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Abstract	The aim of this document is to analyse the end-user reports and inputs provided by DISIRE's members that describe current approaches in the existing inline measurements, PAT analysis tools and IPC strategies. Furthermore, the aim is to investigate the best representative and demanding industrial processes and determine the impact that the DISIRE project should target in a short as well as middle-long term. This document will define the required and expected capabilities of the DISIRE technology in function of the needs of the industrial end-users. Enhancements to DISIRE's capabilities will be thus investigated in relation with the applicability of the examined scenarios and the overall TRL demonstration levels that could be achieved. In order to gather the necessary information, a technical questionnaire

	will be compiled and shared with all the partners. The fusion of technical descriptions and end-user requirements and suggestions will result in the detailed specifications.

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Content

List of Acronyms

ABBREV	Explanation
BC	Belt Conveyor
C2	Ethylene
C3	Propylene
CC4	C4 Crude Fraction – butane, butane, butylenes, 1,3 butadiene, etc..
CSV	Comma Separated Values (file format)
COT	Coil Outlet Temperature (cracking furnace)
DB	Database
DCS	Distributed Control System
DDD	Down Draft Drying
DMC	Dynamic Matrix Control
EBF	Experimental Blast Furnace
EOR	End of Run
HC	Hydro-carbons
HVC	High Value Chemicals
IBA	A commercial data acquisition system
IP	Intellectual Property
IP21	Aspen InfoPlus 21
IPC	Integrated Process Control
KPI	Key Performance Indicator
LHD	Load/Haul/Dump Machine
MEF	Most Effective Technology
MES	Manufacturing Execution System
MIMO	Multiple Input Multiple Output
MISO	Multiple Input Single Output
MOC	Management of Change
MOR	Mid of Run
MPC	Model Predictive Control
OPC	OLE for process control
PAT	Process Analytical Technology
SCADA	Supervisory Control And Data Acquisition
SOR	Start of Run
TPH	Tempered Pre-Heat
TLE	Transfer Line Exchanger

TLV	Transfer Line Valve
UDD	Up Draft Drying

1 Introduction

1.1. Summary

This document indicates the objectives of the DISIRE project in terms of the deliverables and the strategies towards the evaluation, final industrial demonstration and integration of the DISIRE components. The information from the end-user reports and the inputs provided from DISIRE's members have been collected and compiled in this single deliverable document D1.2, which describes the current approaches in the existing inline measurements systems, PAT systems and IPC strategies.

1.2. Purpose of document

This document serves as a basis to investigate which are the specific representative and demanding industrial processes in DISIRE and what is the impact that the DISIRE project should target, with respect to this processes, in a short, as well as middle-long term. Furthermore, this document identifies the required and expected capabilities of the DISIRE technology as requested by the industrial end-users.

The state of the art, outlined by the current industrial deployments and the novel capabilities and characteristics to be developed by DISIRE, will be investigated in relation with the applicability of the examined scenarios and the overall TRL demonstration levels that could be achieved.

1.3. Methodology

For the compiling and integration of this deliverable, a questionnaire was first compiled by LTU and disseminated to the industrial partners of the project and all the peers of workpackages 5, 6, 7 and 8. Based on an iterative and interactive process of communication, the information collection needed for this report has been performed in a satisfactory level to describe in detail the existing DISIRE focused Industrial Processes and the initial starting points and aims in the project.

1.4. Outline

For each industrial process a short introductory description will be provided stating each problem and giving the general picture, as well as the corresponding dependencies and requirements among partners. Furthermore, the integration strategy will be initially discussed, where we will explain the necessary steps to integrate the developments of the project into the current industrial framework. In the sequel, a more technical description of the physical processes will be provided, defining the inputs and outputs of each process, providing links to the mathematical models currently used in practice, suggesting simulation tools (software) that are used to experiment with the process dynamics and presenting existing control-oriented models when and where available. Moreover, an overview of the control systems currently installed in the processes will be provided, discussing their features and possible shortcomings. Finally, the operation of the measurement systems (sensors, data acquisition systems and more) and the actuation systems along with their characteristics will be detailed.

The Industrial partners of DISIRE have also provided information about the data analytics systems currently used and described the evaluation platforms (software or hardware) that they are planning to use to evaluate the technologies that will be proposed by the DISIRE consortium. Evaluation cases are initially stated, which discuss in detail how the evaluation platforms will be used. Finally, we present and discuss DISIRE's initial plan and goals for the final industrial demonstrations, the proposed setups and expected outcomes.

1.5. Partners involved

Partners and Contribution	
Short Name	**Contribution**
LTU	Coordinating and integrating inputs from partners
DOW	Description of the WP8: Combustion Processes
MEFOS	Description of the WP7: Steel Processes
ETEC	Description of the WP6: Ferrous Mineral Processes
LKAB	Description of the WP6: Ferrous Mineral Processes
IMTL	Coordinating and integrating control specific discussions
KGHM	Description of the WP5: Non-Ferrous Mineral Processes
ABB	Description of the WP5, 6, 7 and 8

2 WP5: Non-Ferrous Mineral Processes

2.1. Brief description

The transportation systems used in the KGHM copper ore mines are designed for the so-called “room and pillar” mining system (see Figures 1 and 2).

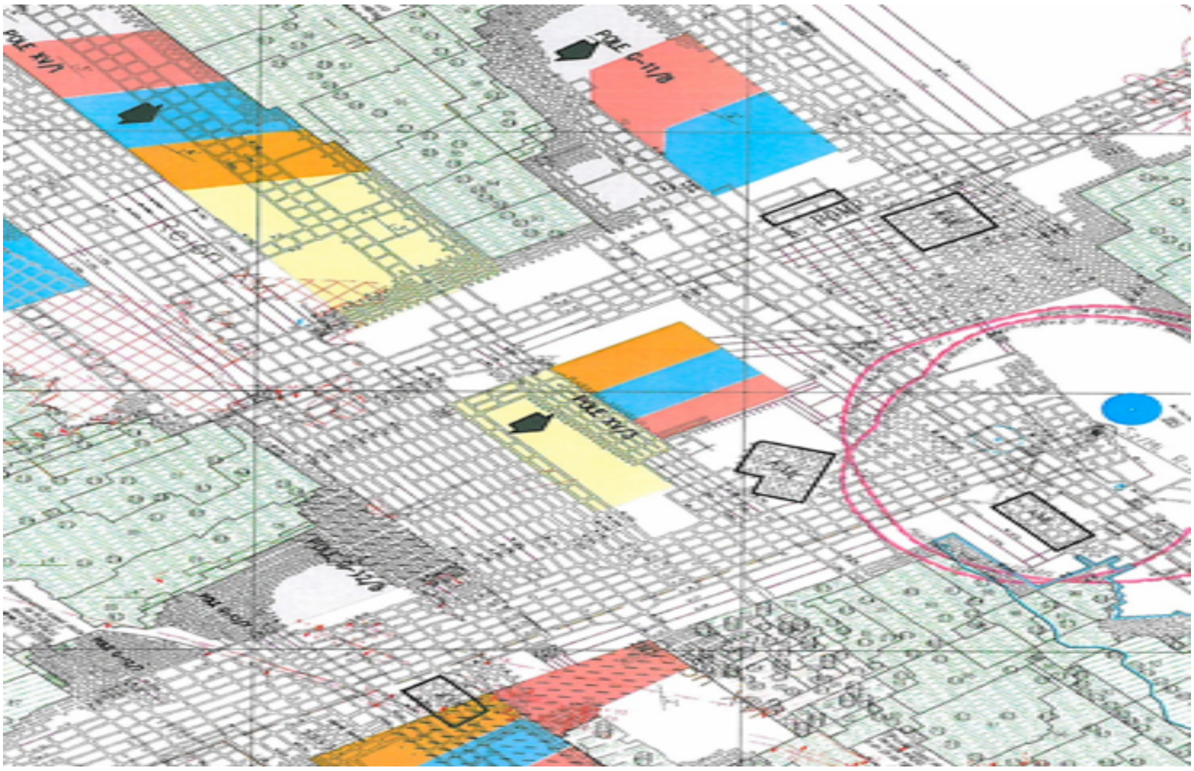


Fig. 1: Overview of the developments in a KGHM ore mine with “room and pillar” mining fields (colors are associated to the mining / production schedule).

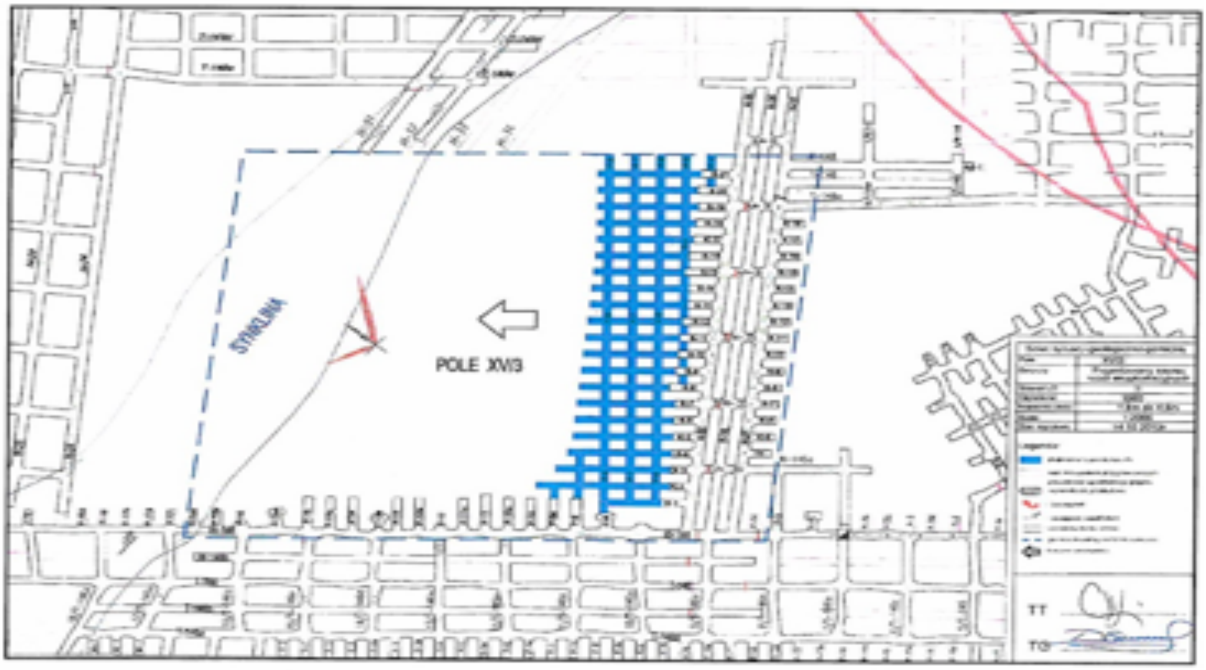


Fig. 2: Advancing of a typical room and pillar mining field. The exploitation development is shown in blue; the arrow indicates the direction of advancement.

The characteristic feature of the horizontal transportation system in the KGHM mines is the use, at the various stages and on different scales, of both *cyclic transport* (LHDs[1], trucks and rail transport) and the *high-capacity continuous transport* (Belt Conveyors / BCs). The transport network on rail will not be discussed further due to a lack of interest in its development (it currently operates only in the oldest part of the mine).

The cyclic transport involves the haulage of the ore, from the mining face to the mining unit discharge points, from which the ore is dumped directly onto a screen (a conveyor feeding point).

The oversize lumps left on the screen are crushed mechanically by hydraulic hammers that are controlled by an operator who monitors the dumping proceeds (see Figures 3 and 4). The ore leaving the mining unit is then usually stored in local storage bunkers, whose purpose is to provide an efficient interface between the continuous and cyclical transport. There is a need to store the output in a bunker to average the erratic flow of the ore coming from mining units and to match the transportation capacities of various links in the transportation system, many of which operate at different output levels and at different times.

[1] **LHD** stands for Load, Haul, Dump machine. LHD loaders are similar to conventional Front end loader but developed for the toughest of underground mining (hard rock) applications, with overall production economy, safety and reliability in mind. More information can be found at: https://en.wikipedia.org/wiki/LHD_%28Load,_Haul,_Dump_machine%29.

Fig. 3: Unloading a truck onto a screen. Notice the very different granulation of the mined ore and the hydraulic hammer used for breaking the oversize lumps.

Fig. 4: A hydraulic hammer for crushing oversized lumps of ore (on the left) and A conveyor feeding point (input into the BC).

The transport capacity of the LHDs depends on the machine payload and the numbers of hauling cycles. These machines cannot operate 24h/day (due to blasting procedures, staff replacement between consecutive shifts, etc.). In addition, the transport capacity of the conveyors depends on their position in the BC system and their technical specifications. Conveyors in the main transportation lines usually operate for longer periods of time because they are supplied both directly by conveyors from mining fields and ore bunkers. Even during a stop (due to, for example, blasting operations) of the conveyors located in the mining fields, the main conveyors can still transport ore from the local storage bunkers to the shaft bunkers.

The operation of the shaft[2] hoist[3] depends on the availability of the ore in the shaft bunkers. In normal conditions, it operates continuously and with planned stops to carry maintenance tasks.

Short breakdowns of individual links in the transportation system do not interfere with the operation of other links and do not restrict system capacity. By stockpiling material in the mining units and by making use of the shaft loading stations, the mining process is made independent of the shaft hoists and of the main transportation system.

[2] **Shafts** are vertical or near-vertical tunnels excavated from the top down where there is initially no access to the bottom. See https://en.wikipedia.org/wiki/Shaft_mining

[3] **Hoists** are used to raise and lower conveyances within the mine shaft. See https://en.wikipedia.org/wiki/Hoist_%28mining%29.

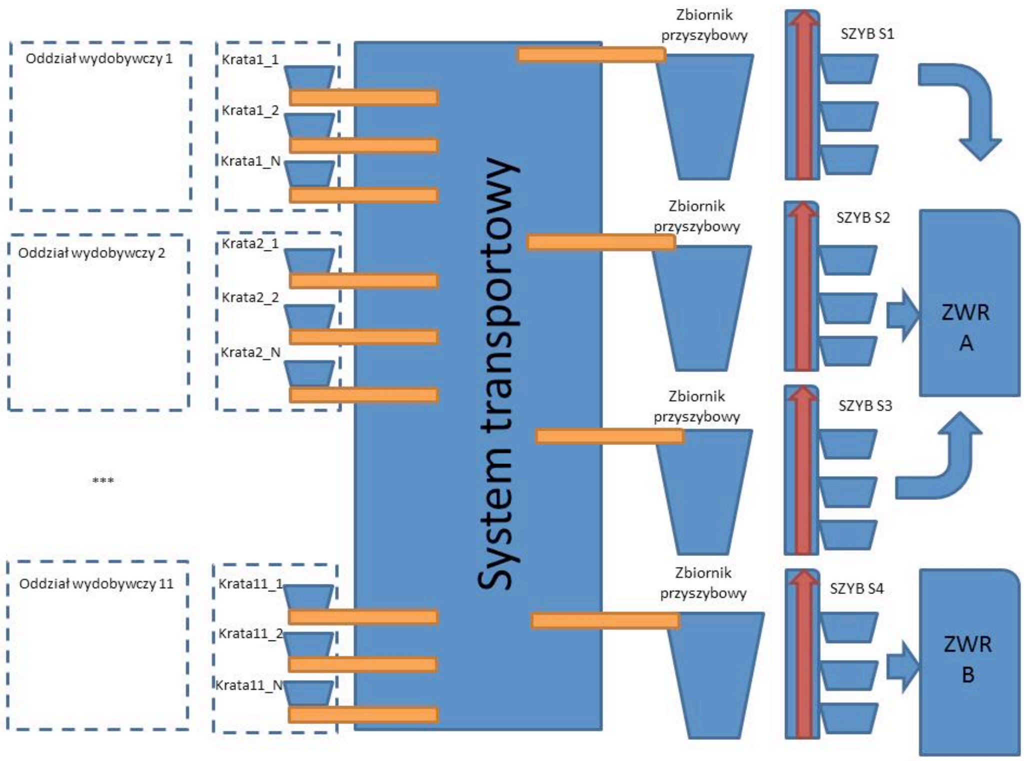


Fig. 5 Block structure of production (mining and transport, both horizontal and vertical).

Ore bunkers increase the transportation system flexibility and reliability and consequently improve the mining operations. However, it is now almost impossible to track the flow of any particular amount of ore from the mining face up to the shaft bunker. At KGHM, there are several (2 or more) hoisting shafts in each mine that are supplied with ore by the local belt conveying system. The belt conveyor system can be thus, on one hand, be modelled as a MIMO system, while, on the other hand, since the ore is hoisted to the mine-mouth processing plant (the processing plant can be considered as the final output of the BC), be studied as a MISO system.

The role of the system is to transport copper ore from mining screens (the places where the cyclic transport supplies the continuous transport based on conveyor belts) to the containers (a.k.a. bunkers) located near the mining shafts and from there to the Mineral Processing Plant located on the surface.

Enhancement in this area will lead to the ability of determining the quality of the ore available in flotation and the lowering of the operating costs for the BC system.

The performance metrics for the BC ore transportation system are:

- transported ore mass, in [mass unit]/[time unit]
- transported metal (Cu, Cu equivalent) tonnage, in [mass unit]/[time unit]
- energy consumed by the BC:

    - overall (in [energy unit])
    - specific (in [energy unit]/[mass unit])
- transportation cost of the BC:
    - overall (in [cash unit])
    - specific (in [cash unit]/[mass unit])
- reliability of belt conveyors.

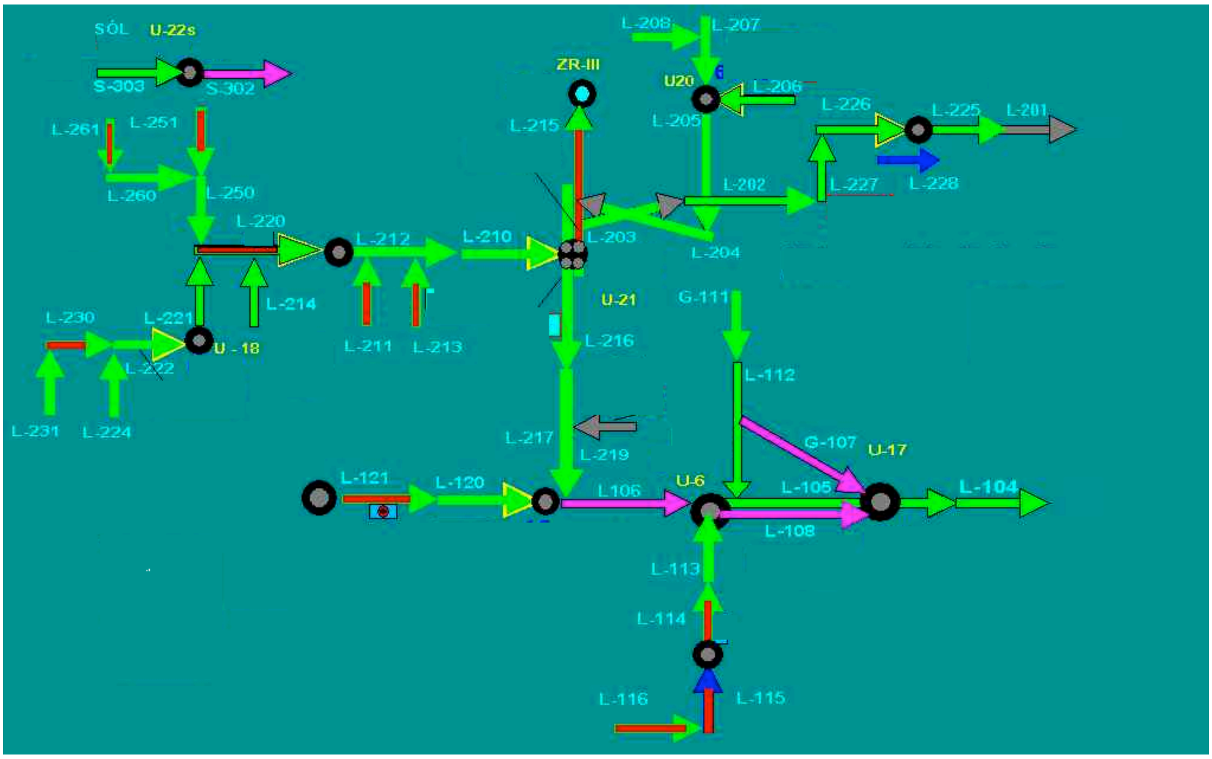


Fig. 6 A selected part of the BC system in the "Polkowice-Sieroszowice" KGHM mine.

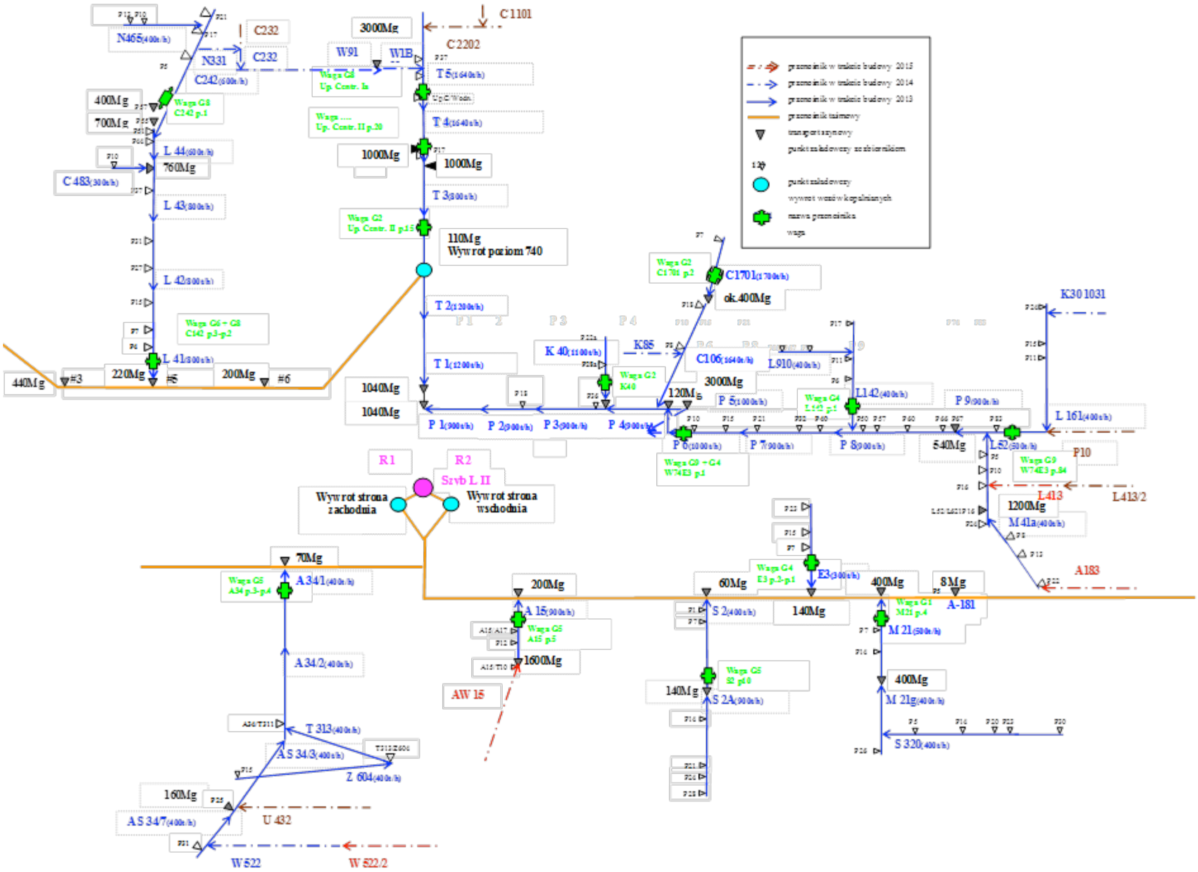


Fig. 7: The transportation system in the “Lubin” KGHM copper ore mine consisting of belt conveyors and railroads (grey arrowheads). Part of this BC system is chosen for further investigation. The ore is transported to shafts R1 and R2. Green crosses indicate weights for weighting the conveyed ore on-line.

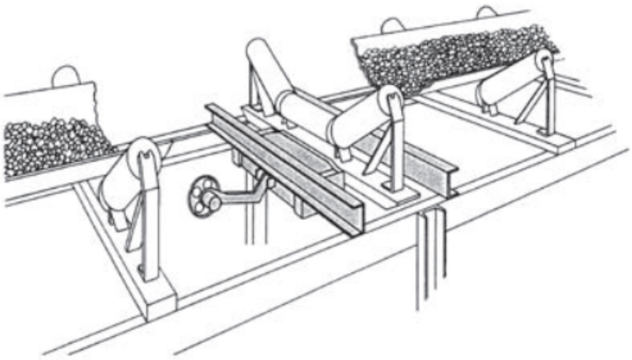


Fig. 8: Graphic description of the weight device for weighting the transported ore together with the measurement of the belt speed. The actual capacity is measured and the moving average (on a given time window) is recorded.

Fig. 9: Picture of the weight device for weighting the transported ore.

The difficulty in monitoring the flow of copper ore is related to the very specific nature of the mining technology used in the considered mine, the complexity of the transport network, the number of internal bunkers and the uncertainties related to the system's operation. At the moment, there is no advanced PAT/IPC technology or infrastructure aiming in optimizing the conveyor belt system. Moreover, at the current situation, the tasks of the modelling, tracing and controlling the transport system in a closed loop and in interaction with other parts of the processes are considered quite challenging and open problems, mainly due to the complexity of the problem, the number of factors that should be considered and the interdisciplinary knowledge required to implement such system. Apart from technical factors, in case of significant improvements in the transportation system, there is still going to be the need to change some organizational aspects and maybe even the corresponding mining regulations.

However, it should be also noted that at an abstractive level, the system already operates in such a way: Instead of a digital control algorithm, a human-based decision process drives the system, where the control action decisions for the transportation system are supported by many constraints, mainly related to the input data characteristics, the capacities of conveyors, bunkers, shafts and finally the Mineral Processing Plant.

It should be also highlighted that by developing novel sensors to measure the quality of the copper ore that could provide suitable real time information regarding the chemical content of the ore (mostly regarding its copper content) would open to the possibility of designing a new control scheme of the whole transport system where the cost function would be defined in terms of output volume and the quality of the ore. Such approach might represent a crucial improvement from the perspective of the mineral processing plant.

To this aim, its important to be aware that the BC system in the KGHM mines frequently transport large lumps of copper ore (see Figures 10 and 11); Therefore any additional objects on the belts have to be impact resistant or will otherwise be fractured.

Fig. 10: Example of oversized lumps of copper ore.

Fig. 11: An oversized lump of copper ore blocking the feeder discharge panel.

2.2. Integration strategy

Within the DISIRE technological frameworks and towards the development of the novel DISIRE components that aim at optimizing the transportation system, the following methodology has been envisioned:

1. System Analysis and Decomposition
2. Identification of crucial features, inertia of the system, Input/Output relationship
3. Identification of steady state and frequent events in the systems
4. Detailed description of the system components (loaders / trucks, screens, conveyors , bunkers and shafts)
5. Identification of inputs and outputs and examination of the currently used human-based control strategies on a large scale
6. Detailed identification of processes and variables
7. Analysis of the state of the art regarding scaling / modelling of the transformation system
8. Description of the available data (character, quality, etc.)
9. Description of existing sensors, monitoring and data transmission systems
10. Description of existing actuators and control systems on the small scale (locally, single conveyor, single components in the transportation system)
11. Formulation of the transportation system as a MIMO or MISO closed loop system using the following criteria: Volume of the production and / or volume and quality of the ore provided to the mineral processing plant (strongly depends on KGHM)
12. Preliminary formulation of the required data, algorithms and actuators to implement an IPC strategy to manage the conveyor based transportation system
13. To be considered: Analysis of the IPC implementation on a micro-scale (single conveyor or small part of the system using 2-3 conveyors and a speed control system taking into account the actual volume of transported ore).

2.3. Description of the physical process

From a control perspective, the physical process has two inputs:

1. *BCP – BeltConveyorsPower-input*: the actual overall electric power consumption of the BC system
    1. The energy consumed by the BC (overall (in [energy unit]), specific (in [energy unit]/[mass unit])), transportation cost of the BC (overall (in [cash unit]), specific (in [cash unit]/[mass unit]));
    2. Faults in the power supply are possible but rare.
2. *BCA – BeltConveyorsAvailability-input*: BC overall availability
    1. It is the reliability measure of the work of BC
    2. It effects the performance in terms of the BC's overall capacity against planning calendar units (shift, day)

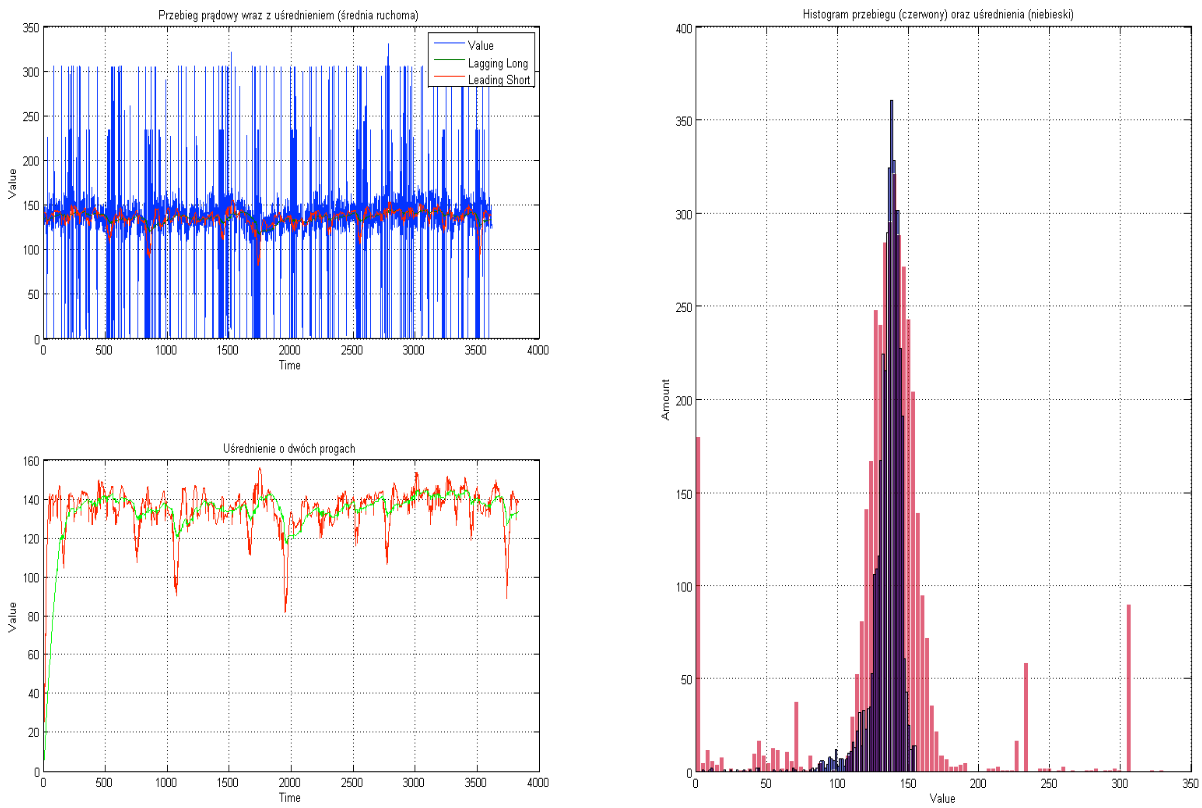


Fig. 12: Recorded and processed (to histogram) values of an electric current supplied to a single drive unit of a belt conveyor. All the drive units are monitored.

2.3.1. Fault conditions

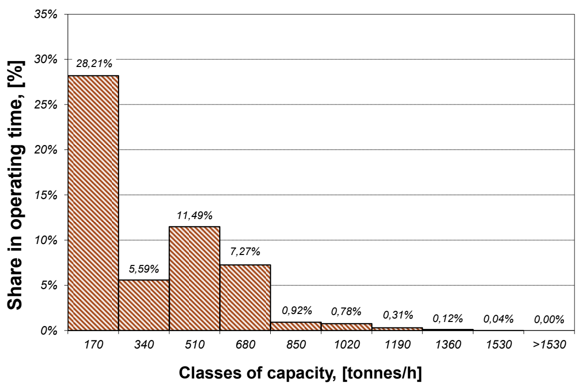
The BC system is subject to continuous and relatively frequent breakdowns. The most critical components are the drive units, the belt splices and the idlers.

Due to the buffering effect of the ore bunkers, an isolated breakdown could but does not necessarily lead to a halt of the whole system.

Fig. 13: Examples of damaged elements of a belt conveyor which cause its breakdown.

Fig. 14: Number of failures related to belt conveyor drive unit elements with respect to type of damaged part.

2.4. Mathematical models



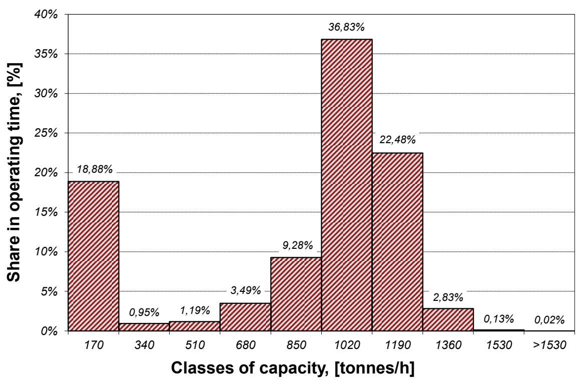


Fig. 15: The distribution of the actual belt conveyor capacity: The secondary transport on the left chart and the main transport on the right chart. The graphs highlight a substantial share of idle work.

Figure 15 shows that the actual capacity has a multimodal distribution. The model of the BC's overall capacity against the planning calendar units does not exist as of yet.

At this point, it should be also noted that due the existence of ore bunkers that can mitigate the impact of a single breakdown onto the availability of the whole BC system, standard parallel or serial reliability systems do not apply.

Fig. 16 Evaluation of the material flow control in Matlab (ABB).

A potential research direction in this area is the control of the material flow from the customer order to the customer deliverable. In this case, the focus could be on control and tracking of the mass and properties from face to flotation process in WP5. The work could then be extended with additional information from the processes in WP6 and WP7 and even include the planning of the blast preparation and LHD at the face, since this would improve the customer order to delivery chain even more.

At the current stage in the KGHM mine, reducing the cost from the continuous operation of the conveyor belts is not an issue as the corresponding benefit is of no importance with respect to the overall production cost. However, modelling the conveyor belts system as a whole system and focusing in the fault detection for preventing fault in the system, based on in situ measurements (e.g. acceleration) and online PAT from existing sensors would be of paramount importance in order to avoid the break down times.

From another point of view, what is of paramount importance is the information on the tractability issues of the ore and more specifically there is a huge demand to determine how much copper is in the ore and where specific batches of ore are currently located or from what place (part of mine) the ore is coming, since there are two components of the ore: sandstones and dolomites and in the corresponding mining technology usually there is a mixture of varying percentages.

Thus in situ pellets, as in the case of WP6, in the overall transportation system in the Mineral Processing Plant (MPP) will adapt the system to the actual processing of the ore and the corresponding actual properties of it, while improving overall the production quality.

2.5. Simulation tools

We plan to use the FlexSim modelling tool to study and simulate the overall capacity of the BC systems during the project. We note that unfortunately it will be difficult to make FlexSim available to other partners due to the licensing policy.

2.6. DISIRE Technological Contribution

The expected DISIRE contribution in this WP and towards the transportation system can be summarized in the following Figure 17, where the expected major contributions from the project will be: a) the DISIRE based in situ sensors for tracking the ore, and b) DISIRE based On Line PAT, with potential extensions in influencing the overall IPC and the fault detection in simulation and hardware in the loop trials, regarding the transportation system.

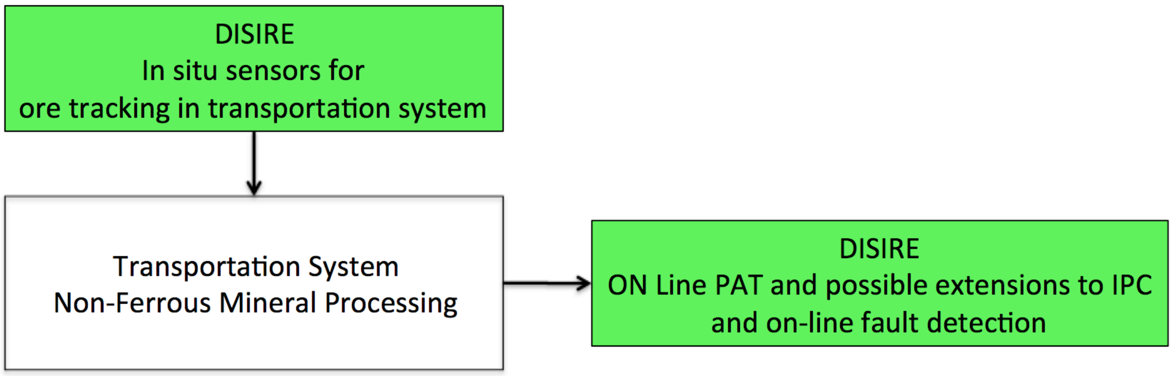


Fig. 17: DISIRE technological impact in the Transportation System.

3 WP6 Ferrous Mineral Processes: Tracing iron ore pellet in transportation chain

3.1. Brief description

The transportation chain of the iron ore pellet starts when the refined product is loaded into temporary storage silos at the production site. Each silo normally contains around 10.000 tons of material. The pellets are then loaded onto special cargo trains (each with a capacity of approximately 6.800 tons) that transport the pellets to one of the two shipment harbors: Narvik or Luleå (depending on the production site). The final steps in the transportation chain (before the product reaches the customers) are loading the product on cargo ships and the maritime transportation as it is being indicated in Figure 18. The loaded amount per ship varies between 70.000 to 140.000 tons.

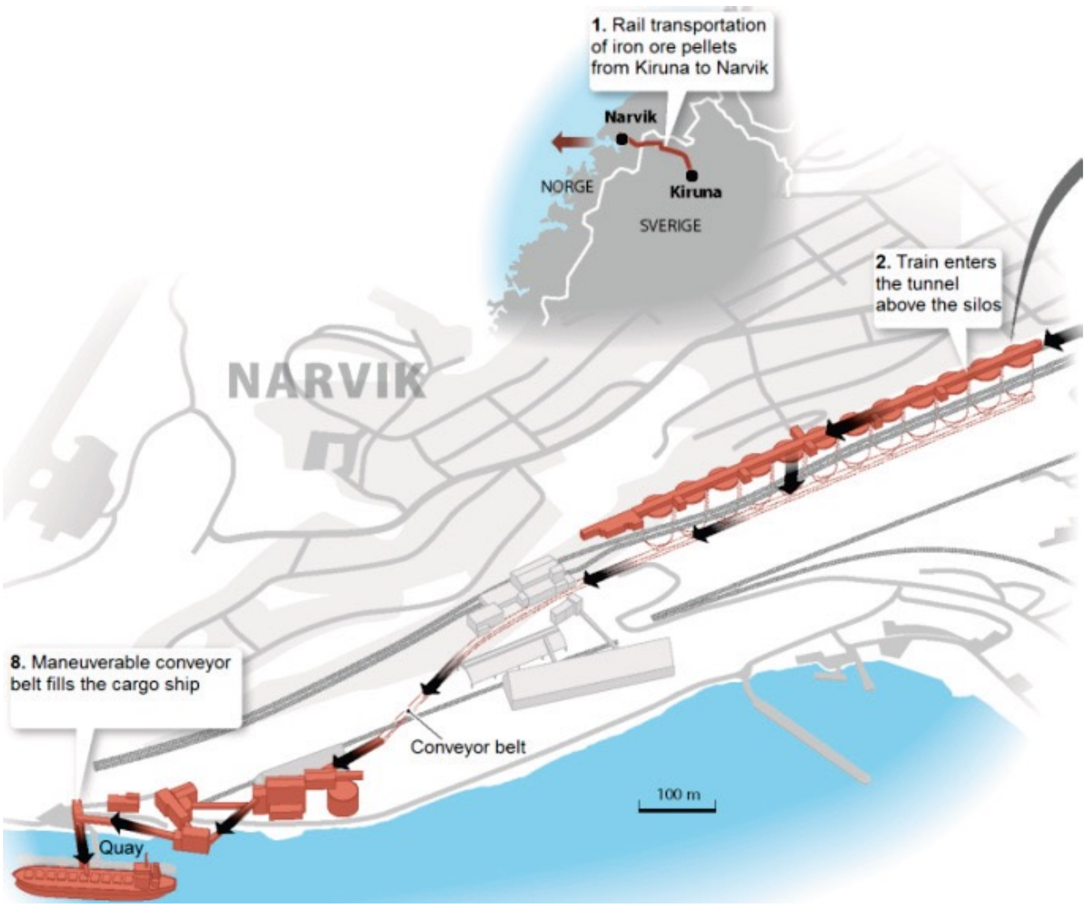


Fig. 18: Overview of the transportation chain of the iron ore pellet from Kiruna to Narvik (courtesy of LKAB).

The main factors affecting the quality of the product are linked to the quality of the ore itself: the ore will have different features depending on where it is mined. The composition of the pellet can vary depending also on the needs of different market segments and the type of transformed goods to which it is destined.

A difficulty in this case is then that different product batches are difficult to separate and this puts restrictions on the production, since the corresponding storage facilities are limited. It is moreover difficult to track products for causal analysis when customers have issues with the properties of a certain product shipment. Therefore there is a need to be able to trace and predict the location of a specific product (batch). Today, tracing products can be both complicated (if not impossible) and very time consuming. For this purpose, it is of great value to be able to know the position of a product from ore to customer.

In this application scenario, the important variables are the time and the position of pellets after production so that the product's properties, which have been selected for a specific customer, can meet certain quality constraints.

The mixing of the same product but from different production batches in the logistics chain (including storage silos) may affect the properties of the material. By using existing knowledge regarding flow of granular material in silos and by creating models to control the mixing from different product batches, it is aimed to reach a more evenly distributed production quality, through mixing when loading onto a ship. This means that the time and positions of a certain production batch, in the logistics chain, are important measurements.

A model, which describes the logistic distribution of pellets, is essential to be able to simulate and suggest appropriate actions to maintain a stable product quality. To be able to validate and/or adjust such a model a corresponding sensor, endowed with tags, will be necessary. Tracing can be performed through, e.g., radioactive marking or by means of RFID based technologies. Any tracing approach that meets the needs of the transportation chain will have to fulfill the following requirements. The method must not be too expensive since the product itself is not; the method needs to be robust due to the harsh environment that the pellets are exposed to during the transportation process, it needs to be a method that is practical, e.g. the tracers must be easily detected, and the tracers must follow the regular product flow without separating from the target batch. However, it is still an open problem to manufacture a RFID tag with the same physical features of a pellet and at the same time make it easily detectable. A pellet of larger size, which could be more easily detected, may with unoptimized physical features, risk being separated. If such separation could occur, the sensors will not behave the same way as the pellets in the transportation chain. RFID tags exploiting currently technology are highly dependent on the size of the tag, antennas and antenna design. Earlier research showed that RFID tags might need to be larger than the pellets themselves to be detected. Different sizes of the tags and pellets may cause the tag to segregate from the batch. Being able to make tags with acceptable readability that follow the product along the logistic chain without segregation is thus of great importance.

Thus DISIRE's main objective in this WP is to trace batches of iron ore pellet using small RFID tags in the transportation chain from LKAB's plants to the ship-out harbours.

Currently, the detectability of each sensor depends on its size. With tags of the same size as the iron ore pellet (Ø 10,0-12,5 mm) the detection rate is around 20%. In fact, sensors of the same size of the iron ore pellets are very difficult to detect in a harsh environment: the already weak signal is drowned in the noise from electrical motors and vibrating transport conveyors. This situation could be improved by means of a more efficient signal processing: the currently available readers do not have the data processing capacity to extract data from the noise background and it would be a meaningful development to address this issue within DISIRE.

Up to this point, an increase of the signal to noise ratio has been achieved by increasing the size of the tags (when shortening the reader range is impossible): larger tags, with a diameter of around 20mm, yield detection rates of up to 80%. It will be thus important to show that the novel sensors can be scaled in size and implemented into the flow without the risk of segregation.

A measurable goal of the DISIRE project will be the increasing of the reading rate for the small tags to at least 50%. A second goal will be to investigate and demonstrate how larger tags can be included without segregation from the real pellets.

The main goal of this WP will be the further application of the PAT sensor platform, miniaturized tag, that will be able to be fitted with suitable off the shelf sensors that could be utilized for in situ measurements in the production process and logistics flow. Currently, already identified challenges towards delivering this technology are the following ones:

- Detection rate of the small RFID tags in a bed of iron ore pellets on a large conveyor belt.
- Encapsulation of sensor based RFID tags to avoid segregation from ordinary iron ore pellets.
- Positioning sensor based RFID tags in silos to verify flow model.
- Integrate pressure/load force sensing capabilities into a RFID tags

3.2. Integration strategy

The segregation will at first be studied on a smaller scale with miniature coloured pellets. Then we plan to run tests with real size pellets in off-line silos where differently sized and shaped sensors will be placed at known positions and detected when they leave the silo. Finally, the sensors will be dropped at LKAB plants in Malmberget and/or Kiruna and detected in Luleå's and/or Narvik's harbours. In the final stage the new readers with this improved signal processing will be used.

3.3. Description of the physical process

Currently, the transportation chain is open-loop and control goals are not immediately applicable. One of the additional DISIRE objectives is to create a flow model of the transportation chain and verify this by utilizing RFID tagged iron ore pellets.

3.4. Mathematical models

Simulation models will be implemented during the project. The plan is to devise both deterministic “plug flow” and “mixed flow” behavioural models as well as probabilistic models of the flow distribution based on data obtained from experiments.

3.5. Simulation tools

The corresponding simulation tools will be based on the previous mentioned mathematical models and will aim at facilitating the prognosis of virtual batches so that different product qualities can be traced and positioned in product warehouses along the transportation chain. This task is non-trivial since the continuous product flow at the plant is made discrete by intermittent use of conveyor systems, by collecting the product into iron ore freight trains and freight boats.

3.6. Control oriented models

The logistic chain as well as the grate process will generate knowledge useful for off-line or open loop control purposes. The LKAB processes are not expected to be controlled in closed loop during the development of the DISIRE project. However, this knowledge will be of paramount importance either for laboratory evaluations with hardware in the loop test bends or for full simulation test cases.

3.7. Control system

The existing control systems for the LKAB processes are open-loop. Human operators perform control decisions based on the simulation of the position of virtual product batches in the transportation chain.

3.8. Measurement and Sensor systems

The goal of the project is that a simulation model should be calibrated using full-scale tests in the production environment. The measurements and sensor systems for the product transportation chain are limited to positioning, that is to measure time and location of virtual batches. These tests should be preceded by laboratory studies using, e.g., granular material of different sizes to study the segregation aspects.

3.9. Actuation

No additional information on how the system is actuated will be provided, since the actuation of the transportation chain is operator controlled and the operator will have better knowledge of the position of virtual batches so that the product quality shipped to customers could be improved. Moreover, this WP will focus in the evaluation of the novel embedded in the flow PAT sensors, on traceability and in situ measurements of the flow behaviour in the aforementioned processes.

3.10. Data Analytics

The data analytics of the product transportation chain will be developed based on statistical models of the mixing and distribution of the pellets along the transportation chain (i.e., inside the silos, on the cargo trains and a ships). The currently performed data analytics are performed off-line using statistical software such as the R programming language. Further investigations in the current Data Analytics and for enabling the online PAT analysis will be performed in WP4.

3.11. Evaluation platforms

During evaluations the only way for sensors to communicate back information will be through a reader. The reader will detect and activate a sensor travelling on a conveyor belt, when it passes through or over the reader antenna. During this passage the sensor's unique serial number is read out. The reader-tag uses inductive coupling and reading in only possible while the sensor is energized for a very short period, while it passes in the centre of an antenna. Sensors will be battery powered and may transfer additional measurement data through radio signals when triggered by the inductive reader.

The reader will store all sensory data until an operator erases it. During the evaluation period (i.e., the project time) all data from all readers will be transferred over GPRS to a database. This database will only be available to the peers of WP6 since the data has no relevance to other partners before it has been processed further and compared with the flow models.

Notice that when the novel sensors will be integrated into the real factory environment, the data will be directly accessible at the reader through IP on Ethernet or WiFi. This could be possible already during the project's phase but usually the test site owner does not allow access through their Intranet.

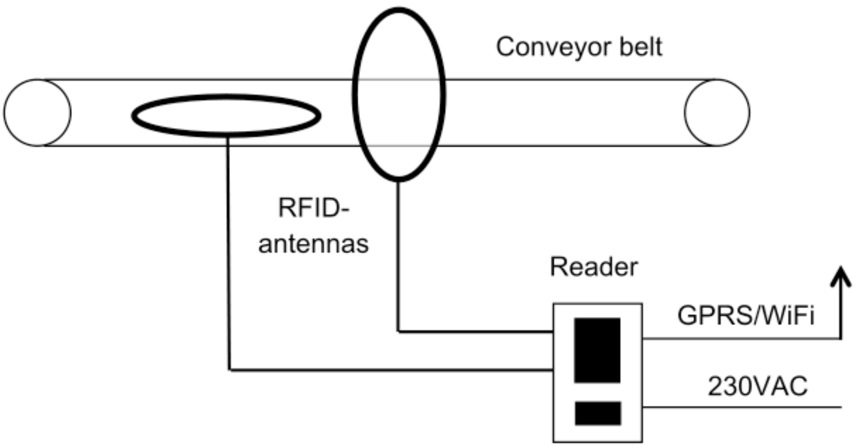


Fig. 19: A schematic description of the novel PAT system to be developed.

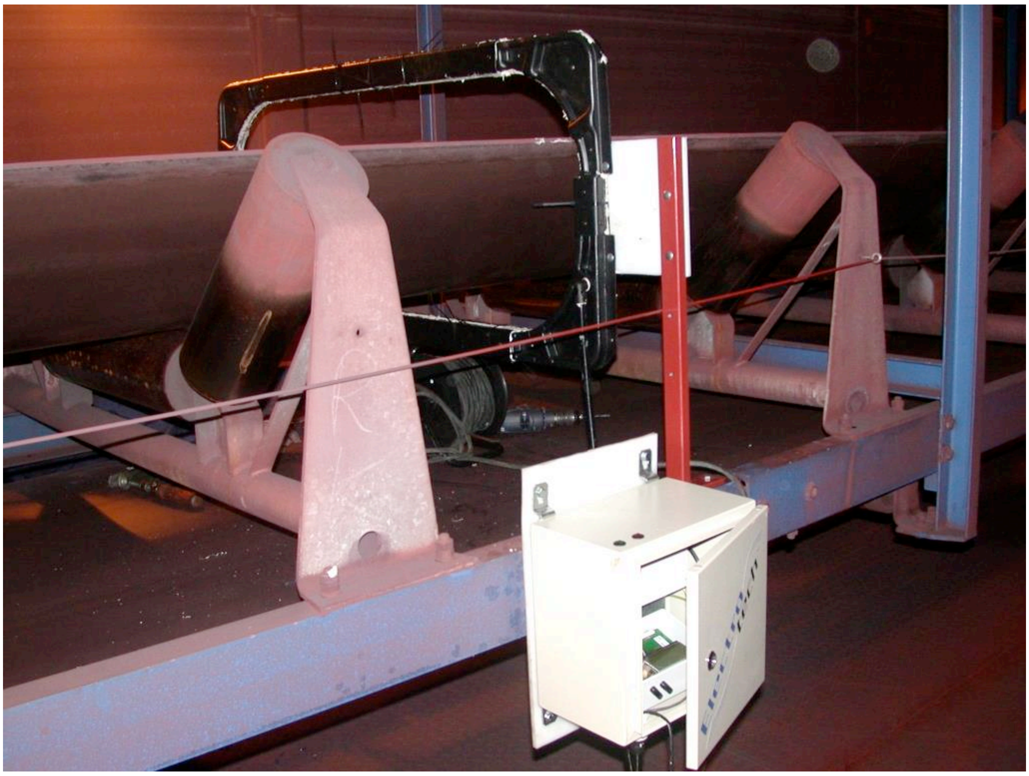


Fig. 20: Reader with antenna installation: the size of the receiving antenna can be up to Ø 2,5 m.

Fig. 21: Sensors with embedded tags and real pellet. Encapsulated tags: Ø 13-25 mm; Real iron ore pellet: Ø 10-12.5 mm.

*Fig. 22: A tag encapsulated in glass: 12*2 mm – 22*4 mm*

3.12. Evaluation cases

Two class of tests are envisioned:

1. Evaluation of the flow and segregation in small scale silos with miniaturized pellet of different size. The different pellet types (size, weight and friction) will be separated and identified through colours and then analysed optically.
2. Evaluation of flow and segregation with real pellet in smaller silos. Suitable silos are located at MEFOS's plant (in conjunction to LKAB's EBF). During EBF's test campaigns one of these silos can be used to run experiments linked to DISIRE. The silo will be manually padded with sensors at different abscissas and in several layers among real iron ore pellets. Then the silo will be flushed and a reader will detect the sensors as they exit the silo outlet. The unique ID of each sensor and the exact timestamp of when they passed the reading point will be used as an input to the flow models.

3.13. Final industrial demonstration

In the final demonstration, a batch of sensors will be dropped in one of LKAB's plants (Kiruna or Malmberget). Readers will be placed at least in the harbours of Narvik or Luleå and possibly at additional reading stations at the plants (before the pellet is loaded on the trains). When the sensors pass the readers their ID and timestamp will be collected and verified later using existing flow models (the timestamp and tag's ID will be compared with the registered data of same tag when it was manually dropped). A reader will be placed typically aside a transport belt conveyor with antennas around and below the belt. The flow of the iron ore pellets and the sensors with embedded tags will pass through one antenna and above the other antenna. This 2-antenna system will increase the detection rate since the small coil inside the sensor can perform poorly depending on its orientation with respect to the reader's antenna.

3.14 DISIRE Technological Contribution

The expected DISIRE contribution in this WP and in the general Industry of the Ferrous Mineral Processing can be summarized in the following Figure 23, where the expected major contributions from the project will be: a) the DISIRE based in situ sensors, b) the DISIRE based traceability capabilities of the pellets, and c) the DISIRE based On Line PAT module for the Ferrous Mineral Processing with potential extensions in influencing the overall IPC in simulation and hardware in the loop trials.

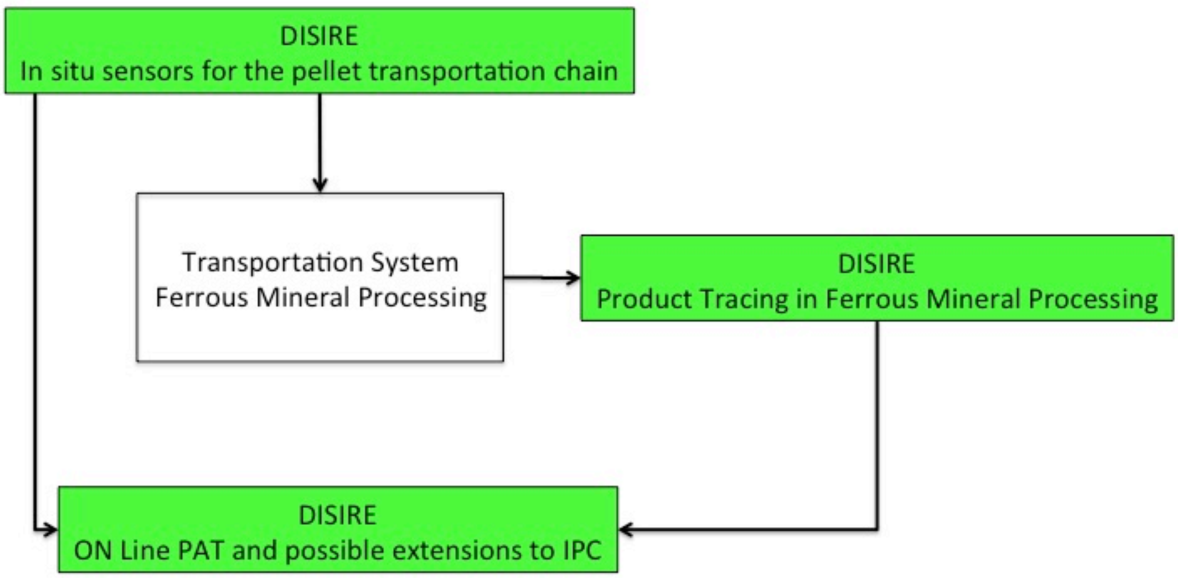


Fig. 23: DISIRE Technological Impact in the Ferrous Mineral Processing Industries.

4 WP6 Ferrous Mineral Processes: Thermal grate

4.1. Brief description

As described in the previous chapter, *green pellets* are ball shaped aggregates of fined ground magnetite and additives such as binders that undergo a refining thermal process in the so-called Grate[4] Kiln[5]. During the passage through the grate, the initially moist pellets (the moisture content varies between 8.5 and 9.2 %) are dried, heated and oxidized before the sintering[6] phase takes place in the kiln and in the final cooling phase. A schematic representation of a Grate Kiln pelletizing plant is presented in Figure 24.

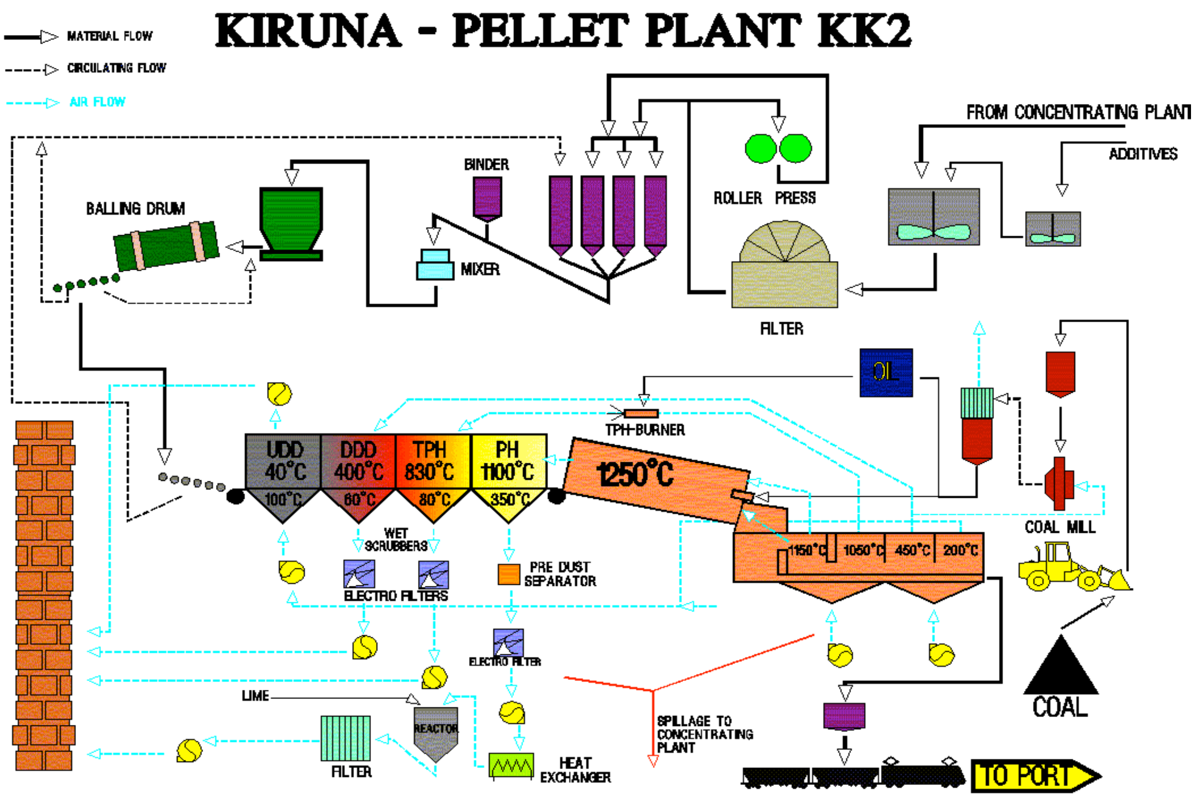


Fig. 24: Overview of a pelletizing plant process at LKAB

The first part of the hot process in a pelletizing plant is the grate, which is divided into different zones. The drying takes place in the first two zones of the grate through the forced circulation of hot air. These zones are called UpDraft and DownDdraft Drying (UDD and

4 A **grate** is where a stationery bed of pellets, approximate 20 cm high, is transported and exposed to the process of drying and heating.

5 A **kiln** is a thermally insulated chamber, a type of oven, that produces temperatures sufficient to complete some process, such as hardening, drying, or chemical changes.

6 **Sintering** is the process of compacting and forming a solid mass of material by heat and/or pressure without melting it to the point of liquefaction.

DDD). In the next zone, the pellets on the bed are exposed to the so-called Tempered Pre-Heat (TPH). The aim is to remove the remaining moisture content and start the oxidation process. The last zone of the grate is the PreHeat zone (PH), where most of the oxidation process takes place. Throughout the Grate the pellets experience widely ranging temperatures that vary between 20°C and 1300 °C. The overall transportation time through the grate can last from 8 to 20 minutes. In the Kiln, the pellets are sintered and the product is refined to meet the customer's quality requirements.

The cooling process (the *cooler* for short) is divided into four (or five) parts. Here ambient air is circulated to cool down the hot pellets. The air-flow is then recycled in the Kiln and on the Grate and an meaningful aim for DISIRE enabled sensors would be to acquire knowledge on how the gas composition varies throughout the grate through measurements.

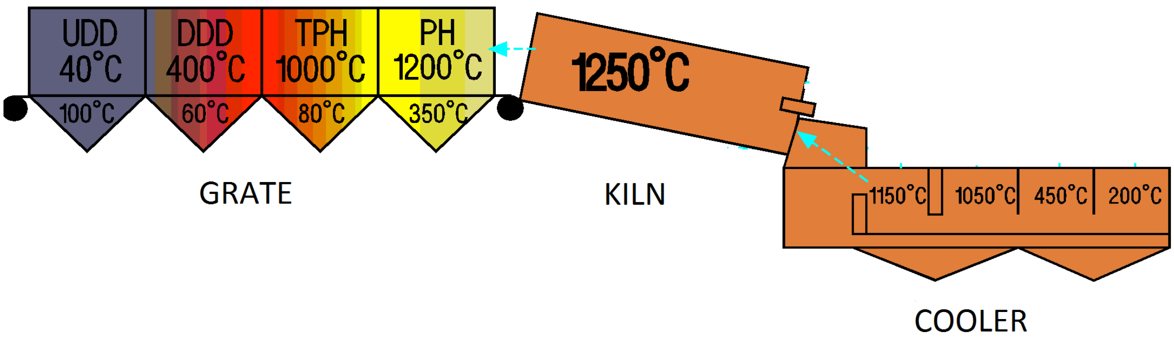


Fig. 25: The hot part of the pelletizing process.

With respect to the involvement in DISIRE the aim is to measure the temperature and gas composition on the grate of the pelletizing plants. The novel sensor technology shall be able to measure temperature in the pelletizing plant’s preheating oven (the grate). The sensor will travel inside the bed of pellets through the oven and continuously report the temperature via radio signals to a reader-equipment.

The high temperatures will be a challenge for the sensor that will have to be insulated with state of the art materials in order to keep the electronics working over the entire measurement cycle. The reader antenna will need to be endowed with a milder form of heat insulation as well. Notice that there are additional challenges in transmitting radio signals within the grate since airborne particles and gases will absorb part of the signal's power. In the case that the radio communication would not be able to be established, a proper reading infrastructure in the cooler parts of the process might also be investigated in DISIRE.

The identified challenges towards working implementations are:

- Encapsulate the sensor to withstand temperatures up to 1200°C for up to 20 minutes
- Wireless transmission of data through that encapsulation
- The size of the sensor must not impact the gas flow
- Measure the oxygen content in process's gasses

4.2. Integration strategy

The PAT sensors will report their data to a reader located nearby. This reader will store all sensor data locally or in a remote database, while the data should be accessed through TCP/IP. No further integration is planned at this stage. First high temperature measurements can be tested and verified in static laboratory ovens at MEFOS to avoid disturbing the production process at LKAB. Detailed integration strategy will be analysed in the future of the project with respect to the corresponding deliverables, from this as well as from other Wps.

4.3. Description of the physical process

From a control perspective, the physical process has two inputs*:*

1. *grate-temperature*: the temperature on the grate
    1. Admissible values for this temperature are in the range 0°C to 1200°C.
2. *grate-gas-composition*:
    1. Admissible values for the oxygen content are from 0% to 100% (ambient air has on average a 21% oxygen content)

4.4. Mathematical models

Empirical models for the temperature dependent thermal conductivity of suitable types of thermal insulation will be developed as required for simulating the thermal conductivity of encapsulations used for enhancing the temperature range of PAT sensors. The material flow model in WP5 could also extended to include information from this process in order to improve the customer order to delivery chain.

4.5. Simulation tools

At the current stage of the project, one possible solution to the problem of building sensors that survive high temperatures is to create a shell of a highly insulating material and fill this shell with a material that absorbs the energy transmitted through the insulation through phase change, high specific heat and/or evaporation. As a part of the work towards a PAT sensor that survives high temperatures a Matlab/Comsol hybrid tool will be developed for optimizing the ratio between the amount of insulation and the amount of heat absorbing material. This tool may be extended to supporting multiple materials of both types.

4.6. Control oriented models

The grate process as well as the logic chain will generate knowledge useful for off-line or open loop control purposes. The LKAB processes are not expected to be controlled in closed-loop within the duration of the DISIRE project.

4.7. Control system

The grate control system is proprietary to LKAB and no additional information will be provided.

4.8. Measurement and Sensor systems

The measurements and sensor systems of the grate process include temperature and oxygen content gauges, such as thermocouples and lambda sensors; These allow to better understand to study the chemical environment and the heat distribution within the process.

The novel in situ sensor technology will be able to report data, while it is transported through the Grate (online PAT). By giving each sample a time-stamp and by knowing the transport conveyor speed, this will make it possible to estimate the temperature and oxygen content at various positions inside the oven. The conveyor speed is very slow and the sampling speed is only relevant in terms of optimising the radio data channel. From LKAB's perspective, a sampling rate of about 1 Hz (or less) could be enough. In general within the DISIRE project we expect that the novel sensors will be able to measure temperatures with an absolute error of 1-3% (depending on thermocouple type).

The reader will be connected to a database over GPRS. The sensors cannot be accessed directly, only via the reader. Further developments to this system could be to devise a sensor technology that can measure the combustion parameters and to support positioning measurements via 3D inductive coils.

4.9. Actuation

The grate process is currently open-loop and operator controlled, and the expected actuation is a better control of the grate environment including atmosphere flow, atmosphere oxygen content and temperature profiles along the grate and at different depths of the grate's pellets bed."

4.10. Data Analytics

The analytics of the data stemming from the grate process includes regular experimental analysis to calibrate the readings obtained from the grate bed oxygen and temperature sensors, and to compare readings performed externally, in fan channels, furnace chamber mounted sensors and so on.

4.11. Evaluation platforms

4.11.1. Tube furnace Pot-furnace Grate Kiln plant

To ensure that the sensor is working in the desired temperature range and can measure the gas compositions wanted, it is important to test it in steps. The first step will be to run multiple tests in LKAB's tube furnace, depicted in Figure 26. Within the furnace it would be possible to run trials while controlling the environment's temperature and gas composition.

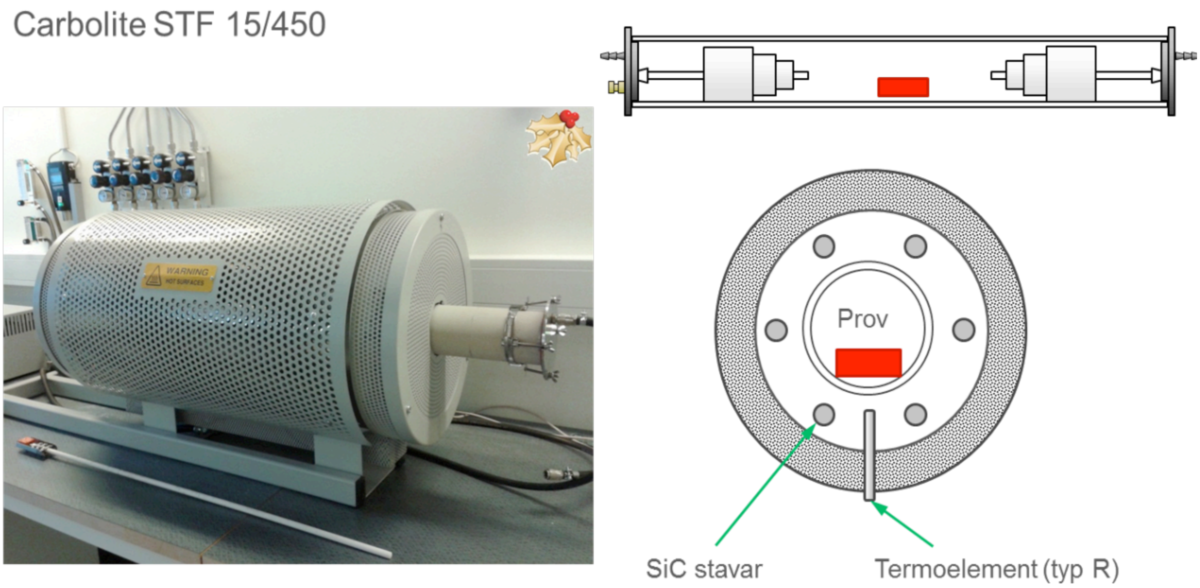


Fig. 26: The Carbolite STF 15/450 *tube furnace.*

The tube furnace is a Carbolite STF 15/450 with a maximal temperature of 1500°C and 5,5kW maximal effect. The furnace is controlled by a Eurotherm 3508P1 PID-temperature regulator with RS232 interface. The regulator can store a program with a maximum of 20 segments in which one has to be of the type "End". The rate of heating up should not exceed 5 K/min, above 1000°C it can be increased slightly (up to 7,5 K/min). A faster increase or cooling can cause damage to the tube. The heating is done by six SiC spiral rods. Both the heating element and thermocouples are placed outside the tube. The temperature inside the tube therefore deviates slightly from the temperature on the display if the furnace is not calibrated. For the same reason the sample is not affected by the IR radiation from the heating elements. The furnace can be connected to a gas supply and allows experiments in different (not corrosive) gases. The only way to communicate with the sensors is through a reader. This reader will access and poll data from the sensor with radio signals over a distance of 10-50 meters.

This long reading distance must be achieved when monitoring hot processes where the reader equipment cannot sustain the harsh conditions. The reader will, at periodic intervals, scan for all the sensors in its vicinity and collect their data. For each successful poll, it will store the tag's id-number, sensor data, link quality, battery status and a time-stamp. Furthermore, the reader will store all the sensor data until the operator erases it. During the evaluation period (i.e., during the project time) all the data from all readers will be transported over GPRS to a database that will be made available to all partners through a web-interface over the Internet. The sensors will be destroyed and eventually burned up at the end of each test. The reader's antenna should survive several test phases but will need to be dismounted between test campaigns. Since each sensor can be used only once, they will be produced in small volume in a serial manufacturing fashion.

Notice that, when integrated into the real factory environment, the data will be directly accessible at the reader through IP on Ethernet or WiFi. This could be possible already at the project phase but usually the test site owner does not allow access through their Intranet.

4.12. Evaluation cases

Sensor survival in high temperatures is the most challenging part and will be tested in static ovens at LKAB or MEFOS. The temperature of the electronic components inside the encapsulation cannot rise above 100°C while the surrounding temperature will reach above 1000°C.

The sensors will continuously report both inside and outside temperature to let the end-user monitor the sensors performance. Notice that the radio environment inside the grate oven will have to be examined in parallel to the tests and most likely on the real site.

4.13. Final industrial demonstration

The sensors will be finally tested / demonstrated in one of LKAB's pellet plants with a Grate / Kiln process. The real data from the process will have to be scrambled due to privacy concerns connected with the use of proprietary IPs.

The sensor data will be provided unscrambled to project partners along with reference data from existing sensors. The available sensor data will be sensor id, timestamps, temperature and oxygen readings. The database will have export functions for .csv formatted files. Finally, the Database with the above listed data will remain and be accessible throughout the project period. No other process data regarding the grate will be disclosed.

4.14. DISIRE Technological Contribution

The expected DISIRE contribution in this WP and towards the Grate process can be summarized in the following Figure 27, where the expected major contributions from the project will be: a) the DISIRE based in situ sensors for temperature and gas decomposition measurements, and b) DISIRE based On Line PAT, with potential extensions in influencing the overall IPC in simulation and hardware in the loop trials.

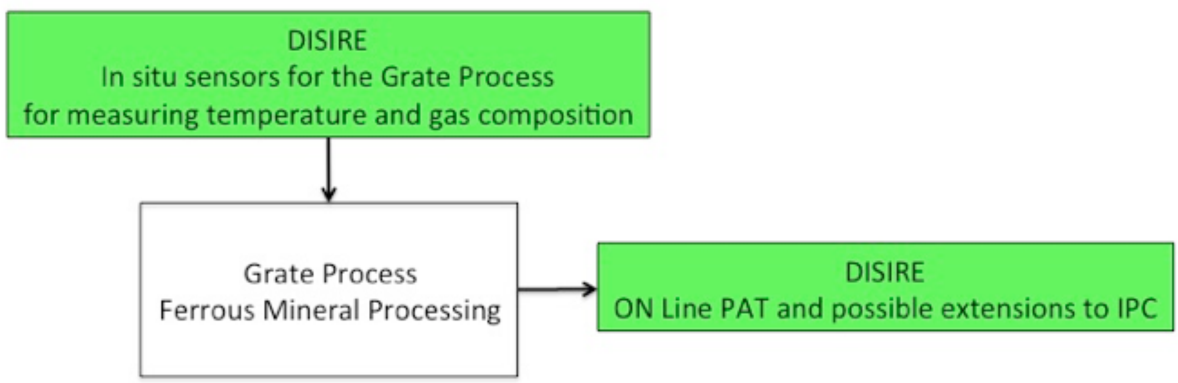


Fig. 27: DISIRE technological impact in the Grate Process.

5 WP7: Steel Processes Blast furnace

5.1. Brief description

The process of smelting[7] the ore into hot metal in a blast furnace is an almost continuous one. The basic material flow is the following: Coke, ore and slag[8] formers are charged at the top of the blast furnace; In the lower part of the furnace, blast is blown and pulverised coal is injected. The slag and hot metal that are separated through the heat, sink towards the bottom of the furnace where they are tapped around every hour.

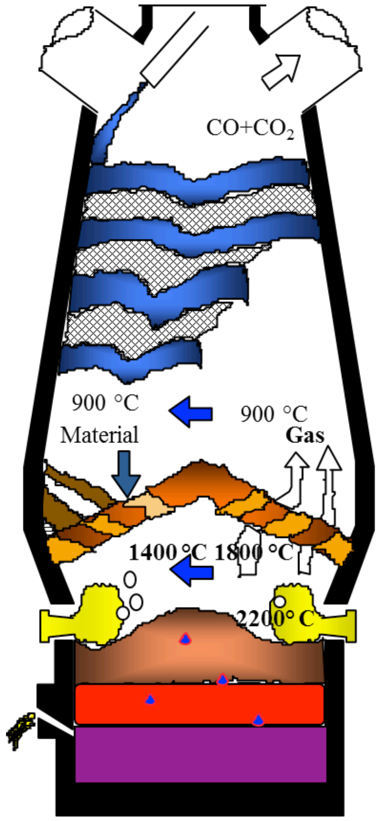


Fig. 28: Schematic description of the blast furnace described in the text: the coke and ore layers are depicted in blue, the blast air in yellow, the liquid slag is shown in red and the purple layer is the hot metal (liquid iron). The reduction gas leaves the system in the top of the furnace while the slag and iron are tapped from the bottom approximately every hour.

5.2. Integration strategy

The integration of the sensors is done stepwise. The first tests will be performed in cold environment and their aim will be mainly to investigate the sensors' wireless transmission capabilities and robustness. During an Experimental Blast Furnace (EBF) campaign the

7 **Smelting** is the heat-driven process by which the metal can be separated from other constituents in the ore.

8 The **slag** is a glass-like by-product of smelting metal from the raw ore.

developed sensors are tested in the hot environment inside the blast furnace. This final test inside the blast furnace is done during an EBF campaign's preliminary towards the end of the project.

5.3. Description of the physical process

The steady state operation of the blast furnace is influenced by several variables (disturbances):

1. Differences in the chemical composition of coke and ore
2. The charged materials contain alkali metals and zinc (whose effect is described later)
3. The permeability of the solid layers is not stable and may cause different gas distributions in the furnace
4. The blast air contains different amount of moisture
5. The charged materials contain different amount of fines[9] (notice that fines are in fact screened before being charged into the furnace)

5.3.1. Material flow of a blast furnace

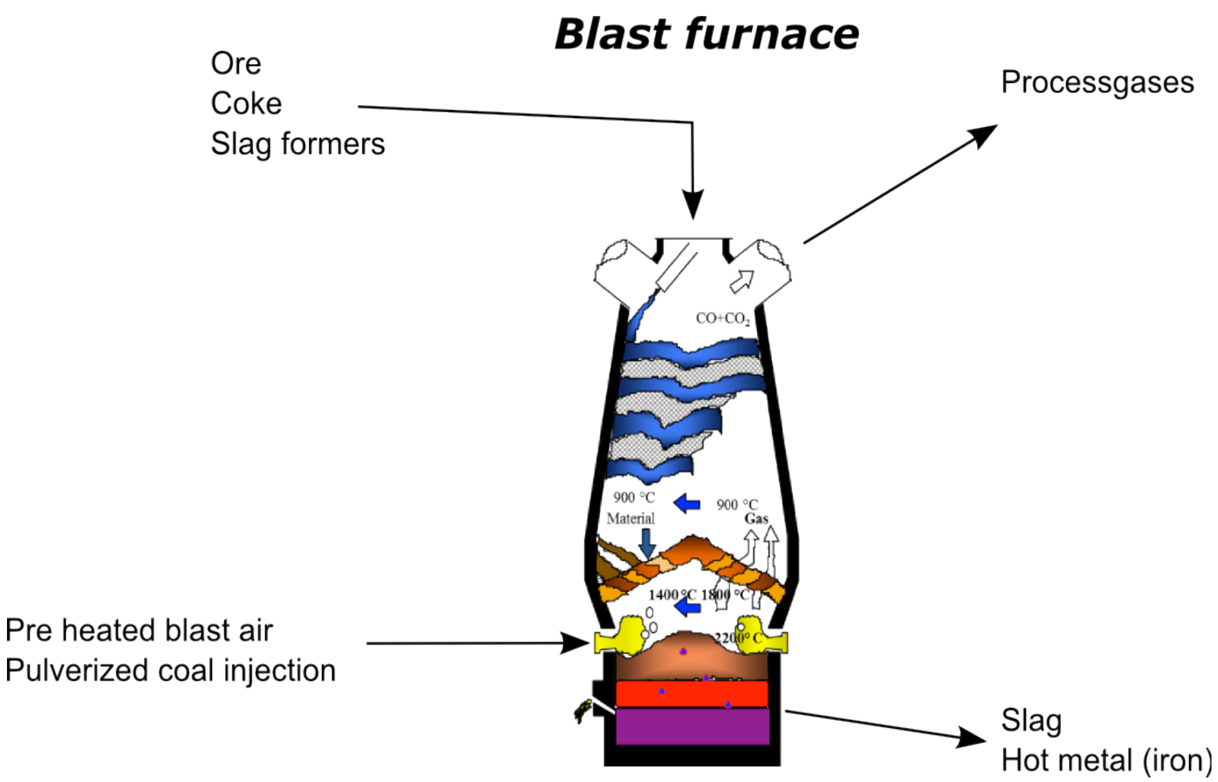


Fig. 29: The material flow in a blast furnace: input flows are depicted as entering the furnace from the left and output flows leave the furnace to the right.

9 The term **fines** indicates iron ore dust.

Overall the process is very slow with time constants up to several hours. The blast furnace process is regulated in different ways and has several limitations:

- If the top gas temperature is not sufficiently high, the burden[10] is not dried effectively
- If the flame temperature is too low, the gasification of the injected pulverized coal is not efficient enough
- If the flame temperature is too high, the descent of the burden becomes unstable
- The temperatures in the blast furnace must be controlled simultaneously with the gas flow through the shaft

The proportions between the charged coke and ore and how the materials are charged in the top are subject to variations. For example, coke may be charged from the center or peripherally in order to control the gas flow. The burden descent is indicated using a stock rod.

Hot blast stoves are heated using burners up to a desired temperature and the blast air is blown through them and the blast pipes, distributing the blast air around and into the blast furnace. The pressure of the blast air may be varied; the air mixture may be enriched with oxygen to maintain a higher flame temperature or water to cool the furnace. The amount of oxygen cannot be increased arbitrarily since in addition to increasing the flame temperature it also lowers the top gas temperature. When the temperatures in the off gases exceed the desired set-point cooling is performed by injecting water in the top of the furnace.

The amount of pulverized coal injected can vary as well (or even turned off). Pulverized coal is desired to be high in order to reduce the consumption of coke but is limited by the reaction speed in the raceway. The injection of pulverized coal has an upper limit, which is decided by the oxygen content in the blast air. If too much coal is injected the available oxygen is reduced and this leads to unburnt coal and thus the cooling of the raceway (this happens because: 1) the injected material is cold and 2) the gasification of the coal consumes energy). Part of the unburnt coal, which is close to the raceways forms the so called bird's nests, which reduce permeability, while the remaining unburnt coal leaves the furnace as soot and dust in the top gases. The pulverized coal has different volatile properties (the energy that requires gasifying the coal).

10 The term **burden** indicates the whole of the materials that are charged into the furnace.

5.3.2. Alkali recirculation

Alkali metals and zinc enter the furnace through the charged (solid) materials. They are reduced and evaporated in the hot part of the furnace and rise together with the process's gases to the upper and colder parts of the furnace where they solidify. If the top gases are hot, the alkali may leave the furnace through the top gases. This leads to undesired transport of heat towards the top of the furnace that leaves the process, through the process gases (sometimes there is also the need to cool the top part by injecting water from the top). Accretions can stuck on the furnace's wall or follow the material flow down to the warmer parts consuming energy, while heated (which has to be compensated by adding more energy into the process). Notice that impermeable accretions may also form from fines in the ore and coke layers independently of the alkali recirculation.

5.3.3. Controlled fuel injection

The injection of fuel can be increased or decreased according to specific aims:

1. The percentage of charged coke may be varied both as different fuel amount but also to affect the permeability of the shaft (amount and position). The effect of a change is slow: It takes several hours for the coke layer to reach the active zone of the furnace where the changes have effect.
2. The amount of pulverized coal that is injected may be varied when faster response times are required but while it does not increase the permeability it may decrease it. The upper limit on the injected amount is set in function of the oxygen content in the blast air.

5.3.4. Gas flow control

Two types of gas flow profiles (“central working” and “wall working”) can be achieved by acting on the burden's distribution. Both profiles have advantages and drawbacks. The central working furnace has a centrum of mainly coke, which transports the reduction gas up in the shaft, the gas is further distributed through the coke layers, closer to the wall and ascending through the furnace, the coke layers are the mainly permeable parts in the shaft. The central coke part also acts like a pressure valve. The drawback of the process is material descending close to the wall may pass the tuyeres[11] causing chilling of slag and hot metal resulting in irregular hot metal quality (and even damage the tuyeres). There is also the risk

[11] A *Tyuere* is a nozzle or tube used to blow air into a furnace.

of losing valuable CO and H2 gas and too high temperature on the top gas. Thus, it is often desirable to minimize the gas flow through the central coke layer.

The wall-working furnace does not have the drawback of cold material at the walls and the leaking of the reduction gas through the top. However, the risk in this profile is that too much heat is lost through the furnace's wall and that the cooling of the reduction gas may make it inactive. Another issue is linked to an increase in the refractory wear. The higher the pressure differences in the furnace, the higher are the limitations in terms of production capabilities. Gas flow control is thus employed to keep the balance between gas flow in the centre and the wall of the furnace.

A connected phenomenon is that of “channelling”, which can occurs if the burden is too fluid: The reduction gas passes the shaft at high velocity with low reduction and at high temperature.

The process's parameters that are continuously monitored are:

1. Temperature, Silicon content and carbon content of the hot metal (which indicate the heat in the furnace). Other chemical components of the hot metal are taken into account as well.
2. The chemical composition of the slag is measured to estimate the drainage of alkali and zinc from the blast furnace.
3. The amount of CO in the off gases in the top of the furnace is measured to detect conditions of potential efficiency reduction.
4. The temperature of the off gas is measured as it represents an indicator of the gas flow through the furnace. The aim is to minimize undesired gas flow through tunnels in the layers or near the furnace wall: A smooth gas flow through the shaft is desired.
5. The temperature of the upper part of the blast furnace (close to the wall and in the whole area where the top gas is present) is measured at different positions and gives indications on the symmetry of the gas flows through the shaft.
6. The temperatures at several positions throughout the shaft are measured to monitor cooling effects of the furnace wall and accretions from alkali and zinc (leakages of the cooling water are logged for the same purpose). Measured cooling effects are studied instead of temperatures, where cooling of the furnace wall is necessary.
7. Cooling effects of the blast pipes are monitored in order to estimate the heat conditions in the race way: Each blow pipe has its own measurement points.
8. The difference in pressure between the blast area and the top area are monitored since high differences indicate disturbances in the descend of the burden.

Beside measurements related to the control of the furnace the system has a lot of recorded signals to monitor the process and plant have limits for alarms.

5.4. Mathematical models

At this point it should be noticed that there has been a change in the scope of WP7 and the focus of the control related task has been shifted from the blast furnace to the walking beam furnace, since the blast furnace is a proprietary system for LKAB and no further tests can be performed there due to IP rights.

Thus an accurate discussion of the mathematical models that are currently in use appears superfluous.

The material flow model in WP5 can be extended to include information from this process to improve the customer order to delivery chain as seen in chapter 2.4, 2.5 and 2.6.

5.5. Simulation tools

No control related effort will be spent in connection with the blast furnace process and thus an accurate description of the current control system appears superfluous.

5.6. Control oriented models

No control related effort will be spent in connection with the blast furnace process and thus an accurate description of the current control system appears superfluous.

5.7. Control system

No control related effort will be spent in connection with the blast furnace process and thus an accurate description of the current control system appears superfluous.

5.8. Measurement and Sensor systems

No additional information on the sensor systems has been provided.

5.9. Actuation

No control related effort will be spent in connection with the blast furnace process and thus an accurate description of how the system is actuated appears superfluous. The following is noted: For the blast furnace, the project aim is more of an analytical problem. The measured properties of the newly developed sensors are forwarded to the blast furnace operator. The information from the sensors will assist the operator to make decisions for optimal control of the blast furnace in open loop.

5.10. Data Analytics

For the blast furnace no data will be delivered to the project members since the remaining tasks are purely concerned with the development of novel sensor devices and their test.

5.11. Evaluation platforms

No additional information on the evaluation platform has been provided.

5.12. Evaluation cases

5.12.1. Sensor Development: Wireless tests in pellets

In this test the sensors will follow the pellets and coke into the blast furnace and an investigation of the wireless communication between the sensors within pellets will be performed. The sensors will be placed gradually at different depths in the pellet pile. In each mode, the signal quality and transmission rate will be monitored. The aim is to explore the depth at which the sensor is still capable of transmitting a detectable signal. The investigation is conducted at normal temperature.

The considered performance indices will be:

1. The transfer rate
2. The maximum distance and depth between transmitter and receiver

A successful outcome requires the corresponding successful transfer of data at an adequate bit rate and distance between transmitter and receiver. A positive outcome is crucial since if the data transmission does not work satisfactorily the sensor system cannot support further improvement of the blast process.

5.12.2. Sensor Development: *Wireless test in the LKAB experimental blast furnace*

This set of tests will be conducted in LKAB's experimental blast furnace when it is cold. The wireless transfer between the sensor and the antennas will be investigated. A sensor with a transmitter will be placed inside the blast furnace and the receiving antennas inside/outside the blast furnace. This test will investigate the functioning of the antennas, the maximal transfer rate, the maximal distance and best location between transmitter and the receiving antennas. The effects of the ceramic lining and steel shell will be investigated.

The considered performance indices will be:

1. The data transfer rate.
2. The maximum distance between transmitter and receiver

A positive outcome is crucial since if the data transmission does not work satisfactorily the sensor system cannot support further improvement of the blast process.

5.13. Final industrial demonstration

The aim is to have sensors that can measure physical properties such as temperature, moisture, gas components and position. The test is planned to conducted at the LKAB Experimental blast furnace. Antennas are mounted on the Blast Furnace (BF) and the sensor is moved inside the BF with a vertical probe. If the signal is successfully collected further tests will be conducted. The next effort will target the basket samples with raw materials containing sensors. Pellets or other raw materials with embedded sensors are filled into baskets and charged into the BF before quenching. The signal is collected and the movement of baskets in the upper part of the BF are explored. Furthermore, measurements are also conducted during quenching in order to state the burden movement after stopping the process and contribute with additional information that can improve the understanding of results from evaluation of charged basket samples. The temperature development will be compared to possible endothermic reactions occurring in the materials as e.g. calcination of $Ca(OH)2$ in cold bonded agglomerates (in-plant material in cold bonded bricks), $CaCO3$ in limestone, direct reduction in cold bonded agglomerates. The tests are planned to be conducted as the last part of the blast furnace campaign. The sensors is placed in baskets (max diameter 45mm) and dropped into the blast furnace. The signal is measured as the sensor travels through the burden material inside the blast furnace. After the campaign the sensors is excavated and the exact location inside the blast furnace is determined. If the sensor has a logging function, data can be retrieved even if the wireless transfer has failed.

The considered performance indices will be:

1. The ability of the sensor to measure the desired property (position, temperature, moisture, particle size, gas components).
2. The ability of the sensor to transmit data containing important information on the properties of interest.

For a successful evaluation it is required that the sensor can measure the desired properties and transfer the data to the receiver. The accuracy of the measures will be established starting from the available thermodynamic and material information for the considered reaction.

5.14. DISIRE Technological Contribution

The expected DISIRE contribution in this WP and towards the Blast Furnace process can be summarized in the following Figure 30, where the expected major contributions from the project will be the DISIRE based in situ sensors for measuring temperature, moisture, gas composition and position in the Blast furnace as an initial and mandatory phase in testing the in situ sensors prior to moving to online PAT and IPC concepts.

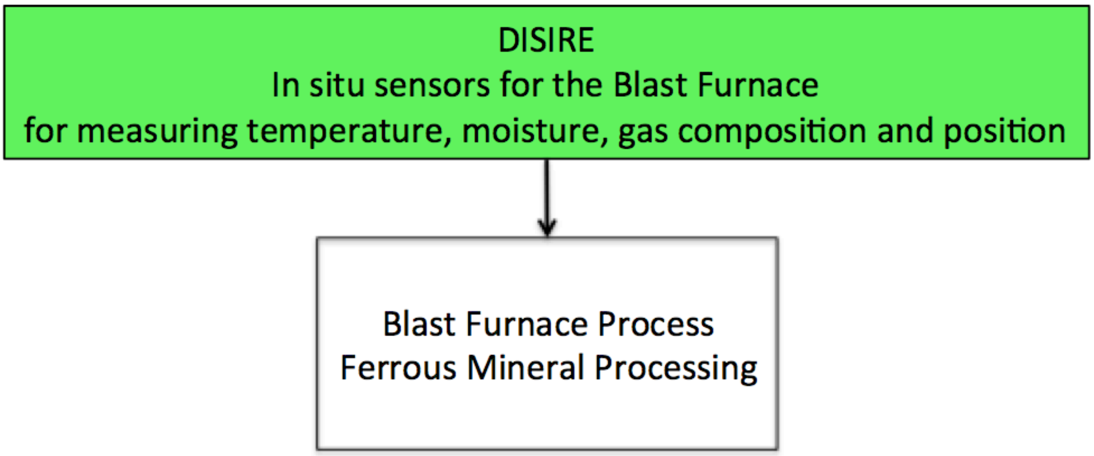


Fig. 30: DISIRE technological impact in the Grate Process.

6 WP7 Steel Processes: Walking beam furnace

6.1. Brief description

Due to the restrictions in the LKAB's blast furnace, MEFOS is interested in the exploitation of the DISIRE technological platform for the optimal control of a *walking beam furnace,* as it is indicated in Figure 31 and can be considered as a similar and also very important process, which can be further generalized in both the Grate process, the Blast Furnace and other related process.

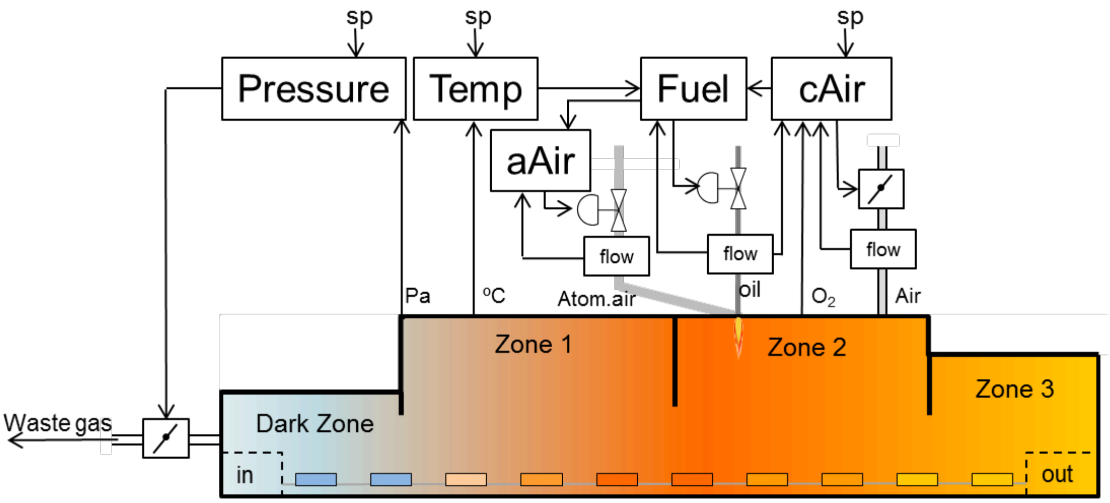


Fig. 31 Schematic description of the walking beam furnace showing the variables used for controlling the heating in various zones of the process.

The corresponding furnace is utilized to re-heat *slabs* (unfinished products such as e.g., large steel beams) to a specific temperature. The slabs are "walked" from the feed to the output of the furnace by the cyclic movement of so-called walking beams. During this passage, the items are directly exposed to the heat produced by burners located inside the furnace. From a control perspective the aim of an optimal controller is to regulate pre-assigned temperatures, while minimizing the energy expenditure for the heat generation.

The walking beam furnace at MEFOS is an experimental furnace and lacks some of the features of an industrial furnace. Specifically, the temperatures throughout the furnace are not feedback controlled (as it is otherwise customary in the industry), i.e., the furnace operates "open loop". Currently, a human operator configures the furnace set-points manually (the set-point values are, however, computed numerically) and then measures the slabs temperature at the furnace exit using a pyrometer. In fact, under normal operating conditions, the open-loop control can be tuned to work well. Differently, this industrial installation is affected by stops and other variations that influence the control performance and correspondingly the need for a feedback control loop. At this point, it should be also highlighted that since this furnace is an experimental one, it will be possible to equip the infrastructure with more sensors than it is usually done in the industry.

The main variables that need to be controlled are thus

1. The furnace temperatures in several zones of the furnace.
2. The temperature of slabs at the output (the *target temperature*).

Furthermore, the main objective is to reduce the operating costs through the reduction of energy consumption. In this respect, a small decrease in energy consumption such as 0.5% translates into a saving of 2kWh per tonne of heated product. In addition, optimal control strategies could lead to quality improvements as well. To achieve these goals there is a need to gather more information about the process on-line. Specifically, MEFOS suggests considering the development of an improved understanding of the reheating process and the deployment of novel sensors than can measure both the temperature and the gas composition within the furnace (these abilities are considered vital). As a further important improvement, the ability for a novel sensor technology to measure position (as the sensors travel through the furnace) and pressures could be exploited towards the above objectives.

6.2. Integration Strategy

In the beginning of the process, MEFOS will provide all participants with past data gathered on the experimental furnace for pre-study analysis, while additional trial runs with the new in situ sensors will be performed. In the sequel these acquired data will be utilized in order to:

- Build models of the process
- Further processed, integrated and evaluated to perform online PAT
- Utilize the streaming of data from the in situ sensors and the online PAT to reconfigure the overall IPC of the process.

The industrial members of MEFOS come from the whole world and many of them are market leaders in the respective fields. Several members have already shown interest in the DISIRE technology and will have access to the results from this WP. In addition, they will represent a valuable dissemination and innovation channel.

6.3. Description of the Physical Process

From a control perspective, the physical process has 5 inputs:

1. *WBF_Z[01-03]_temp-input*: the reference variable for the desired temperatures in various zones of the furnace
    1. These variables affect the final temperature of the slabs and their tight control affects the quality of the results.
    2. Plausible values vary in the range 500-1300°C.
2. *Oxygen-input*: the reference amount (in percent) of oxygen in the oil-air mixture inside the furnace.
    1. Plausible values vary in the range 1-10%, usually 2-3%.
3. *Fuel-input*: the amount of fuel fed to the burners in the furnace.
    1. It affects the heat flow inside the furnace.
    2. Plausible values vary in the range 0-50Kg/h.
4. *Pressure-input*: the reference pressure inside the furnace.
    1. Constantly set to 10Pa during normal operation.
    2. Having small pressure reduces the influence of outside air entering the furnace. .
5. *Air-flow-input*: amount of fresh air fed to the furnace.
    1. Plausible values vary in the range 0-650m^3/h.

and 4 outputs:

1. *Oxygen-output*: the measured amount of oxygen (in percent) in the oil-air mixture inside the furnace (see *Oxygen-input*).
2. *Fuel-output*: the measured amount of fuel fed to the fuel burners (see *Fuel-input*).
3. *Pressure-output*: the measured pressure inside the furnace (see *Pressure-input*).
4. *Atomization-air-flow-output*: measured air-flow to the burners.
    1. The burners must operate with continuous air-flow to atomize the oil during the combustion.

6.4. Mathematical Models

No mathematical model has been provided by MEFOS, since such a model does not exist and thus the following references have been pointed out

1. Leden - A control system for fuel optimization of reheating furnace
2. Leden - Mathematical reheating furnace models in steeltemp
3. Leden - STEELTEMP a program for temperature analysis in steel plants
4. Leden - STEELTEMP for temperature and heat transfer analysis of heating furnaces with on-line applications
5. Madsen - STEELTEMP A program for temperature analysis in steel plants

A starting-level tutorial on the above models and on how to use them in the context of a walking beam furnace can be found at:

http://www.swerea.se/Global/Swerea_MEFOS/Dokument/Scanheating_II_(1988).pdf

Furthermore, it should be highlighted that no dynamical models, based on first principles, are currently in use at MEFOS.

6.5. Simulations Tools

Currently, there are two software applications that are being utilized at MEFOS to form decisions on how to operate the furnace:

1. FOCS-RF: a simulator with a dynamical model of the walking beam furnace (for additional background information on FOCS consult the website http://prevas.com/focs_furnace_optimization_control_system.html).
2. STEELTEMP: to compute and optimize the heat transfer within the furnace.

These tools have been developed at MEFOS together with ABB and Prevas and are released under commercial licences. The software cannot be freely shared with the partners in DISIRE. However, these software, is a typical example of an off line PAT analysis for tuning all the previous control parameters of the process in an online manner. Thus the aim of the DISIRE project in this WP would be to evaluate the possibility of creating an DISIRE enabled integrated system that will be able to measure the process internally, through the embedded in flow sensors and based on the gathered and evaluated online PAT to be able to retune and optimize the overall performance of the process based on IPC.

6.6. Control oriented models

Currently, no control-oriented models have been provided by MEFOS. However, it has been noted that specific scientific literature exists on the subject of controlling furnaces of this type as:

1. Hurd, G.R., Kaufman, J., Wu, H.C., Ward, J., Rodriguez, E. Process control and automation systems advancements for reheat furnaces (2011) Iron and Steel Technology, 8 (9), pp. 67-74.
2. Xu, J., Bu, J. Research of furnace temperature optimization control method in hot rolling process (2011) Advanced Materials Research, 230-232, pp. 7-11.

6.7. Measurement and sensor systems

As a whole, the walking beam furnace is monitored by around 100 sensors and mastered by an ABB AC800M with S800 I/O. The currently deployed hardware is:

1. Sensing of the air-flow: ABB 265DS.
2. Sensing of temperatures and exhaust temperature: through a thermo-element connected to the ABB system, Type S, Range 0-1320°C.
3. Gas composition O_2 / CO / CO_2: ABB ZDT Oxygen sensor (range 0-25%). (No CO or CO_2 sensor).
4. Fuel to the burners: ABB 10MM2102. Range 0-50kg/h.
5. Sensing of pressure: Honeywell ND144Y-1122W. Range -50 – 50Pa.
6. Sensing of the atomization air – flow: Honeywell LIIE3-0011-12-00-00.

The air-flow, O_2 and fuel sensors are in sets of 3, one set for each heating zone. The temperature sensors are located in all 3 heating zones both in air and walls. For measuring the pressure only one sensor is used.

The sensor measurements are available as soon as the reading is performed (e.g., there is no batching). Sensors interconnections are point-to-point (no network). The sampling rate is variable and can be adjusted in the range 0.05Hz to 100Hz.

6.8. Control System

The furnace at MEFOS is operated through *FOCS-RF Mini*, a version without feedback control of the FOCS-RF control system (i.e., the “Mini” version exploits a simpler feed-forward control strategy).

The three set-points for the temperatures across the furnace are pre-computed, given the target temperature of the slab, using the Steeltemp software. Additional parameters used by Steeltemp are the slab's properties and the furnace properties. The output from Steeltemp is then used by an operator to manually set the set-points for different zones within the furnace.

The control system implementation is digital with a MIMO structure. The controller parameters are tuned off-line from empirical data. The low control level system is "closed" and thus it is difficult to alter the system for running dedicated control tests on the independent control loops. This will have no effect on the overall DISIRE IPC framework, since the proposed IPC will create components that will alter and optimize the setpoints of the controlled variables and thus, the existing low level and already fine tuned control loops will be utilized. In Figure 32, a general description of the FOCS-RF system is depicted.

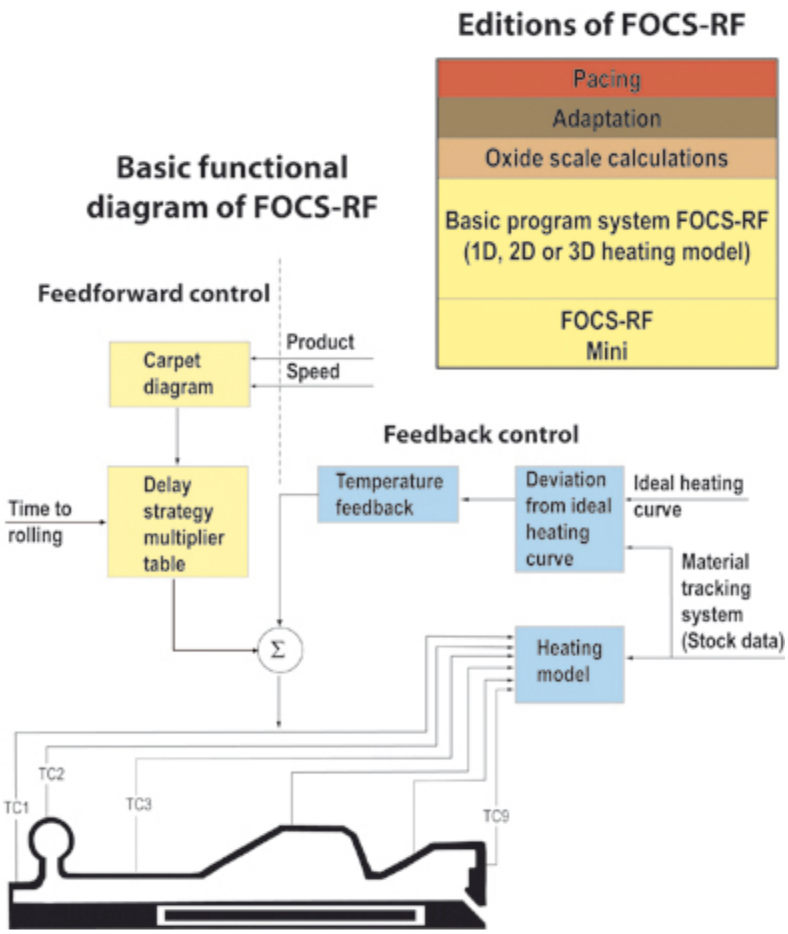


Fig. 32: Schematic overview of the FOCS-RF system.

6.8.1. FOCS-RF

FOCS-RF is a supervisory system for optimization of heating and energy consumption in reheating furnaces, which controls the set points of the different control zone temperatures based on predetermined ideal heating curves. The system consists of a feedforward and feedback control block. The feedforward control block contains a carpet diagram and a delay strategy multiplier table. The carpet diagram is made up of a number of tables, one for each type of product, which give the primary optimal control zone temperatures (feedforward temperatures) as a function of the transfer speed of the stocks at steady-state operation. This diagram is set up from mathematical model calculations, with e.g. STEELTEMP 2D, and used in production practice to drive the rolling mill. The delay strategy multipliers are used to turn down the control zone temperatures during a stop in the rolling mill.

The dynamics of the process are taken care of by the feedback control. The heating curve of the stocks is calculated, on-line, by the heating model, based on STEELTEMP® 2D, using measured furnace temperatures, fuel flow rates to the control zones and data from the material tracking system. The difference between the calculated and ideal heating curve gives via a feedback controller a fine adjustment of the control-zone-temperatures set points. In this way the heating will be controlled according to the ideal heating curve.

The ideal heating curves form the basis for the feedback control and pacing. These curves are given as per mille values of the target drop-out temperatures for a number of length positions of the furnace. The actual value of the temperature of the ideal heating curve is obtained by multiplying the target drop-out temperature for a certain stock with the per mille value of the ideal heating curve for the current position of the stock. In this way one ideal heating curve can suit a range of dropout temperatures.

The ideal heating curves are determined from quality requirements on the rolled products. This will give individual heating curves for the heated stocks, which are not always possible to achieve due to physical limitations in the furnace. Heating of stocks with different sizes and/or steel grades, positioned close together will always be a compromise. This is illustrated in Figure 33 showing heating curves for two different steel grades after a stop in the rolling mill.

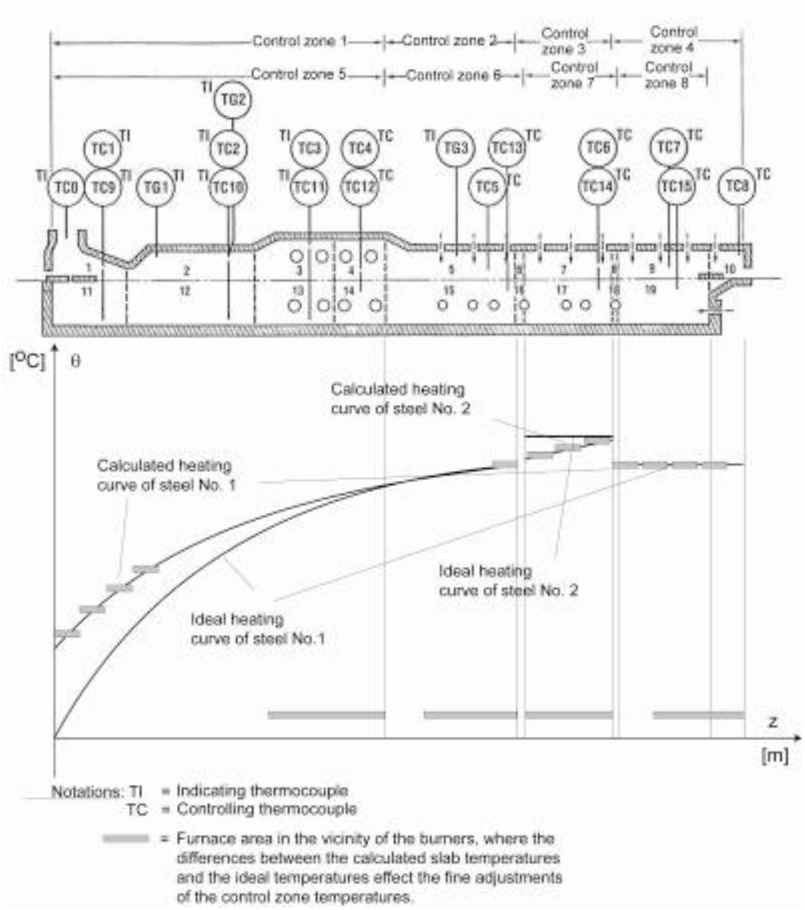


Fig. 33: Optimal heating curves for the walking beam surface.

For additional details on the control systems and an introduction to the terminology the reader is referred to Leden's manuscripts referenced in Section 6.4.

6.9. Measurement and sensor systems

The system continuously gathers measurements of approximately 100 variables. The sensors data are stored in different types of data loggers: IBA system, ABB's Argus measurement system, the sensor's manufacturer system or in a Labview measurement system (see http://www.ni.com/labview/). The sampling frequency is selectable in the range 0.05-100Hz.

The sensors that are accessible from the walking beam control system are about 100. With a sampling rate of 10Hz we get ~1000 values/s. For a 8 hour trail we get 28.8 GS/day.

Notice that this experimental furnace is operated only in short campaigns of one week or so. All the data are collected and stored each time.

With regard to sharing datasets of measurements from the running process with the partners, it is planned to create first a document explaining all the variables and then to share the data.

6.10. Actuation

1. *Oil-valve*: actuates the oil flow to the burners inside the furnace (3 units).
   1. Actuation capacity: 0-50Kg/h per unit.
2. *Combust-air*: actuates the air-flow to the furnace (3 units).
   1. Actuation capacity: 0-650m^3/h per unit.
3. *Atomz-air*: a Honeywell 43297067 is used to atomize the air-flow.
4. *Waste Gas / Pressure*: actuates the air flow (waste gas) from the furnace / the pressure inside the furnace's.
   1. Actuation capacity: 0-2000m^3/h.

6.11. Data Analytics

All the data are stored in an IBA system (a commercial data acquisition system) database that reads the data from a Profibus network. MEFOS will make data from past campaigns available to the DISIRE partners in a generic format (tab separated ASCII tables).

6.12. Evaluation Platforms

It should be highlighted that the changes to the experimental furnace (i.e, integrating new sensors and a new control system) for the following tests are to be explored in the project's continuation stage as well as that it is of paramount importance for all the modifications and additions to comply with safety regulations.

Finally, it should be highlighted again that as it has been mentioned before that the low level control system is not allowed to be replaced due to safety regulations, which is a fact that is causing no restrictions to DISIRE based on the previous mentioned approach, that all the IPC structures have.

6.12.1. Walking beam furnace

On this experimental platform it will be possible to test the developed sensor technologies in an adequate environment. Tests will be aimed at comparing the new technology with conventional sensors in use today.

Two kinds of scenarios are envisioned:

1. The first set of tests will explore if the sensor and its components can sustain the harsh conditions inside the furnace.
2. The second set of tests will investigate the reliability, precision and accuracy of the sensors (the benchmark performance will be provided by the currently deployed sensors).

Furthermore, there will be a number of trials whose exact number depends on the results from the trials. Each trial can last from minutes to hours. With the assumption that the tests are successful, the sensor data are transferred to the main data storing system. How to incorporate the sensor data with the main system will be explored during the project.

6.13. Evaluation Cases

6.13.1. Sensor Development: Protection Shield

Tests will be conducted in an existing furnace at MEFOS that has ceramic lining and steel shell. Initial tests will be conducted in one of the smaller furnaces. The sensor protection shield will be investigated. The purpose of the shield is to protect the sensor electronics from heat and other negative impacts on the sensors. A thermocouple will measure the temperature inside the protection shield chamber.

This test will investigate the temperature rise time inside the protection chamber. From the rise time one can estimate how long the sensor electronics will be able to withstand the temperature inside the reheating furnace (or the blast furnace). An estimated lifetime below a certain threshold will indicate a test failure. It should be also noticed that currentlythere are no wireless sensors of this kind employed in the furnace.

A successful outcome is crucial: If the protection shield cannot withstand high temperatures, then the sensors might be destroyed before the important quantities are measured.

6.13.2. Sensor Development: Wireless transfer

The aim of the test is to investigate the wireless transfer capabilities of the sensors. A sensor with a radio transmitter will be placed inside the furnace and receiving antennas inside/outside the furnace. This test will investigate

1. the maximal transfer rate
2. the maximal distance

3. the best location between transmitter and receiving antenna
4. the effects of the ceramic lining and steel shell.

A successful test will require the transfer of data with adequate bit rate and distance between transmitter and receiver. Good performance results are crucial since if the radio links cannot function satisfactorily the whole sensor system cannot support further improvements to the process.

6.13.3. Sensor Development: Measured properties

The aim is to test sensors that can measure the physical properties of interest:

1. Temperature (~300-1300°C).
2. Moisture.
3. Gas components (O_2, CO, CO_2).
4. Position.

The temperature measured by the wireless sensor will be compared with conventional thermocouple sensors. The gaseous composition measured by the new sensor will be compared with an existing conventional gas emission analyser. The position test is done by moving the sensor in a predetermined path inside the furnace. The moisture test in the heated gas is compared with a conventional sensor system.

The considered performance indices will be the error in the measures and the reliability of the sensors. The sensors should be able to measure the desired properties with high accuracy. The uncertainty should be comparable to conventional sensors. If the sensors cannot measure the desired property then the test is regarded as a failure.

Finally, It is important that the new sensors reach satisfactory performance since otherwise the sensor system cannot support further improvements to the process.

6.13.4. Sensor Development: Walking beam furnace test

After successful outcomes from the above initial tests, a full-scale test will be conducted in a walking beam furnace at MEFOS. The objective is to evaluate whether the new sensors can manage the environment in a walking beam furnace during the entire movement through the furnace. First, the furnace runs in normal mode. Thereafter, the sensors are sent into the furnace. The information from the sensors are received with antennas and evaluated.

In general, the performance will be evaluated in terms of successful and reliable transfer of accurate measurement data. A comparison with the data gathered from conventional sensors will be performed.

6.14. Final industrial demonstration

The integration of the sensors is done stepwise. The first tests are done in a cold environment. These tests are mainly to investigate the sensor wireless transmission and robustness. And will be conducted when the sensors or the sensor modules are available. During an Experimental Walking Beam Furnace (WBF) campaign, the developed sensors are tested in the hot environment inside the furnace. The developed MPC system will also be tested during the same campaigns. This final test in the WBF is done during a WBF campaigns preliminary at the end of the project.

6.15. DISIRE Technological Contribution

The expected DISIRE contribution in this WP and towards the Walking beam Furnace process can be summarized in the following Figure 34, where the expected major contributions from the project will be the DISIRE based in situ sensors, the online PAT and the IPC reconfiguration.

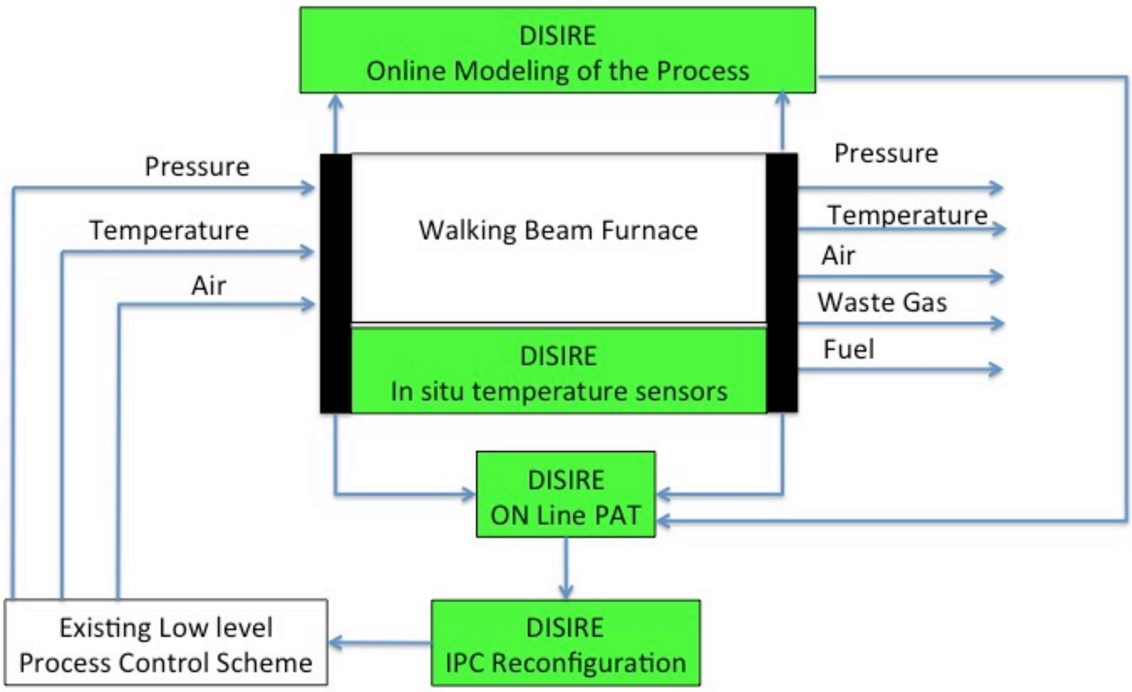


Fig. 34: DISIRE technological impact in the Walking Beam Process.

7 WP8 Combustion Processes: Cracking Furnace at Dow Chemical Co.

7.1. Brief description

Dow Chemical Co. (DOW) is interested in the exploitation of the DISIRE technological platform for the optimal control of a *cracking furnace* producing ethylene, propylene and CC4s (butane, butane, butylenes and butadiene), presented in Figures 35.

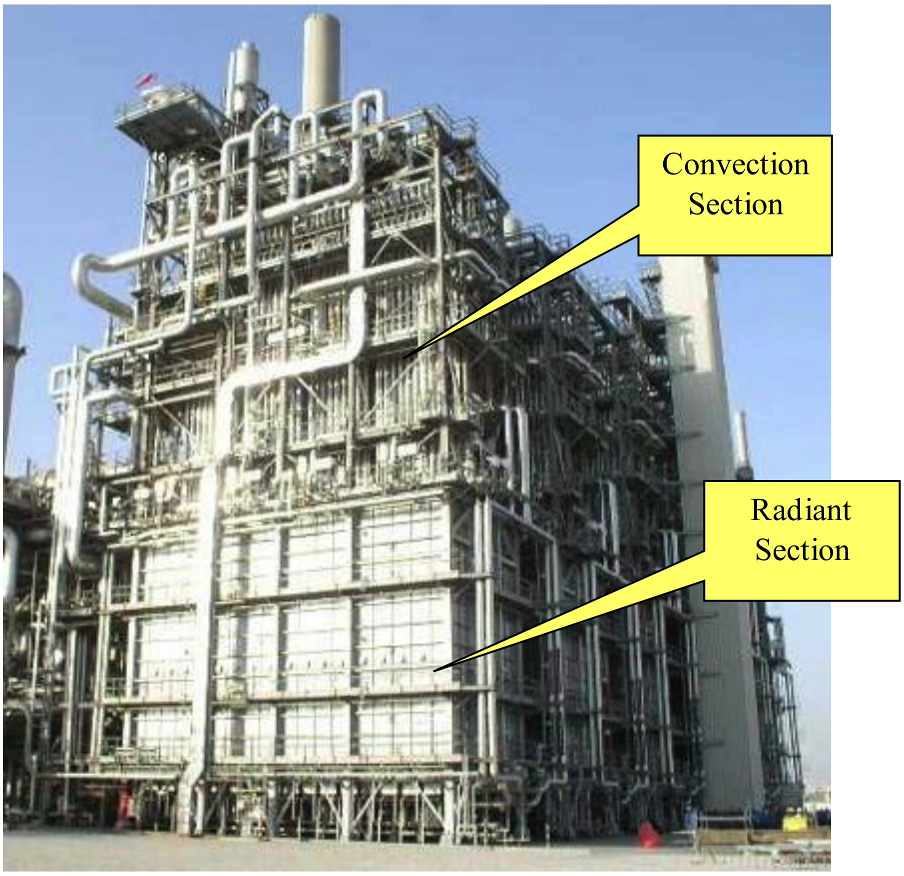


Fig. 35: Picture of a state of the art cracking furnace.

A schematic description of the plant process under consideration is given in Figures 36 and 37. In brief, an *hydrocarbon feedstock* (naphtha or Liquefied Petroleum Gases) is diluted with steam and cracked (i.e., the long hydrocarbon chains are split into shorter ones) by an endothermic reaction. The heat required to reach the cracking temperature is provided by the combustion of *fuel gas* inside a firebox at the bottom of the furnace.

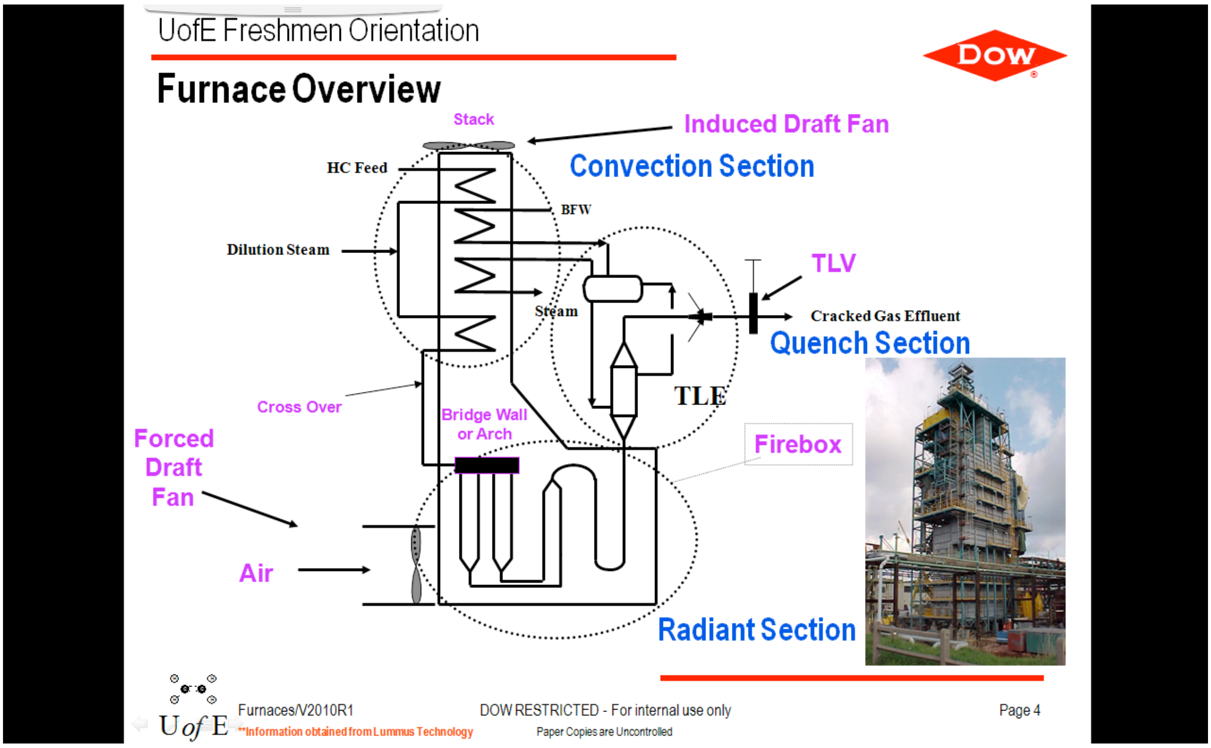


Fig. 36: Schematic representation of DOW's cracking furnace.

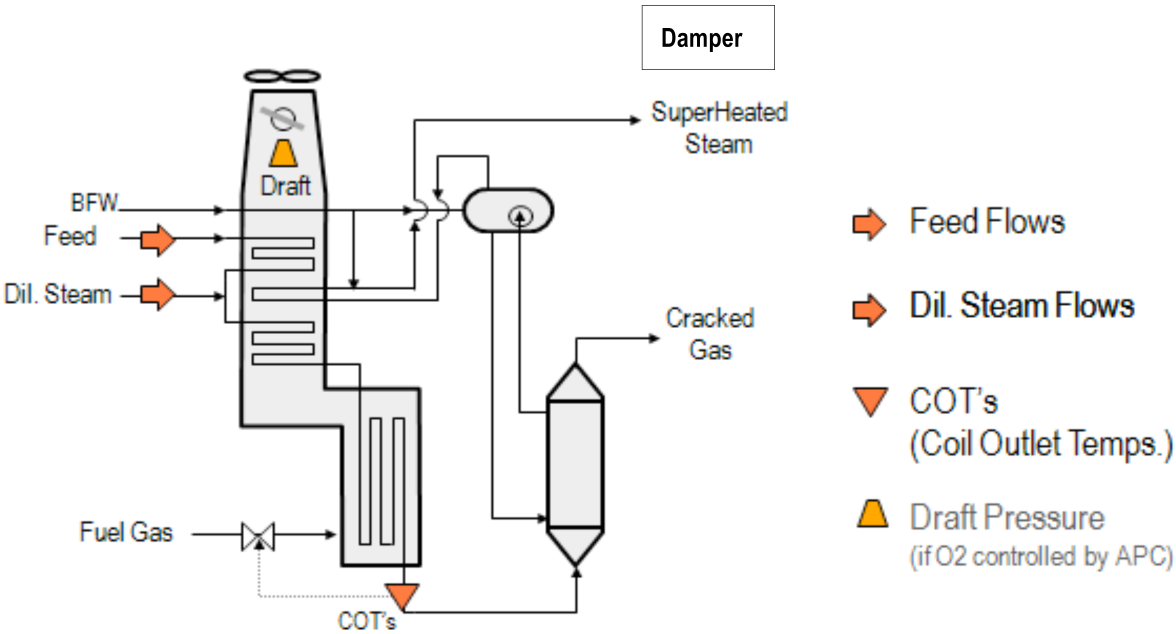


Fig. 37: Block scheme for DOW's cracking furnace.

The meaning of the acronyms in the figures are the following ones:

- BFW: Boiler Feed Water to feed the cracking furnace steam drum.

- Dil. Steam: Process Steam to dilute the Feed (Naphtha, Propane, Butane, etc..) and get the desired Steam / Feed ratio to optimize the cracking reaction (the selectivity parameter).
- HC Feed: Feedstock processed in the plant (liquid – naphtha, consensate – or gasesous – propane, butane ...) to produce the desired range of olefins (mainly ethylene and propylene)
- COT (Coil Outlet Temperature): Controlled temperature at the outlet of the radiant section. It is a key parameter to optimize margin according to the feed that is being cracked (the severity parameter).
- TLE (Transfer Line Exchanger): Vertical Heat Exchanger to cool down (from 850°C to 400°C) the raw gas (tube side) produced in the cracking furnace while generating very high pressure steam at 110 bars (shell side).
- Fuel-gas: Stream (mainly composed by methane and hydrogen) to be burnt in the cracking furnaces to get the desire COT. Fuel-gas is burnt in a even and uniform way in multiple burners located in the radiant section of the cracking furnace (firebox or combustion chamber).
- Draft pressure inside the cracking furnace: Critical parameter from the process's safety point of view. It controls the vacuum inside the firebox to avoid the exit of flames out of the combustion chamber. The draft can be either controlled by a inducted fan located at the top of the cracking furnace duct (above the convection section) or by a forced fan located in the bottom of the cracking furnace (the radiant section).
- Cross over: The transition zone of the cracking furnace from convection section to radiant section.
- Quench Section (Transfer Line Valve (TLV)): Fuel-oil injection through the TLV to control the cooling down of the raw gas leaving the cracking section to the fractioning system (from 400ºC to 200ºC).
- Bridge Wall / Arch: Entrance to the radiant section where each of the inlet coils are split in smaller coils to assure high speed flow and low residence of the feedstock and steam mixture time inside the radiant section.
- Damper: An adjustable flap controlling the air admitted beneath the firebox located in the furnace stack

At steady state, the feedstock is diluted with steam and preheated in the convection section by the combustion gases rising from the firebox. The cracking reaction occurs within the firebox at a specified temperature that depends on the properties of the feedstock and the desired *severity* of the reaction (i.e., the cracking temperature; changing this temperature changes the ratio of the refined products in the output). The reaction is stable with time until the furnace is fouled with coke and needs to be taken out of service for cleaning.

The variables that need to be controlled (for example, for performance and safety) or monitored (for example, for environmental reasons) during operation are:

1. The fuel gas consumption for heat generation.
2. The by-products of the combustion of gas and specifically the amounts of O2, CO and Nox.
3. The air draft inside the furnace.

Within DISIRE, the main objective is to reduce the operating costs of the plant by optimizing the fuel consumption, i.e., decreasing it for a given operational set-point. DOW suggests that novel control strategies of the firebox, leading to an improved use of the combustion products that maximizes heat transfer through the convection section and improves safety of operation, are to be based on a more reliable and accurate measurement of the by-products O2 / CO / NOx. To this aim, the relevant engineering problems are:

1. The design of more accurate and reliable sensors to measure this quantities.
2. How to optimally locate the measurements sensors throughout the plant.
3. How to optimally decide the system input variables, as presented in the following sections, so as to achieve reduced operation cost while respecting the technical and safety specifications of the controlled process.

7.2. Integration strategy

DOW will share its knowledge about operating cracking furnaces, from the combustion process control point of view, with the rest of the DISIRE partners and will be able to test at plant scale the results and improvements from the project in order to validate and quantify them with real data.

In case of successful and sustainable developments and results, we consider that DISIRE developed technologies can be leveraged or extrapolated to any other kind of fired equipment (boilers, furnaces, etc..) not only within the chemical industry but also in other industry sectors operating energy intensive fired equipment.

In the specific case of Dow Chemical, our company operates a total of 13 ethylene crackers around the word (5 in Europe, 2 in Latinamerica, 1 in Canada and 5 in the United

States) that could potentially benefit of those developments upon completion of DISIRE project, assuming:

- Suitability of the developed solutions in all different cracking furnaces designs existing in the Dow's Ethylene plants (13 in total spread around the world).
- Approval from Dow's LHC Technology Center, by following the Dow internal established protocols (MOC – Management of Change Work Process -, MET – Most Effective Technology -, certification, etc..)
- Capital availability for their implementation in the different Dow's premises what represent a high number of equipments (cracking furnaces and boilers) across Dow (more than 100 pieces of equipment.
- According to the above paragraphs, and in the more optimistic scenario, we do not envision to have it implemented before 2025 in all applicable premises.

7.3. Description of the physical processes

From a control perspective, the physical process has four inputs*:*

1. *O2-Excess-input*: the desired (optimal) excess of O2 in the combustion gasses
    1. This value influences the amount of air inside the furnace and thus the amount of fuel gas required for reaching the same cracking temperature (affecting the energy efficiency[12] of the plant).
    2. The amount of air fed into the furnace affects the combustion also from a safety point of view: One objective is to ensure the complete combustion of the fuel.
    3. This variable is at steady state during normal operations, which may vary slowly. The optimal value is below 2% of excess oxygen, but due to the reliability of the technology of analysers the O2 measurement it can vary in function of the analyser in use.
2. *Cracking-Temperature-input*: the reference variable for the desired cracking temperature inside the furnace (that will be adjusted depending on the type of feed, severity & selectivity parameters).

[12] The energy efficiency is a parameter that establishes the relation between heat to the furnace (fuel gas flow) and real heat absorbed by the process side for reaching the optimal cracking conditions.

    1. The given cracking temperature affects the cracking reaction in terms of the ratio of the refined products in the output (e.g., the ratio of ethylene and propylene)
    2. This variable is kept constant during normal operations. Its value can be varied depending on the status of the furnace in its operation cycle and the prices of the final products in the market.
3. *Hydrocarbon-Feed-input*: the flow / amount of hydrocarbon feedstock introduced into the plant.
4. *Steam-Feed-input*: the flow / amount of steam diluted in the hydrocarbon feedstock.

The system has five observable outputs*:*

1. *O2-Excess-output*: the measured excess of oxygen in the combustion gasses*.*
2. *CO-output*: the measured amount of CO in the combustion gasses.
    1. It can be used as an indicator of a complete combustion in the firebox.
3. *NOx-output*: the measured amount of NOx in the combustion gasses.
    1. The measured NOx must comply with environmental regulations.
    2. It can be used as an indicator of malfunctioning of the burner and other problems affecting the combustion.
4. *Draft-output*: the measured air draft within the column.
    1. For safety reasons the plant must operate with draft.
    2. The measured draft is used to control the rotating speed of the air feed fan and of the damper (an adjustable flap controlling the air admitted beneath the firebox located in the furnace stack).
5. *Fuel-Gas-Consumption-output*: the flow / amount of fuel gas that is combusted in the firebox for heating purposes.
    1. This value depends on the amount of hydrocarbon and air fed into the furnace and the desired cracking temperature.
    2. It indicates the energy consumption of the furnace and thus the overall energy efficiency of the cracking process.
6. *Fuel-Gas-Pressure-output*: the pressure of the fuel gas feed. See Fuel-Gas-Consumption-output.

7.4. Mathematical models

No analytical model is available but the following is noted:

Internal process side is done through SPYRO (commercial and proprietary program) whose results cannot be disclosed without specific authorization from the software developer.

External (combustion process) is the task to be performed by CIRCE in task T8.1 by applying CFD techniques and in task T8.2 by applying imaging diagnosis.

There are a few very compelling documents on Industrial Combustion:

- Industrial Combustion Vision. Facilitated by the U.S. Department of Energy.
- Industrial Combustion Technology Roadmap. A Technology Roadmap by and for the Industrial Combustion Community. Facilitated by the U.S. Department of Energy
- Barrington, E. et al.Fired Process Heaters, The Center for Professional Advancement.
- Hallee, L.P., Zdonik, S.B., Green, E.J. Manufacturing Ethylene.
- Beasly, K. Furnace Operations Tutorial.

7.5. Simulation tools

Simulations models are expected to be developed as part of the DISIRE scope by CIRCE. CIRCE will use the commercial codes supplied by ANSYS for modelling and simulation of the thermo-chemical-fluid-dynamic processes with an integrated approach, specifically ANSYS CFD 16.1, also known as Fluent. This code allows a sort of standard simulation, based on the most accepted expedients for numerical treatment and iteration of complex, interacting equation sets, homogeneous, partially pre-mixed combustion, homogeneous chemistry, gas radiation and turbulence and its interactions. Given the specificity of the fuel (refinery fuel gas) and loads (cracking tube bundles of diverse geometry and thermal boundary condition), specific User Defined Functions (UDFs) will be developed for physical properties, turbulence and radiative and kinetic models, and a solid numerical discretization (converged if possible, at least for simple non isotherm flow) will be built.

7.6. Control oriented models

The information regarding furnaces control strategy is available internally in DOW's intranet. In the University of Ethylene web page the proposed control strategies for cracking furnaces and the most effective technologies to perform this control can be consulted as the project progresses.

7.7. Control System

The plant in Tarragona normally operates under feedback control. The current controller structure is MIMO and is based on a Model Predictive Control (MPC) strategy (in particular, a widely-used and well-established flavour of MPC known as DMC, that is, Dynamic Matrix Control) with real-time adaptive tuning (i.e., the controller is being fine-tuned on-line). The controller implementation is digital.

The multivariable control has several inputs. In the furnace, the controlled variables are the severity operating rate, the steam ratio, the fuel gas pressure and the temperature inside the furnace. In order to regulate these variables the control loop acts on the manipulated variables: the feed flow, the steam flow and the fuel gas flow. The multivariable control scheme is showed in the figure below:

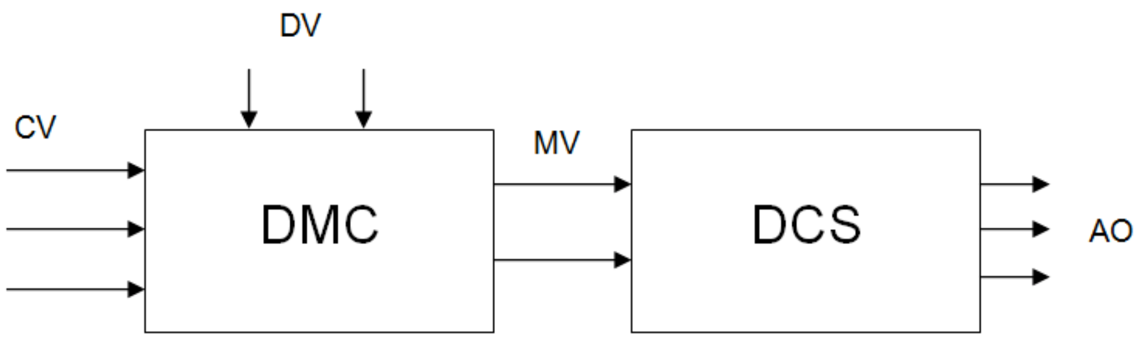


Fig. 38: Schematic diagram for the multivariable control used for the cracking furnace.

As it is seen in the figure above, the controlled variables give the set-point to the DMC which calculates, using models, the value that the manipulated variables should have. Afterwards, the value of manipulated variable is changed in the process, for example moving a valve (AO), by the Distributed Control System, which is a single loop control. There are two main single loops: The first regulates the cracking temperature and the second regulates the excess of oxygen in the combustion gasses, see Figures 39 and 40.

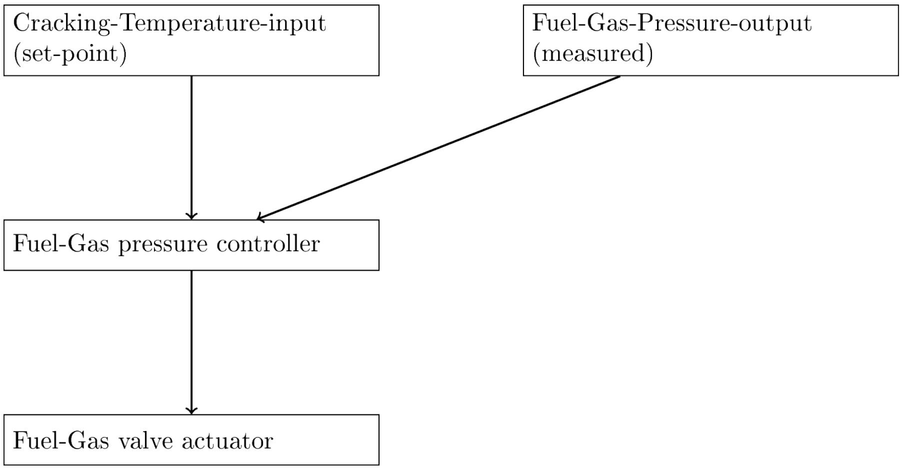


Fig. 39: Schematic diagram for the cracking temperature controller.

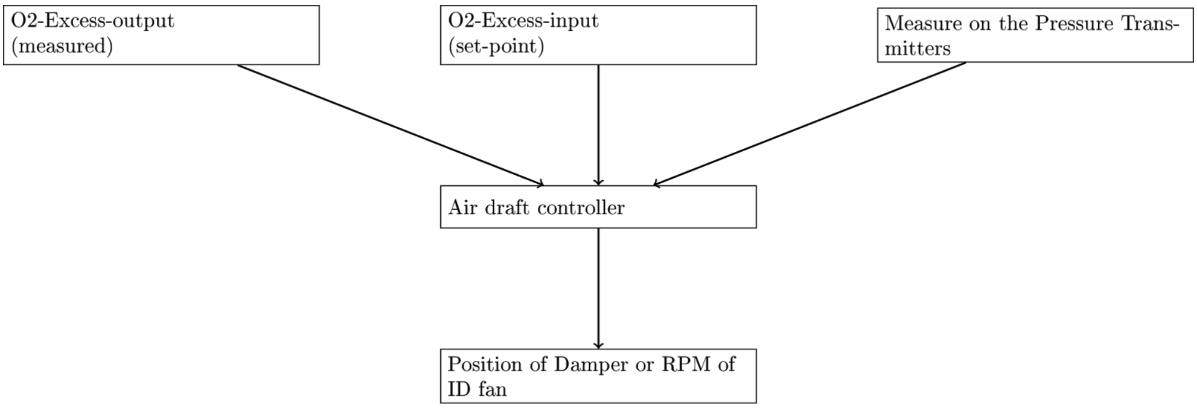


Fig. 40: Schematic diagram for the excess O2 controller: The measure in the pressure transmitter means the draft (vacuum) of the furnace. The radiant box has an O2 set point, this is translated in a vacuum pressure and this leads to the final element that is the position of the damper.

No direct access to the actual control infrastructure is provided to partners. Test changes will have to be first evaluated on the available control system simulator architecture and by assuring full compliance with the established protocols applicable within DOW (MOC – Management of Change - and DPA WP – Dow Process Automation Work Process).

7.8. Measurement and sensor systems

As a whole the cracking furnace is monitored by a number of sensors between 10 to 15. The currently deployed hardware is:

1. Sensing of CO and NOx: two SERVOMEX / XENDOS 2700 analyzers .

2. Sensing of Fuel-Gas consumption: One flow transmitter, ROSEMOUNT / 1151DP4E22B1I8D2.
3. Sensing of Fuel-Gas pressure: three pressure transmitter, ROSEMOUNT / 3051CD4A02A1AH2I1CN.
4. Sensing of draft: ROSEMUNT 3051CD1A02A1AH2I1D3L4, three instruments inside the firebox of the furnace are used for redundancy.

The sensor measurements are wired to the I/O of the control system and are available as soon as the reading is performed (e.g., there is no batching). The sampling rate is variable and can be adjusted between 10-60s per sample. The volume of the collected data is constant in time: The system collects at most 1 row every 10 seconds which is a total amount of 8640 rows per day. Historical data are available (see Figure 41).

	Fuel Gas			
Value	Tag	Units	Description	Value
1,088326018	EB_AC_0084	kg/h	F-1001 Caudal de FG corregido FT-0101 - kg/h	3483,921
44,11607314	L_16_AE8401_H2	%_Vol	AE8401 COMP-LPGAS HIDRÓGENO	25,86911
24,51618564	L_16_AE8401_MET	%_Vol	AE8401 COMP-LPGAS METANO	71,43438
637,7652476	L_16_AE8401_O2	%_Vol	AE8401 COMP-LPGAS OXÍGENO	0,03
330,446971	L_16_AE8401_ACET	%_Vol	AE8401 COMP-LPGAS ACETILENO	0
342,3331766	L_16_AE8401_CICLOP	%_Vol	AE8401 COMP-LPGAS CICLOPROPANO	0,005
355,9220045	L_16_AE8401_PROPI	%_Vol	AE8401 COMP-LPGAS PROPILENO	0,031543
359,910165	L_16_AE8401_PD	%_Vol	AE8401 COMP-LPGAS PROPADIENO	0,005005
2,767650356	L_16_AE8401_MA	%_Vol	AE8401 COMP-LPGAS METILACETILENO	0,005
633,0404302	L_16_AE8401_Ibuta	%_Vol	AE8401 COMP-LPGAS isoBUTANO	0,01179
2,623957337	L_16_AE8401_nbuta	%_Vol	AE8401 COMP-LPGAS n-BUTANO	0,020274
624,0271058	L_16_AE8401_1BUTE	%_Vol	AE8401 COMP-LPGAS 1-BUTENO	0,033361
2,722017722	L_16_AE8401_CICLOB	%_Vol	AE8401 COMP-LPGAS CICLOBUTANO	0,005
617,2303479	L_16_AE8401_IBUTE	%_Vol	AE8401 COMP-LPGAS isoBUTENO	0,049937
2,459727448	L_16_AE8401_T2BUTE	%_Vol	AE8401 COMP-LPGAS trans-2-BUTENO	0,020423
604,3821797	L_16_AE8401_C2BUTE	%_Vol	AE8401 COMP-LPGAS cis-2-BUTENO	0,01009
826,4573925	L_16_AE8401_13BUTA	%_Vol	AE8401 COMP-LPGAS 1,3-BUTADIENO	0,009242
826,6302577	L_16_AE8401_12BUTA	%_Vol	AE8401 COMP-LPGAS 1,2-BUTADIENO	0,005
826,6329445	L_16_AE8401_IPENTA	%_Vol	AE8401 COMP-LPGAS isoPENTANO	0,005
826,5910607	L_16_AE8401_NPENTA	%_Vol	AE8401 COMP-LPGAS n-PENTANO	0,005
1194,912904	L_16_AE8401_C5	%_Vol	AE8401 COMP-LPGAS C5 INSATURADOS Y SUPERIORES	0,005
1190,316952	L_16_AE8401_H2S	ppm_Vol	AE8401 COMP-LPGAS ÁCIDO SULFHÍDRICO	0,01
1217,237781	L_16_AE8401_OCS	ppm_Vol	AE8401 COMP-LPGAS SULFURO DE CARBONILO	0,01
-6,199400794	L_16_AE8401_CH4S	ppm_Vol	AE8401 COMP-LPGAS METIL MERCAPTANO	0,01
-5,883071033	L_16_AE8401_C2H5SH	ppm_Vol	AE8401 COMP-LPGAS ETIL MERCAPTANO	0,01
-6,631698482	L_16_AE8401_CO	%_Vol	AE8401 COMP-LPGAS MONÓXIDO DE CARBONO	0,274365
830,7153943	L_16_AE8401_CO2	ppm_Vol	AE8401 COMP-LPGAS DIÓXIDO DE CARBONO	6,332053
830,5274272	L_16_AE8401_ETA	%_Vol	AE8401 COMP-LPGAS ETANO	1,261055
830,6079849	L_16_AE8401_ETI	%_Vol	AE8401 COMP-LPGAS ETILENO	0,797947
830,3365865	L_16_AE8401_N2	%_Vol	AE8401 COMP-LPGAS NITRÓGENO	0,131825
44,11607314	L_16_AE8401_PROP	%_Vol	AE8401 COMP-LPGAS PROPANO	0,105978
0,411170111	L_16_AE8401_CC	kcal/kg	AE8401 CALC-LPGAS Calor de Combustión	12504,03
314,6018745				
667,9888032				
336,9006547	Analizador general de humos (Hornos + Caldera)			
350,9541794	Tag	Units	Description	Value
346,8971857	EA_AC_2863	MG/NM3	SO2 en mg/Nm3 [mg/Nm3]	14,0432
357,962726	EA_AC_2869	MG/NM3	NOX en mg/Nm3 [mg/Nm3]	102,3077
2,99993873	EA_AC_2875	MG/NM3	CO en mg/Nm3 [mg/Nm3]	25,45803
589,4013522	EA_AC_2834	%	Oxigeno seco en % [%]	7,593279
2,92943173	EA_AC_2835	%	Oxigeno humedo en % [%]	6,699944
610,5093733				
2,94266277				
607,8427859				
2,735721948				
583,6887506				

Fig. 41: Example of historical data extracted and downloaded from Dow's Control System.

Notice that currently there are leakages inside the furnace and the measurements of O2, CO and NOx are not accurate.

7.9. Actuation

The system is actuated through the following components:

1. *Fuel-gas valve*: actuates the fuel-gas flow to the cracking furnace.
    1. Valve: MASONEILAN DRESSER Model 35-35212 (CANFLEX II). ISOPERCENTUAL.
    2. Cv: 135.
    3. Range: 0,49 Kg/cm2 to 1,05 Kg/cm2.
    4. Actutaor: MASONEILAN 35. Supply : 1.4 Kg/cm2.
    5. Positioner: MASONEILAN. SVI 2 AP. 1.4 Kg/cm2. DIRECT.

6. Actuation capacity: 2275 – 3600 Kg/hr fuel-gas per side (2 units).
2. *Damper*: actuates the the furnacestack's damper.
    1. Actuator: GULDE IBÉRICA. R-300V.
    2. Range: 1,5 Kg/cm2 to 3.5 Kg/cm2.
    3. Actuation capacity: 0 – 184 m3/hr per unit (2 units).

7.10. Data analytics

The current PAT system is IP21. All the plant data (e.g., set-points and sensor measurements) are collected and stored as-is in a single database. The formats used for saving the data are MES (Manufacturing Execution System) and DCS (Distributed Control System).

The MES server store to IP21 (Aspen InfoPlus. 21) both data in real-time and historical data on process variables, quality variables and other variables from other information systems. The InfoPlus21 database resides in the memory and consists of a number of different types of records and associated structures that are used to locate and process the records. The DCS is the basic control loop used to control the process. Dow uses MOD 5 for the ethylene plant control.

Historical sequences for the quantities of interest are available for the last 3 years of operation. The process data related to the project will be made available by DOW for the DISIRE partners in excel format: The IP21 system has an application (MesDataReporter) that allows to export the historical data in an excel spreadsheet and this tool will be used to communicate data between DOW and CIRCE.

7.11. Evaluation platforms

All development can be assessed for performance and robustness in one of the similar existing cracking furnaces (according to DOW's internal protocols / authorization processes and MOCs).

7.12. Evaluation cases

Developments will be assessed in the following scenarios:

- Cracking Furnace operated at different feedstock loads (full, medium).
- Cracking Furnace operated with different feedstocks (liquid, gaseous).

- Cracking Furnace in different lifetime between decokings (SOR / Start of Run, MOR / Mid of Run, EOR / End of Run).

7.13. Final industrial demonstration

DOW offers the possibility of simulating the proposed software improvements on their control system infrastructure.

Assuming we carry out all needed Dow internal protocols / authorization processes (MOCs, etc…), we could potentially modify some parameters of the existing controller and try some completely new control methodologies.

The considered performance indexes should be:

1. The ability to control the amount of O2 in the exhausted gases.
2. The overall energy efficiency (as measured by the unitary energy intensity).

We in Dow internally report energy consumption / efficiency in terms of ratios; i.e. BTU/lb HVC, BTU/lb C2+C3 (HVC stands for High Value Chemicals, C2 stands for Ethylene, C3 stands for Propylene).

The evaluation should be based on the comparison of before / after performance for the same operating conditions (throughput, feed composition, severity and selectivity parameters). Notice that the current performance of the plant will be assessed by CIRCE as part of WP8.

The main expected impact of a successful demonstration is considered to be an increase in the competitiveness across the European industry (multiple sectors) in terms of energy efficiency and environmental friendliness.

7.14. DISIRE Technological Contribution

The expected DISIRE contribution in this WP and towards the Cracking Furnace process can be summarized in the following Figure 42, where the expected major contributions from the project will be the DISIRE based in situ imaging sensors, the online PAT and the overall IPC reconfiguration based on the online PAT.

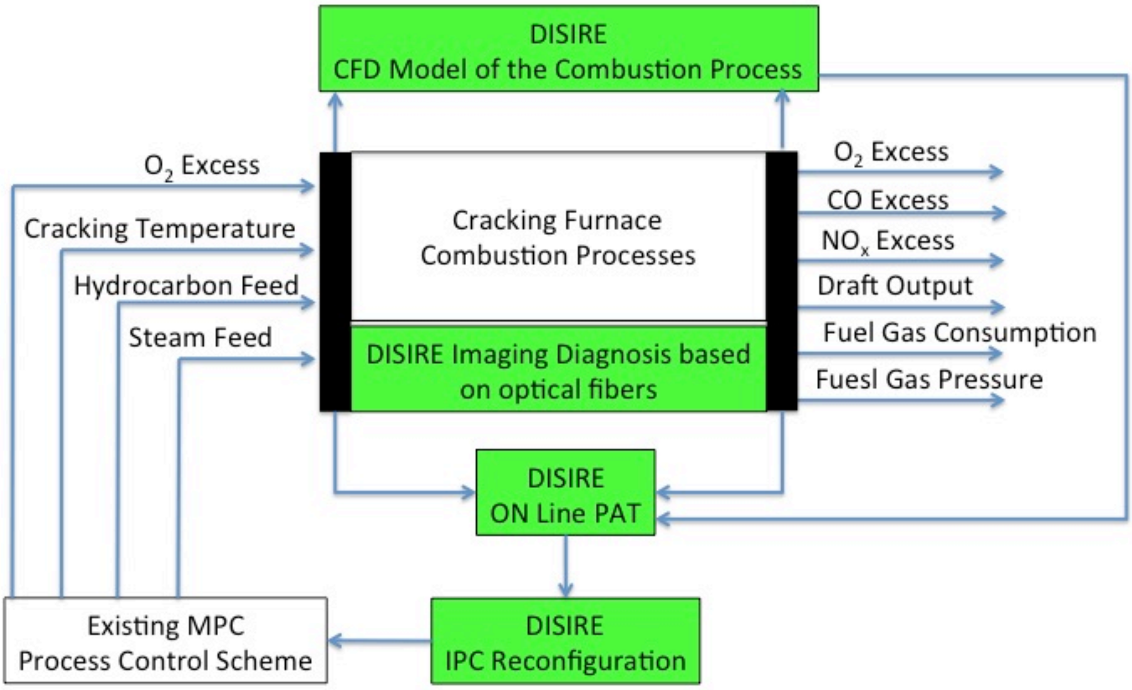


Fig. 42: DISIRE technological impact in the Cracking Furnace Process.

8 Target impact of the DISIRE project in the short/middle term

The involvement of all DISIRE partners will be crucial in the presented processes and aims, while the application of the industrial demonstration scenarios to be elaborated will have to comply with the specifications of the individual processes.

Key Performance Indicators: A Key Performance Indicators, henceforth KPI, is a measurable and quantifiable index which is used to evaluate the performance of a plant or process. The European Commission seems to have put effort into establishing such indicators, of technical and/or economical nature, for the evaluation of processes and organizations. Such an example is a 2011 report on KPIs for the Solar Europe Industrial Initiative (SEII), see https://setis.ec.europa.eu/system/files/Key_Performance_Indicators_SEII.pdf, for photovoltaic systems.

DISIRE will propose such, mainly non-financial indicators, so as to quantify and communicate the quality of performance of an industrial process. This will be done through the case studies of DISIRE and for the needs thereof, but in an as generic and re-useable fashion as possible.

8.1. WP5 Steel processes: Non Ferrous Mineral Processes; Transportation system at KGHM

DISIRE in WP5 will aim to facilitate and demonstrate the use of DISIRE enabled sensors in the flotation process and evaluate measured data in combination with existing process data and off line PAT, while adjusting or identifying means for advanced control of the conveyor belts. In general the mining process in KGHM (and in all the similar production types) has the difficulty of monitoring the flow of the copper ore, a fact that makes quite complex the transport network to be controlled as well as to optimize its operation, in combination with the internal bunkers that could circulate the ore for a large period of time, without further processing it or operating the overall transportation process not in the optimum level, and thus wasting huge amounts of energy and without increasing the quality of the production by tracking the ore.

Specifically, the ore bunkers increase the transportation system flexibility and reliability and consequently improve the mining operations. However, it is now almost impossible to track the flow of any particular amount of ore from the mining face up to the shaft bunker. At KGHM, there are several (2 or more) hoisting shafts in each mine that are supplied with ore by the local belt conveying system.

Thus, DISIRE in this WP will investigate further the development and the applicability of online PAT for the transport processes at KGHM. The initial aim will be to determine the quality and the quantity of the available and online gathered data from the existing and the additional DISIRE data acquisition systems. In the sequel specific DISIRE online PAT will be developed for demonstrating their applicability in the application of the conveyor network control, in the transport system of KGHM, while achieving an overall operation optimization. The PAT based IPC will be based on MPC and the online PAT measurement methods, resulting from the streaming of the in situ ejected sensors in the flaw of the materials.

At the moment, there is no advanced PAT/IPC technology or infrastructure aiming at optimizing the conveyor belt system. Moreover, at the current situation, the tasks of the modelling, tracing and controlling the transport system in a closed loop and in interaction with other parts of the processes are considered quite challenging and open problems, mainly due to the complexity of the problem, the number of factors that should be considered and the interdisciplinary knowledge required to implement such system. Apart from technical factors, in case of significant improvements in the transportation system, there is still going to be the need to change some organizational aspects and maybe even the corresponding mining regulations, which is also another specific aim for DISIRE.

8.2. WP6 Ferrous Mineral Processes: Tracing Iron Ore pellet in transportation chain

DISIRE in WP6 will aim to perform evaluation of the technological developments carried out in WP03 Sensors and Electronics in relevant industrial environments, as well as create a framework for generating data that will be further processed in WP04 Data mining to develop an in situ product and process measurement for iron-ore pellets capable of characterizing the transportation conditions. Secondary objective linked to the main objective is to develop strategies for tracking and communicating with the PAT sensors in the product and logistics chain. The overall goal is to generate a fundamental knowledge-base about the product properties and their behavior in the processing machines and identify the specific measurement conditions and related challenges that are specific to ferrous mineral processing.

The main factors affecting the quality of the product are linked to the quality of ore itself: the ore will have different features depending on where it is mined. The composition of the pellet can vary depending also on the needs of different market segments and the type of transformed goods to which it is destined.

A difficulty in this case is then that different product batches are difficult to separate, while this puts restrictions on the production, since the corresponding storage facilities are limited. It is moreover difficult to track products for causal analysis when customers have issues with the properties of a certain product shipment. Therefore there is a need to be able to trace and predict the location of a specific product (batch). Today, tracing products can be both complicated (if not impossible) and very time consuming. For this purpose, it is of great value to be able to know the position of a product from ore to customer. In this application scenario, the important variables are the time and the position of pellets after production so that the product's properties, which have been selected for a specific customer, can meet certain quality constraints. The mixing of the same product but from different production batches in the logistics chain (including storage silos) may affect the properties of the material. By using existing knowledge regarding flow of granular material in silos and by creating models to control the mixing from different product batches, it is aimed to reach a more evenly distributed production quality, through mixing when loading onto a ship. This means that the time and positions of a certain production batch, in the logistics chain, are important measurements. The developed PAT sensor platform will be fitted with suitable off-the-shelf sensors that can be used for in-situ measurements in the production process and logistics flow. This PAT sensor platform will be larger than the pellets to accommodate for large sensors such as loading cells, robust electronics encapsulations, batteries, memories and larger antennas for long-range communication in a harsh environment.

8.3. WP7 Steel processes: Blast Furnace and Walking Beam Furnace

With the use of additional sensors, important additional information about the internal process state such as position, temperature, pressure, and gas composition is expected. Better knowledge of both the blast furnace process and the walking beam furnace process is therefore possible. With improved knowledge reduced energy consumption is expected. For instance, this new information could influence the principles for charging of material at the top of the blast furnace. And therefore enable reduction of fossil fuel. Also proper temperature measurements inside the walking beam furnace can assure a homogeneous temperature in the material.

This specification is needed for product quality and process stability as well as optimization of energy consumption. The proper control of oxide content in the various zones in the furnace can minimize losses caused by excessive oxide scale and degraded surface quality and also control combustion and cost for oxygen.

8.4. WP8 Combustion Processes: Cracking Furnace at Dow Chemical Co.

Better knowledge and further control of combustion process, including flame shape and characteristics, and of flue gases distribution in the energy intensive cracking furnaces which will be impacting in improving their energy efficiency.

Expectations targets on the overall energy efficiency that could be achieved through the improvement of instrumentation and by performing more accurate measurement are in 2%-5% range improvement. This figure could appear too low or a bit challenging, but in absolute terms, this range of improvement represents a huge impact for this kind of fired equipment.

As this improvement will be performed in one of our cracking furnaces as the pilot one to test and verify the developed methodologies, instrumentation, new sensors, controls strategies, etc, in case of success those ban be expanded or extrapolated / leveraged to other existing fired equipment units within other Dow premises.

Other energy intensive industrial sectors can be impacted by these findings: Any energy intensive industrial sectors operating fired equipment (boilers, furnaces of almost every design, etc) might benefit of the work done in combustion process sustainable improvements under the umbrella of DISIRE.

As improvements developed under the scope/umbrella of DISIRE will be focused in being more energy efficient, the impact will allow the chemical industry to be more competitive and sustainable in terms of GHG emissions.

In case that successful and sustainable improvements are achieved, a significant breakthrough in competitiveness (linked to energy efficiency) will be achieve for the European energy intensive industries. At this point is should be also mentioned that Per 1 Cracking Furnace. 1500 TOE/year (Tonnes of Oil Equivalent), meaning 3200 Tonnes/year CO2 (GHG) emissions reduction.

9 Conclusions

In this deliverable, the DISIRE related industrial processes with respect to the corresponding WPs and the aims and objectives of DISIRE have been presented. More specifically six application areas have been described in detail where it is envisioned that DISIRE will have a major impact. At this point it should be also highlighted that special focus has been provided to present the actual processes and the real life approaches in testing the DISIRE technological contributions, a fact that adds a significant amount of importance for the expected DISIRE results.

As it has been indicated, in the described processes, DISIRE will significantly contribute in the area of: a) in situ sensors, being able to measure necessary parameters that currently no such measuring technology exists, b) on-line PAT based on the on-line gathering and processing in close to real time existing sensory information, as well as integration with the additional in situ DESIRE sensors, c) on-line IPC reconfiguration based on the on-line PAT analysis.

In general, the demonstration scenarios of DISIRE can be separated in two categories: a) the open loop case and b) the closed loop case. The open loop case is focusing more in the traceability issues of the ore, and how this information could add value in the logistic chain or in the quality of the production. The closed loop case is focusing more on how we could reconfigure the overall IPC based on on-line information from internal parameters of the processes, which have never been measured before, since such in situ sensors were not existing before. In both cases the existence of the novel DISIRE sensors are of paramount importance to be merged with the existing measurement systems in order to provide an on-line PAT. In the open loop case the on-line pat will assist further the characterization of the product and the overall quality of the process in former stages, while in the closed loop system the on-line PAT will assist in the global and distributed optimization of the overall IPC.

Summarizing the DISIRE related processes, the open loop processes are the following ones:

- Traceability in Non-Ferrous Mineral Processes in the transportation system
- Tracing Iron ore pellet in transportation chain
- Thermal Grate in pelletizing
- Steel process Blast furnace

While the closed loop processes are the following ones:

- Steel process walking beam furnace control

- Cracking furnace control

One very important remark is that even in the case of the open loop processes DISIRE will investigate further the applicability of these concepts of on-line pat based IPC but this will take place in simulations or hardware in the loop experimentations, since the project, at this time, has no access to the closed loop plants, or because the traceability issues have been evaluated with a high and significant value for KGHM and LKAB. Another important remark is that the consortium has added two additional evaluation applications, the Thermal Grate and the Walking beam that have not been mentioned before in the DOA, a fact that indicated the strong interests of the beneficiaries in the activities, the vision and the impact of the project.

The envisaged operations will undergo a further feasibility study by the DISIRE partners that will be responsible for their implementation. Therefore a sketch of modular elementary sensing capabilities, sensor miniaturization, endurance in harsh environments, communication limitations, computational complexity, computational timing, realization efficiency, integration and estimated impact will be investigated. The resulting functional primitives will then be elaborated further and this will lead to the development of feedback control diagrams that highlight the current status, dependencies among components and novel DISIRE components.

At this point it should be highlighted that this document is considered as a live one, and as the project evolves and matures, the descriptions of the specific processes and the corresponding testing and evaluation scenarios will become even more specific and detailed. However, at the M6 stage of the project, we believe that the current document provides a very good detailed overview of what DISIRE will aim for and specific directions on the impact that we envision for the project.

ANNEX – A The Questionnaire

Questionnaire on Specifications and Requirements[13]

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The aim of this document is to identify and specify specific attributes for the DISIRE components in the areas of abstraction, scalability, adaptability and to align these attributes to specific real life applications.

1. Identify the important physical processes

(If there is more than one process, copy, paste and fill the following information separately for each process.)

1. Name: (give a coded name for the process, e.g., KGHM-ConveyorBelt -- this will identify the process among partners)
2. Dependencies: (e.g., KGHM-Flotation depends on Cuprum-ConveyorBelt)
3. Key partners: (list the involved partners and describe their role)
4. Application scenario: (describe in brief the process's aim / function and how it operates / how it is currently operated; use functional blocks in your description)
5. Performance metrics: (identify performance and quality indices taking into account current performance gaps and possible improvements)
6. Objectives: (quantify meaningful goals for each of the above metrics, e.g., improving a certain metric by a 105% proportion after the application of DISIRE technological framework)
7. Technological obstacles: (describe the main technological problems towards the achievement of said objectives; describe identified technological gaps)
8. Integration strategy: (describe your cooperation and development strategies to integrate DISIRE components)
9. What is the volume and the frequency of data in the process? (Rows per unit of time, total number of rows per process per day)

2. Description of the physical processes

(If there is more than one process, copy, paste and fill the following information separately for each process. Use block schematics in your description: sub-blocks should also be presented and analyzed.)

1. Physical variables: (compile the following information separately for each variable)

a. Name of variable: (give a coded name, e.g., ConveyorBelt-Speed)

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This questionnaire is part of all the activities and deliverables in WP1.

b. Input/Output: (is it an input or an output ?)
c. Physical role: (how does it affect the process ?)
d. Variability: (is it constant or varying in time ? is it highly variable ?)
e. Bounds: (upper and lower bounds on the admissible values of the variable. e.g., maximum flow, maximum speed, or, possibly, more complex bounds in the form a*{temperature} + b*{pressure} < 1)
f. Stability: (is it critical to control this quantity to have a stable system ?)
g. Effects on performance: (which performance metrics it affects and how ?)
2. Operating point(s): (describe the operation of the system at steady state)
3. Stability: (is(are) the operating point(s) stable or unstable ?)
4. Mathematical model: (are accurate models of the physical system available ?)
a. Is it a static or dynamic model ?
b. What are the advantages and disadvantages of the model ?
c. References: (list references to existing documents and scientific publications)
5. Existence of simulation tools:
a. Name: (name of the simulation tool)
b. Features: (short description of its features)
c. Requirements: (what are the system requirements to run it? (operating system, dependencies, etc…))
d. Access: (is the tool open or available to the partners? If no, have you got any suggestion for developing a control oriented model?)
6. Control oriented model: (are accurate control oriented models of the physical system available ? what is the state of art ?)
a. Is it a static or dynamic model ?
b. Is it obtained from first principles or model identification ? (what approximations are assumed ?)
c. What are the advantages and disadvantages/limitations of the model ?
d. References: (list references to existing documents and scientific publications)
7. Fault scenarios: (describe common failure scenarios)
a. Frequency:
b. Effects on the performance:
c. Current self-reconfiguration procedures:
d. Plausible self-reconfiguration procedures: (list novel self-reconfiguration procedures whose implementation might improve the performance metrics)

3. Actuation

(For each input variable describe how the system is actuated, use block diagrams where appropriate.)

1. Source / Reference signal:
2. Signal elaboration: (describe how reference signals are elaborated before being sent to the actuator ?)
3. Effects on performance: (is this actuator critical for performance ?)
4. Hardware: (list the hardware in use, its specifications, operational limits and effects on the performance.)
5. Actuation capacity: (what are the technical limitations of your actuators. For example, a pump may lead to flows from 0 to 100 L/s, a valve can be from 0 to 100% open, the motor of a conveyor belt can run at a minimum speed of […] and a maximum speed of [...] m/s, etc)
6. Are the actuators controlled over a network? If so, is it wireless? Are there significant packet drop-outs? (please, specify their magnitude)

7. Industry trends: (are there better performing technologies ? what are the current trends ?)

4. Measurement and sensor systems

(For each output variable describe how the given physical quantity is measured / sensed. Use block schematics where appropriate.)

1. Use: (Why is this output measured ? for control ? for monitoring ?)
2. Effects on performance (is availability of accurate measurements of this output critical for control ?)
3. Is the data transmitted as soon as the sensor gate gets the reading from the sensor or by a batch process when a certain amount of data is collected ?
4. Hardware: (list the hardware in use, its specifications, operational limits and effects on the performance)
5. Sampling rate:
6. Existence and availability of historical data:
7. What are some typical measurement errors you encounter? (e.g., the hardware guarantees a standard error of 1%; or, less than 1% missing measurements)
8. Are the sensor data accessible over a network? If yes, is the network wireless? Are there significant information packet drop-outs? (please, specify their magnitude if any)
9. What is the data type for the output of the sensors ? (e.g. integer, varchar, json , xml).
10. Elaboration: (how are measurements elaborated before being presented ?)
11. Industry trends ? (are there better performing technologies ? what are the current trends ?)
12. Are there critical measurements that are performed by humans but could be automated ?
13. New measurements and sensors: (what measurements and/or sensors do you foresee that would enhance the process control possibilities?)

5. Control Systems

1. Type of existing controllers: (analog or digital)
2. Control Structures: (Single Input Single Output, Multiple Input Multiple Output)
3. Ability of altering the control system in the real process: (does the system have an open architecture? can we apply changes in the control system?)
4. How is the controller being tuned? (empirically? with optimal on-line tuning strategies, from simulation models, etc.)
5. How fast is the control loop closed? (sampling time and associated technological / economical obstacles)
6. Can you estimate how many sensors of each type will be in each process?
7. Is there variation in the volume of data collected (e.g. in the night the amount of data is significantly lower? in some periods, like summer, the volume of the data supposed to be higher? Are there lower and upper bounds for the volume?)

6. Data analytics

1. Available data: (what measurements / data are available on the various processes ?)
2. Current PAT: (describe currently implemented PAT system)

a. How are the data stored: (SCADA? Other DBMS?)
b. How are the data interfaced: (How can one access the data? Can they be exported in some file format? Is there some software that allows the system operators to access and inspect these data?)
c. Does the collected data goes through manipulation/analysis before being available?

d. Do all the sensors send the information to one DB or to multiple DBs and from there synchronized to a central DB?
3. Access: (how do you plan to make the above data accessible to partners ?)
4. Plausible PAT: (describe novel extension to the PAT and their impact)

7. Evaluation platforms

(Describe each platform separately)

1. Type: (simulators, actual deployments)
2. Test scenarios: (what kind of tests can be performed on this platform? what can be measured? what can be controlled?)
3. Access: (how many, how often and how long can tests be performed on these platforms to e.g. test novel control approaches and sensor technologies)
4. Scaling: (describe your strategy for escalating these tests to larger scale experimentation)

8. Evaluation tests

Evaluation tests are specific multiple small tests for the evaluation of the DISIRE components, before the final industrial demonstration.

(Discuss the specifics of each evaluation test separately)

1. Procedure: (describe the test procedure)
2. Performance indices: (give measurable indices of performance)
3. Evaluation: (describe how the overall test will be evaluated and give success and failure conditions)
4. Current performance: (give indications of how the current system performs under the above scenario and metrics)
5. Impact: (describe the expected impact of the proposed test)

9. Final industrial demonstration

1. Procedure: (describe the test procedure)
2. Performance indices: (give measurable indices of performance)
3. Evaluation: (describe how the overall test will be evaluated and give success and failure conditions)
4. Current performance: (give indications of how the current system performs under the above scenario and metrics)
5. Impact: (describe the expected impact of the proposed test)