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Leveraging Optical Emission Spectroscopy (OES) for Enhanced Process Control in Electric Arc Furnace (EAF) Steelmaking

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Abstract

The electric arc furnace (EAF) serves as the main unit process in scrap-based steelmaking and is expected to be the main unit process for melting high-grade DRI produced using hydrogen direct reduction. Due to the energy intensity of the process, efficient process control and measurement solutions are needed. This work aimed to study how optical emission spectroscopy (OES) data can be used in tandem with other measurements to support EAF process control. To this end, data from a major steel company was employed for comparing an OES-based system (ArcSpec) with standard measurements of the arc stability factor. The results show that OES can be used to provide real-time data about the furnace condition and replace the old methods effectively in certain control issues at the furnace operations. Finally, some special benefits of using OES in steelmaking are discussed, specifically, the ability to estimate the charging time for the second scrap basket in the EAF in real-time, thereby yielding more information than traditional methods and helping operators make accurate decisions.

Keywords: Optical Emission Spectroscopy, Electric Arc Furnace, ArcSpec, Process Control

1. Introduction

Steel is one of the most recycled materials in the world, and electric arc furnaces (EAFs) are the main units to process recycled scrap metal. The European Union, in response to the significant impact of climate change on the environment, has prompted the European Green Deal (EGD). This comprehensive strategy aims to establish the EU as the world's first carbon-neutral continent by 2050. Moreover, as part of the EGD, the EU has committed to reducing greenhouse gas (GHG) emissions by a minimum of 55% by 2030 compared to levels observed in 1990 [1]. Hydrogen direct reduction is one of the efficient ways to decrease GHG in steelmaking. EAFs have also been envisioned as the main process for melting direct reduced iron (DRI) produced using hydrogen direct reduction. Although the EAF process is well-established, there is still room to improve its energy and materials efficiency further.

Operators of EAFs are striving towards dynamic control, granting operators new possibilities to monitor and adjust the EAF process during the heating phase [2]. However, there is a shortage of sensors capable of withstanding the harsh conditions of EAF operations. The lack of real-time data, along with imprecise knowledge of scrap composition, results in significant variations in tapping temperature, metal yield, and energy efficiency, which may only be detected after tapping [3]. Owing to the scarcity of information from the process, complex modeling and simulation tools have been developed to predict phenomena [4] or the course of the process [5].

Optical emission spectrometry (OES) is an experimental technique of material science, that focuses on measuring the wavelengths of the spectrum of light [6]. OES offers a way to measure the characteristics of matter in the electric arc. Visible (VIS), ultraviolet (UV), and near-infrared (NIR) radiation emitted contains data about the excited elements [7].

Optical emission spectroscopy has numerous advantageous features. Firstly, spectrum analysis can be conducted remotely in a protected environment by utilizing optical fibers for light gathering, ensuring minimal signal loss during transportation. Secondly, emission spectroscopy offers the advantage of low delay between measurement and data acquisition. This method is very fast, typically measured in seconds at most. This enables real-time analysis of the EAF process [6]. The results show that OES can be used for a more detailed analysis during hydrogen plasma smelting reduction of iron ore [8].

This work aimed to study how OES data can be used in tandem with other measurements to support EAF process control. To this end, data from a major steel company was employed for comparing an OES-based system (ArcSpec from Luxmet Ltd.) with standard measurements of the arc stability factor.

2. Materials and methods

ArcSpec, an OES-based technology for light measurement, was implemented in an electric arc furnace operated by a European steel producer. The furnace operates by charging 2 baskets of scrap metal. Figure 1 illustrates the schematic of the ArcSpec installation within the electric arc furnace. The furnace has a capacity of 60 tons and operates on alternating current (AC), producing carbon steel.

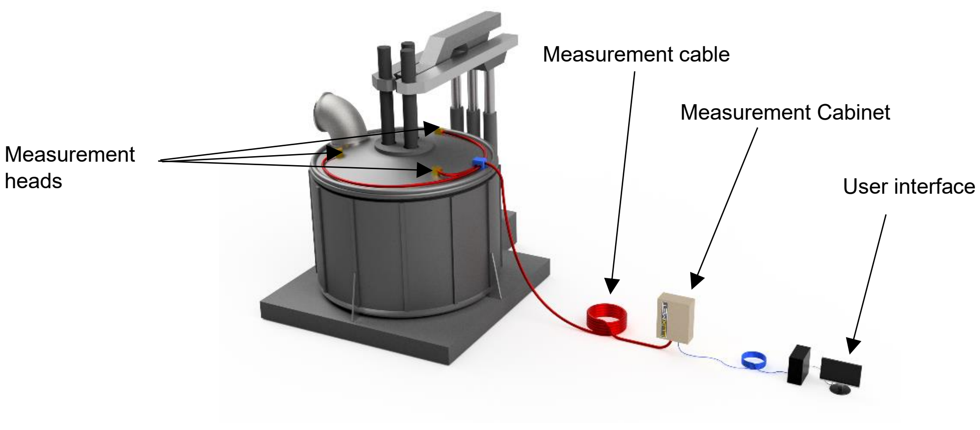

Figure 1. ArcSpec system configuration

ArcSpec consists of three measurement heads, which are connected to the measuring cabinet via measurement cables. Within the measuring cabinet, data is processed, and the collected data is displayed on the user interface. The data from 420 heat cycles have been collected for this article. Each heat cycle starts from the time that the furnace is opened to charge the scrap metal and ends when the furnace is ready for tapping.

3. Results and discussion

The ArcSpec technology is an important tool in monitoring scrap melting progress in the electric arc furnace (EAF), helping operators make informed decisions. Figure 2 presents data obtained from an industrial EAF, showing heat cycle data based on specific criteria. The blue dots demonstrate the time when ArcSpec indicates furnace readiness for charging the second scrap basket based on OES data, while the red dots show the actual time the furnace is shut down for the second scrap basket charging. This data is collected throughout 420 heat cycles.

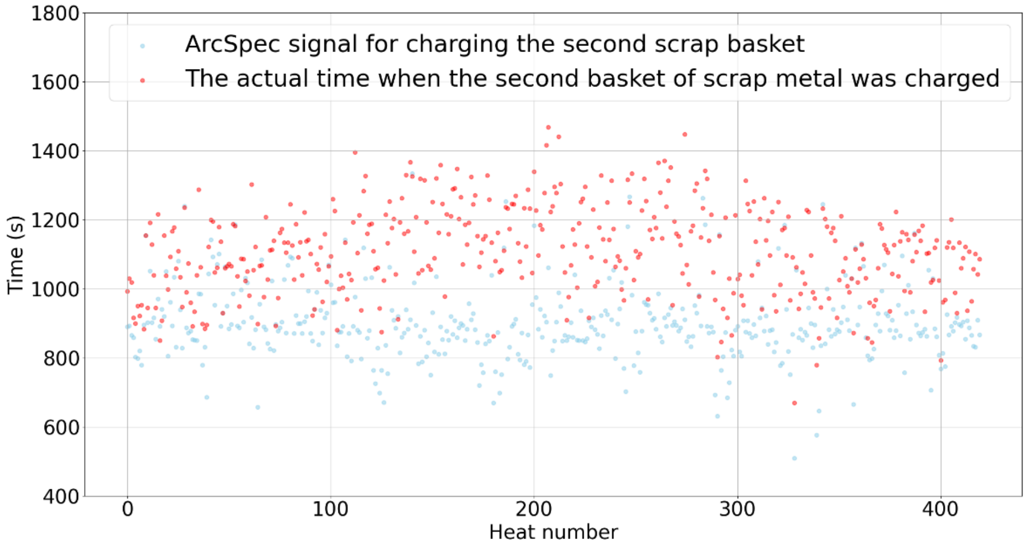

Figure 2. The time difference between the suggested charging time for the second scrap metal basket by ArcSpec and the actual charging time.

The data clearly shows that these two values are close to each other. Typically, operators rely on factors like arc stability and water temperature of cooling panels to adjust the optimal time for charging the second scrap basket. However, ArcSpec offers an advantage by analyzing emitted light from molten slag, and sending a signal on the user interface when the majority of the charge is melted, and the second basket can be charged. Given the energy-intensive nature of the EAF process, even a one-minute saving per heat cycle translates into significant electricity savings annually.

Figure 3 presents a histogram illustrating the time difference between ArcSpec's signal for charging the second basket and the actual charging time. The time difference is segmented into 50-second intervals, with negative bars indicating instances where charging was delayed based on ArcSpec data.

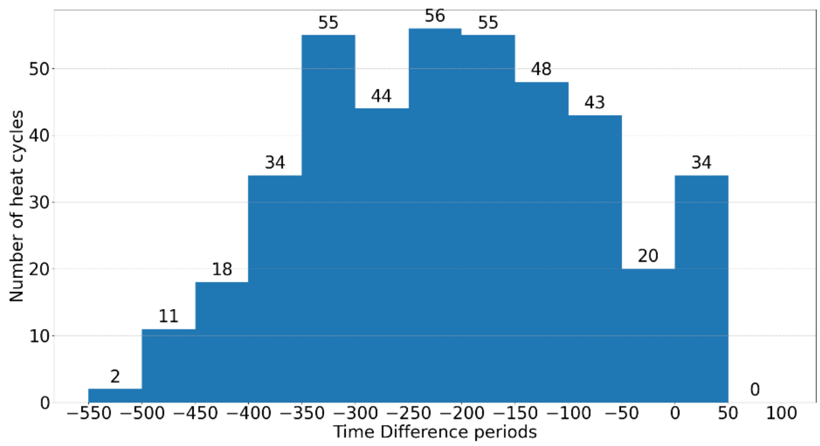

Figure 3. Histogram of time difference

Calculation shows that approximately 2480 kWh of electricity could be saved per heat cycle. Considering an electricity price of 0.08 euros per kWh, this equates to an average savings of 3.3 €/ton of steel. The modular structure of ArcSpec allows it to be implemented for different EAFs and other melting processes. Because of the real-time information, it can also be used for process status monitoring in DRI using EAF or Hydrogen Plasma Smelting Reduction furnaces.

4. Conclusions

Robust sensors are needed for the control of the EAF process. The ArcSpec system is based on optical emissions spectroscopy. By providing real-time data on scrap melting progress, ArcSpec enables operators to make informed decisions, optimizing furnace operations and maximizing process efficiency.

In this study, the ArcSpec monitoring system was tested at a 60-ton EAF. The results of 420 heat cycles presented in this study demonstrate the effectiveness of ArcSpec in accurately signaling the optimal time for charging the second scrap basket, based on analysis of emitted light from inside the furnace. This capability not only streamlines the charging process but also leads to substantial electricity savings over multiple heat cycles.

Finally, the modular design of ArcSpec enhances its versatility, allowing for seamless integration into various EAF configurations and processes. This adaptability extends its utility beyond traditional

steelmaking applications, making it suitable for use in EAFs using Direct Reduced Iron (DRI) as raw material or the Hydrogen Plasma Smelting Reduction process. Overall, ArcSpec shows potential for enhancing operational efficiency and reducing energy consumption within the steel industry.

Acknowledgments

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