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ENERGY EFFICIENCY THROUGH COMBUSTION SYSTEM OPTIMIZATION IN REHEATING FURNACES

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Abstract

Reheating processes, which constitute a critical stage in steel industry production, hold significant importance in terms of energy efficiency due to their high energy consumption. In reheating furnaces, by-product gases, natural gas, or fuel oil are typically utilized. The walking beam reheating furnace examined in this study heats billets to the required temperatures—depending on product size and type—through 32 burners positioned in different furnace zones, providing stepwise heating. However, the imbalance in heat transfer within the furnace and the non-uniform distribution of heating rates lead to deviations from the target heating curve, thereby intensifying the scaling problem that causes production losses. The primary aim of this study is to reduce unnecessary natural gas consumption and minimize the carbon footprint by improving the control of the air–fuel mixture inside the furnace through burner optimization and automation systems. As a result of the implemented measures, considering the annual production *capacity, a total of 1,950,000 Sm³ of natural gas savings was achieved, corresponding to approximately 3,705–3,900 tons of CO2 equivalent emission reduction. These findings demonstrate a successful large-scale industrial application aimed at enhancing energy efficiency in reheating furnaces while mitigating environmental impacts.*

Keywords:

Energy Efficiency, Natural Gas Savings, Carbon Footprint, Air–Fuel Ratio Control, Reheating Furnace

1. INTRODUCTION

The global demand for steel has been steadily increasing, leading to a parallel rise in energy consumption [1]. Among the equipment used in the steel industry, reheating furnaces rank as one of the largest consumers of energy. Therefore, implementing energy efficiency improvements in these furnaces is of critical importance, not only for industrial sustainability but also for reducing environmental impacts. Optimization efforts in reheating furnaces can contribute significantly to both lowering carbon emissions and enhancing energy efficiency.

Several studies have been reported in the literature regarding this subject. For instance, Chakravarty et al. analyzed operational data, measurements, and energy balance calculations of a plant to evaluate the potential for reducing fuel consumption in billet reheating furnaces. Their study achieved an 11% increase in efficiency and a 14% reduction in oil consumption [1]. Renault et al. proposed an artificial intelligence–based reinforcement learning approach for the control of gas-fired furnaces, diverging from conventional control methods. Their findings demonstrated that reinforcement learning–based control provides a strong alternative to traditional techniques, improving temperature regulation, reducing fuel consumption, and enhancing overall energy efficiency [2].

Similarly, Liu et al. investigated the influence of furnace length on key performance indicators such as fuel consumption, efficiency, and surface temperature uniformity of billets. Using numerical simulations of different furnace lengths, they concluded that furnace length is a critical parameter for both heating efficiency and billet temperature distribution [3]. Wang et al. focused on optimizing the exergy efficiency of walking beam reheating furnaces by employing numerical simulation and entropy generation analysis. Their study revealed the impacts of various operating conditions on energy losses and available energy, identifying entropy generation during the combustion process as the most critical factor limiting exergy efficiency [4].

In another study, Xu et al. aimed to dynamically model the air–fuel ratio under variable fuel conditions. By incorporating fluctuations in lower heating values and fuel composition into their model, they highlighted the effects of these parameters on furnace performance and developed a method for dynamic air–fuel ratio control [5]. Wang et al. concentrated on the control of NOx emissions by utilizing online combustion data and artificial intelligence–based predictive models. Their approach enabled accurate prediction of NOx levels and facilitated optimization strategies to reduce emissions [6]. Similarly, Cao et al. developed a fuzzy neural network–based model to precisely adjust the air–fuel ratio in gas furnaces. The results showed that this method successfully optimized the air–fuel ratio, thereby improving energy efficiency and reducing emissions [7].

In the present study, the key parameters influencing energy consumption and efficiency in reheating furnaces are first examined in detail. The Methodology section outlines the data collection process and analytical steps. The Results section presents the findings of the analyses, emphasizing their impact on energy consumption, temperature distribution, and efficiency. Finally, the Conclusion discusses the overall outcomes of the study, highlighting the achievements in improving energy efficiency and reducing carbon emissions in reheating furnaces.

2. METHODOLOGY

The walking beam reheating furnace examined in this study consists of four zones, each equipped with eight burners, for a total of 32 burners. These burners gradually heat the billets to the required temperature depending on the size and type of the product, thereby supplying the production line. The study was carried out through a three-stage methodology: (i) implementation of maintenance and revision activities, (ii) improvement of automation and control systems, and (iii) execution of performance measurements.

2.1. Maintenance and Revision Activities

In the first stage of the study, maintenance and revision activities were conducted to enhance the reliability and efficiency of the system. Within this scope, the main gas inlet pneumatic valves and regulators at the pressure reduction station were inspected, and leak tests were performed. Malfunctions were addressed, and 16 pneumatic on–off actuators along with 16 flameless mode valves were replaced with new units. The external view of the reheating furnace following the maintenance and refurbishment activities is presented in Figure 1.

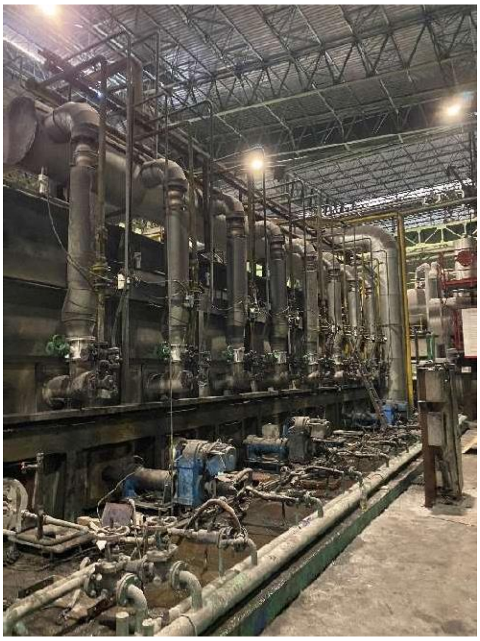

Figure 1. *External View of the Reheating Furnace*

In addition, the burner diffusers, refractory sections, and the connections in the gas–air pipelines were thoroughly inspected. To prevent potential leakages, all air and gas connections were reconfigured using flexible hoses. The furnace instruments employed during these activities are illustrated in Figure 2.

Figure 2. *Furnace Instruments Subjected to Revision*

2.2. Improvement of Automation and Control Systems

In the second stage, optimization studies were carried out on the automation and control infrastructure of the furnace. Data filtering processes were implemented within the SCADA system to enhance measurement stability. In addition, new algorithms enabling the automatic control of air and gas flow rates were developed and commissioned. Furthermore, flowmeters were integrated into different zones of the furnace, allowing real-time monitoring of the air– gas mixing ratios.

2.3. Performance Measurements

In the final stage, the performance of the system after the revision was evaluated. Using flue gas analyzers, the concentrations of O2, CO, NO, and NOx, as well as the flue gas temperature, were measured, and combustion losses were calculated. In addition, natural gas consumption values were systematically compared with the pre-revision measurements to conduct a comprehensive evaluation.

3. FINDINGS

3.1. Combustion and Emission Values

The measurement results obtained after the maintenance and optimization activities indicate significant improvements in furnace performance. The recorded values were as follows: O2 concentration at 1.1%, CO concentration at 19 ppm, NO concentration at 139 ppm, NOx concentration at 146 ppm, flue gas temperature at 821 °C, and combustion losses at 27%. These results, as captured from the analyzer display, are presented in detail in Figure 3.

Figure 3. *Measurement Results*

These data indicate significant improvements when compared with the pre-optimization values. In particular, the reduction of the previously elevated O2 levels to 1.1% demonstrates an enhancement in combustion efficiency. The decrease of CO emissions to 19 ppm confirms that combustion has become more homogeneous and complete. Furthermore, the stabilization of NOx levels at 146 ppm verifies compliance with environmental standards.

3.2. Energy Consumption and Savings

Following the revision, a significant reduction in natural gas consumption was recorded. A saving of 3 Sm^3 per ton was achieved, which corresponds to approximately 1.95 million Sm^3 of natural gas annually, based on a production capacity of 650,000 tons. This outcome provides substantial economic benefits to the plant in terms of energy efficiency.

3.3. Effects on Production Quality

The improvements achieved were not limited to energy and emission parameters. Ensuring homogeneous heat distribution within the furnace resulted in a reduction of scale formation on the billet surface. This, in turn, contributed directly to minimizing production losses and enhancing product quality.

4. CONCLUSION

This study examined the impacts of maintenance and optimization practices implemented in large-capacity reheating furnaces on process performance, energy efficiency, and environmental outcomes. Through actuator replacements, improvements in the SCADA system, and the integration of flow control mechanisms, a significant enhancement in furnace efficiency was achieved. As a result of these applications, approximately 1,950,000 Sm^3 of natural gas savings were realized annually, corresponding to a reduction of 3,705–3,900 tons of CO_2 equivalent emissions.

The findings demonstrate that the implemented energy efficiency measures not only yield economic benefits but also align with sustainable production goals by reducing emissions. While the reduction in natural gas consumption decreases operating costs, the improvements in emission levels emphasize the environmental benefits. Furthermore, achieving homogeneous heat distribution enhanced product quality and contributed to minimizing surface losses.

From a future perspective, the integration of artificial intelligence and machine learning–based control algorithms into furnace operations is anticipated to enable real-time and adaptive optimization. This approach is expected to elevate energy efficiency to even higher levels, offering strategic contributions to steel production processes in terms of both economic and environmental sustainability.

References

Cao, H., Du, D., Peng, Y., & Yin, Y. (2006). Air–fuel–ratio optimal control of a gas heating furnace based on fuzzy neural networks. In Advances in Neural Networks – ISNN 2006 (pp. 876–884). Springer. https://doi.org/10.1007/11760023_128

Chakravarty, K., Mondal, S., & Kundu, R. (2024). Improving the energy efficiency in a walking hearth type reheating furnace by energy balance method and optimizing the resources. Measurement: Energy, 3, 100010. https://doi.org/10.1016/j.meene.2024.100010

Kilinc, E., Kaya, D., Kilic, F.Ç. & Eyidogan, M. (2014). An Energy Efficiency Analysis of an Industrial Reheating Furnace and an Implementation of Efficiency Enhancements Methods. Energy Exploration & Exploitation, 32(6):989-1004. https://doi:10.1260/0144-5987.32.6.989

Liu, T., Dai, F., Zeng, W., Guo, Y., Zheng, S., & Li, H. (2023). Effects of furnace length on the thermal performance of a walking beam reheating furnace. Metals, 13(12), 1946. https://doi.org/10.3390/met13121946

Renault, M., Viaquart, J., Meliga, P., Grandin, G.-A., Meynet, N., & Hachem, E. (2023). Investigating gas furnace control practices with reinforcement learning. *International Journal of Heat and Mass Transfer, 209*, 124147. https://doi.org/10.1016/j.ijheatmasstransfer.2023.124147

Wang, C., Xu, J., Xu, K., Jiang, L., Wang, Y., Su, S., Hu, S., & Xiang, J. (2025). Real-time prediction and optimization of NOx emissions using artificial intelligence and online combustion data. Fuel, 391, 134836. https://doi.org/10.1016/j.fuel.2025.134836

Wang, D., Zhang, X., Zhu, Y., & Jiang, Z. (2024). Optimization of exergy efficiency in a walking beam reheating furnace based on numerical simulation and entropy generation analysis. Processes, 12(3), 451. https://doi.org/10.3390/pr12030451

Xu, J., Tian, G., Li, B., Qi, F., Wang, C., & Liu, Z. (2025). Modeling of dynamic air-fuel ratio under fuel calorific value and composition fluctuation: A case study of an industrial-scale reheating furnace. Applied Thermal Engineering, 279(Part C), 127671. https://doi.org/10.1016/j.applthermaleng.2025.127671

Zanoni, A., Feretti, I. & Zavanella, L.E. (2020). Energy savings in reheating furnaces through process modelling. Procedia Manufacturing, Volume 42, 2020, Pages 205-210.

https://doi.org/10.1016/j.promfg.2020.02.071

Zhao, J., Ma, L., Zayed, M.E., Elsheikh, A.H. Li, W., Yan, Q. Wang, J. (2021). Industrial reheating furnaces: A review of energy efficiency assessments, waste heat recovery potentials, heating process characteristics and perspectives for steel industry. Process Safety and Environmental Protection, Volume 147, March 2021, Pages 1209-1228. https://doi.org/10.1016/j.psep.2021.01.045