GreenHeatEAF

Gradual integration of REnewable non-fossil ENergy sources
and modular HEATing technologies in EAF for progressive CO2 decrease

# Report of results from off-gas temperature and heat recovery monitoring system

**Deliverable D1.4 (D4) (PU)**

Toste Jonsater (HOG)
Emanuel Thienpont, Thorsten Hauck (BFI)
Maximilian von Campenhausen (B&D)

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# 1. Introduction

## 1.1 Purpose and scope of the present document

The document summarises the installation and adjustment of the AGAM measurement device in the duct of the Höganäs (HOG) EAF and shows the first results of offline and online off-gas temperatures values and exploitation of indirectly derived metrics.

## 1.2 Structure of the document

The document is structured as follows:

- Section 2 reports on the measuring principle of the AGAM device (Section 2.1)), its installation (Section 2.2), the initial and actual adjustments to the internal parameters (Section 2.3), and the initial outcomes of the offline and online temperature values, as well as the potential applications of the new measurement device (Section 2.4).
- Section 3 concludes the results.

# 2. Report of results from off-gas temperature and heat recovery monitoring system

This section presents the measuring principle and installation location of the acoustic gas temperature measuring device (AGAM), along with the results of adapting its internal parameters and the preliminary results of indirectly derived values.

## 2.1 Fundamental measuring principal of AGAM

AGAM is based on a simple but reliable acoustic principle for measuring contactless temperatures in harsh environments. The speed of sound in a gas depends on the temperature. The temperature can be determined using the known distance between the sensors. As a contactless measurement method, AGAM has no wear parts in the exhaust gas flow. All components are located outside the measurement atmosphere and are thus protected from the rough conditions in the off-gas duct. The measuring setup is shown in Figure 1. AGAM uses compressed air to generate sound, which makes the sensors self-cleaning [1]. AGAM measures the real gas temperature free from radiation errors with a measuring range of the system between 50–1,500 °C.

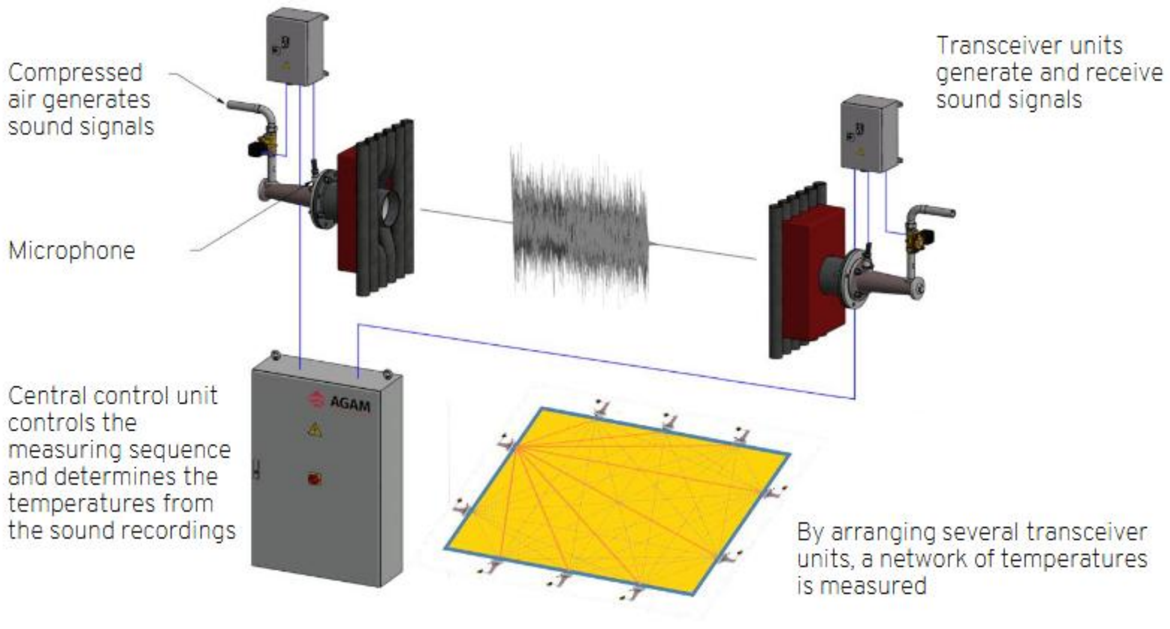


Figure 1 : AGAM measurement principle [2]

The propagation of sound is significantly influenced by the temperature of the medium, whether it be gaseous, liquid, or solid. In various fields such as meteorology, hydrology (e.g., SONAR), and industry, the sound's time of flight is crucial for accurate distance measurements. The determination of the time of flight is also the fundamental working principle of the AGAM system. Knowing the distance between transmitter and receiver, the temperature in a gaseous medium can be calculated from the speed of sound. This relationship is quantitatively expressed by the following formula [2]:

$$v = \sqrt{\frac{\gamma\, RT}{M}} \tag{1}$$

where:

| | |
|---|---|
| $v$ | is the speed of sound |
| $\gamma$ | is the adiabatic index |
| $R$ | is the molar gas constant |
| $M$ | is the molecular mass of gas |
| $T$ | is the absolute gas temperature |

By accurately measuring the travel time of an acoustic signal through hot gas, the speed of sound can be determined. Since this speed is directly correlated to the temperature of the gas, this measurement enables the precise calculation of the average temperature along the signal's path.

AGAM utilizes transceiver units to transmit and receive acoustic signals. A transceiver unit generates acoustic white noise by releasing pressurized air through a nozzle. This signal is then recorded by microphones in both the transmitting and receiving transceiver units. When one transceiver unit is transmitting, all others are set to receiving mode, enabling simultaneous evaluation of the direct paths between the transmitting unit and all other receivers, cf. Figure 1. The recorded audio signals are amplified and then forwarded to the control unit. The control unit digitizes and analyses the audio signal, subsequently calculating the temperatures based on this analysis. [2]

## 2.2 Installation of AGAM

At the start of the project, the AGAM system should be installed directly after the EAF elbow, within the first few metres of the Water-Cooled Duct (WCD), as indicated by the yellow box in Figure 2. Due to safety constraints and to avoid damaging the cooling system, no adequate location could be found within the water-cooled section of the duct. However, it was possible to install the AGAM system directly after the cooled section of the WCD, in the non-cooled section, cf. Figure 2.

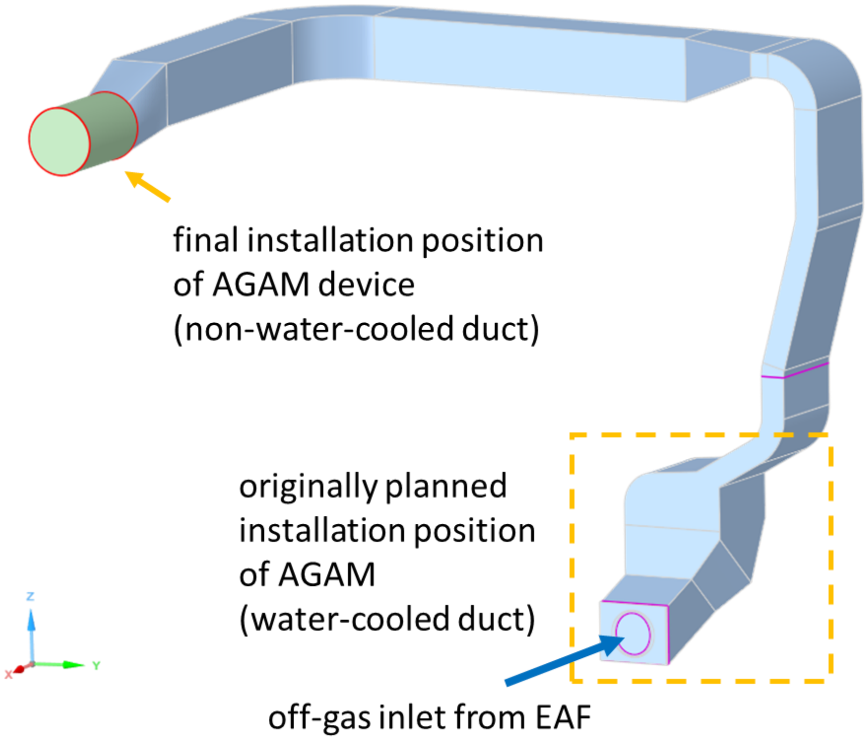


**Figure 2 : Installation location of AGAM at HOG EAF duct**

Figure 3 shows the installation location, together with a schematic representation of the system consisting of four horizontally (cf. Figure 5) arranged sensor horns (two on each side of the duct). Figure 4 shows the AGAM sensors (transceivers) before they were installed in the HOG duct.

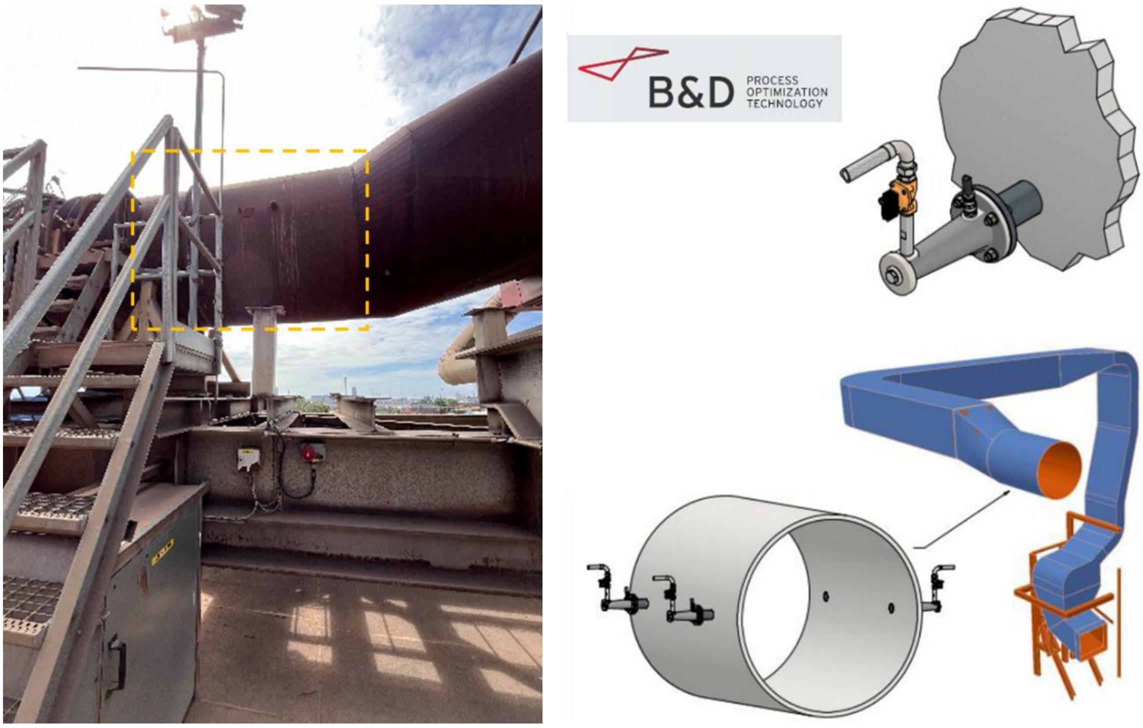


**Figure 3 : Final installation location of the AGAM system in HOG EAF duct (non-water-cooled section)**

**Figure 4 : AGAM horns before installation**

The horizontal plane between the AGAM horns is depicted in Figure 5 including the 4 measuring paths between the horns.

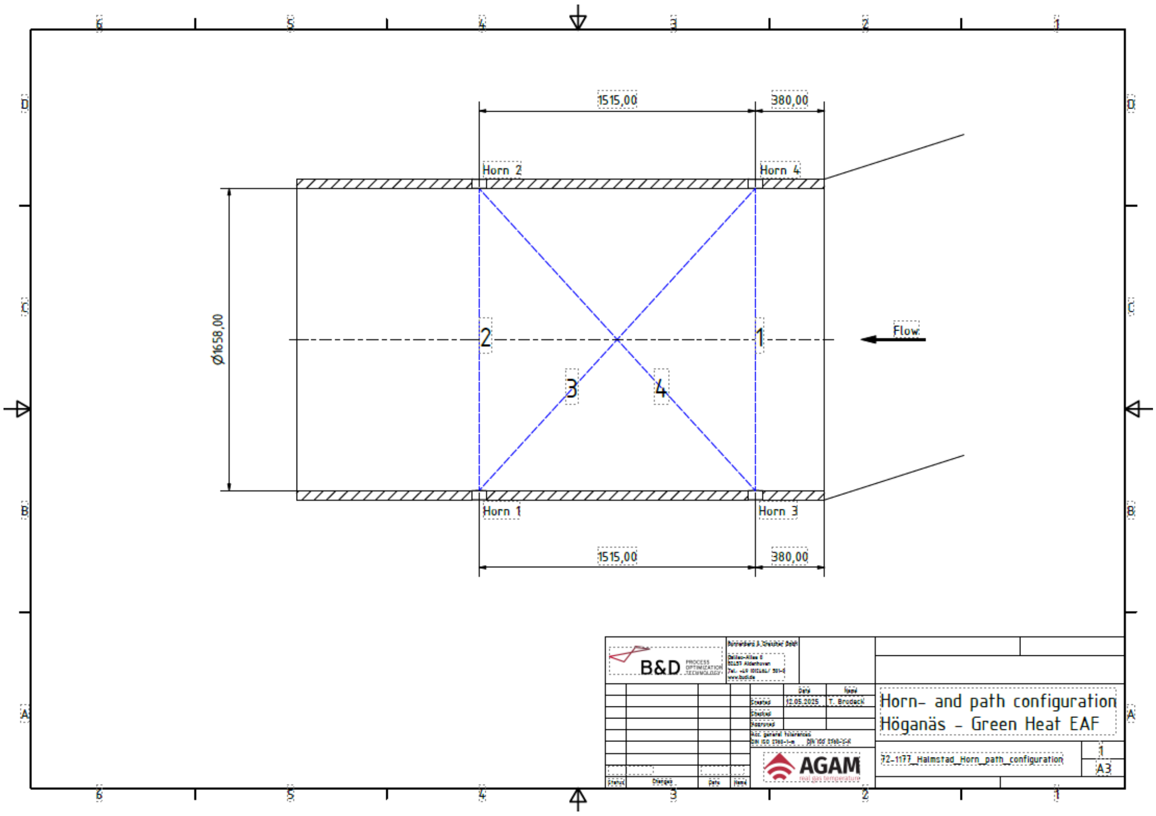


**Figure 5 : Arrangement of AGAM horn, horizontal cross section**

## 2.3 Adjustment of internal AGAM parameter

After the AGAM system was installed in the duct of the HOG EAF, the system was initialised, and the first continuous temperature values were recorded. These initial temperature values are shown in Figure 6. The dashed line represents the first measurements taken during Heat 250490 in February 2025, following installation. The red line in Figure 6 shows the temperature values recorded by a thermocouple located directly after the AGAM installation point in the uncooled duct, which is used as the reference temperature.
The initial recorded temperature values generally follow the trend of the reference thermocouple, but considerable deviations are observed in some sections (see Figure 6 at 14:47 and 15:10). Consequently, the AGAM system's internal calculation parameters were adjusted to enhance the temperature calculation, producing the temperature values represented by the blue line in Figure 6. The new temperature curve shows significant improvement in the critical section from the initial output. At least, the AGAM temperature values are higher than those of the reference thermocouple. In some cases, the deviation is only minor, at around 20 K; however, it can also deviate by up to 170 K.
The deviation is particularly noticeable during periods of rapid temperature change, such as between 14:15 and 14:20, or at 14:50. During these periods, which mark the beginning of the melting cycles of buckets 1 and 2 respectively, extremely high temperature fluctuations are to be expected. It is unclear whether the slow response of the conventional thermocouple contributes to the damping of the temperature values, or if the fast AGAM measurement, which is independent of internal components, reflects the true gas temperature without any slow response effects. As the off-gas composition and temperature fluctuate significantly during these periods, it is unclear whether the AGAM measurement can respond quickly enough to these changes in the internal calculation algorithm.

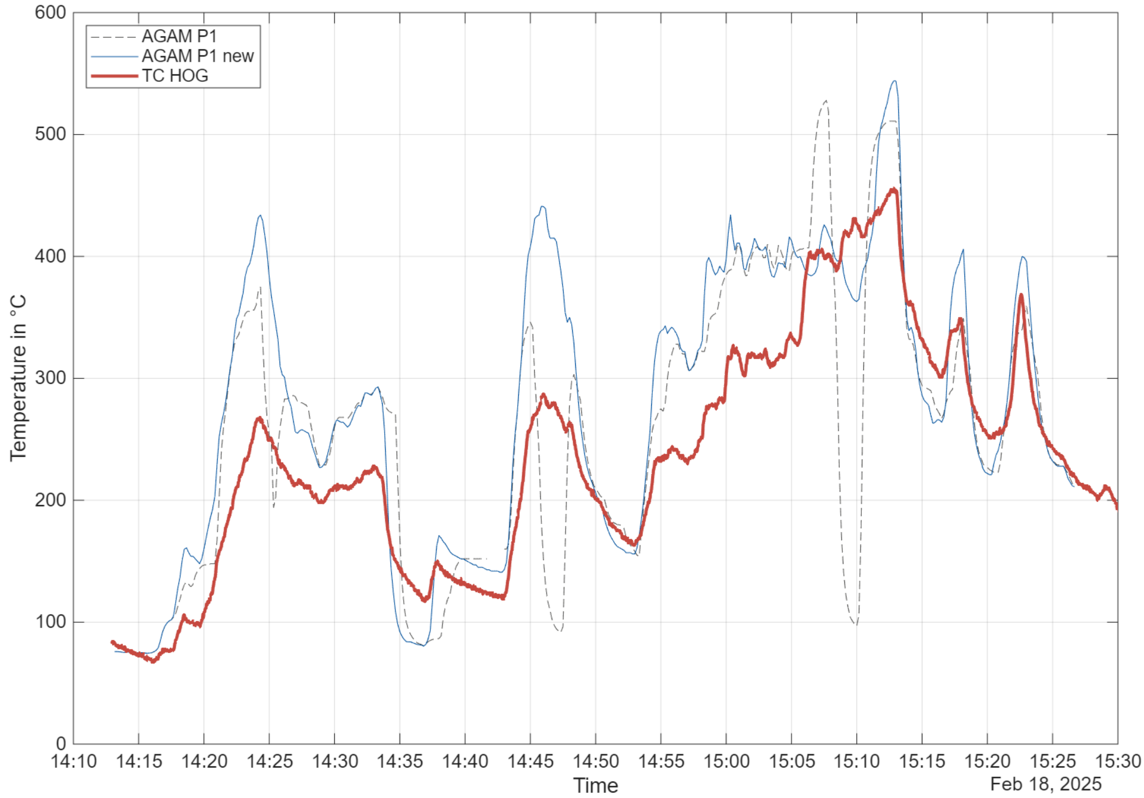


**Figure 6 : Temperature output of AGAM device (Q1 2025), initial and improved AGAM parameter, Heat 250490**

The AGAM system can be used to estimate the gas velocity in the duct. This can be calculated using the velocity differences on paths 3 and 4 (see Figure 5), for example by measuring the time taken for the gas to travel from horn 3 to horn 2 in the flow direction and in the opposite direction (from horn 2 to horn 3) against the flow direction. Figure 7 and Figure 8 show the estimated gas velocity during heat 250490, calculated using the initial AGAM parameters and the improved parameters, respectively. The fluctuations with the improved parameters are smaller than with the initial ones. After removing outliers[1], the average gas velocity is 7.5 m/s, as shown in Figure 8. This estimated gas velocity can then be used to validate the gas velocity at the AGAM position in the CFD calculation.

[1] Outliers are defined as elements more than three local scaled MAD from the local median over a window length k

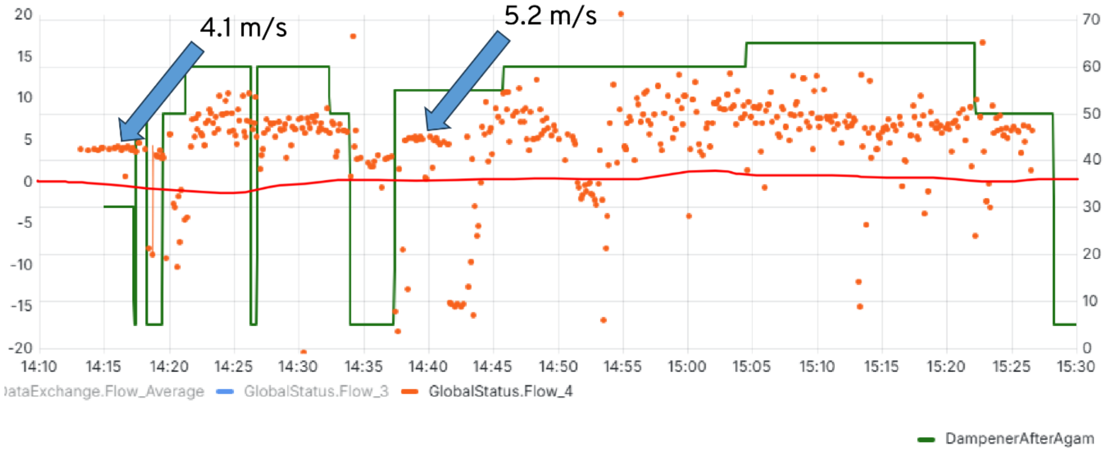


**Figure 7 : Gas velocities derived from initial calculations (Q1 2025), Heat 250490**

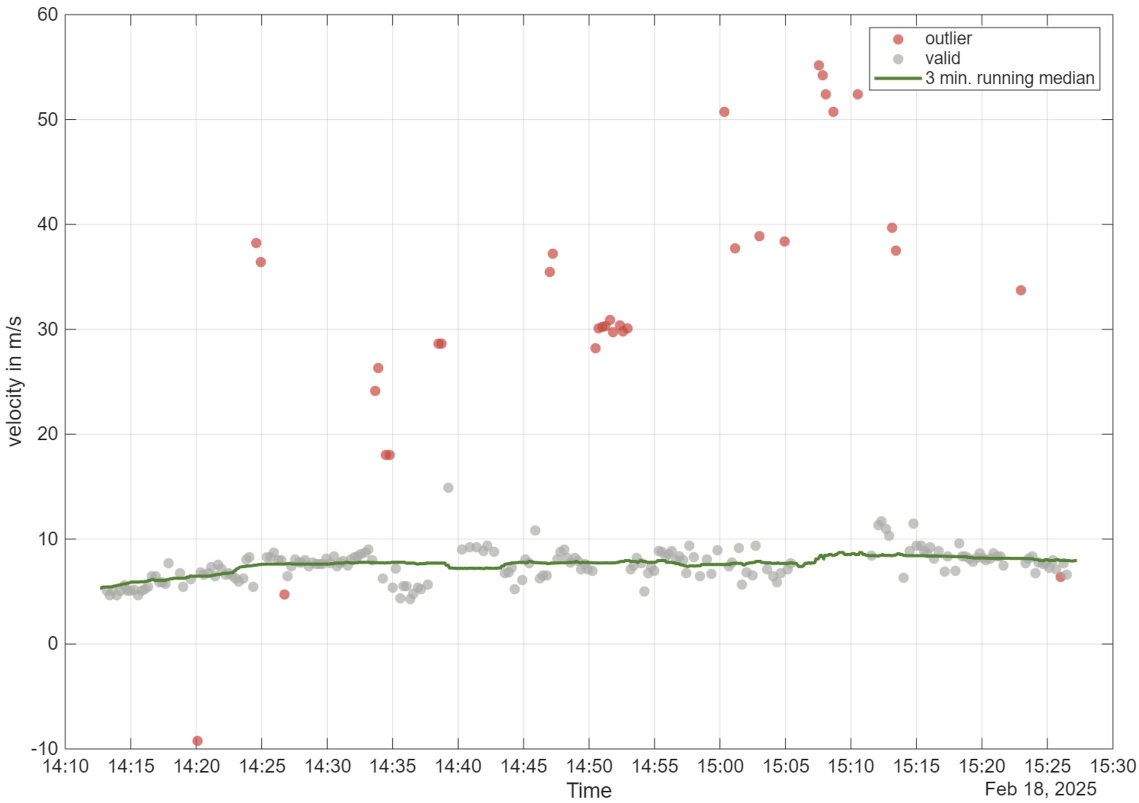


**Figure 8 : Gas velocities derived from new calculations (Q1 2025), Heat 250490**

## 2.4 HOG off-gas temperature and exploitation

Measurement data obtained online from the AGAM system can be used to calculate the indicative heat loss of the EAF furnace following the water-cooled section. The heat loss can be calculated by:

$$\dot{Q} = \dot{m} \cdot C_p \cdot \Delta T \quad (2)$$

where:

$\dot{Q}$ is the heat loss of the off-gas

$\dot{m}$ is the mass flow of the off-gas

| | |
|---|---|
| $C_p$ | is the heat capacity of the off-gas |
| $\Delta T$ | is the temperature difference of the off-gas |

The gas velocity can be used to calculate the volume flow; the mass flow can then be estimated using the off-gas composition and density. Therefore, the off-gas composition can be used to determine the heat capacity. The temperature difference is given by subtracting the measured off-gas temperature (AGAM) from the ambient temperature.

The heat loss value can be used to obtain direct information about the actual heat loss of the EAF, as well as providing information about the heat recovery limit of the WCD, which is used for steam production at HOG. Information on the heat loss of the off-gas provides further possibilities to optimise, for example, the (false) air intake into the EAF furnace and the post-combustion in the WCD. By limiting the air intake into the WCD, the post-combustion reaction can be shifted towards the furnace, thereby increasing the furnace's energy availability for the melting reaction.

# 3. Conclusions

The contactless temperature measurement system AGAM was installed in February 2025 at the duct of the HOG EAF after the water-cooled section of the duct. The first online measurements and evaluations was then carried out. The internal temperature calculation algorithm has been optimised for EAF off-gas conditions and has shown significant improvement over the initial settings. However, in some highly unstable operating conditions, the results still deviate from those of conventional temperature measurement. One possible reason for this is the rapid and significant changes in the off-gas composition or dust load. Another possible reason is that the conventional thermocouple cannot respond quickly enough to fast temperature changes due to its slow reaction time. The AGAM temperature values are higher in those regions due to the fast reaction time of the measuring system. These values are not damped by the thermocouple shell material because the AGAM system measures temperature contactless. The temperature and velocity information can be used to calculate the indicative heat loss of the EAF through the off-gas online. This information enables the false air intake through the gaps to be adjusted more effectively and provides additional information on the limits of the existing heat recovery system (steam production).

# 4. List of Figures

# 5. List of acronyms and abbreviations

| Acronym | Full Name |
|---|---|
| HOG | Höganäs |
| EAF | Electric Arc Furnace |
| AGAM | Acoustical gas measuring device |
| WCD | Water-Cooled Duct |

# 6. References

1] GmbH, Bonnenberg & Drescher, „www.budi.de,“ 02 12 2025. [Online]. Available: https://www.budi.de/en/agam-2d-gas-temperature-measurement.html

[2] Bonnenberg & Drescher GmbH, „https://acoustic-gas-temperature.com,“ 02 12 2025. [Online]. Available: https://acoustic-gas-temperature.com/