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Selection of two automated metal level detection systems (AMLDS) for testing in pilot scale

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1 Introduction

A central part of the RECOBA project is the use of real-time sensing as a basis for advanced control and optimisation of the batch processes in question. Elkem is looking into how to increase the availability of sensor measurements in the ladle refining and casting process. The process is thoroughly described in RECOBA Deliverable 2.3, and a preliminary description of the sensors is given in Deliverable 3.1.

The purpose of the document is to describe available methods for measuring ladle metal level in order to select two automated metal level detection systems for testing during the project. Previous attempts and tests in Elkem have been surveyed in addition to available suppliers. The selection of the measurement methods will also be based on its compatibility with the application and surrounding environment. Manual operations are needed in the refining process today for obtaining measurements, and it will be highly beneficial to be able to remove the operators from the process.

The measurements will also give valuable input to the off-line and online process models developed for the refining process in the RECOBA project, which in turn shall lead to advanced control and optimization of the process.

2 Process requirements

The benefits of having online measurements of the ladle metal level can be described as follows:

- Environment, health, safety:
 - Remote monitoring of ladle filling by operator
 - Operator warning for ladle overflow or during “crash” tapping
- Process:
 - Operator input to when metal flow from furnace is decreasing
 - Operator input and prediction to when ladle is full and needs to be replaced (ladle fill rate)
 - Optimize tapping logistics and manage tap-hole blockages
 - Measurement of metal mass flow from furnace as input to diagnosis of clogging, tapping, and furnace conditions
 - Stable mass flow from the ladle during casting

Direct ladle level measurements are not implemented or available in the oxidating refining process at the Elkem plants today. The operators perform manual dip level measurements during tapping of metal from the furnace into the ladle. It is of great importance to the operators' safety to enable remote monitoring of the tapping and refining process.

The project will select two different measurement methods for level detection to be tested. The selection will not be limited to direct measurement methods. By choosing complementary and redundant methods, other process states may be obtained and corresponding measurement accuracy can be assessed.

The measurement accuracy requirements for the methods will be determined by the application.

Using the dimensions as given in Figure 1, the metal level in the ladle can be plotted as a function of the weight of the metal, see Figure 2. In the example, it is assumed that a weight of the molten metal can be measured +/- 100 kg, which results in an uncertainty of the metal level by +/- 2.5 cm. By our preliminary analysis, this is acceptable for industrial scale refining.

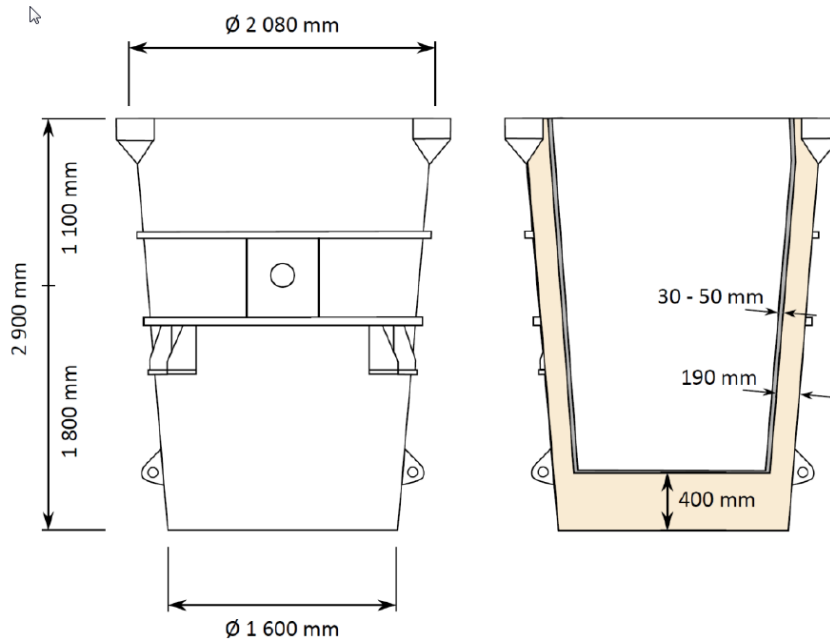


Figure 1 Typical size of tapping ladles

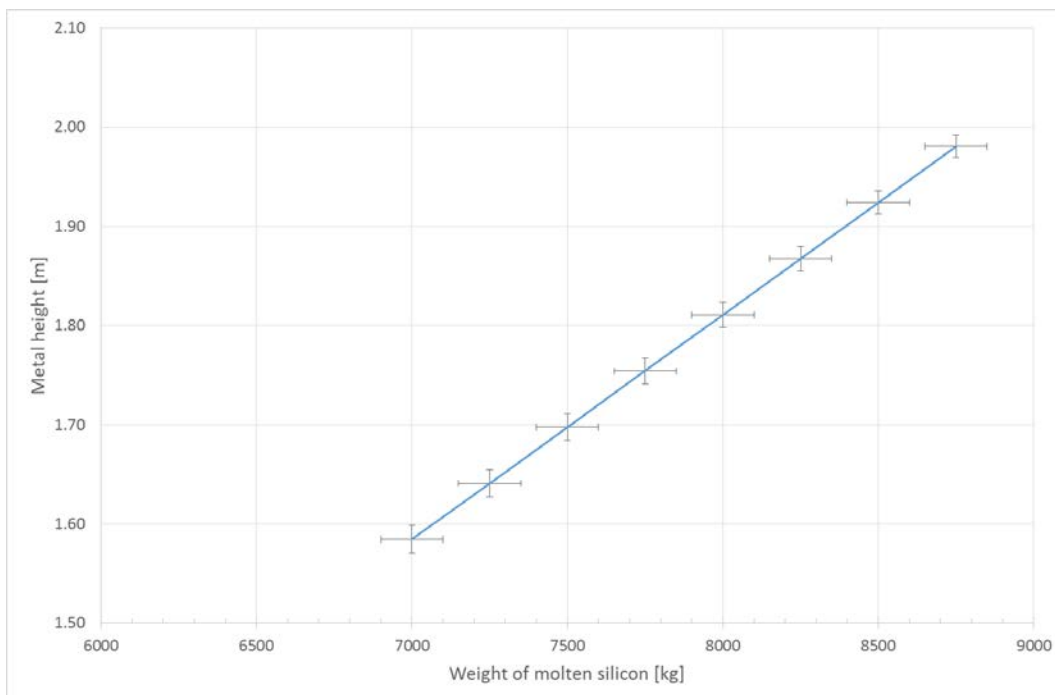


Figure 2 Weight measurement error analysis

The work that is carried out in the industrial production facilities is heavy-duty. Transportation is carried out by cranes, large forklifts and other heavy equipment. All of this is carried out manually, which leaves room for human error. As such, equipment and measurement technology must be built to last and protected against possibly “collision candidates“. In addition, the surroundings are hot and dusty, increasing the

wear and tear on all equipment in the area. A separate durability analysis must be carried out for each piece of new equipment that is put in place in current production facilities.

Challenges with available power and communication cabling may be a show-stopper as well for locating instrumentation in the ladle surroundings, making it necessary to not only focus on measurement methods, but wireless communication and battery capacities as well.

In some locations, there may be limitations as to space around the ladle, particularly if the equipment is to be placed near the tapping area. Here, large hoods are placed over the ladles to remove the microsilica that is continuously being released from the molten bath.

The furnace is revolving at a slow speed changing the tapping position continuously, which in turn complicates the use of stationary installations.

3 Survey of available measurement methods

3.1 Available measurement methods

The following measurement methods have been identified as plausible for measuring ladle metal level:

- Weighing cells
- Electromagnetic
- Laser
- Radar
- Acoustic
- Ultrasonic
- Thermal radiation

Within the RECOBA project scope, several sensing principles will be addressed for investigation and are included in the evaluation of the methods in Chapter 4.

3.2 Previous experiences and tests

Elkem has previous experience with metal level measurements from other applications. The most relevant tests and experiences are listed below.

Weight measurements are being tried out at two Elkem plants. A new concept has been introduced at one of the plants during 2015 with wireless connection and batteries installed locally on the ladle car. The measurements are in use for monitoring the tapping, but does not give a direct measurement of the metal level. Knowing the ladle size, the weight can be used for calculating the level, but the accuracy will vary with ladle fouling.

In 2013-2014, the company Agellis performed a 6-month test by installing sensor loops behind the refractory inside the ladle shell, using electromagnetic field propagation. Four ladles were equipped with this equipment for operative testing. The test was

successful as a measurement method, but challenges regarding connection and cabling in the tapping area had to be further investigated. The need for special fitting of all the ladles were considered cumbersome, and needed special attention during the three-day refractory pre-baked period of the ladles. More information can be found in [3]. The preliminary assessment was that the technique was promising, but the investment cost was likely to be too high.

Elkem is also familiar with using an automatic dip level measurement for measuring metal level in a stationary induction furnace as opposed to the moving refining ladles that are of interest in this project. The bath level can be measured by using a small induction coil to induce a weak electric field within the ladle. The induction coil is located within a vertically moving lance. The interaction between the surrounding phase and electromagnetic field is measured and gives information about the conductivity and thereby the phases (air, slag, or metal). Knowing the position of the coil as it moves vertically, this will enable the determination of the exact position. These are commercially available systems commonly used in the steel industry.

In 2015, Elkem did a lab-scale test using a high-temperature high-penetration laser for measuring metal level in an induction furnace. The results were promising, but further investigations are needed to understand the effects of dust scattering and surface motion.

Elkem also has a ferrosilicon plant in Canada that has used ultrasonic techniques for measuring the metal level in a ladle similar to silicon refining ladles. The process layout is less complicated than for silicon refining as the entire melt treatment takes place at a fixed location. However, the use of ultrasonic measurements is an alternative for the silicon process and will be considered among other techniques.

A former Elkem company, ERAMET Sauda, has been using a radar for metal level detection in silicon-manganese ladles since the 90s. The radar is part of a permanent refining station for ladles. The fuming of silica dust is at similar level and character as of the refining of pure silicon.

The University of Cambridge is developing sensor technology that potentially can be used for fluid level acoustic imaging. In the original proposal, it was suggested that this technology could potentially be used in silicon production, but as of yet the technology is not sufficiently developed to allow actual testing in an environment representative for silicon refining and will not be further pursued in this project.

BFI has developed a system for measuring the coverage of a melt by slag (deliverable D.3.8). The system has been tested both in lab scale and in an industrial environment to measure the radiation energy losses from the hot surface of a molten bath. It has been considered to be used as a way of detecting the metal level in silicon refining ladles, based on the different emissivity between the liquid silicon and the refractory lining in the ladle. In principle, this is the same problem as determining the slag coverage of the steel.

4 Selection of measurement methods for pilot scale testing

In the evaluation of which measurement methods to test, the criteria have been identified and rated for each method. The criteria have been weighted with High and Low importance as indicated below.

High (rating 1-5)

- Previous experience in Elkem or other relevant metallurgical applications
- Practical feasibility for installation in ladle surroundings
- System reuse on multiple ladles
- Non-contact measurement avoiding melt contamination
- Cost

Low (rating 1-3)

- Lead time from selection of method to installation at a pilot plant
- Robustness to withstand ladle surroundings
- Ability to measure through fuming
- Requirements regarding infrastructure (power and communication)
- Measurement accuracy

The ratings are listed in Table 1:

Table 1 Rating matrix for measurement methods

Method	Lead time (1-3)	Robustness (1-3)	Adaptability to application (1-5)	Reuse (1-5)	Infrastrcuture (power&comm) (1-3)	Cost (1-5)	Previous experience (1-5)	Non- contact (1-5)	Fuming (1-3)	Accuracy (1-3)	TOTAL
Weighing cells	3	2	5	4	3	5	5	5	3	2	37
Electromagnetic	3	3	1	3	2	2	3	1	3	3	24
Laser	2	1	3	4	2	3	2	5	1	3	26
Radar	2	2	3	4	2	4	1	5	1	3	27
Acoustic	1	1	1	2	1	1	1	2	1	2	13
Thermal radiation	1	2	3	4	2	1	1	5	2	2	23
Ultrasonic	3	2	3	4	2	4	4	5	1	3	31

As indicated in the table, weighing cells as a measurement method are highly recommended for obtaining level measurements. The main reason for this, is that it is a well-tested concept in Elkem. Challenges regarding installation, power, and communication have already been solved. However, its accuracy is dependent on accurate ladle size information, which is a dynamic parameter due to ladle fouling. Combining this measurement with a direct level measurement method will increase the information level of the ladle state and be valuable input to the process models being validated during the project.

Based on this assessment, Elkem wants to test ultrasonic and radar as direct measurement methods to be combined with weight measurements already installed in the refining process. The combination of non-contact, direct observation of the metal level with an indirect measurement using weights offers flexibility, robustness and redundancy, and is at this point the preferred path forward in the RECOBA project.

5 Concluding Remarks

A survey of potential methods for automatic detection of the metal level in a silicon refining ladle has been carried out, and based on an evaluation considering technical feasibility, robustness and cost, among others, two technologies will be further studied under the auspices of the RECOBA project. There are a number of unknowns associated with most of the considered techniques, in particular cost of implementation and reliability during operation. At this stage, the combination of weight measurements with a non-contact technique offer the best chance for a successful implementation in an industrial environment.

6 Bibliography

Ref. no.	Title	Authors	Year
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[2]	RECOBA D3.1: Preliminary models for evaluation of sensor signals	Åslaug Grøvlen, Kjetil Hildal (Elkem), John Suberu, Andrew Flewitt, Alexei Lapkin (UCAM), Preet Joy, Johannes Knab, Adel Mhamdi, Alexander Mitsos (RWTH), H. Köchner (BFI)	2015
[3]	An automatic ladle level measurement system for monitoring ladle fill rate during tapping	A. Rödfalk, J.P. Nilsson, N. Brogden, P. Bloemer, A. Lyons, and O.J. Østensen	2014