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CONTENT

1 Introduction

The purpose of the deliverable D9.4 is to summarise the evaluation of the technical project results, as well as to evaluate their economic and social impact within one report. As such the report refers to the list of criteria for technical evaluation of the performance of the different components and the integrated process control for the three industrial processes which has been provided in deliverable D9.1. Furthermore, the results of the eco-balance, which have been set up and described in deliverable D9.2, are included for final evaluation of the achievement of the set targets regarding reduced energy and resource consumption as well as CO_2 emissions.

2 Evaluation of technical project results

Regarding the technical evaluation of the project results, the report refers to the list of criteria for technical evaluation of the performance of the different components (sensors, models, control strategies) and the integrated process control solutions, which has been provided for the three industrial processes in deliverable D9.1. Furthermore, the results of the eco-balance, which have been set up and described in deliverable D9.2, are included for final evaluation of the achievement of the set targets regarding reduced energy and resource consumption as well as CO_2 emissions.

The evaluation of the technical project results regarding the different components of the integrated process control solutions as well as of the achievement of the expected project results (improved product quality, reduced energy and resource consumption, CO_2 emissions) are listed in the following separately for the three industrial processes.

2.1 Emulsion polymerization process

Within scope of RECOBA, the main purpose in the use case of the polymerization process was to develop and implement new hard sensors, process models and real-time control to overcome current problems of polymerization problems which are

a. Lack of understanding of the emulsion polymerization coupled with nonlinearity of the process

b. Unpredictability of the exact process conditions due to e.g. variations in inlet water temperature or monomer quality

c. Lack of insight into the process resulting in longer batch time or inhomogeneous product quality

d. Variance in product quality due to controlling implicit product quality parameters like e.g. reaction temperature

Use of hard sensors, process models and real-time control can overcome most of the above-mentioned problems for the polymerization batch processes improving significantly the current state of the art by enabling simultaneous measurements of different process or product parameters like particle sizes, concentrations and particle morphology.

The use of model based soft-sensors and hard sensors for real time monitoring, and feedback control can exploit:

- Energy and raw material utilization improvement – manipulation of manipulated variables based on model predictions
- Shortening of batch time (recipes based on product quality rather than on time)
- Improved product quality (with information about particle morphology)

2.1.1 Energy and raw material utilization

Usually, an emulsion polymerization batch starts with initial charge in the reactor, which is heated to certain given temperature, mainly based on experience, followed by dosing of reactants with given rate for specific time. For most of the part of the batch, the reactor temperature is kept constant since the temperature is considered to be implicitly affecting product quality. The reaction heat released during the batch time is cooled by some type of cooling (jacket, coils, or evaporative). The start of batch is time dependent based on experience.

Availability of hard sensors (Raman, TEM, viscosity meter) provide better information about the polymerization process, thus allowing to start the reaction at lower temperature as well as maintain the reactor temperature within given bounds, rather than given set-point. Since the control variable is product quality, it is easier to conserve energy while operating the batch process at optimal conditions.

Within scope of RECOBA, hard sensors, such as Raman, have been implemented at lab-scale as well as pilot plant reactor to obtain the information of reactant concentrations. Process models, consisting of reaction kinetics and morphology, have been developed, validated and implemented in real time applications to improve insight to the process. This ensures to conduct batch operation at optimal conditions, thus saving the energy in heating batch, followed by cooling of reactor at optimum.

The better insight to polymerization process has resulted in better control of the temperature. On the one hand, the reaction can be started at about 2-3 K lower temperature which is directly reducing heating and cooling effort. On the other hand, the reactor temperature is then not controlled at a set-point (e.g. 95 °C), but within given bounds (e.g. 80-95 °C), positively influencing the cooling operation. Due to that, the heating and cooling effort has been reduced which results in energy savings of about 3-4%.

Additionally, the use of the model based methods and hard sensors assist comprehend the better understanding of the emulsion polymerization at each stage of reaction, thus enabling control of particle morphology directly. This ensures accomplishment of product quality mostly, eliminating the need of filtration process as well as mixing, thus saving the energy, CO_2 foot print and improving overall safety. Furthermore, the stability of colloids has been investigated during the course of the project, thus directing the process to achieve desired product.
Exact savings in raw materials by reduction of waste materials cannot be shown in a lab environment or with the limited number of pilot runs. However, the demonstrated increase of the process stability and the better particle control helped to estimate potential savings of up to about 2% for raw materials and energy consumption.

In summary, the improvements sum up to savings in energy consumption of about 5-6% and in raw materials of up to about 2%.

2.1.2 Batch time reduction

A higher batch temperature results in faster reaction, thus decrease in batch time. However, it can have negative impact on the product quality due to increasing influence of side reactions like e.g. branching and cross-linking reactions. Furthermore, the reaction heat has to be removed, and the inlet temperature of the cooling medium is limited. Also without model-based optimization, a faster reaction is theoretically possible with impact on batch time, though this is not often implemented because of lack of insight into the polymerization process and the risk of bad product quality.

The use of the developed tools facilitates optimum process operation. This is achieved by controlling the product properties (particle morphology in this scenario) directly while manipulating the recipe reactants and inlet temperature of the cooling medium. The models have been successfully validated for some specific emulsion polymers and implemented into process models. At lab scale, it could be demonstrated that the model predictive control can capture all important factors relevant for the product properties.

Better insight to the polymerization process have been resulting in batch time reduction without negatively impacting the product properties: The reaction can be started at an earlier state as the heating time can be reduced. The possibility to work within certain temperature bounds instead of a given set-point together helped to reduce polymerization batch time further. By artificially adding cooling water limitations (which are usually not present in lab scale reactors), it could be shown that with real-time control one can make use of the full cooling water potential.

As a summary, it could be estimated that in a production environment, the developed methods help to reduce batch time by about 5-7 %.

This will be further shown by extending the demonstration to a pilot plant environment before due date of the final project report.

Beyond that, the newly developed kinetic and process models help to increase the understanding in the main and side reactions of an emulsion polymerization. This knowledge will help to find the optimum reaction temperature which then can influence batch time further. Of course, such a process change has to be validated for each product and reactor, and implemented in production carefully.

2.1.3 Improved product properties

Better understanding of the emulsion polymerization process through kinetic model and morphology descriptors helps to control the nonlinear and complex process optimally. The developed models have been implemented in online application, i.e., real time control and optimization tool box, with feedback to find the optimum process operation and control the process at optimal conditions.

This was not possible before the start of the project. In the project, new sensor technologies for polymerization processes have been developed like inline TEM e.g. measurements. Online Raman sensoring has been shown in lab scale for emulsion polymerization. For the specific products studied in the scope of this projects, no substantial fouling on Raman probe was noticed at lab scale, and each polymerization experiment was followed up with a cleaning procedure. This, of course, needs to be shown also in the mentioned pilot demonstration and tested for other products in the future.

Models have been developed which help to link the sensor signals to polymer properties like particle sizes, morphology, or composition. The project has enabled production of emulsion polymerization with real time monitoring and explicit control of product quality, e.g. particle morphology. This enables not only to reduce the reduction of carbon foot print by optimally using the energy resources and reducing the batch time as mentioned in 2.1.1 and 2.1.2, but it also helps to decrease the number of non-optimum or even bad batches, thus increasing the safety of workup.

Furthermore, the improvements in control of the particle morphology will help to develop products with more complex morphology which promise new and improved product properties. In the past, such products could hardly be transferred from lab scale to a production environment as they could not be run in a robust way in large scales. The newly developed methods will help to launch those products in the future.

It can be summarized that the overall goals which have been set for the polymerization use case, have been mostly fulfilled.

2.2 Liquid steelmaking process

The main objective of the RECOBA project regarding the liquid steelmaking process was to develop an improved process control for the steel melt temperature. For this purpose, new sensor technologies for in-line liquid steel temperature measurement were developed and applied. Furthermore, dynamic process models to calculate and predict the steel temperature evolution for the complete chain of batch processes for liquid steelmaking were developed. Both components, sensors and process models, were integrated within new process optimization and control strategies.

First, the evaluation regarding the main components (sensors and process models) of the process control system is described. Secondly the evaluation for the overall performance and the expected results of the integrated process control system are is described.

The evaluation criteria regarding the sensor for in-line liquid steel temperature measurement as well as for monitoring of the thermal state of the reactors are listed in **Table 1** together with the actually achieved performance.

For the in-line temperature measurement of the liquid steel melt it can be concluded that most of the targets which have been defined have been fully achieved by the DynTemp measurement system. The accuracy and reproducibility is with 3 K slightly lower than targeted, but the measurement duration is with up to 10 minutes much longer than expected.

Further important achievements of the continuous in-line liquid steel temperature measurement are:

- Provision of valuable insights in the dynamic process behaviour
- Tighter control of melt temperature with more accurate achievement of target values
- More detailed estimation of model parameters possible

The features of this optical measurement system, which is based on the immersion of an optical fibre into the steel melt, are described in deliverable D3.7, whereas its application at the different batch processes of the liquid steelmaking process route is described in detail in the deliverables D7.2, 7.3 and 7.4.

Regarding the sensors for monitoring of the thermal state of the refractory-lined reactors, i.e. the ladle and the vacuum vessel, it can be stated that the functionality of the selected optical sensors based on a fibre bragg system is in principle provided. However, these sensors together with the required data acquisition system are not robust enough for a permanent installation under the harsh conditions of the batch processes for liquid steelmaking.

Table 1: Evaluation criteria for sensors applied at liquid steelmaking process

Sensor for in-line liquid steel temperature measurement

Criterion	Target value / property	Achieved value / property
Temperature range	1475 °C to 1750 °C	1475 °C to 1750 °C
Reproducibility (Standard deviation)	1 – 2 K	3 K
Measurement duration	Several minutes	Up to 10 minutes
Response time	< 1 second	100 ms
Reliability & Robustness	High	High

Sensors to monitor the thermal state of the refractory-lined reactors

Criterion	Target value / property	Achieved value / property
Temperature range	200 °C to 900 °C	200 °C to 976 °C
Accuracy	5 %	0,12 % = 1,5 K
Measurement duration	1 to 2 weeks	15 days at 600°C
Response time	< 1 min	NA
Reliability & Robustness	Applicable at least for measurement campaign	Low, instrumentation of refractory material not feasible (interrogator unit cannot travel with the batch, optical fibre too delicate to install in refractory material)

The evaluation criteria regarding the process models for monitoring and prediction of the liquid steel melt temperature evolution along the batch process chain of liquid steelmaking are listed in **Table 2** together with the actually achieved performance.

Table 2: Evaluation criteria for process models to calculate liquid steel melt temperature

Criterion	Target value / property	Achieved value / property
Response time for on-line monitoring	< 1 second	< 1 second
Response time for prediction for one batch within optimisation algorithms	< 100 ms	< 100 ms
Model error standard deviation		
After homogenisation stirring	7 Kelvin	7.3 K for decarburised steels 11.3 K for alloyed steels
After RH degassing treatment	6 Kelvin	5.4 K for decarburised steels 4.6 K for alloyed steels
After final argon stirring	4 Kelvin	n./a. for decarburised steels 2.3 K for alloyed steels
Robustness	High	High

It can be concluded that the set targets for the performance of the dynamic process models for the liquid steel melt temperature have been mostly fully achieved. The only exception is the model accuracy after the batch process for homogenisation stirring. Here for the alloyed steel grades the resulting model error standard deviation is with 11.3 K significantly higher than the targeted value of 7 K. The reason for that is that the strong impact of the deoxidation reaction as well as of high amounts of alloy and slag former material additions performed during tapping has to be covered by the model calculation. However, it can be stated that this batch process is the first one in the entire process chain, so modelling errors in this phase can be easily compensated within an application for on-line control by adaptation of the model calculations to a spot temperature measurement by a thermocouple.

The final release of the process models and their validation with industrial process data from the different batch processes of the liquid steelmaking process route have been described in detail in the deliverable D4.6. With the help of a final fine tuning of the model parameters it was possible to further improve the prediction accuracy compared to the status described in D4.6.

The potential of application of integrated control solution for liquid steelmaking regarding reduced energy and resource consumption have been estimated based on the steel production in Europe, as described in more detail in the eco-balance provided in deliverable D9.2.

The tighter control of melt temperature with more accurate achievement of target values under less correction actions can lead to **primary energy savings of up to 270 GWh/year**. This value is slightly lower than originally estimated

Furthermore it was estimated that the yield of the metallic raw materials can be increased by 0.12 %, which is lower than originally estimated. A reduction of the refractory material consumption is difficult to estimate, as besides the improved process control several other influencing factors, as for example variations in the material quality, play a dominating role.

On the other hand the **greenhouse gas (CO_2) emissions** can (according to the eco-balance model calculation which refers to oxygen steelmaking plants) be reduced **by around 590,000 t/year**. This value is significantly higher than originally estimated.

Overall the application of integrated control solution reveals the potential for a significant reduction of the carbon footprint of the liquid steelmaking process.

Further, the following not quantifiable benefits and overall performance features of the integrated process control system can be identified:

- The new developed sensors and models will provide important process parameters like melt temperature, accessible in a real-time and continuous manner
- The continuous in-line liquid steel temperature measurement provides valuable insights in the dynamic process behaviour
- Based on in-line information on the process state, the batch processes of liquid steelmaking can be run closer to the optimal trajectory, leading to higher reliability and more consistent product quality
- Operators are enabled to detect deviations from expected process performance in real-time, which makes the process safer and more sustainable, and the product quality more reliable

- Less product has to be discarded due to low quality. Production losses will be reduced.
- The production of new steel qualities, requiring tight and complex process control along the process route of liquid steelmaking becomes feasible

2.3 Silicon process

The project goal for the silicon process is to establish a model for refining of silicon that allows for real-time predictive control of the operation and utilization of the superheat in the liquid silicon. Secondary goals are use of new sensor techniques developed for steel applications in the silicon process, as well as bringing existing process measurements on-line in order to reach the full potential of a MPC-methodology.

The process of production, refining and casting of high Si-alloys was described in deliverable D.2.3. To evaluate the project results, the following key areas are of particular importance:

1) **Yield of silicon** – i.e. the ratio of Si poured from the refining ladle to the casting mold divided by the amount of Si received from the furnace.

2) **Lifetime of ladle** – the number of tapping cycles each ladle goes through before ladle refractory has to be rebuilt.

3) **Safety for operators** – number of operations/total duration during the refining and casting cycle that requires the presence of operators nearby vessels that contain molten slag or metal.

4) **In-spec product** – percentage of produced Si that meet the product specifications set by the production plan.

The evaluation criteria are established to determine whether improvements are made within these four areas. These reflect sensor performance, model performance and integrated performance.

Sensor technology tested in this project includes in-line temperature measurements of liquid silicon, temperature measurements of refractory lining and metal level in ladle. The criteria are shown in **Table 3**.

Table 3: Evaluation criteria for sensors used in silicon production.

Sensor for in-line liquid silicon temperature measurement

Criterion	Target value / property	Achieved value / property
Temperature range	1475 °C to 1750 °C	1400 – 1600 °C
Measurement duration	2 hours	30 minutes
Response time	< 5 seconds	< 5 seconds
Reliability & Robustness	High	Moderate reliability Low/moderate robustness

Sensors to monitor the thermal state of the refractory-lined reactors

Criterion	Target value / property	Achieved value / property
Temperature range	200 °C to 1100 °C	300 – 1000 °C
Accuracy	5 %	unknown
Measurement duration	1 week	6 weeks (in cycles of 3 days)
Response time	< 1 min	< 1 min
Reliability & Robustness	Ladle lifetime	Cycle time, maintenance needed for next cycle

Sensors to monitor the liquid silicon level in the ladle

Criterion	Target value / property	Achieved value / property
Level range	0 – 2 meters	Up to 5 meters
Accuracy	2 %	5 %
Measurement duration	2 hours	No limitation
Response time	< 5 seconds	< 2 seconds
Installation	Retrofitted to existing infrastructure	Retrofitting ok
Cost	< 20 000 Euro	< 40 000 Euro (including infrastructure)

The evaluation criteria for the model are given in **Table 4**.

Table 4: Evaluation criteria for models used in silicon production.

Criterion	Target value / property	Achieved value / property
Response time for on-line monitoring	< 5 second	< 15 minutes (limited by sample analysis)
Accuracy	< 2% deviation from off-line complete model	< 3 %

The integrated system (sensors+model) were evaluated under the criteria given in **Table 5**.

Table 5: Evaluation criteria for integrated MPC-system used in silicon production.

Criterion	Target value / property	Achieved value / property
Silicon yield	Increase 1 %	Increase > 4 %
Ladle lifetime	Increase 2 % (number of refining operations)	No change
Manual operations near ladle	Remove 1 (metal level measurement)	One operation removed
In-spec product	Increase 1 %	Insufficient data to conclude

The results of the sensor tests have, as can be seen from Tables 5-7, for the most part been satisfactory. The evaluation is in many cases complicated since the testing of new equipment/procedure/technology in industrial practice requires much more time than is available in the project period. In many cases 6 months or more is needed to detect a shift in data trends.

Testing of the continuous temperature measurement system DynTemp, developed by RECOBA project partner Minkon, has shown a potential for this method to be used for silicon refining. There is still development work ahead to ensure the method to be practically and economically viable.

For the ladle refractory temperature, a system consisting of embedded thermocouple and wireless transmission of signals have been proven reasonable robust in industrial applications. However, the cost of the measurement compared to the demonstrated net effect has been too high and no further development work is planned at this stage.

The on-line model has been installed and is running in parallel with current process control systems. Elkem will continue evaluating the model during 2018.

3 Economic evaluation of the project results

Based on the results of the industrial application cases the economic gain of the integrated process control for the different types of batch processes was evaluated. The costs of the necessary hardware components (e.g. computer systems, sensors, etc.), software and implementation were compared with the gain due to improved product quality, lower energy and raw material consumption and disposal of waste.

3.1 Emulsion polymerization process

The technical results show that by using the developed hard sensors together with online process models, an estimated increase in production capacity of 5-7 % can be achieved, the energy and raw material consumption can be reduced by 5-6% and up to about 2%, respectively, while maintaining product quality parameters.

The benefit from these figures is estimated to be in the order of magnitude of the expected implementation costs resulting in a positive return on investment.

The developed sensors and models have been tested extensively at lab scale for some representative emulsion polymerization recipes. Before rolling out real-time control to production, the methodology has to be extensively tested in a bigger scale as e.g. fouling might be a bigger problem in production. As a first step, the implementation in the pilot scale.

In the frame of this project, only a small number of representative emulsion polymers could be included in the testing. Also, the demonstration needs to be limited to one lab and one pilot reactor. As emulsion polymers are complex and sensitive products, the developed models need to be validated and calibrated for each individual product and also for each reactor system before deciding about specific implementations. However, the models and methodologies developed in this project are developed to handle these differences so that no severe problems are expected in the transfer to other products and reactors.

But RECOBA is not only helping to improve the capacity and energy and raw material utilization of existing products by implementing real-time control in a production environment with the process models developed by RWTH Aachen and the tools from Cybernetica. With these tools, it is also possible to control the product quality parameters with tighter specifications.

Additionally, the developed sensors and models can and will be used in the lab environment for future product development. Emulsion polymerization is one of the most complex polymerization processes. Unfortunately, the important parameters which decide about the product properties, is not always fully understood. For instance, a slight increase might cause on the one hand side reactions which change the architecture of the polymers and directly lead to different product properties. On the other hand, the stability of the multi-phase system is very sensitive to temperature, too, which can cause changes in particle sizes, morphology or even the risk of coagulation.

One important outcome of RECOBA are the new tools to measure (by inline TEM developed at Cambridge University) and to model the development of the particle morphology (by models developed at POLYMAT and Prague University). These models will help in the future to develop totally new products in the lab even without online control implementation.

The newly developed kinetic models help to understand the generation of specific product morphologies. This will enable the development of new and tailored products in an efficient way. With the sensors and models, we will be able to get totally new insight into the polymerization process as we can study and understand what is going on in the reaction vessel in much higher quality and frequency. This will improve the understanding and enable the development of new products with better product properties. New products can be tailored specifically to customer needs and thus increase their value. With the developed process models such new products can be transferred to production.

The further improvement of the polymerization models and the transfer to more and more products will be conducted after end of RECOBA so that new products can be developed for many different emulsion polymers.

On the long-term, this part of RECOBA can be of higher value than the mentioned yield increase of raw material savings.

3.2 Liquid steelmaking process

The main issues regarding the economic gains of an application of the integrated control solution for liquid steelmaking are:

- Savings in primary energy consumption
- Savings in indirect costs for greenhouse gas (CO2) emissions
- Improved product quality by increased process reliability

These savings fully compensate the costs for additional hardware (in-line temperature sensor) and implementation of process model and control software.

3.3 Silicon process

There are two ways in which the silicon production benefits economically from the RECOBA project. First, the process output, i.e. the yield can be maximized by using excess process heat to re-melt scrap silicon. Secondly, the correct product quality (chemical composition) can be reached in a way that minimizes slag and slag forming additives.

After the completion of the off-line model an extensive use of the model was carried out to investigate various process routes. In silicon refining, the most important process parameters is gas flow (oxygen, air) and addition of solids (quartz, limestone). By a systematic approach the best procedure for a given input composition and product specification can be determined. It was demonstrated that optimization of scrap silicon additions during the refining process could increase the yield by 4%, without investing in new equipment. However, the number of manual operations with the current equipment increases. In order to evaluate the overall cost/benefit of such a modified procedure one plant (Elkem Salten, furnace 3) is currently testing out the suggested scrap silicon addition procedure. This testing will not be completed until May 2018. However, it is already clear that the yield increase of 4% can be met, but the extra cost associated with equipment wear, operator training and other relevant costs must be determined after a longer industrial campaign and cannot be done within the time frame of the RECOBA project.

It was already mentioned that a 4% yield increase has been demonstrated using current equipment. In parallel with the ongoing test campaign at Elkem Salten 3, a couple of spin-off projects from RECOBA have been initiated internally in Elkem. By applying a different technology for addition of scrap silicon, the yield input can be increased as much as 7%. This additional increase comes from combining frequent temperature measurements of the silicon melt with a continuous addition of silicon scrap. However, this requires investing in injection technology which is well-known in steel industry. Currently there are projects ongoing in Elkem where the cost/benefit of such a new process is evaluated in terms of the potential 7% yield increase.

The impact on quality has not been as obvious as the yield increase. However, it is somewhat early to conclude and further testing of the on-line model and process control approach must be done. This work will continue after the RECOBA project has ended.

4 Social evaluation of the project results

It was evaluated to which extent the new technology will influence the situation of workers at the different batch processes, especially regarding training needs, risk management and safety at workplace. A special focus was additionally laid on the acceptance of the new integrated control solutions by the operators and process engineers.

4.1 Emulsion polymerization process

Batch processes are usually operated with time-based recipes. However, due to process fluctuations, e.g. due to changes in raw material quality of changes in the cooling water, and due to process disturbances, production staff is confronted with a high number of process warnings and alarms. The corrective actions which need to be decided by the operators, are very time-consuming and need many manual decisions by the operators. RECOBA was aiming in consequently integrating a sensing and control system, which will always achieve the maximum efficiency of the process.

The developed sensing and control systems can be compared with an auto-pilot system in an airplane. Sensors are gathering a lot of information about speed, position, and surroundings. The information is processed automatically in a very structured and efficient way which is reducing his stress-level and the overall safety.
For the polymerization process in RECOBA, sensoring systems have been developed giving information about concentrations, particle sizes and morphology. They are used by the process models which give information about the current state of the process (monitoring) in a very structured way to the operators, and predict into the further behavior of the process enabling automatic control of the batch. The process is running in an optimum way, incorporates physical and safety constraints automatically, gains in-spec product in the shortest possible time.
The new process control will enable operators to detect serious deviations from expected process runs in real-time and make the process safer and more sustainable, and the product quality more reliable. The number of process warnings and alarms will be reduced rapidly, the number of manual decisions is reduced so that the stress-level of the operators is improved.

With higher reliability of product quality, the amount of product workup is reduced which is also positively influencing the stress-level of the plant.

Overall, this kind of support of the operators leads to safer, more reliable and sustainable process operation improving process efficiency and, thus, improving safety and health situation of the plant staff massively.

The newly developed methodologies can also help to visualize other deviation from the usual processing so that e.g. problems in the plant can be detected in an early state and maintenance tasks can be prepared in a longer term.

Operator training is a key aspect to achieve state of the art batch process operation. Within RECOBA, real-time operation was being used in extensive way in a research laboratory environment. As the systems have been implemented and explained step by step, the real-time control has gained high acceptance by the lab technicians. In the preparation of the pilot experiments, the lab technicians who have been working with the real-time control, have been playing an important role so that there is also a high acceptance in the pilot plant for the upcoming demonstration.
Of course, the change from time-based recipes to online controlled recipes which results in state-based operation, is very new in batch production in the chemical industry. Thus, the successful implementation by a demonstration in the lab or in the pilot plant is only a first step towards acceptance in a production environment. An important step towards acceptance in production is transferring experience from the pilot plant to production. In typical advance process control plant project, operator training is the most important mile-stone. Thus, people from the production need to be invited to one of the demonstration runs in the pilot plant. Furthermore, the roll-out of this technology needs to be done stepwise by implementing it firstly in a first plant to which people can come and see how reliable and robustly it works. This is increasing the trust in this new kind of technology. With increasing trust and knowledge, it can be transferred to many other plants.

4.2 Liquid steelmaking process

The impact of the application of the integrated control solution for liquid steelmaking on the situation of the workers in the plant can be summarized as follows

Training needs

The workers would have to be trained for adapted process control system as well for the maintenance of the new in-line temperature measurement technique.

Safety at workplace

Less additional spot temperature measurements and better process control would result in less stressful environment for the operators at the batch processes.

Acceptance by the operators and process engineers

The acceptance of the integrated control solution by the operators and process engineers is expected to be high, as it provides

- Better process control
- Basis for digitalization and further improvement of working conditions
- Improved data acquisition and more detailed view on the process

4.3 Silicon process

The current production process depends on several operations either carried out by or controlled by the operator. One of the stated goals for this project was to reduce the number of direct manual operations. This will reduce the overall risk exposure for the process operator and also reduce the effect of human-induced process variations. In this chapter we quickly review how the techniques and methods explored in this project will benefit the operator.

4.3.1 Data capture

The project has resulted in automatic registration of gas flow for the refining process, as well as automatic registration of solid additions to the ladle. Both of these types of variables had to be manually entered by the operator after the actual operation was carried out, resulting in both faulty and missing entries in the process database. With the new setup the correct time and value of the parameter is recorded. This will positively benefit the operator by reducing the data entry operation.

4.3.2 Metal level in ladle

The use of radar and load cells on the ladle wagons allows for automatic detection of the filling level. Upon implementation, this will remove the necessity of the operator to visually observe the filling level, thus removing him from an operation where risk is increased. All near-ladle manual operations should be avoided and in the future completely eliminated.

4.3.3 On-line process model

The on-line model will give the process engineer a much more detailed view of the process and allow for quick and accurate response to process deviations that traditionally may have caused off-spec products. With this new and innovative approach a tailor-made response can be given to any type of deviation, whereas with the current methods the control possibilities are limited due to lack of sensor technology, data acquisition and process models. The process model and its off-line counterpart can be used to educate process operators and make them better suited for proper response to their process observations.