Deliverable 8.6

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Cross-sectorial real-time sensing, advanced control and optimisation of batch processes saving energy and raw materials (RECOBA)

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Pilot scale test of ladle refractory temperature monitoring system

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Lead contractor for this deliverable: ELKEM

Author:

Company	Name
BASF	
TKSE	
ELKEM	Kjetil Hildal, Lars K Jakobsson
UCAM	
RWTH	
VSCHT	
PMAT	
BFI	
CYB	
MINKON	

Dissimination level

PU	public	☒
PP	restricted to other programme participants (incl. the Commission Services)	☐
RE	restricted to a group specified by the consortium (incl. the Commission Services)	☐
CO	Confidential, only for members of the consortium (incl. the Commission Services)	☐

CONTENT

FIGURES

1 Introduction

The refining of silicon takes place in a ladle made up of a steel casing, a layer of insulating refractory materials and a bottom plug supplying air and oxygen to the molten silicon, as previously described in deliverable D.2.3. Furthermore, the heat loss from the molten silicon at about 1600 °C to the ladle refractory has a significant impact on the overall heat distribution in the system. As shown in deliverable D.8.5, the temperature distribution in the ladle refractory depends on the cycle number. It may take as many as 5-8 fillings of the ladle before the temperature through the ladle has reached a quasi-steady state. This heat loss impacts the overall economy of the process in several ways:

- Heat lost to the ladle refractory could have been used to re-melt silicon fines and B-grade material
- The temperature drop requires oxygen ($Si + O_2 = SiO_2$ is strongly exothermic) to supply heat to the ladle, but this may cause the silicon to be over-refined in order to keep the desired temperature, decreasing the yield of Si.
- Loss of heat causes solid deposits (sculls) at the ladle wall that must be removed mechanically, causing wear and tear to the ladle refractories and reduces lifetime of the ladle and establishes the need for costly repairs and re-building of the ladle refractory.

Addressing these issues brings about solutions like

- Sufficient pre-heating of the ladle refractory
- Monitoring the refractory temperature
- Modelling the overall temperature distribution in the ladle
- Proper ladle design
- Refractory materials selection

In deliverable D.8.4, various techniques (invasive and non-invasive) was discussed for measuring the temperature of the ladle refractory. Based on this previous report, Elkem decided that only thermocouples would be sufficiently cost-efficient to be used in the day-to-day operations at a smelting plant. This report describes testing of embedded thermocouples to measure the temperature in the ladle refractory (directly and continuously). The following points have been emphasized:

- Temperature measurements should be carried out with minimal work for the operators.
- Temperature signals should be recorded automatically and logged on a server accessible for the on-line model.
- Thermocouples must last the lifetime of a ladle.
- Insertion of thermocouples must not negatively affect the overall integrity of the ladle.

In addition, due to moving ladles the transmission of signal must be based on a wireless system, minimizing the length of any cables.

2 Measurement campaign

The test campaign will be carried out at Elkem Thamshavn, furnace #2. The initial campaign was originally planned for week 14-16, but it has been postponed since the ladle which has been prepared for the test does not go into production untill week 23-24. These are plant decisions involving ladle logistics that was beyond the control of the Recoba-project. As soon as the ladle is used in the production the temperature measurements will be acquired.

2.1 Setup for test

The refining ladle is shown in Figure 1, together with the position of the thermocouples. The refractory walls are about 30 cm thick, mostly alumina-based. A steel casing surrounds the cast refractory. Holes were drilled through the steel casing into the refractory prior to firing (sintering) as it is virtually impossible to drill into the fired refractory with normal drilling equipment available at the plant. Thermocouple wires, type N, (Figure 2, left) will be inserted into these pre-drilled holes and the temperature signal transmitted through cables protected by a rubber hose to wireless transmitters (Figure 2, right) which transmit the signals to a reciever connected to a stand-alone computer, where the temperatures are stored.

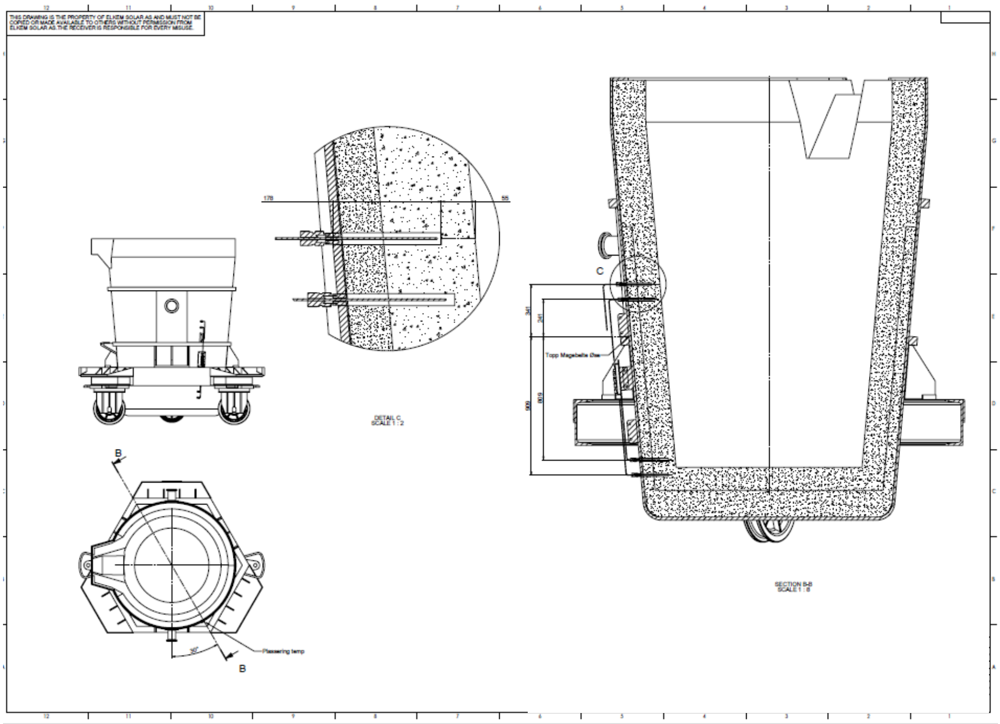

Figure 1 - Ladle with TC positions.

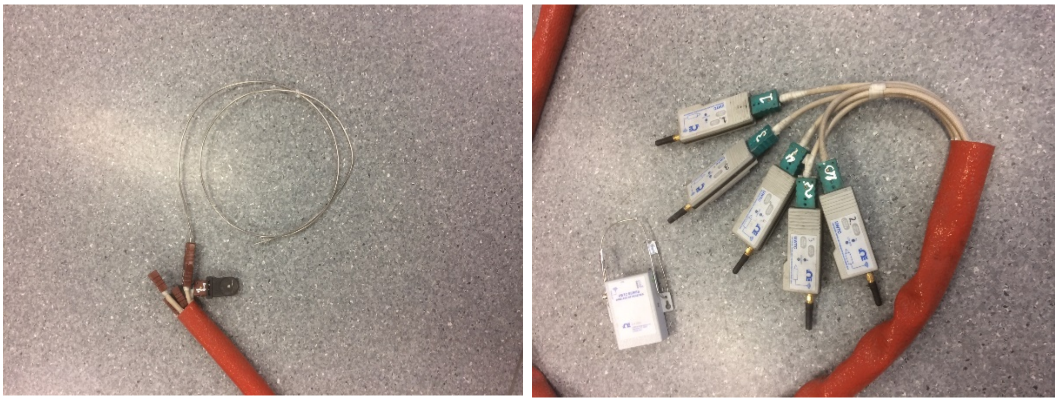

Figure 2 - Thermocouples for refractory measurements (left) and transmitters (right).

The setup has been tested in a laboratory environment with success. It is not anticipated that the harsh conditions at the plant (dust, heat, mechanical impact) will negatively affect the measurements, but this remains to see. Sensitive components are protected inside steel casings, such as the outside ladle connection from the thermocouple to the transimission cable.

2.2 Results

At the time of reporting, the actual measurements has not yet started due to delays at the plant. They are expected to commence May 2017. Once data is acquired, these will be compared to the model previously described in Deliverable D.8.5.

3 Conclusion

The use of thermocouples embedded in the ladle refractory lining offers the most cost-efficient and reliable way of acquiring temperatures for on-line monitoring of the thermal status of the ladle. Some of the anticipated challenges are combatted by using a wireless transmission system of the signal, minimizing the need for cables that are vulnerable to mechanical and thermal impact.