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COGNITWIN

Cognitive plants through proactive self-learning hybrid digital twins

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Deliverable Report

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Executive Summary

The purpose of this report is to define the existing level of digitalisation in the Engineering pilot of the COGNITWIN project and describe its limitations and opportunities, including the identification of novel fuel sensors and collected information for cognitive modelling. The characteristics and challenges of the pilot environment are also discussed, as well as the innovative aspects gained by the novel cognitive tool.

This pilot case deals with optimization and operation of energy boilers, designed and delivered by Sumitomo SHI Energia Oy (SFW), aiming at fast adaptation to new and variable energy sources. The Engineering pilot will be concentrated on an energy conversion process called Circulating Fluidized Bed (CFB). A specific challenge for today's CFBs, as wells as for energy boilers in general, is the variation in fuel quality, which contributes largely to harmful fouling and corrosion phenomena.

The innovation of the Engineering pilot is to combine new kind of fuel quality data to process data from the power plant. This would enable to anticipate the effects of fuel quality changes to the process, which could enable early detection and prevention of process disturbances. This kind of system, with some cognitive abilities, may potentially help the operator of the power plant to optimize the boiler controls in such a way that the (anticipated) changes in the fuel properties would be better managed, boiler emissions and operation economy would be optimal, and the downtime of the boiler would be reduced.

This document will set the baseline for the development work of the Engineering pilot and enable to define needs for the following tasks. Future work will continue by setting up the digital environment for being able to demonstrate the Engineering pilot, including the implementation of possible new fuel monitoring approaches and the development of required models for the Digital Twin and, after that, by developing the necessary cognitive elements to finally achieve the Cognitive Twin phase.

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Acronyms

CFB – Circulating Fluidized Bed
CHP – Combined Heat and Power
DCS – Distributed Control System
LIBS – Laser-induced Breakdown Spectroscopy
OPC – Object Linking and Embedding (OLE) for Process Control
SFW – Sumitomo SHI FW Energia Oy
VPN – Virtual Private Network
XRF – X-ray Fluorescence

1 Introduction

Boilers are a critical element in the current energy industry and will play an important role within the group of forthcoming green energy technologies. This pilot case deals with optimization and operation of energy boilers, designed and delivered by Sumitomo SHI FW Energia Oy (SFW), aiming at fast adaptation to new and variable energy sources. Input to the plant is both developed technology (design and operation), combustible raw materials with a large variety in chemical composition, energy contents, and air that is sucked in, to support the combustion. A specific challenge is the variation in fuel quality, which contributes largely to combustion instability, corrosion and fouling phenomena. Output from the process is energy, combustion products and ash.

The customers of SFW face challenges in plant operation, maintenance and asset management. The plant operators may struggle with the optimal operation when the fuel is continuously changing, especially when firing challenging renewables such as biomass and bio-residues. The fuel quality may be decreasing, and new challenges are set to maintenance and equipment lifetime as the harmful components in fuel are increasing.

SFW aims at expanding its service pallet in the existing market area, i.e. the whole world, for both existing customers with SFW boilers and to new service customers. The company's business model will be based on continuous operations and maintenance services for the customers, and on the benefits these services bring to the customer as added value to their operations. The preferred earning model will be based on a bonus or subscription system with a very small or non-existing charge for the IoT system delivery and basic service fees.

The key stakeholders in the Engineering pilot case are SFW, owner of the pilot plant (i.e. the end-user and final customer), and different technology vendors that include measurement technology vendor(s), and possible other vendors operating in different fields related to IoT data collection, storage and analyzing platform, for example edge technology and devices, cloud environment, connections and communication etc. The role of SFW is to provide domain expertise for the pilot, as well as being the owner of the pilot and benefits.

2 Sumitomo Engineering pilot

2.1 Process description

The Engineering pilot will be concentrated on an energy conversion process called Circulating Fluidized Bed (CFB). A CFB boiler consists of a CFB loop and a convective section. The main parts of the CFB loop are furnace, gas-solid separator, solid recycle system (loop seal) and optional fluidized bed heat exchanger. The convective section, also referred to as back-pass, is composed of superheater, reheater, economizer and air preheater [1]. The main parts of a CFB boiler are presented in Fig. 1.

In a CFB boiler, preheated combustion air is delivered into the furnace in two stages by air fans. Primary air is delivered through an air distributor grid that is located at the bottom of the furnace. Secondary air enters the furnace through ports located on the walls above the furnace floor. The velocity of the gas in the combustor is typically in the range of 3 to 6 m/s generating good mixing. Fuel is delivered directly into the lower section of the furnace or through the loop seal. The fuel burns in the bed of solids generating heat. The heat from combustion flames and flue gases is transferred to the water-steam circulation of the boiler and preheating of air. [1, 2]

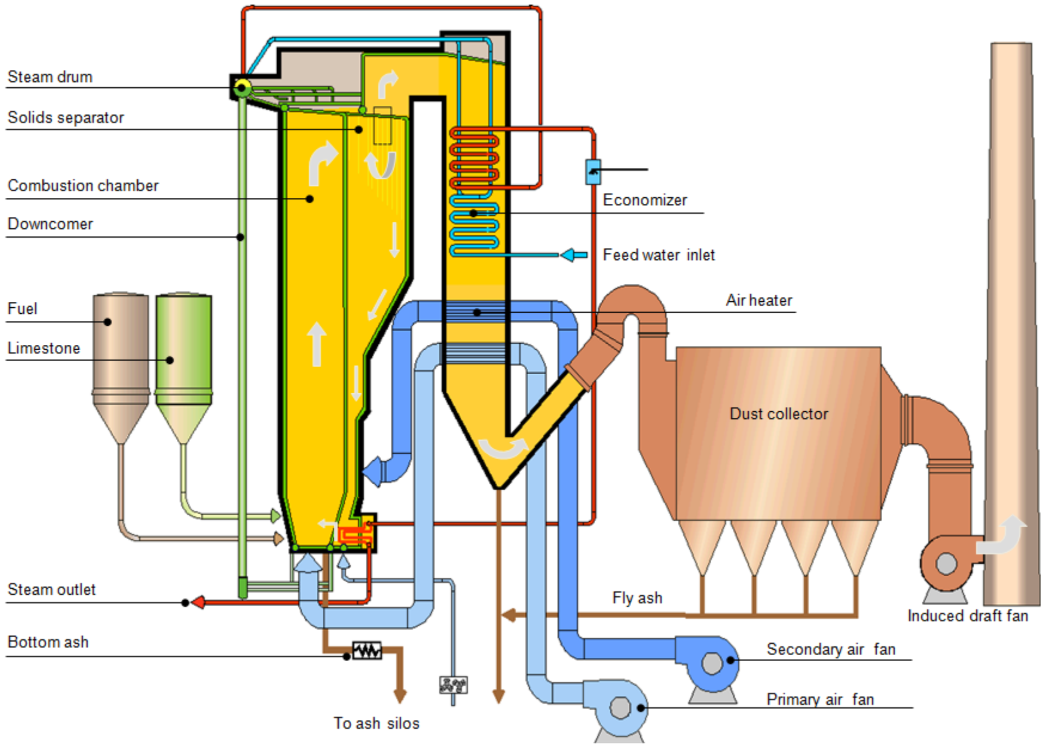

Fig. 1. A CFB boiler with compact design

Due to the high velocity of gas in the furnace, hot solids drift continuously out of the furnace into the solids separator. Majority of the solids are captured by the separator which is typically a cyclone. The captured solids are recycled back to the lower part of the furnace through a loop seal. Finest particles leave the separator along the flue gas that is absorbed to the conventional section by an induced draft fan. After the convective pass, the particles are collected from the flue gas by an electrostatic precipitator or equivalent. [1]

Heat transfer to the water-steam circulation of the boiler occurs mainly in the furnace and in the convective section. The walls of the furnace are generally made of evaporative water tubes. In the convective section, heat from flue gas is used for superheating and reheating of steam and for preheating of water and air. Additional surfaces, such as wing walls and omega tube panels, are also used in furnaces to maintain temperatures at optimum level. Other possible locations for water or steam cooled heat transfer surfaces are solid separators and fluidized bed heat exchangers in the circulation loop. The demand of additional heat transfer surfaces is determined based on the boiler capacity. [1, 3]

Temperature level in the furnace is typically in the range of 800 to 900°C in order to prevent agglomeration of solid particles, to achieve efficient sulphur capture and to lower the level of NO_x emissions.

2.2 Pilot plant

The pilot customer is a municipally owned local power company, located in a mid-sized town in a Nordic country. The customer company works in several branches and functions:

- combined (district) heat and power generation
- other electricity production (water power, renewables)
- district heating and electricity sales
- district heating and electricity network operations

The customer covers 100% of the district heating demand with own generation in CHP (combined heat and power) units located inside the city limits. The customer's CHP generation is mainly done in company's own CHP generation facilities at one dedicated site. The power plant site comprises of several CFB boiler plants, all from different ages. The older plants in active operation are from 2000's and 2010's, whereas the latest one is to be handed over to commercial operation in spring 2020. All the plants have CFB type of boilers for conventional power generation. All the boilers utilize slightly different fuel diet and thus have slightly different basic designs.

The latest boiler unit, of approximately 150 MW thermal power, has been chosen for the Engineering pilot. The unit has been selected based on the challenges in the operation and the on-line optimization of the combustion process, such as ash deposits on the convective heat exchangers and consecutive corrosion phenomena as well as potential slagging and circulation problems in boiler hot loop area, that are caused by the specific fuel properties, especially the corrosion and fouling tendency. The unit utilizes wood-based fuels such as clean wood, recovered wood, demolition wood etc. collected from both households and industry. The unit covers total 36% of the heat demand and production of the customer.

Schematic view of the power plant site and the selected unit for the Engineering pilot can be seen in Fig. 2. It shows the layout of the unit, including the boiler house, turbine house, flue gas cleaning house and auxiliary and ancillary buildings (on left) as well as the fuel receiving, preparation, storage are (on right) and the conveyor lines in between.

2.3 Current challenges

SFW customer's business requires high flexibility in their operation, e.g. amount of energy produced together with new and more challenging fuels. These challenges are a consequence and necessity from the decarbonation targets in EU, and the consequent transition of the energy sector to renewables, especially solar and wind. To enable that transition, other power plants must assure highest flexibility. As usual, this EU environmental target will eventually extend worldwide.

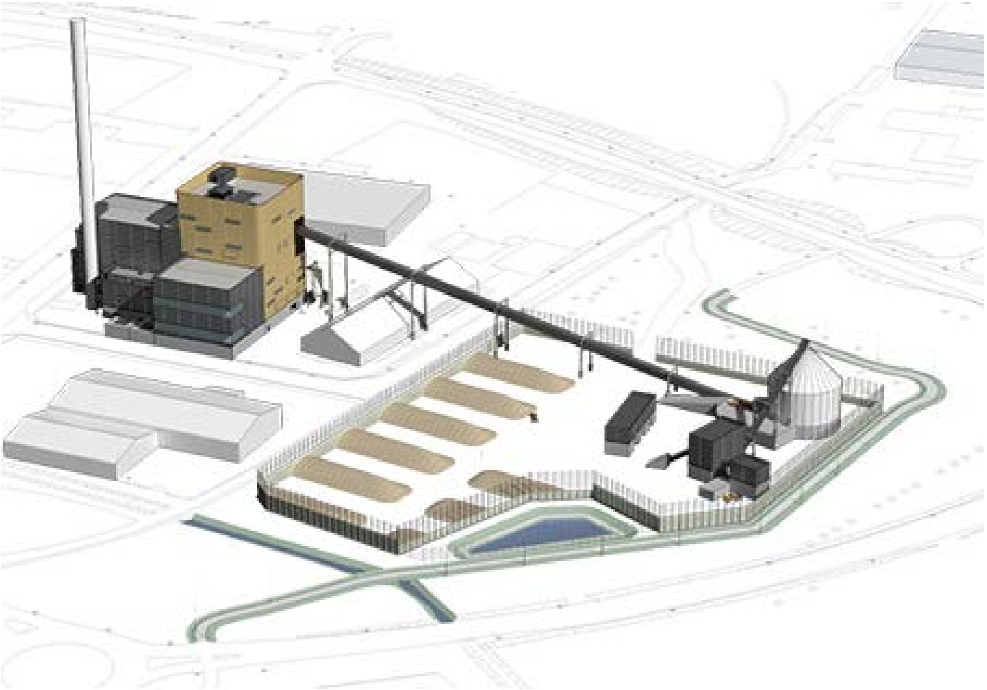

Fig. 2 Schematic view of the power plant site

With new and more difficult fuels many of the customers of SFW face new challenges in both plant operation, maintenance and asset management. The plant operators may struggle with the optimal operation when the fuel is continuously changing, especially when firing challenging renewables such as biomass and bio-residues. The fuel quality may be decreasing, and new challenges are set to maintenance and equipment lifetime as the harmful components in fuel are increasing.

One of the prevailing trends in the energy plant business is that the requirement for fuel flexibility is increasing fast. Therefore, the main challenges in today’s energy boilers are ever more difficult fuels and the changing fuel quality, which make optimal operation of boilers extremely challenging. Therefore, there is a demand for adaptive systems that involve cognitive elements to learn the most efficient and cost-optimal ways of operating or controlling the process in order to maximize power output and minimize fouling and corrosion effects and emissions. On the other hand, there are no measurements available for certain fuel components that are causing problems in the process, so there is a need to develop either direct measurements or indirect measurements, such as soft sensors that could be utilized by the cognitive model.

Regarding the CFB process, the most critical harmful phenomena affecting the plant performance and lifetime of the boiler pressure parts which should be minimized are (See Fig. 3):

- Fouling (build-up of ash) on heat exchanger tubes
- Corrosion rate of heat exchanger tubes

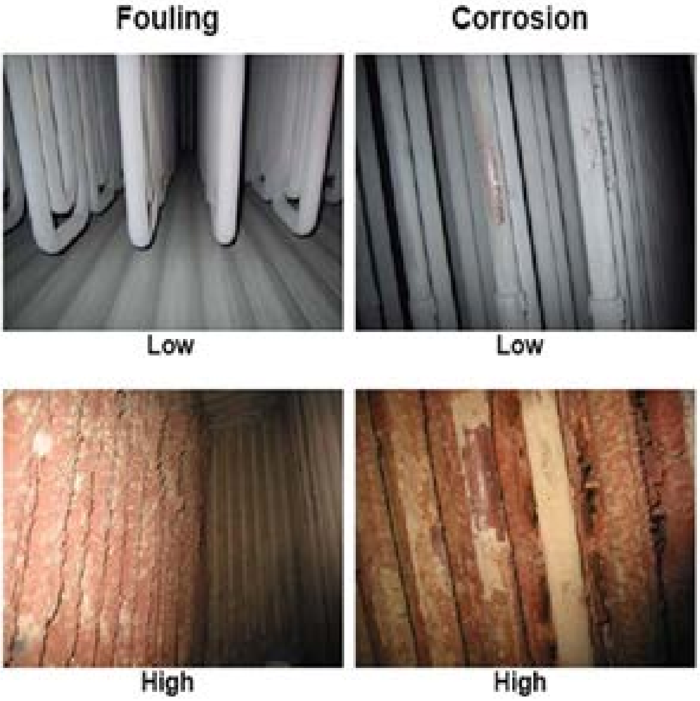

Fig. 3 Fouling and corrosion of heat exchanger tubes

The most important recognized factors that influence fuel quality are:

- Elements connected to fouling and corrosion phenomena (the focus of WP3: K, Na, Cl, S, Ca; secondary focus: Si, Al, Fe)
- Moisture content in fuel
- Ash content in fuel

For SFW, the development of the CFB product also involves a continuous search of promising and feasible technologies for improving the monitoring of the CFB process. Especially when it comes to the monitoring of alkali metals, this far SFW has been unable to identify cost-effective sensors or measurement techniques with adequate performance, accuracy and applicability to boiler plant environment. The most typical challenges in these environments are as follows:

- Fuel particles are often coated with dirt and dust
- Fuel particles are often covered with surface moisture (from rain) than disturbs the measuring of total moisture
- Fuel particles have too irregular shapes and sizes for many sampling and measurement techniques
- Lack of continuous sampling methods for samples representative for the whole fuel mixture
- Concern that random sampling with too small fuel samples will give incomplete picture of mixed fuels.

2.4 Pilot specific aim

The goal of the pilot project is to develop and build a model-based system that utilizes both new monitoring technologies (physical and/or soft sensors) and process data. More specific fuel information would enable us to study how fuel quality changes affect the process. The system can potentially help the operator of the power plant to optimize the boiler controls in such a way that the changes in the fuel properties are better managed, boiler emissions and operation economy (i.e. the efficiency and operating costs) are closer to the optimal, and the downtime of the boiler is minimized.

In order to improve and optimize the CFB process, one should be able to monitor all or at least some of the most important factors influencing the fuel quality:

- Elements connected to fouling and corrosion phenomena (the focus of WP3: K, Na, Cl, S, Ca; secondary focus: Si, Al, Fe)
- Moisture content in fuel
- Ash content in fuel

The measurement method, including possible sampling, should be able to cope with solid fuels (wood chips, peat). Typical particle sizes for the fuels are:

- Peat: 0.6-10 mm (80% of weight within this range)
- Clean wood, chipped: 3-150 mm (> 90% of weight) and 3-80 mm (> 50% of weight)
- Recycled wood, crushed: 3-100 mm (75% of weight)

The weight percentages in the list above describe the share of the total fuel (sample) weight composed of particles within the presented size range. The remaining weight is in smaller or larger particles.

Based on typical variations for peat / virgin or recycled wood, the recommended concentration ranges (in weight percentages, wt-%) to be detected would be as follows:

- Minimum required detection range for ash: 0…50.0 wt-% (dry), 0…20.0 wt-% (wet)
- Minimum required detection range for K+Na, S, Cl: 0…10.0 wt-% (dry), 0…5.0 wt-% (wet)
- Minimum required detection range for moisture: 0…60 wt-%

The measurement resolution should be better than 0.05 wt-%, but this may be specified in a further stage.

Currently, the available fuel quality measurements are under evaluation in the COGNITWIN project, and the decisions on the technology to be used will be made based on this. The target is to decide this during Spring 2020 so that possible sensor assembly works could be performed during plant summer outage 2020. It is important to note that it is also a possible result that currently there is no feasible technology available for fuel quality monitoring, due to different drawbacks such as lack of accuracy or high price. In such a case, one must consider different soft sensor approaches for monitoring the fuel quality in the pilot.

2.5 Innovation

The innovation and the cognitive element of the pilot is to combine new fuel quality data to process data from the power plant. This would enable us to predict how fuel quality changes affect the process, which enables early detection and prevention of process disturbances and overall process optimization. It would also make it possible to optimize fuel usage. For example, when knowing the fuel type and composition which is put into the system, one could use the cognitive tool to estimate future fouling tendency and based on this decide, what kind of fuel should be preferred in the near future to avoid problems. This system can then potentially help the operator of the power plant to optimize the boiler controls in such a way that the (anticipated) changes in the fuel properties are better managed, boiler emissions and operation economy are optimal, and the downtime of the boiler is minimized.

2.6 Current platform and architecture in use

The current platform that SFW is using for data collection is called SmartBoiler™. It is a server-based data collection, storage and analysis system developed by SFW in early 2000's for plant operators and managers to monitor their boiler's operation through a host of plant sensors and analytics. The SmartBoiler remote connection brings the customer's process data available for SFW's process specialists who monitor the plant performance in order to detect any process deviations and disturbances for risk management purposes. SFW process specialists also provide operation support and remote troubleshooting services and offer regular process performance reporting.

SmartBoiler collects process data from the boiler control system. It comprises a server equipped with a database and data analyzing software, an operator station and VPN (Virtual Private Network) firewall for network connections. SmartBoiler server is running on a standard Microsoft Windows Server operating system. The main parts and connections of the SmartBoiler system can be seen in Fig. 4.

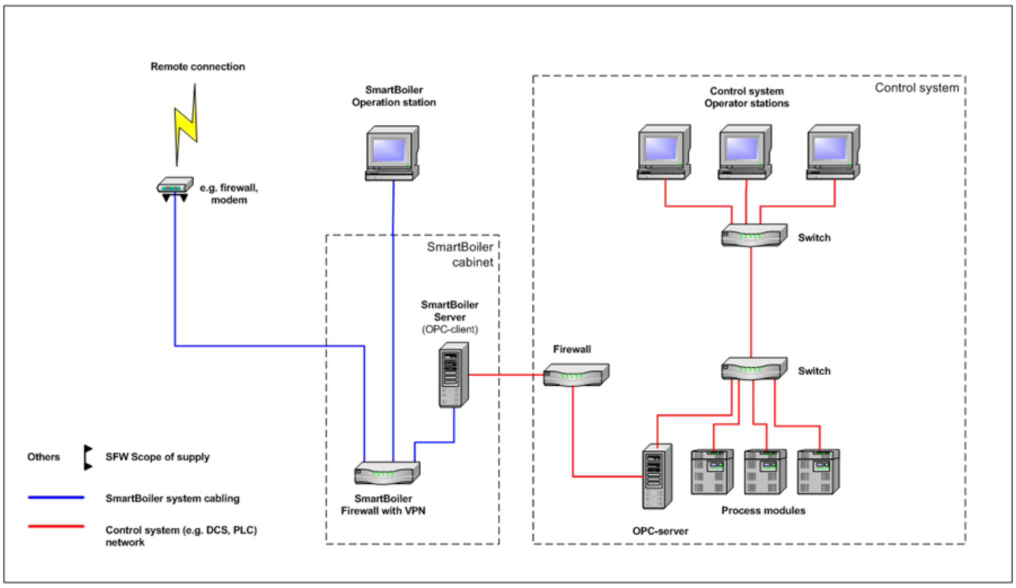

Fig. 4 SmartBoiler system and connections

SmartBoiler requires a communication link to a boiler control system (e.g. DCS) which is implemented with OPC-technology (OLE for Process Control). The data acquisition is implemented with OPC DA-protocol that is compatible with OPC DA 2.0 or 2.05a standard for data acquisition. Since the SmartBoiler is equipped with OPC-client, for example Matrikon OPC tunneller, the control system shall be equipped with OPC-server software.

For data storage the SmartBoiler server contains a database for the timestamped time series data collected form the DCS system. The database is a commercially available third-party database for real-time data collection. The size of the database history is limited by system hard disk size. The server hard disks are RAID controlled including a spare disk for redundancy. The database SFW currently uses is purchased and licensed from an external partner.

The remote connection to SFW premises is based on a standard network technology. It utilizes xDSL-based (Digital Subscriber Line) modem or the boiler plant network for the connection. The remote connection is secured by VPN and therefore the interface shall have a public and static IP-address. The minimum line speed of the connection is 20.0 Mbit/s for download and upload.

2.7 Existing models and tools

2.7.1 State of the art

It is a well-established fact that, in comparison to conventional fuels such as coal, gas or oil fuelled boilers, fouling in the heat exchangers when using fuels such as bitumen, wood chips, biomass etc is far more intense. The primary reason for this is the presence of higher concentrations of alkali metals and chlorine in bio-based fuels. The fouling mechanism itself is a very complex phenomenon and not fully understood. The deposits on the heat exchanger tubes are usually charred remains of burnt fuels, solid particles and unburnt fuel melts that are carried over by the flue. With time the thickness of the deposit layer increases, and the efficiency of the heat exchanger decreases exponentially [4].

Several methods are suggested in the literature to deal with this phenomenon. They are broadly classified into two categories, mechanical and chemical cleaning methods. Modelling the fouling phenomenon was previously based on fouling factor approach however, it received much criticisms on its limitations to heat exchanger design [4, 5]. Following this, much effort has been devoted towards development of alternative methods that are more effective in capturing, simulating, predicting, managing and mitigating fouling.

Based on experimental observations and data, several correlations have been used to model the changes in heat transfer coefficients due to fouling that are described as a function of process variables. Several mathematical models (both first principle and empirical) also have been developed [6–9] with an intent to improve the existing heat exchanger design and monitoring programs. However, many of these models only assist in describing the fouling phenomenon on the tube-side, which restricts their applicability to shell-side fouling phenomenon.

For the shell-side fouling phenomenon, a method based on the “*fluid flow fraction*” concept was first introduced where the impact of hydraulic resistance and geometry of the heat-exchanger were considered. In this approach, the heat transfer coefficient and pressure drops are calculated as a function of the geometrical parameters [10]. Following this, other methods such as Bell–Delaware [11], [12] and the Flow Stream Analysis [13] were also developed and proposed and are widely used in the industry to calculate the performance of the shell side *in clean conditions*. As much as they are used in the industry they fall short when there is a fouling build-up. Shell-side fouling affects the performance of the heat exchanger in two ways:

a) The resulting deposition on the shell-side can impair the heat transfer from the surface to the inner walls of the tube. In addition, due to the reduced space available for fluid flow, the velocities of the fluid increase thus resulting in increased convective heat transfer coefficient and pressure drops.

b) When the tubes of the heat exchangers are clean, the fluid flow fraction is determined by the tube geometry. However, as the fouling builds up over time (almost always uneven and non-uniformly) the fraction of fluid passing through between the outer walls of adjacent tubes reduces. Which in-turn results in poorer heat-exchanger performances.

While it is acknowledged that there are no models that consider the above two affects, there are some attempts made to mathematically describe the shell-side fouling. For instance, in one study CFD (computational fluid dynamics) model was used to model the fluid flow inside the heat-exchanger using time-varying flow characteristics along the surface of the tubes [14]. Furthermore, there are studies where the authors considered fouling with simpler tube geometries [15, 16] and heat transfer properties around the tube in crossflow pattern [17]. Nevertheless, none of these models are sufficiently accurate due to the complexity of the process. Some of the existing fouling models are already made available through a variety of commercially available software tools and are already being used by the industry.

Hot corrosion is a common challenge in boilers when firing aggressive fuels such as recycled wood and waste. Mitigating the losses caused by corrosion requires an optimal balance between 1) pricy preventive actions, 2) time-consuming scheduled maintenance, and 3) the risk of unscheduled failures causing loss of production and repairs [18]. Corrosion on heat exchange surfaces is a caused by interaction of several factors such as humidity, temperature, and the presence of corrosive gases and chloride salts. The main difficulty in developing reliable online-working models for corrosion is the lack of reliable online data on the quality of (e.g. moisture and the elemental composition) of the fuel. Currently, there are some existing models based on fuel composition, heat exchanger materials, and steam and flue gas temperatures, but their improvement and upgrade to online systems would require a working online monitoring solution which could provide online information on the fuel quality. There are also some approaches for the predictive modelling of corrosion in heat exchanger tubes presented in the literature [19, 20].

2.7.2 Existing SmartBoiler tools

The existing state of digital analysis tools in the CFB environment can be illustrated through the SmartBoiler concept. SmartBoiler™ has a suite of modular tools and services to provide a means to identify trends, diagnoses problems, and provides performance analysis so that plant staff can operate the plant at peak efficiency and availability [21]. SmartBoiler modules can be seen in Fig. 5. The calculation modules of the SmartBoiler are mainly based on first principles calculations or modelling, and at the moment they do not comprise any cognitive elements.

In the first phase of the piloting, SmartBoiler environment will provide ready-made means for collecting and recording the process data for the model development from the beginning of the commercial operation of the plant. Later on, if the models will be implemented to cloud environment, SmartBoiler system can serve as a kind of benchmark for the platform. In addition, more exact information on the fuel quality would make it possible to improve the existing modules and calculations.

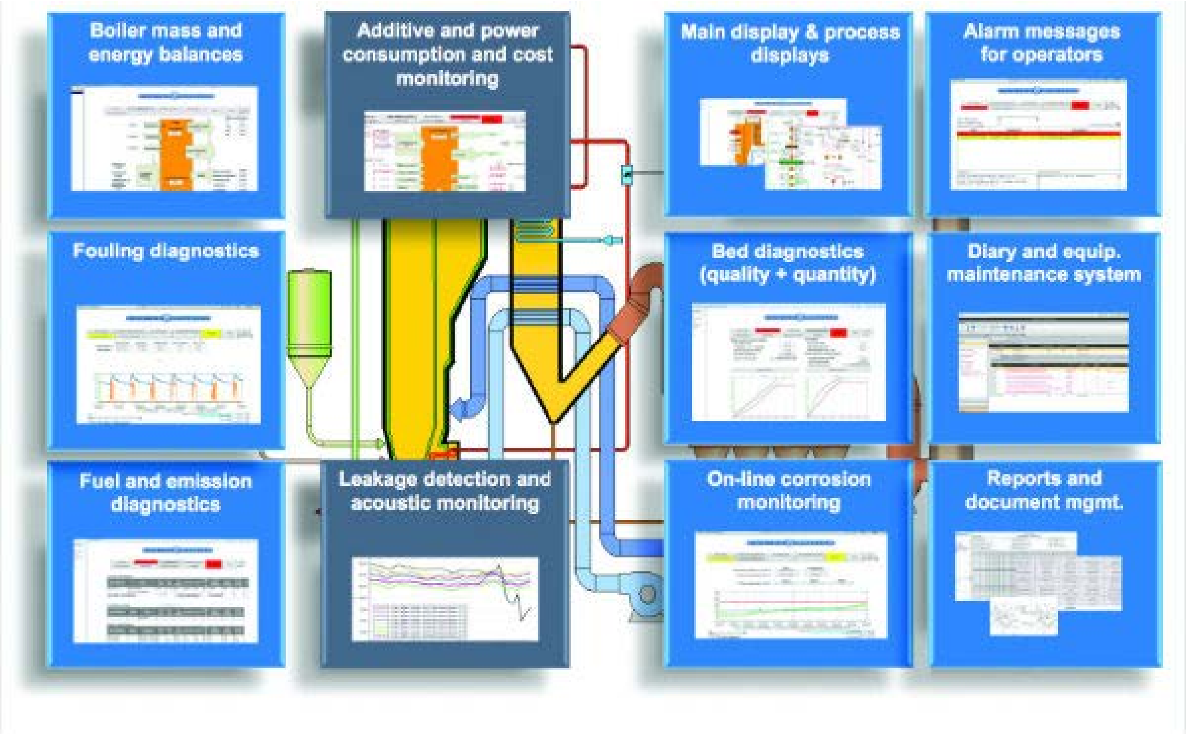

Fig. 5. SmartBoiler™ tools and applications

The use cases of the SmartBoiler modules are various. For example, using data collected from the plant's sensors, the tools continuously calculate the boiler mass and energy balance to ensure the boiler is operating optimally and with high efficiency. The SmartBoiler fuel diagnostic module monitors variation in boiler fuel moisture content, along with other manually entered basic fuel data, such as elementary composition of the fuel, to optimise combustion and reduce fuel costs. The fouling diagnostics module optimises soot-blowing to maximise steam generation, minimise erosion and reduce outage costs. A series of monitor screens graphically presents the plant's process data and analytic data for the plant operator in the plant control room. [21]

The existing corrosion monitoring system is based on the MECO system developed by SFW [18]. MECO system is designed to be installed while plant is in operation. It consists of a measuring probe which is installed in the flue gas duct, and a control unit which controls the probe cooling and executes the necessary measurements, and subsequently calculates the projected corrosion rate. The drawback of the system is that it is not yet online, and it requires manual work because different condition tests need to be conducted.

2.8 Description of data

2.8.1 Standard measurements in CFB

In the delivery projects of SFW, the provider of the automation and DCS systems vary depending on the customer. Therefore, there is not a single standard DCS system that would be in use in every delivered power plant.

However, the most important measurements usually remain the same in every plant. Typically, there are about 1 500 measurements in each CFB, of which around 150 are critical process indicators. The critical process parameters that are currently measured downstream of the furnace are:

- Temperature and pressure measurements in critical locations (bed, air, flue gas, steam, input water)
- Flow measurements (air, steam, water)
- Flue gas composition after the boiler (e.g. oxygen, emissions components, H_2O concentration)

The format of data obtained from the OPC is typically defined in the configuration phase and may slightly vary from delivery project to another. The data format will be specified after the target plant has been determined.

Data volume from existing measurements is approximately 2.5-7.0 GB/month in the reference units, the estimate for pilot plant would be around 4-5 GB/month. Data rate (for bandwidth) is expected to be relatively constant, the estimate would be around 1.9 kbit/s for the basic process data without any special sensors or analysers. Data sampling frequency from DCS is 2-5 seconds. Any new measurement will add data rate from the given estimate and will affect the need for bandwidth. The final data rate cannot be estimated before the measurement techniques and/or the sampling rate are decided.

When it comes to fuel-related measurements, there are some measurements that monitor the mechanical side of fuel distribution (e.g. fuel conveyor speed or, in the best case, the fuel flow), but the key point is that there are no standard, direct fuel quality monitoring technologies included in a typical CFB installation.

2.8.2 Identification of possible new fuel sensors

At the outset of the project, a technology review was carried out with the aim of identifying technologies, vendors, and established products and systems that could provide on-line measurement of the key fuel quality parameters:

- Elements connected to fouling and corrosion phenomena
- Moisture content in fuel
- Ash content in fuel

The effort was primarily invested in the first point, because knowing the elemental composition would enable us to develop more accurate fouling and corrosion models and would serve as a solid basis for the cognitive tool development in the future. All technologies evaluated here basically have the capability of monitoring the elemental composition of fuel, although some restrictions for their use may arise from some physical constraints like the particle size, measurement environment etc. Elemental analysis is a highly sophisticated task, which is typically performed with expensive equipment in lab environments. The most common approaches – mass spectrometry, plasma-induced atomic emission spectroscopy, neutron-gamma scattering – are all poorly suited for on-line operation.

Furthermore, a candidate technology must be suitable for the test conditions. The preferred test point is at the infeed to the fuel silo. This is an outdoor environment with varying temperature and humidity, and the fuel is likely to be wet and/or dirty. The second-preferred test point is on the conveyor from the silo to the furnace.

The technology review produced two promising methods for elemental analysis. Both technologies have been demonstrated on feedstock for coal power plants. For each technology, a preferred vendor was chosen who has relevant experience and is willing to assist in development and adaptation for the novel COGNITWIN use case. The novel sensor technologies are currently under evaluation, and their feasibility in the pilot case will be decided during spring 2020.

2.8.2.1 *Laser-induced Breakdown Spectroscopy (LIBS)*

LIBS is an analysis method that applies a short, intense laser pulse to the surface of the sample. The laser pulse briefly heats the atoms on the surface to a plasma, and the resulting flash of light may be analysed by high-sensitivity atomic emission spectroscopy.

The method is non-contact, non-destructive and may be adapted to on-line (conveyor) operation. The non-contact nature of LIBS makes it easy to deploy, adapt and adjust. Fiber-optics allow for electronics and sensitive optics to be away from the test site, which makes it less sensitive to weather conditions.

In order to make LIBS a quantitative technique (measuring the amount of each element, as opposed to identifying if they exist), careful calibration is needed. The measurement is affected by surface moisture. Furthermore, because only a few atoms on the sample surface are interrogated, dirt and dust may affect – or completely invalidate – the measurement. Finally, LIBS technology requires a more-or-less constant working distance, which could be challenging for fuel types that have widely varying particle size.

2.8.2.2 *X-ray Fluorescence (XRF)*

XRF is a method that uses high-energy X-rays to strip electrons from atoms in the sample. The remaining electrons around each atom will settle into a stable configuration, emitting light at characteristic wavelengths in the process. This light is analysed using techniques related to atomic emission spectroscopy.

XRF is a non-contact, non-destructive technique that may be adapted to on-line (conveyor) operation. Unlike LIBS, it penetrates thin layers of dirt, dust and moisture on the material surface, making it less sensitive to contamination.

A drawback of XRF is the relatively large on-board X-ray source, which requires some mechanical design to install. And, like LIBS, the setup requires a fixed working distance, leading to reduced sensitivity and reliability on fuel samples with large particles.

2.8.2.3 Microwave Absorption Analysis

Both the above techniques are to some extent affected by moisture in the fuel. To reach the required accuracy, moisture content should be measured and included in data calibration. This in addition to moisture being an identified quality parameter for boiler operations.

The established technique for measuring water content is microwave absorption. The principle, like in a household microwave oven, is to pass microwave radiation through the sample, and allow water molecules to absorb some of the energy. The remaining energy is measured by a receiving antenna, and the difference is used to calculate the amount of water in the wave path.

The candidate XRF analyser will include an on-board microwave analyser. Off-the-shelf microwave analysers are also available from several manufacturers and may be installed as a stand-alone sensor.

2.8.2.4 Deployment schemes

There are two main identified setups for deploying an analyser, shown in Figure 6. Both setups account for the need for a constant working distance.

The first setup may be implemented in the preferred location above the silo infeed belt conveyor. To smooth the surface of the feedstock, a plough is suspended in front of the analyser. By angling the ploughshare like a "cow-catcher," larger particles are pushed to the side of the conveyor and allowed to pass around the analyser.

The analyser itself may be suspended above the belt, or it may be mounted on a toboggan-like sledge that rests on the feedstock. The sledge maintains the shortest possible working distance and helps further smooth the material.

The second setup is a bypass scheme, where material from a chain conveyor is collected in a small, vertical silo. From here, the fuel is finely crushed, and analysed on a separate belt conveyor. The bypass line may be operated continuously or in batches. Analysed fuel may be returned to the main line, or it may be archived or discarded.

The second setup offers much higher expected accuracy. This is because the fuel is finely crushed, ensuring a smooth surface, and because the auxiliary conveyor may be run at a lower speed. The main drawback of this setup is that is requires greater mechanical complexity and at least two additional motors. It is not known whether the pilot site can afford the physical space beneath the chain conveyor. Finally, this setup introduces a pinch point at the far end of the silo, where large particles could get trapped and obstruct the conveyor blades. This issue can probably be mitigated with some careful mechanical design.

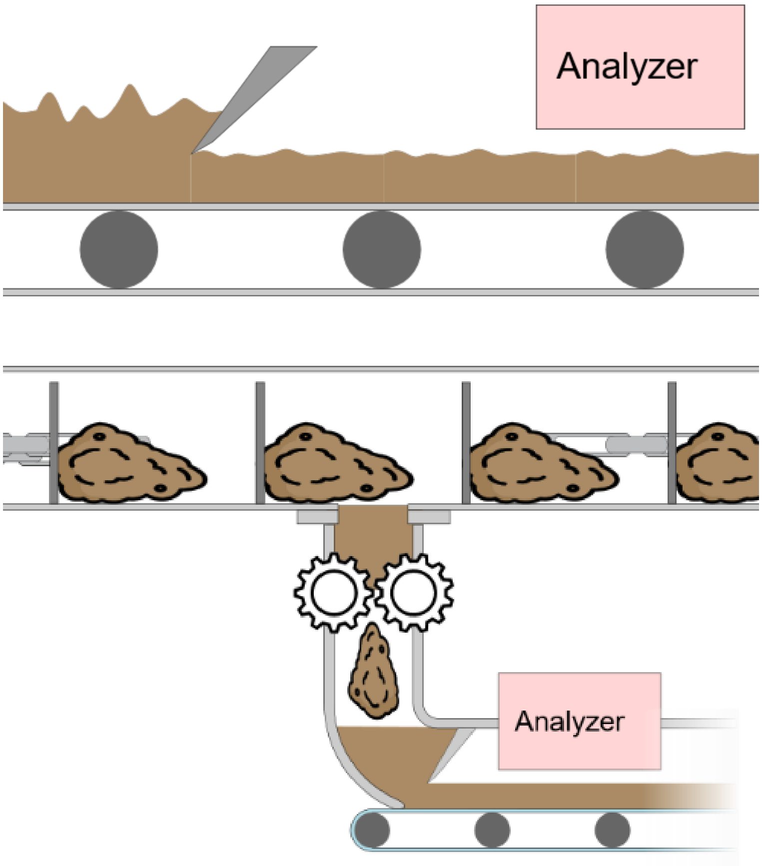

Fig. 6. Suggested deployment schemes. Above: On-line above belt conveyor. Below: Side-stream below chain conveyor.

2.9 Measurable KPIs and expected impact

2.9.1 Measurable KPIs

For the Engineering Pilot, SFW has identified some Key Performance Indicators (KPIs) to evaluate and measure the success of the development efforts. The original set of the measurable KPI targets were selected in order to highlight the various overall aspects of the plant operation performance:

1. Technical performance
2. Reliability and availability
3. Operation economy

4. Environmental performance
5. Safety

The technical performance of the boiler is measured by boiler operating efficiency which is believed to be improved by cognitive systems by enabling the operators to use optimal operating parameters and set values for each precise fuels, including the process controls, such as O2 set values, the usage of additives and steam coil air preheaters as well as to optimize the boiler cleaning practices by optimizing the boiler sootblowing frequency directly based on the fuel quality.

The overall boiler reliability and availability are improved by cognitive methods both directly, by decreasing the bed related process disturbance and erosion/corrosion related pressure part defects, and in-directly, by minimizing factors that may cause or accelerate the boiler ageing or degradation, such as variations in process conditions or forced emergency shut downs.

Operation economy will improve together with the technical performance and reliability by lowering the operating costs related to consumption of fuels, additives and auxiliary power as well as the maintenance costs for repairing the boiler damages and restoring the boiler back to normal operation.

Environmental issues related to the boiler are mostly related to boiler flue gas emissions. The improved boiler monitoring means and predictive controls decrease the variations in the combustion process and help to optimize the combustion temperature dependent NOx and CO emission, especially emission peaks in load change situations and disturbance events.

Last but not least, the operator and environmental safety will be improved, as a combination of improved emission controls and the avoidance of process problems and unintended and unexpected shut downs of the plant.

2.9.2 Current situation of KPIs – initial values

The original measurable KPIs were defined based on average performance of an average plant (in the SFW customer fleet with various unit sizes and fuels) that has been in operation for several years, experienced some degradation and is not operated in the optimal way anymore. The original KPIs were defined as follows:

1. Improved boiler operating efficiency, target 0.05-0.10 % improvement on average
2. Lower operating costs, target 100-200 k€ saving in annual boiler O&M cost
3. Smaller emissions, target to decrease emission peaks and overall levels up to 30 %
4. Improved reliability and availability, target 0.5-1.5 % improvement in plant availability
5. Improved safety, target incident rate in process disturbances causing Lost Time (LTI) is ~ 0.00

Nevertheless, the piloting plant has a new boiler unit that will be handed over to commercial operation in spring 2020. Thus, it has not been experiencing any natural degradation, the used fuels are according to contract specs and the operations is more optimized as the boiler process controls have been tuned by experts right before the hand-over. Therefore, the improvements in the piloting project are expected to be somewhat lower than in an average unit in the SFW fleet.

The current situation of the KPIs is partly not known, as the unit has not been in commercial operation yet. Some of the KPIs can be estimated based on the design and guarantee values of the boiler, but not all. For example, the O&M costs are confidential business figures of the end user (i.e. the customer company) and can be only estimated by SFW. The current safety figures from customer’s other units are not available from the customer and the current status cannot really be estimated by SFW.

The current status of the measurable KPIs is (typical value / range):

1. Boiler operating efficiency: Typical ~89.5-92.0%
2. Operating costs, boiler O&M cost / year: Typical 600-700 kEUR/year (first 5 years)
3. Emissions, peaks as hr-avg, overall day-avg: Permit NOx and CO both 100-150 mg/m3n (fuel)
4. Reliability and availability: Typical ~98.2-98.3%, estimated by SFW
5. Safety, Lost Time Incident Rate (LTI): Status not available from customer’s other units

2.9.3 Future situation of KPIs – calculations and target values

The improvements in the selected KPIs will be calculated after two years warranty period i.e. during spring 2022 by comparing the measured performance (KPIs) after the implementation of the cognitive systems to the measured performance prior to the implementation. This measured performance type of evaluation will be available for Technical performance, Environmental performance and Operation economy (if figures available from the end user).

Technical performance will be evaluated by calculating the average plant efficiency in normal commercial operation, not in a specific performance test. Normal EN stardards will be used for the calculation (DIN1942 etc). For the evaluation, 6-months periods for ‘before’ and ‘after’ will be specially selected in such a way that the fuel and load conditions of the boiler are as similar as possible. Some correction curves can be used for fuel quality, if the fuel quality is not similar during the measurement periods.

Also the ***Environmental performance*** will be evaluated by calculating the average performance in normal commercial operation, not in a specific performance test. The Performance will be evaluated by two key factors:

- Number of the short emission peaks when exceeding the emission limits for hourly average given in environmental permits (hourly average limits) for CO and NOx separately
- Overall emission limits over the 6-months periods as long average for CO and NOx

Correction curves can be used for fuel quality, if the fuel quality is not similar during the measurement periods.

The ***Operation economy*** will be evaluated in similar 6-months periods based on the direct impacts:

- Effiency improvement and it’s effect to boiler operation economy (fuel consumption)
- Improvements in other operation economy, such as additive consumptions etc
- Possible effect of the avoided downtime during the period, if the availability can be measured

The overall effect to O&M costs, especially the maitenance cost and any indirect cost savings, will be anyways measurable only after several years in operation, i.e. is longer than the program timeline.

Availability will be measured by comparing the plant operation hours and load levels compared to the ones required by customers power and district heating demand. Only the unavailability incidents will be counted to the evaluation, that are both attributable to the equipment delivery and related to the fuel quality, process controls or can be or could have been detected by cognitive systems.

Typically, the ***Safety*** KPI would be measured by interviewing the customer plant management and the number of reported and recorded incident would be the measured value. The improvement evaluation would be made by comparing recorded number to customers records of previous years. This improvement evaluation is, anyways, consent to customers willingness to provide the details also from the other units, so it is possible that we may not have access to these data. Therefore, we will not evaluate the safety KPI further.

Based on these marginal conditions, the measurable target improvements of KPIs are set to:

1. Improved boiler operating efficiency: +0.05-0.10 % in average as cont. performance
2. Lower operating costs, boiler O&M cost: -100 k€/year during the first 5 years
3. Smaller emissions, decrease emissions avoid limit exceedings: overall levels -20%
4. Improved reliability and availability: +0.3-0.5 % in plant availability

3 Summary

In this deliverable we have defined the existing level of digitalisation in the Engineering Pilot of the COGNITWIN project and described its limitations and opportunities, including identification of novel fuel sensors and collected information for cognitive modelling. This pilot case deals with optimization and operation of energy boilers, more exactly circulating fluidized bed boilers, designed and delivered by Sumitomo SHI Energia Oy (SFW) and aiming at fast adaptation to new and variable energy sources. It is typical that the plant operators struggle for reaching the optimal operation when the fuel is continuously changing, especially when firing challenging renewables such as biomass and bio-residues. The fuel quality may be decreasing, and new challenges are set to maintenance and equipment lifetime as the harmful components in fuel are increasing.

In the Engineering pilot we seek to combine new kind of fuel quality data (provided by physical and/or soft sensors) to the process data already measured in the power plant. Especially, we will concentrate on better monitoring of the fouling and corrosion phenomena in the heat exchanger surfaces through new means of more efficient direct or indirect fuel monitoring approaches. This kind of improvement would assist in anticipating the effects of fuel quality changes on the process, which again could enable early detection and prevention of process disturbances. This kind of system and digital products based on it, hopefully with some cognitive abilities, can potentially help the operator of the power plant to optimize the boiler controls, so that the anticipated changes in the fuel properties would be better manageable, boiler emissions and operation economy would be more easily optimized, and the downtime of the boiler could be reduced.

The benefits gained by the new Engineering pilot (CFB) will be improved operating efficiency, lower operating costs, lesser total amount of emissions, and improved reliability and availability. The improvements in the selected KPIs will be calculated after two years warranty period by comparing the measured performance after the implementation of the cognitive systems to the measured performance prior to the implementation.

Deliverable 3.1 will set the baseline for the pilot development work and enable to define the needs for the following future tasks in the COGNITWIN project. Future work will continue by making up the necessary decisions on the monitoring technology, setting up the digital environment for being able to demonstrate the Engineering pilot, including the implementation of possible new fuel monitoring approaches and the development of required models for the Digital Twin and, after that, by developing the necessary models and cognitive elements to finally achieve the Cognitive Twin phase

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