Things (IoT) devices throughout the plant to monitor the health & performance of equipment in real-time. These devices continuously collect data from the machinery, which is then transmitted to the cloud for analysis. The advanced signal processing algorithms parse through this complex machine health data to

detect anomalies and predict potential equipment failures. This enables cement manufacturers to anticipate maintenance needs, helping plants optimize maintenance schedules, improve resource allocation, and avoid unplanned downtime.

Digitalization paves the way for implementing advanced digital solutions, that can help maintenance teams transition from reactive to proactive maintenance strategies. Early detection of equipment issues enables planned maintenance, reducing costly unplanned downtime and minimizing repair expenses. The state-of-the-art condition monitoring solutions available in the market, have the potential to revolutionize inventory management due to their predictive capabilities, thereby allowing for optimized resource allocation and reduced wastage of raw materials. This optimization of inventory levels minimizes carrying costs and mitigates the risk of overstocking or stockouts. Moreover, digitalization allows for better monitoring of equipment's energy consumption. By identifying the energy consumption patterns of equipment under faulty conditions, cement plants can take corrective actions to reduce energy wastage and carbon footprint, thereby achieving significant cost reductions over time.

Customization

Customers generally have needs & requirements that are unique, and a one-size-fits-all approach may not meet their specific requirements. We are working with businesses across a wide range of sectors around the world, to deploy customized solutions that help them drive their digital transformation journey. Customization is an essential component of Industry 4.0 as each cement plant has unique operating conditions and equipment configurations.

Our structured process involves conducting a comprehensive assessment of the plant, gathering real-time data using our ultra-low-power wireless sensors, and analyzing it using patented cloud-based software that detects even small changes in the machine performance and predicts the remaining useful life of any industrial asset. The solution can be customized to monitor a wide range of equipment including complicated machines like the roller press due to its ability to monitor low and ultra-low-speed applications with ease. It also allows for seamless integrations with various vertical and horizontal stacks. Moreover, the system can also be deployed on cloud or on-premise servers, thereby allowing for a simple plug & play, hassle-free deployment, without worrying about any extra IT infrastructure.

AI-based machine productions

AI-based machine productions involve utilizing artificial intelligence algorithms to optimize the cement production process. Through machine learning, AI algorithms can analyze historical production data, sensor readings, and other relevant factors to make accurate predictions and recommendations.

AI algorithms can monitor and analyze vast amounts of data pertaining to various production parameters to maintain consistent product quality. Moreover, by analyzing data from various stages of production, AI can also identify inefficiencies and bottlenecks, suggesting optimizations to enhance overall process efficiency. Furthermore, AI can be applied to predict equipment failures and schedule maintenance activities, leading to minimized disruption and downtime. It can also optimize energy consumption by suggesting the most efficient operating conditions for equipment, thereby reducing energy costs and environmental impact.

Automation systems

Automated AI-based predictive maintenance solutions consist of 6-in-1 wireless sensors that measure the 6 most important parameters of Tri-Axial Vibration, Acoustics, RPM, Temperature, Humidity & Magnetic Flux. These sensors act as the vigilant eyes and ears of the manufacturing plants, continuously monitoring the vital indicators of the health and performance of machinery.

The combination of these six vital parameters equips cement plants with a holistic view of their industrial assets, allowing for data-driven decisions to optimize operations and prevent costly downtime. The collected data is then transmitted to the cloud through an encrypted & secured network for analysis. The AI analyzes complex machine health data to discern subtle patterns, identify anomalies, and even predict potential equipment issues well in advance. This predictive capability is a game-changer for cement operations, as it empowers maintenance teams to take proactive measures before any critical failure occurs. By leveraging the power of automation and AI-driven analytics, the cement industry can reduce maintenance costs, enhance equipment reliability, and achieve higher energy efficiency, ultimately leading to improved productivity and profitability.

Implementation of digital technologies such as predictive & prescriptive maintenance solutions is a challenging process in asset-intensive sectors like cement manufacturing. For instance, Cement plants consist of various complex machines and equipment, each with its unique operating parameters and intricacies. Integrating and optimizing technology solutions for such diverse machinery requires a deep understanding of the equipment and its operations. These plants operate in harsh and rugged environments, exposing the machines & equipment to extreme temperatures, dust, moisture, and vibrations, which necessitates robust solutions that can withstand these conditions. Our solution comprises of robust hardware that can monitor such machines, thereby bringing peace of mind to our customers. Our solutions undergo robust testing and validations to ensure their resilience in the rugged plant environment.

Secondly, the introduction of new technology is generally followed by an adoption curve, which is why we provide extensive customer support. We focus on gaining staff acceptance and support as that is vital to the successful implementation of technology solutions. We achieve this by conducting effective training programs that address staff concerns and promote acceptance of the new technology.

Moreover, implementing technology solutions in large cement plants can be a time-consuming process. However, with our plug & play solutions, we closely collaborate with teams in these plants to streamline the implementation, allowing for hardware installation in less than 5 minutes and facilitating seamless integration of digital technology. This expedites the adoption of our solutions, minimizing downtime and ensuring a smooth transition.

Principles of Circular Economy in Cement Production

The circular economy model emphasizes sustainability, resource efficiency, waste reduction, and the continual use of resources. In the context of cement production, adopting circular economy principles involves rethinking traditional practices to minimize environmental impact and promote sustainable development. This paper explores the key principles of circular economy as they apply to cement production, supported by relevant literature and case studies.

Resource Efficiency

By maximising the utilisation of alternate raw materials, such as industrial by-products like fly ash, slag, and silica fume, the dependence on primary resources can be greatly diminished. Geopolymer cements, which make use of discarded materials, demonstrate this concept.

Waste Minimization

By recycling concrete and utilising demolition waste as aggregate in the creation of new concrete, the amount of trash is reduced and valuable natural resources are conserved (Aleksandrova et al., 2019, Dimov et al., 2020). Smart crushers are advanced technologies that enable the efficient separation and recycling of different components of concrete.

Energy Recovery

Integrating waste heat recovery systems in cement factories enables the capture and reuse of energy, hence enhancing the total energy efficiency. Alternative fuels, such as biomass and fuels obtained from waste, decrease reliance on fossil fuels and decrease carbon emissions.

Product Longevity

Enhancing the longevity and durability of concrete decreases the necessity for frequent repairs and replacements, therefore preserving resources and minimising the environmental footprint over the lifespan of the product.

INNOVATIONS IN CEMENT PRODUCTION

Low-Carbon Clinker Substitutes

The production of conventional Portland cement clinker significantly contributes to CO₂ emissions due to the high-temperature calcination process required to transform limestone into lime. To address this environmental challenge, several low-carbon clinker substitutes have been developed to reduce carbon emissions associated with cement manufacturing by utilizing alternative materials and methods.

Belite-rich clinkers are a notable example of this innovation. Composed primarily of dicalcium silicate, belite forms at lower kiln temperatures compared to alite, the main component of traditional Portland cement. The production of belite-rich clinkers typically occurs at temperatures around 1250-1350°C, as opposed to 1450°C for alite-rich clinkers. This lower production temperature leads to decreased energy consumption and reduced CO₂ emissions (Buchwald et al., 2019). Additionally, cements with high belite content exhibit superior long-term strength development, although they may demonstrate slower initial strength gain, which can be a disadvantage in applications requiring rapid setting (Gartner, 2004).

Calcium sulfoaluminate (CSA) cements represent another significant advancement in low-carbon alternatives. The production of CSA cements involves mixing bauxite, limestone, and gypsum, with ye'elimite being the primary component of CSA clinker. During hydration, ye'elimite reacts with gypsum to form ettringite and monosulfate, which enhance the cement's strength. CSA cements generate lower CO₂ emissions during production due to reduced limestone content and typically lower calcination temperatures, usually around 1250°C. These cements also set quickly and exhibit high initial strength, making them suitable for fast-track construction projects while demonstrating excellent resistance to sulfate attack (Shi et al., 2011). However, the reliance on specific raw materials, such as bauxite, can pose challenges related to availability and cost (Wang et al., 2020).

Magnesium-based cements, including magnesium oxychloride and magnesium oxysulfate cements, utilize magnesium compounds instead of calcium compounds. A noteworthy variant is magnesium silicate hydrate (MSH) cement, which has the ability to absorb CO₂ during the curing process. This property allows magnesium-based cements to capture and sequester CO₂, thereby reducing net emissions. Additionally, these cements can be produced at lower temperatures compared to traditional Portland cement, leading to energy savings and decreased CO₂ emissions (Meyer, 2009). However, the durability and long-term stability of magnesium-based cements can be compromised in humid environments, and the raw materials required can be more expensive and less accessible than those used for conventional Portland cement (Powers, 2018).

Alkali-activated materials (AAMs), which include geopolymers, are created by activating aluminosilicate materials, such as fly ash or slag, with alkaline solutions. This process eliminates the need for high-temperature calcination, resulting in significantly reduced CO₂ emissions during

production (Davidovits, 1994). AAMs often utilize industrial by-products, which minimizes waste and reduces the demand for virgin raw materials.

Furthermore, AAM products demonstrate exceptional durability, including resistance to chemical attacks and high-temperature stability. However, the handling of strong alkaline solutions can present safety challenges, and the lack of standardized production methods can hinder wider acceptance (Van Jaarsveld et al., 2002).

In summary, low-carbon clinker substitutes offer viable solutions for reducing the carbon footprint of cement production. Each alternative presents unique advantages and challenges, and their adoption will depend on regional material availability, cost considerations, and specific application requirements.

Utilization of Industrial By-Products

The utilization of industrial by-products in cement production is a critical strategy for enhancing sustainability and reducing environmental impact. Incorporating materials such as fly ash, slag, and silica fume not only minimizes waste but also improves the performance characteristics of cement (Koprev et al., 2007).

Fly ash, a by-product of coal combustion in power plants, has gained significant attention for its pozzolanic properties. When used as a partial substitute for Portland cement, fly ash can enhance the durability and workability of concrete while reducing overall CO₂ emissions associated with cement production. Studies have shown that incorporating fly ash can lead to improved resistance to sulfate attack and reduced permeability in concrete, contributing to longer service life and reduced maintenance costs (Mehta & Monteiro, 2014).

Similarly, ground granulated blast furnace slag (GGBFS), a by-product from the steel manufacturing process, serves as an effective supplementary cementitious material. The use of slag in cement not only recycles industrial waste but also contributes to the production of low-carbon cements. Slag-based cements exhibit excellent mechanical properties and durability, making them suitable for a variety of construction applications. The hydration products formed with slag lead to increased strength development over time, further enhancing the longevity of concrete structures (Bentz & Stutzman, 2015, Hristova, 2022).

Silica fume, produced during the production of silicon metal or ferrosilicon alloys, is another valuable by-product that enhances the properties of cement and concrete. Its high silica content and fineness improve the density and strength of concrete, making it particularly effective in high-performance applications. The inclusion of silica fume can significantly increase compressive strength and reduce the permeability of concrete, thereby enhancing its durability against environmental stresses (Hooton & Bickley, 2006).

The incorporation of these industrial by-products not only contributes to the circular economy by diverting waste from landfills but also helps in the production of more environmentally friendly cements. By utilizing such materials, the cement industry can significantly reduce its carbon footprint while maintaining or even enhancing the performance of cement and concrete products (Scrivener et al., 2018).

In summary, the utilization of industrial by-products in cement production offers a promising avenue for achieving sustainability goals. By integrating materials like fly ash, slag, and silica fume, the cement industry can promote resource efficiency, reduce environmental impact, and enhance the overall quality of cement and concrete.

Energy Efficiency

Energy efficiency is a crucial aspect of modern cement production, significantly impacting both operational costs and environmental sustainability. The cement industry is inherently energy-intensive due to the high temperatures required for clinker production, making the optimization of energy usage a priority. One effective strategy for enhancing energy efficiency is the implementation of waste heat recovery systems. These systems capture excess heat generated during the manufacturing process, converting it into usable energy for various applications within the plant. By utilizing waste heat, cement producers can reduce their reliance on external energy sources and lower overall production costs (Zhang et al., 2018).

Advanced kiln technologies also play a vital role in improving energy efficiency in cement manufacturing. Innovations such as multi-channel burners and pre-calcination techniques enable more efficient fuel combustion and better thermal management within the kiln. These advancements not only enhance energy efficiency but also contribute to reduced CO₂ emissions. For instance, the use of pre-calcination allows for a portion of the Limestone to be calcined before entering the kiln, which can lower the energy requirements and increase the overall efficiency of the process (Hendriks et al., 2018).

Additionally, optimizing the operation of existing equipment through automation and process control systems can further enhance energy efficiency. By employing real-time monitoring and data analytics, cement plants can fine-tune their operations to minimize energy consumption while maintaining product quality. This integration of digital technologies enables manufacturers to make informed decisions and adopt best practices in energy management (Mourtzis et al., 2020).

Internet of Things

The Internet of Things (IoT) is essential for modernising cement production, alongside AI and ML. The Internet of Things (IoT) devices enable the gathering of extensive quantities of data from different phases of the production process, offering valuable insights that can result in enhanced operational efficiency. Embedded sensors in machinery and infrastructure have the capability to monitor performance characteristics in real time. This allows firms to make well-informed decisions using precise and fast information. The connectivity not only improves the visibility of operations but also enables preventive maintenance approaches, resulting in cost reduction and productivity enhancement (Li et al., 2018).

Integration of Artificial Intelligence and Machine Learning

The integration of artificial intelligence (AI), machine learning (ML), and Internet of Things (IoT) has a synergistic impact that enables cement makers to adopt intelligent production systems. For example, the use of AI-powered predictive analytics can enhance the efficiency of the supply chain by accurately predicting demand trends and making necessary adjustments to production schedules. This capacity is especially crucial for effectively managing resources and minimising surplus inventories, which can aid in achieving sustainability objectives (Wang et al., 2020).

Furthermore, the use of these digital technologies enables more effective environmental management. Cement plants can achieve substantial reductions in carbon emissions and energy usage by optimising their manufacturing processes and resource utilisation. Aligning with sustainability objectives not only ensures compliance with regulations but also strengthens the competitive edge of enterprises in a dynamic market (Mourtzis et al., 2020).

CONCLUSION

To summarise, the cement business is being transformed by the implementation of digital technologies such as artificial intelligence, machine learning, and the Internet of Things. These

advancements enhance the effectiveness of operations, facilitate preventative maintenance, and encourage environmentally-friendly practices. As the sector increasingly adopts these technologies, there is great potential for improved productivity and decreased environmental impact. Advanced technology improves cement quality by enabling real-time process monitoring, enhancing the stability of clinker composition, reducing energy consumption, and allowing for the development of new, sustainable materials like geopolymers concrete. Digital transformation, AI, and smart sensors provide greater insight into production data, leading to more efficient operations, higher quality control, improved reliability, and reduced waste.

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