

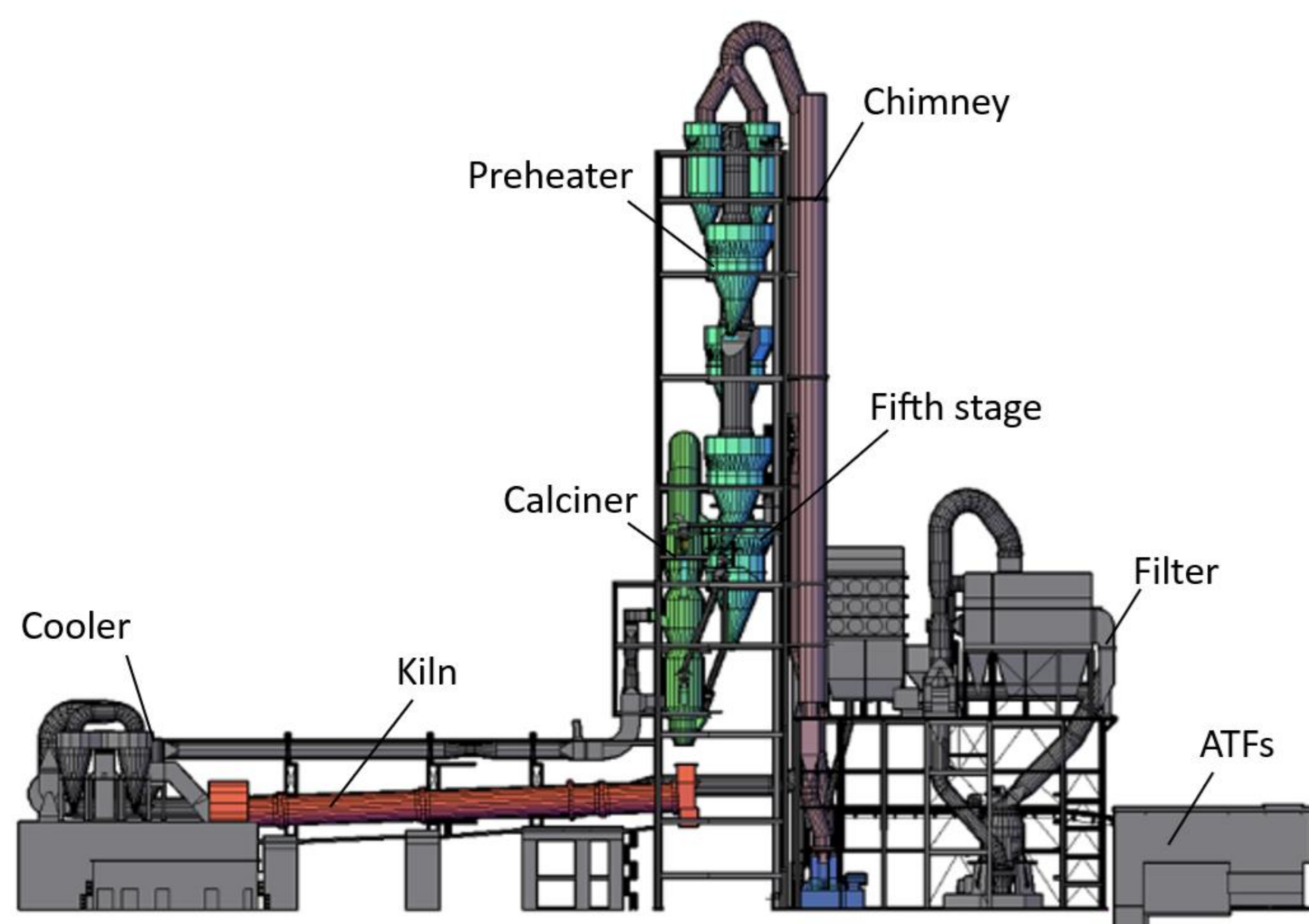
# OPTIMIZING CEMENT KILN OPERATION WITH EXPERT SYSTEMS

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## INTRODUCTION

The cement industry contributes significantly to global CO<sub>2</sub> emissions, driving the need for more efficient and sustainable operations. Clinker production is especially energy-intensive, making process optimization crucial. Traditional control systems struggle with the complexity of kiln operations. In response, this study presents a Kiln Expert System (KES) based on symbolic artificial intelligence, designed to stabilize critical variables, improve energy efficiency, and increase alternative fuel (ATF) usage, thereby reducing costs and environmental impact.



**Figure 1.** A typical preheater installation with five stages.

## METHODOLOGY

The KES was developed and implemented in a cement plant with a production capacity of 3,300 tons of clinker per day. The facility featured a five-stage preheater and multistage calciner, providing a complex environment for advanced control testing.

To reduce implementation risks, the initial phase prioritized stabilizing calciner combustion due to its critical role in energy efficiency and ATF use. KES employs symbolic AI to control essential variables like temperature and oxygen through predictive models and real-time regulation. To ensure reliable operation, redundant sensors were incorporated, and user-friendly graphical interfaces were designed for intuitive control. Its modular architecture, developed in close collaboration with plant staff, allowed seamless integration. A phased rollout and targeted training further supported operator engagement and system adaptability in an industrial environment.

## RESULTS AND DISCUSSION

**Table 1.** Comparison of calciner temperature before and after the implementation of KES.

Period [months]	STD Deviation [°C]	Max Deviation [°C]	Relative Error [%]	Type of Control
8	15.00	19	0.76	Traditional
17	8.31	13	0.21	KES

The KES significantly enhanced thermal stability in the calciner, as shown in Table 1. Before implementation, temperature deviation reached up to 19 °C, with a standard deviation of 15.00 °C and a relative error of 0.76%. After KES deployment, deviation dropped to 13 °C, the standard deviation reduced to 8.31 °C, and the error decreased to just 0.21%. This represents a 44.6% improvement in temperature stability and over 70% reduction in control error.

**Table 2.** Comparison of the use of ATFs before and after KES.

Years	ATFs Calciner [%]	ATFs Kiln [%]	ATFs Total [%]	Type of Control
1	31.85	6.75	38.6	Traditional
2	37.86	8.74	46.6	Transition
3	39.26	5.54	44.8	KES
4	46.53	4.57	51.1	KES
5	49.1	0.4	49.5	KES

The improved thermal stability achieved by KES enabled a consistent increase in alternative fuel (ATF) usage. In the first year under traditional control, ATF substitution in the calciner reached only 31.85%. After KES implementation, this figure steadily increased, reaching 49.1% by the fifth year. These gains reduced fossil fuel consumption and CO<sub>2</sub> emissions while minimizing refractory wear and maintenance needs. Table 2 summarizes the evolution of ATF usage across five years.

## CONCLUSION

The Kiln Expert System (KES) offers a novel solution for optimizing cement kiln operations by integrating symbolic AI and real-time control. Its deployment improved thermal stability, boosted ATF use from 31.85% to 49.1%, and reduced emissions and costs. Despite challenges like sensor calibration and operator skepticism, KES proved scalable and effective. Future work aims to incorporate subsymbolic AI to enhance optimization and extend its application to other energy-intensive industries.

## ACKNOWLEDGMENTS: