Deliverable 3.8

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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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Coverage efficiency sensor to monitor temperature loss of high-temperature fluid by radiation

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Author:

Company	Name
BASF	
TKSE	
ELKEM	
UCAM	
RWTH	
VSCHT	
PMAT	
BFI	Herbert Köchner, Tobias Kordel
CYB	
MINKON	Mark Potter, Marek Cichonski

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

1 Coverage efficiency sensor

1.1 Theoretical background

The coverage of the batch can change from batch to batch and can have an important impact on process properties. In the steel application the coverage of the steel will influence the temperature loss due to the varying isolation. During vacuum treatment most of the energy is lost by thermal radiation. The power P radiated from a surface depends on temperature T and spectral emissivity $\varepsilon(\lambda)$ of the surface and can be calculated by the Stefan-Boltzmann law

$$P = \varepsilon A \sigma T^4,$$

where A is the radiating surface area and σ the radiation constant.

Since the properties of the cover are usually not well known, it is difficult to calculate the thermal losses of the cover by a model. However, for a process model, which is often used to predict the melt temperature, the energy loss of the cover is an important term in the energy balance calculation. Thus, the energy losses need to be measured in an appropriate way.

To estimate in which range of the electromagnetic spectrum most of the power is radiated, black body radiation is assumed. The wavelength of highest spectral intensity can be calculated using Wien's displacement law

$$\lambda_{max} = b/T,$$

where b = 2,9 µm K. Thus, the intensity spectrum of a black body at a temperature of 1000 K has its maximum at a wavelength of λ_{max} = 2,9 µm, which is in the infrared (IR) spectral range. For this reason for coverage efficiency monitoring a detector was developed, which is sensitive in the IR.

1.2 Construction

In principle, the coverage efficiency sensor (CES) has a very wide spectral sensitivity range from VIS to the FIR (0,2 to 50 µm). To be applicable in a steel shop, the sensor element was placed in a rugged stainless steel housing to withstand the harsh industrial environment. For protection an exchangeable window is placed in front of the detector element. Here, a Si window is used which is transparent in the IR range from 1,2 to 7 µm. Depending on the application also other filters can be easily mounted.

The field of view can be adjusted to the specific application by an aperture. In this case the opening angle was chosen to be 20°. The coverage efficiency sensor is supplied internally with pressurized air, which cools the sensor element and makes it robust against high ambient temperature and thermal radiation from the melt surface. The filter glass is rinsed with compressed air to reduce deposition of vapor from the melt. The price of the sensor is low cost compared to an IR-Camera which makes replacements more affordable. The small structural shape of the sensor (90x120x225 mm^3) reduces the constraints on the mounting place and makes thermal protection easier.

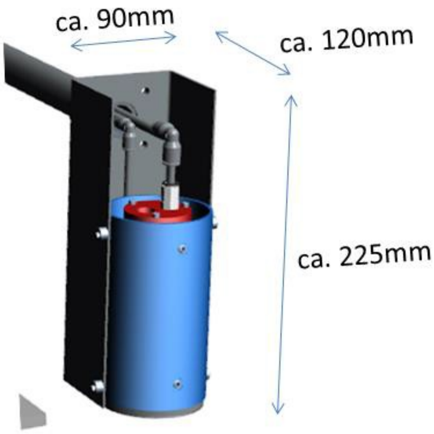

Figure 1: CAD drawing of the CE-sensor with outer dimensions

1.3 Industrial trials

The developed coverage efficiency sensor has been tested in laboratory trials as well as in trials in industrial environment. First the principle functionality has been proven. A piece of scaled steel was heated inside a resistance furnace up to 1000°C. Then the furnace was switched off and the door was opened. The emitted thermal radiation of the scaled steel plate was measured with the coverage efficiency sensor. At the same time, the temperature inside the furnace was measured using a thermocouple element. Both measurements showed a good correlation indicating good functionality in radiation detection.

Subsequently the sensor was tested in the industrial environment of a foundry. The sensor was mounted 40 cm above a steel melt in an induction furnace. For comparison, a camera was mounted in an air cooled protective housing directly next to the CE sensor. The radiation of the slag surface was measured for more than 10 minutes. Meanwhile, the steel melt was heated up to 1571°C. During the process material additions were made, slag was opened manually on purpose, and the furnace was deslagged. The measurement was finished right before tapping.

During the measuring time the housing temperature was monitored using a thermocouple element. The internal temperature did not exceed 40°C during the whole process. Thus, the air cooling is very effective. During production process images of the melt surface were recorded at specific moments using an infrared camera. These images helped to interpret the graph and served as a reference.

It was shown that manual opening of the slag surface increases the brightness of the slag and has a clear influence on the CES signal. Also during deslagging the surface becomes thinner and hotter and the signal of the CES increases significantly. Thus, the CES signal provides valuable information on the temperature loss of the melt surface, and the CE sensor is applicable also to industrial environments.

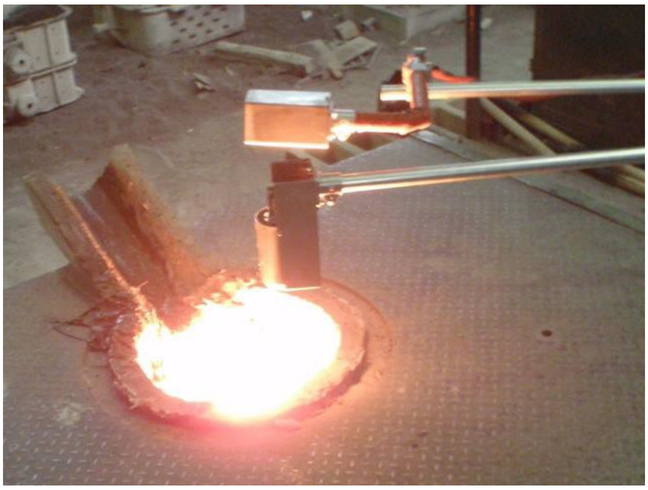

Figure 2: Trials at a foundry induction furnace containing liquid steel with the CE sensor (lower device) together with a housed camera for comparison (upper device)

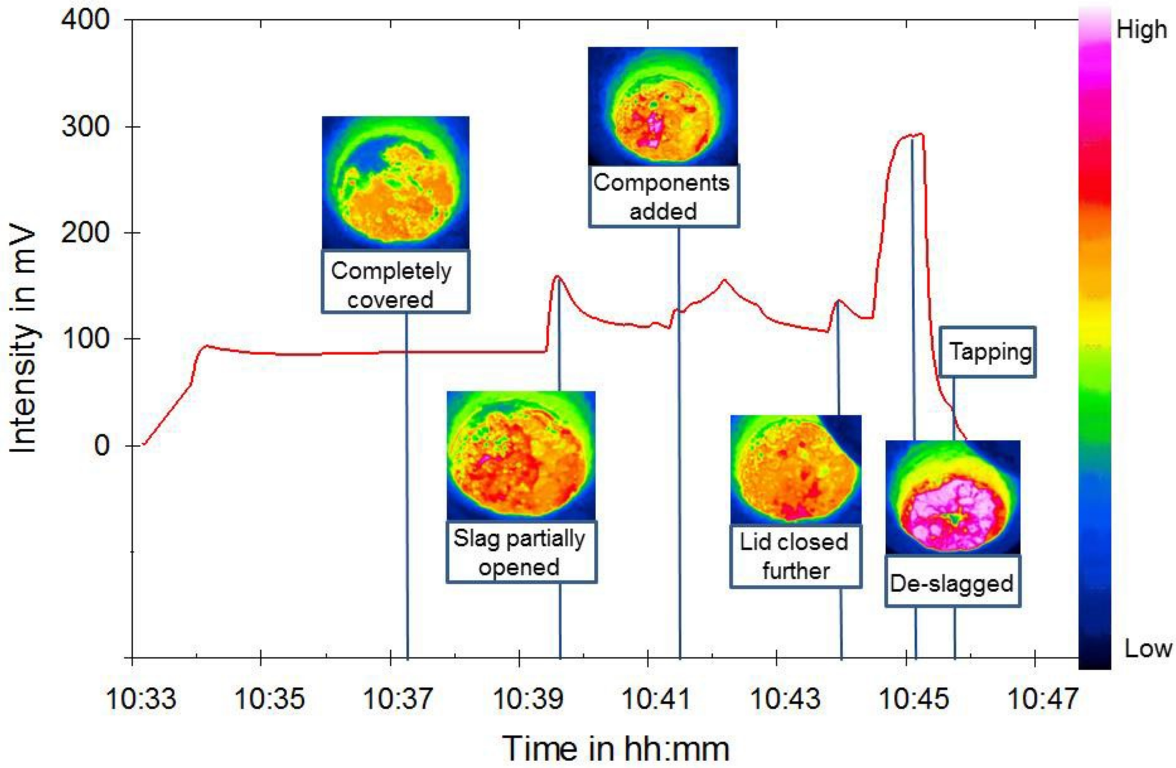

Figure 3: Time evolution of intensity of the CES signal together with IR images at selected events for comparison

1.4 Conclusion

A sensor was developed, built and tested in industrial environment for the measurement of the radiation energy losses of a cover in high temperature batch processes. With this information the energy efficiency of batch processes can be optimized. The sensor is rugged and can withstand hot industrial environments. With its small dimensions, many possibilities for application and mounting exist. Compared to other thermal detectors thermal cameras it is very cost effective, which means financial investment is low.