Deliverable 9.2

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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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Duration:	36 month

Eco-balance of the real-time controlled polymerisation, steel and silicon alloys process

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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 Introduction

The application of the project results will benefit the three respective industrial partners in several ways:

1) Process optimization
2) Internal health and safety
3) Economic gain
4) Reduction of greenhouse gases
5) Reduced energy consumption

These improvements are mutually linked to each other. The first two items will be process-specific, while the three last items are of general character. In this deliverable, the focus will be on the relative improvement of items 3-5 for the respective processes.

The ecological advances due to the new process control are evaluated, focusing on the reduction of energy consumption, efficiency regarding raw materials, production of waste and other environmental impacts. In particular, the reduction of greenhouse gas emissions will be deduced.

The economic gain for each of the three processes is estimated based on testing and verification trials during the project period.

2 Emulsion Polymerization process

2.1 Eco-balance

For the emulsion polymerization process, described in detail in D.2.6, process models consisting of reaction kinetics, particle morphology and reactor periphery have been developed and validated. This has been done for given recipe and process conditions. The models are now being implemented in online application (CENIT).

The infrastructure for the real-time application has already been installed at lab-scale (3L) reactor as well as pilot plant reactor (2300 L). Experiments will be conducted at both scales, replicating the real production process limits (e.g., constraints on cooling etc.) and data for the optimized batches will be compared with the traditional batches (for the same product/recipe). The performance measures for comparison are batch time, product quality, and energy savings (heating/cooling of the reactor). The comparison will illustrate the yield improvement and effect on energy and carbon footprint.

The effect of the model-based process control system and the results are given in the following paragraphs based on the current experience on lab and pilot scale.

2.1.1 Yield improvement

Process modeling as developed in RECOBA (kinetic, morphology, reactor periphery) gives more insight to the process by delivering total heat and mass balance, product quality and concentrations of monomers as a function of time and key process parameters.

A major improvement in the production is estimated to be achieved by reduction in batch time by using the energy removal efficiently and optimally. Estimation of online parameters, such as heat transfer coefficient, help to guide the recipe in accordance with process constraints as well as product quality constraints. By optimally operating the process at recipe based on process conditions and variables (rather than fixed time), the batch time can be reduced by 5-7% of the normal batch.

Yield improvements like these are important for the European industry to be able to compete with producers in other regions in the world.

The European annual production of dispersions is currently estimated to be about 5.2-5.6 million ton/a. According to that, advanced process control methods developed in scope of RECOBA-project, will help to increase the production capacity for European dispersion producers by about 260-370 k ton/a for Europe.

2.1.2 CO_2 and carbon foot print reduction

Emulsion polymerization is an energy intensive process. It is estimated that the better heating and cooling control by improved process models result in 3-5% less energy consumption for heating and cooling of the polymerization process. Furthermore, 2% savings in raw materials can be achieved by reduction of waste.

With an estimated consumption of 1.5 kg CO_2 per kg produced dispersion, an annual production of 5.2-5.6 million ton/a dispersions will result in savings of around 390-500 kt CO_2/a due to less energy consumption. Furthermore, reduction of waste leads to utilization of less fossil fuel which is translated to about 130 kt CO_2/a. Overall, the reduction of energy consumption adds up to about **520-630 kt CO_2/a** for European dispersion production.

2.1.3 Energy reduction – emissions

The production of emulsion polymerization batch is energy intensive – it requires heating of the batch initially to increase the temperature suitable for emulsion. Once the reaction starts and energy is generated, it needs to be removed by cooling system to keep the reactor safe. The energy for heating or cooling the reactor is substantial.

With a typical energy mix the CO_2-emission is about 600 kg/MWh. The improvements in energy consumption of 520-630 kt CO_2/a is as mentioned in the previous sub-section is equivalent to about **390-560 GWh/a**.

2.2 Comparison with initial estimates

The updated eco-balance show comparable numbers with given estimates in the project proposal document. With the current results, the effect onto yield increase in increased from 5% to about 5-7%, whereas the effect on energy reduction is calculated to about 520-630 kt CO_2/a compared with 525 kt CO_2/a from the beginning of the project. As such, the estimate is conservative and it is anticipated that the numbers after the project will reflect the real impact of model based monitoring, control and optimization for emulsion polymerization process.

3 Steelmaking process

3.1 Eco-balance

For the liquid steelmaking process, which has been described in detail in D 2.2 and D.2.6, a novel sensor for continuous fibre optical measurements of the melt temperature was developed. It has been successfully applied at the tkSE steel plant to measure the melt temperature evolution in the ladle during the batch processes of RH vacuum degassing and Argon stirring with high dynamics and accuracy, as described in detail in D 7.2 and 7.3.

Furthermore, a dynamic model for calculation and prediction of the melt temperature throughout the complete chain of batch processes from BOF tapping up to delivery of the melt to the continuous casting plant has been developed by BFI and validated off-line with historical process data provided by tkSE. A slightly simplified version of this model has been implemented within real-time applicable model predictive and iterative learning control algorithms, which are currently tested within off-line simulation calculations. The performance of the model calculations and the control algorithms is currently compared to actual production results as far as possible, and expected improvements in terms of energy savings, yield and raw material savings, as well as reduced CO_2 emissions will be estimated.

At this stage of the project, the combined effect of the novel continuous temperature measurement and the model-based process control system can be estimated as described in the following paragraphs.

3.1.1 Energy reduction

With application of the continuous temperature measurement and an improved model-based process control for the batch processes of liquid steelmaking, the evolution of the melt temperature can be monitored and predicted more precisely. This means that the need for correction actions on the melt temperature, as cooling scrap addition to lower, or oxygen blowing for chemical heating to increase the melt temperature can be reduced. If it is assumed that the temperature losses induced by the correction actions can be cut by half by applying the more precise temperature control, this leads to a reduction of about 6 K. For oxygen steelmaking plants, where the temperature loss has to be compensated by a higher tapping temperature of the BOF converter, the model based approach converts into primary energy savings of around 2.7 kWh/t. Assuming an annual European oxygen steelmaking production of about 100 Mio. tons of liquid steel, European production sites would save around **270 GWh/year.**

3.1.2 Yield improvement

As described above, the diminished temperature losses to be compensated by primary energy input at the BOF lead to a lower BOF tapping temperature. This in turn allows to lower the iron losses by about 1.2 kg per ton of liquid steel, thus leading to a yield improvement of about 0.12 %. In addition, due to the lower BOF tapping temperature and the lower iron oxide content in the BOF slag, the consumption of alloy and refractory materials can probably be diminished.

3.1.3 CO_2 emissions

For the oxygen steelmaking process, the primary energy savings described above are resulting mainly in a reduced specific amount of hot metal produced in the blast furnace, which is estimated to 4 kg / t of liquid steel. Typically, the specific CO_2 emissions of the blast furnace are 1475 kg per ton of hot metal. Thus, alone by these savings the CO_2 emissions of the European oxygen steelmaking plants with a total production of 100 Mio. tons of liquid steel could be reduced by about **590,000 t/year.** In addition, CO_2 emissions are reduced indirectly by a lowered consumption of alloy and refractory materials.

3.2 Comparison with initial estimates

The updated eco-balance shows regarding the primary energy savings and the metallic yield improvement slightly lower figures compared to the upper limits predicted in the project proposal document. On the other hand, the estimated reduction in CO_2 emissions is higher than predicted in the proposal, when referring to oxygen steelmaking plants.

4 Silicon process

4.1 Ecobalance

For the silicon process, described in detail in D.2.6, a complete dynamic model has been developed and has now been implemented at one of Elkem`s silicon plants for testing. The performance of the model will be compared to actual production results, and improvements in terms of yield, raw material savings, energy savings and reduced CO_2 emissions will be calculated. At this stage, we can estimate the effect of the model-based process control system and the results are given in the following paragraphs.

4.1.1 Yield improvement

The process models calculate a total heat and mass balance as a function of time and key process parameters. The primary improvement in yield is achieved by using the melt superheat more effectively. By adding cooling metal continuously during the refining process, the remelting capacity can be increased from **1 percent to 5 percent** of the initial tapped silicon melt under normal process conditions. During this project, Elkem has already utilized some of this potential by increasing from 1 to 2 % at selected furnaces. Further improvements can only be made by investments in equipment and technology for adding cooling metal.

A typical silicon furnace produces 25 000 tons/year. Using the process control methods developed in the RECOBA-project, the re-melting potential during the refining process for a single furnace can be increased from 250 tons/year to 1250 tons/year. The amount of silicon delivered to the casting process (furnace process + refining process) totals 26 250 tons/year for a typical Elkem silicon furnace.

4.1.2 Energy reduction

The energy consumption for producing silicon is typically 12 MWh/ton silicon produced. The yield increase described in the previous section will reduce the energy consumption to 11.42 MWh/ton. Assuming an annual production of 120 000 tons of silicon, Elkem with its European production sites would save **70 GWh/year.**

4.1.3 CO_2 – emissions

The production of silicon requires use of fossile and biological carbon-sources. Referring to D.2.6, the total amount of CO_2 released per ton Si produced from the electric arc furnace is 6100 kg. The emission from one single furnace is

*25 000 ton Si * 6100 kg CO_2/ton Si = 152.5 kt/year per furnace.*

With the new methodologies developed in the RECOBA-project, the output from the furnace + refining process is increased without using extra carbon. The same amount of CO_2 is produced, but the specific emission is reduced to

152.5 kt/year / 26250 ton = 5800 kg CO_2/ton Si produced.

This represents a decrease of 5% in the specific CO_2-emissons from silicon plants. For Elkem and its European production sites, the savings in CO_2-emissions will be

*125 000 metric tons Si (producing CO_2) * 300 kg CO_2 per ton Si produced = 37.5*

Thus, the savings in CO_2-emissions will be **37.5 kton/year** for Elkem in Europe. These savings are assuming that the electricity needed for the production is “green”. For a non-renewable electricity generation, these savings will be even higher. For a typical energy mix, the CO_2-emission is about 600 kg/MWh. With energy savings of 70 GWh/year (see previous section), the CO_2-savings are estimated to an additional 42 kt/year for non-renewable electricity production.

4.2 Comparison with initial estimates

The updated ecobalance shows improved numbers compared with those predicted in the project proposal document. For example, the yield increase originally stipulated to 2% has been increased to 5%. This affects the specific energy consumption and CO_2-emissions accordingly. As such, the original estimate was too conservative and the latest numbers reflect the true improvement based on a model-predictive process control approach.