MODERN, RELIABLE AND CARBON NEUTRAL HEAT SUPPLY IN THE AARHUS AREA (DK): OPERATIONAL OPTIMIZATION WITH ONLINE MEASUREMENT TECHNOLOGY AND DATA ANALYTICS AS PART OF THE BIOFFICIENCY PROJECT

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1 INTRODUCTION

The EU funded project "Biofficiency" has been originated in order to ensure a highly efficient, reliable and carbon neutral heat and power supply by biomass fired CHP plants. Studstrup Power Station in Denmark is one of the collaborating project partners, since the operator Ørsted A/S performed the retrofit from coal- to wood pellets firing of Unit #3 in 2016, supplying the Aarhus area with green district heating and power. [1]

Fuel flow balance, particle fineness and air-fuel ratio of the burners have a strong impact on the combustion and the boiler efficiency. They influence combustion efficiency, loss on ignition (LoI) as well as slagging, fouling and emission levels. In order to meet the project goals like adjustment and optimization of the combustion process, understanding and solving ash-related problems with the new fuel type (biomass), deep comprehension of the performance of grinding and firing systems as well as their continuous optimization is essential. [2]

Among these challenges related with the different fuel type, also the stability and efficiency of the combustion process, especially due to the fuel conversion to biomass, induces ongoing high requirements for measurement technology and the workflow regarding continuous measurements, as well as the extraction of information of the same.

In this context, EUtech could showcase the potential of optimization by use of online measurement technology combined with an automated data management- and analysis system to manage the increasing demand of operational, maintenance and optimization tasks.

2 COMBUSTION PROCESS ASSESSMENT AT STUDSTRUP POWER STATION

As part of the "Biofficiency" project, a test program to measure fuel distribution of the six burners of one mill, operating 100% on wood pellets, under different operating conditions with both, online and in-situ measurement methods, was set up together with Mitsubishi Hitachi Power Systems at Studstrup PS in Q1, 2019. Thereby, the power plant was supported by online and inline fuel flow and particle size distribution measuring system.

At different operating conditions the mass flow and pipe-to-pipe distribution as well as pipe specific cross section distribution of wood pellets has been assessed by online measurements with the EUcoalflow (ECF) system. Simultaneously, particle size distribution of grinded wood pellets was measured with both, isokinetic sampling plus sieving, known as the standard method, and laser based online in-situ measurement with EUcoalsizer (ECM).

The article includes the assessment of the base status of one mill, operating on wood pellets with and without ash injection, and the relative findings at different operation conditions (i.e. mill load, classifier speed, primary air flow and ash injection).

2.1 APPLICATION

In order to apply the EUcoalflow system at Studstrup Power Station, four access ports were applied at each burner pipe (BR41-BR46) of the mill at different layers as depicted in Figure 1 and Figure 2.

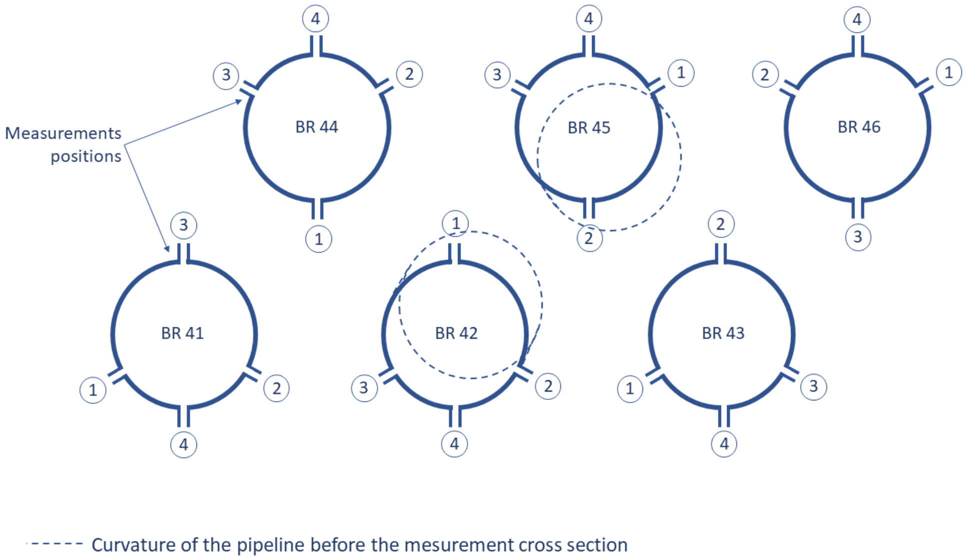

Figure 1: Access ports for ECF sensors at PF pipes

Unlike the others, pipes BR42 and BR45 show a non-vertical course below the measurement layer. Thus, different flow conditions must be expected between the pipes, which can lead to complex data assessment. EUcoalflow is designed for dynamic solid fuel flow balancing and control. It is based on non-intrusive micro-wave sensors (ECF-BAD) and ECF-ELS sensors, equipped with a different measurement technology. The sensor configuration continuously measures, among other values, the mass flow and velocity inside PF pipes (pulverized fuel pipes) and quantify the imbalance of fuel flow from pipe to pipe.

Figure 2 shows the arrangement of the ECF sensors at the PF pipes. Three sensors (micro-wave measurement principle) are positioned 120° apart in one level while the fourth one is applied at a second level 500 mm downstream.

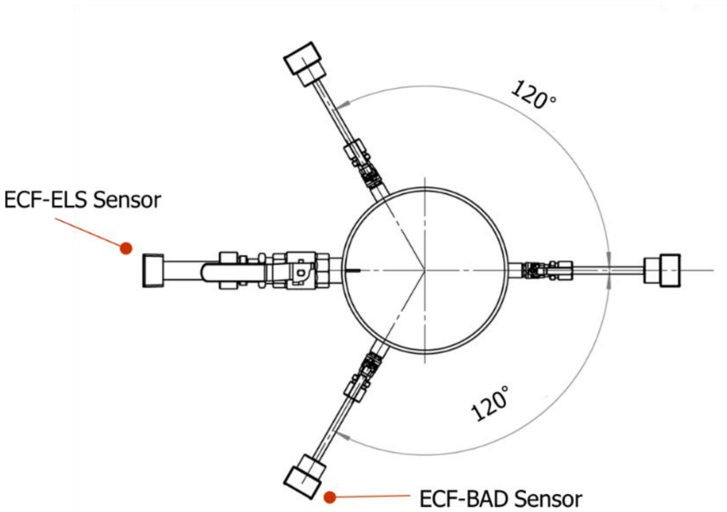

Figure 2: Position of the ECF sensors at the PF pipe

Each sensor type, ECF-ELS and ECF-BAD, has its own characteristics in corresponding flow situations and operating points. Especially in complex flow situations, combining the advantages of different measurement principles is a leading edge for reliable results. This can be pursued by feeding the different sensor signals and optionally other DCS data to a virtual physical model of the underlying process. The common picture of a virtual sensor system can be used to describe the entirety of the system (Figure 3). [3]

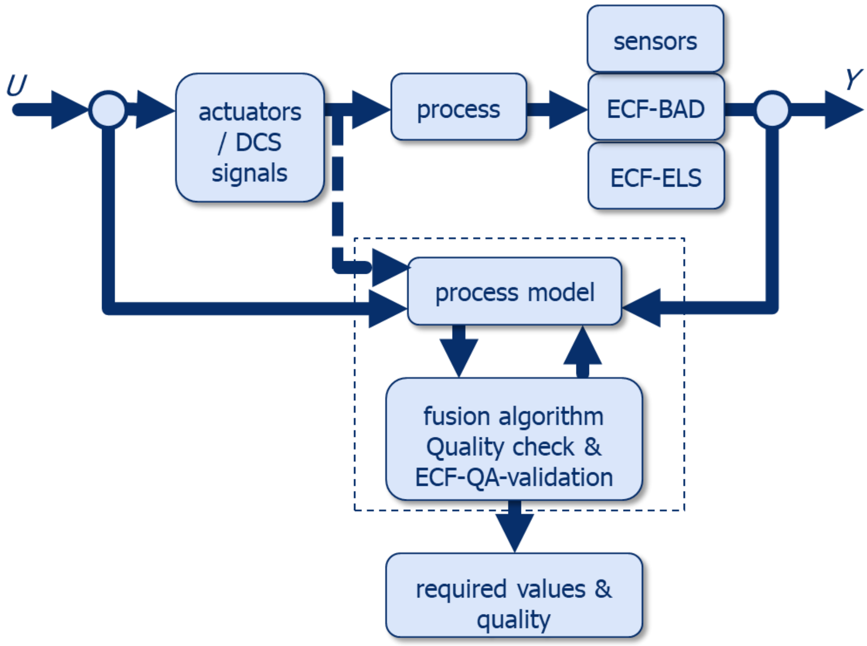

Figure 3: Scheme of model-based sensor fault and validation

The used process model is a grey box model, which is able to adapt itself regarding real process data. The process physical relations are well known and implemented as mathematical equation systems, where parameters can be evaluated and chosen within physical plausible boundary conditions. [4]

By using all available signals based on the process model, the values of interest, e.g. specific pipe mass flow, can be provided and validated over the complete operation range. Furthermore, the early detection of fault situations is a big and essential step for online process optimization and operational optimizations like condition based- / predictive maintenance.

2.2 DATA MANAGEMENT AND ANALYSIS

Already by the end of the 1990s, the availability of measurement data in a power station is not an issue anymore. On the other hand, the wide range of data with their diverse formats, different sources and sometimes missing context information especially for such measurement campaigns still constitute great challenges. Therefore, for real operation and performance improvements as well as for combustion control and optimization a suitable measurement data analysis environment is required.

Supporting performance engineers as well as maintenance personnel in these not easy tasks do not simply require additional tools. An efficient measurement data management and analysis system should connect directly to existing workflows and tools in such a way that no major changes in operations and restructuring become necessary. This requires flexibility and defined interfaces for such a system.

In connection with the performance monitoring of grinding and firing systems, the status of health of the measurement systems themselves are important for quality-compliant, correct use and analysis of generated measurement data. This should include for example the easy and clear management of calibration data and adopted physical scaling.

The collected measurement data should be combined in a central data platform via defined interfaces, where the new data should be linked with the corresponding test cases and automatically evaluated. Thus, the consolidated results and findings can be directly assessed to extract useful knowledge and derive adequate actions.

Moreover, with the use of historical data as well as typical data for same components, series, etc., even a benchmarking statement can be derived.

EUtech's online measurement systems as the EUcoalflow are all equipped with the EU-MDM data management system nowadays, allowing data and contextual information from the different sources to be accessible for automated uniform analysis as described in chapter 2.1(measurement data, DCS-data, test reports, maintenance reports, etc.). The required steps for a successful measurement data analysis are already fully functional, from data import to report generation (Figure 4).

The web-based tool is designed to make sustainable use of the growing amount of data out of measurement campaigns, different plant components, such as the grinding and firing systems of different mills and units in a power plant or even in power plant fleets, in parallel.

While measurement data is recorded or at the end of a measurement campaign, the EU-MDM system imports and process the data automatically in the desired way, including consolidating, filtering, calculation of virtual or fused signals. Additionally, the processed data are directly linked to the necessary context information (which measurement system is used, which component at which plant is observed, etc.) and with regard to certain events (tagging) and data patterns, e.g. alarms, load conditions, system or process faults (clogging, etc.), implausible data. This feature enables online state of health (SOH) information of plant components and measurement system maintenance requirements.

The standardization of the semantics of signals in a semantics catalog can make an important contribution to the company-wide utilization of existing data. In order to best support the existing workflows, target group-oriented evaluations can be generated. Reports are possible in all common formats (PDF, Excel, HTML, etc.). For example, for reporting a measurement campaign all the necessary tasks can be preconfigured and the final report with all necessary information, including benchmarking against other comparable plant components or earlier measurements, is provided directly to the performance crew and plant operator to decide for further actions.

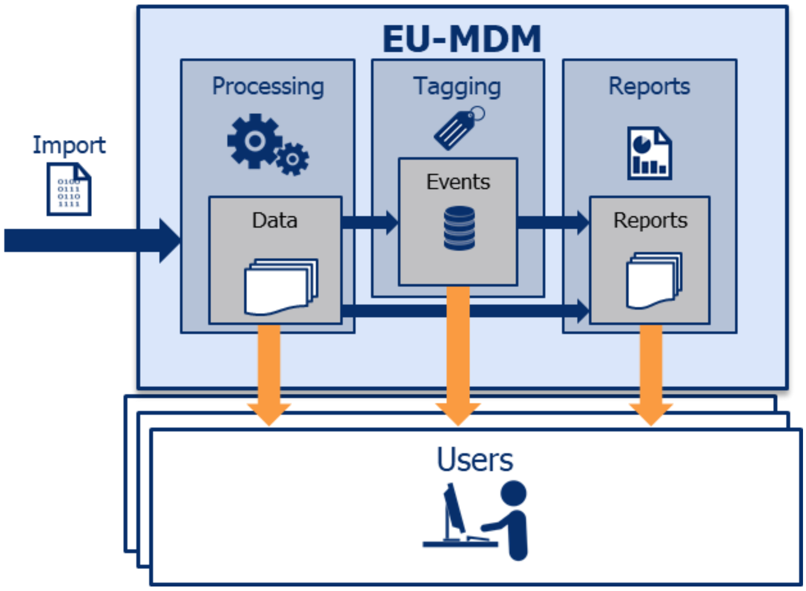

Figure 4: Function scheme of EU-MDM

2.3 Measuring campaign

Considering constant wood qualities and status of the mills, the effects of the following parameters have been assessed during the campaign:

- mill load
- classifier speed
- ash injection
- primary air flow.

Twelve tests were specified for this measuring campaign. Each test got a name and the corresponding set of parameters as summarized in Table 1.

Test	Mill load [%]	Classifier speed [rpm]	Ash injection	Primary air flow [Nm³]	Date	Time period
M40V1	100	20	on	default	29.01.2019	09:30 - 11:30
M40V2	100	20	off	default	30.01.2019	09:30 - 11:00
M40EU1	100	20	on	incr. 1 Nm³	29.01.2019	15:50 - 17:16
M40V3	100	~20	on	default	30.01.2019	12:45 - 14:45
M40EU5	80	20	on	default	31.01.2019	15:40 - 16:30
M40V4	66	20	on	default	30.01.2019	16:00 - 17:30
M40EU3	66	~20	on	default	31.01.2019	11:30 - 12:55
M40EU4	66	20	on	incr. 1 Nm³	31.01.2019	13:15 - 14:15
M40V5	66	35	on	default	31.01.2019	09:20 - 10:40
M40EU2	66	20	on	default	29.01.2019	18:33 - 19:05
M40EU6	100	20	on	default	31.01.2019	17:05 -18:35
M40EU7	66	20	on	default	31.01.2019	18:55 -19:20

Table 1: Tests parameters

3 RESULTS

Each performed test (Table 1) have been performed with all their process parameters at a stable and constant condition. Enough transient and stabilization time needed to step from one condition to the next have been considered. Using data fusion algorithms within EU-MDM, all following pipe specific mass flow signals are validated signals.

The time series data of signals of varied test parameters are shown in Figure 5. The ECF system was able to measure the mass flow of wood in the pipelines within acceptable deviation and the test results in different time frames, parameters and pipelines do not have exceptionally high differences regarding the pipe-to-pipe distribution of mass flow.

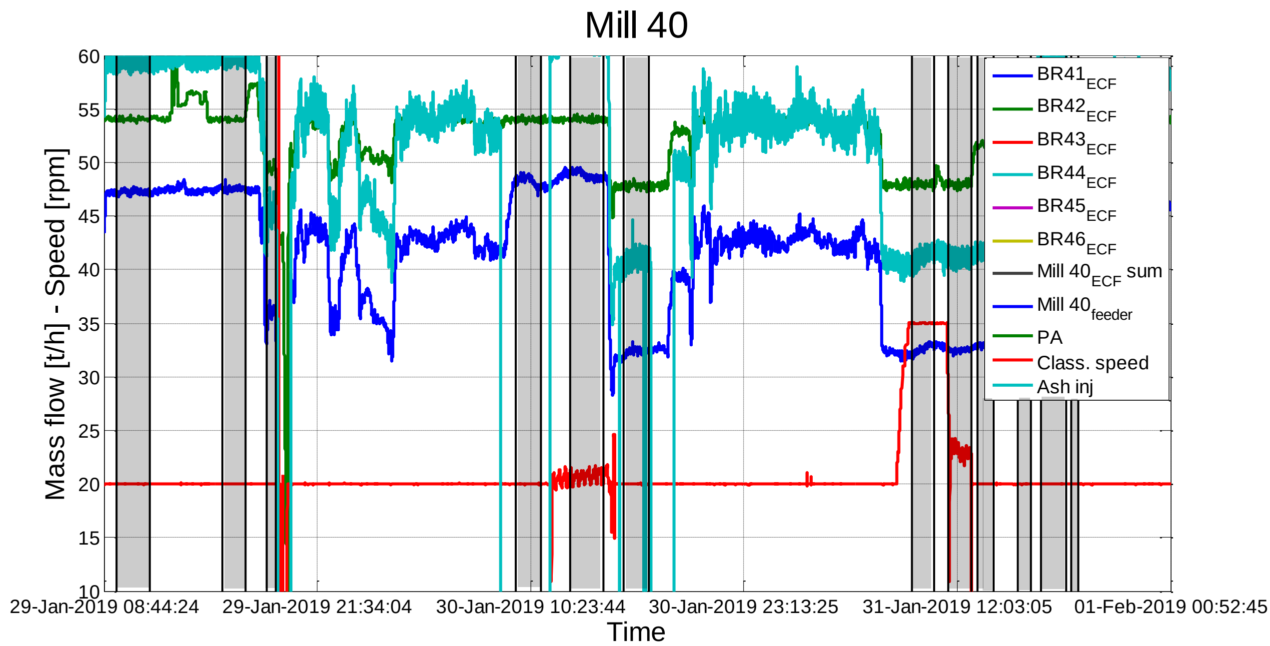

Figure 5: Time series data of varied parameters during measurement campaign

One fact that draws attention is the recognition of flow concentration in certain parts of the pipeline, especially in the pipe BR42. The curvature, that lead to the measuring cross section, is significant for pipes BR42 and BR45. Similar effects can be seen in pipes BR43 and BR46 in comparison of test M40EU6 and M40EU7, as shown in Figure 6 and Figure 7. The assessment of this local information is possible due to the usage of multiple ECF sensors applied to the PF pipes (Figure 2). This result shows, that flow conditions in the pipes are significantly changing with change of power plant load.

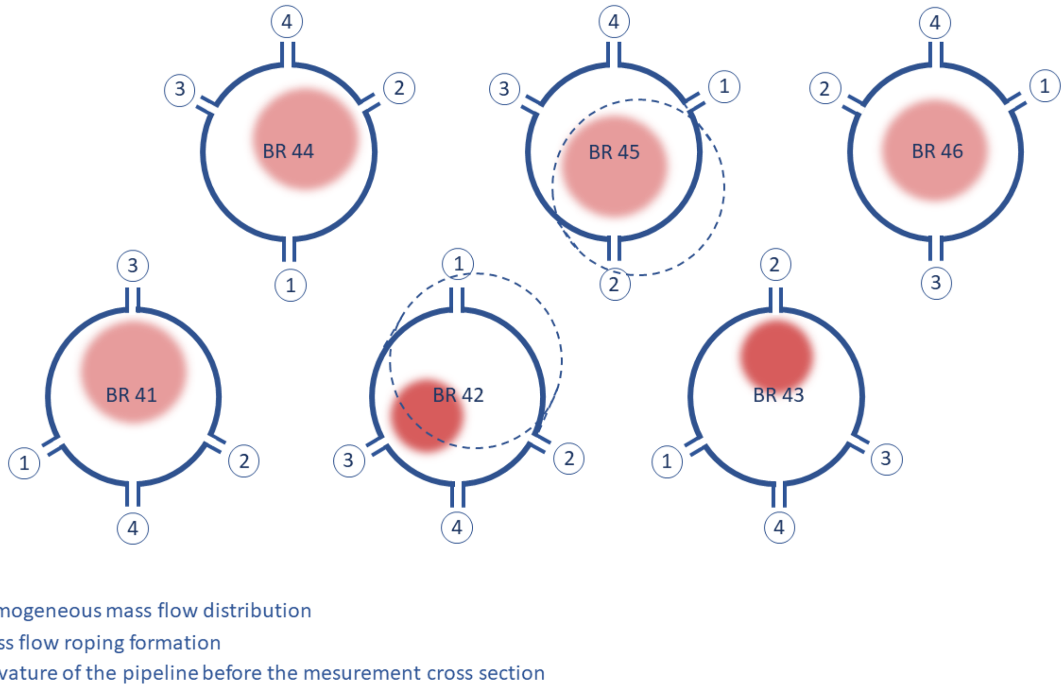

Figure 6: Qualitative representation of mass flow distribution at the pipeline's cross section for M40EU6

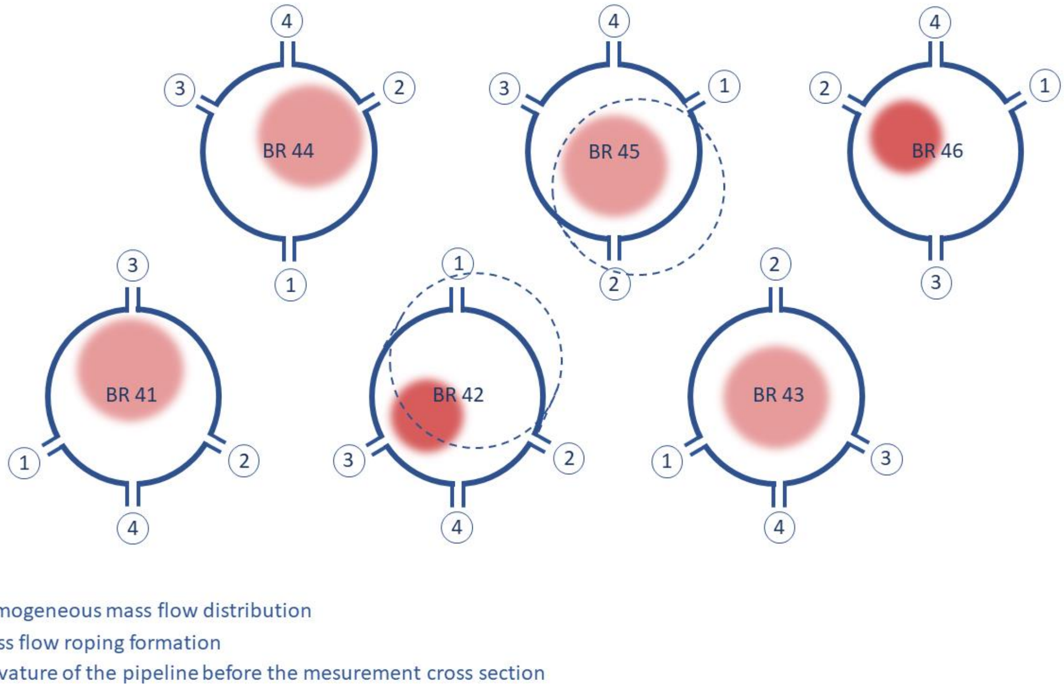

Figure 7: Qualitative representation of mass flow distribution at the pipeline's cross section for M40EU7

3.1 WOOD MASS FLOW

The EUcoalflow system allows online measurement of wood mass flows for all six burner pipes at the same time. With the help of online signals, the fuel flows and the pipe-to-pipe distribution can be directly monitored on site and thus easily investigated at any operation condition.

The wood mass flow at the six burner pipes at the mill reveals a noticeable imbalance and dynamic variations for some specific operation conditions. Imbalances cause high deviation from the desired air-fuel ratio causing losses in efficiency and increase of emissions.

Figure 8 shows the wood mass flows in each single PF pipe as well as for the complete mill at all the different operation conditions investigated (i.e. mill load, classifier speed, primary air flow and ash injection). It can be recognized, that deviations in signal levels as well as differences of mass flows distributions of the single pipes (BR41-BR46) are mainly due to load changes.

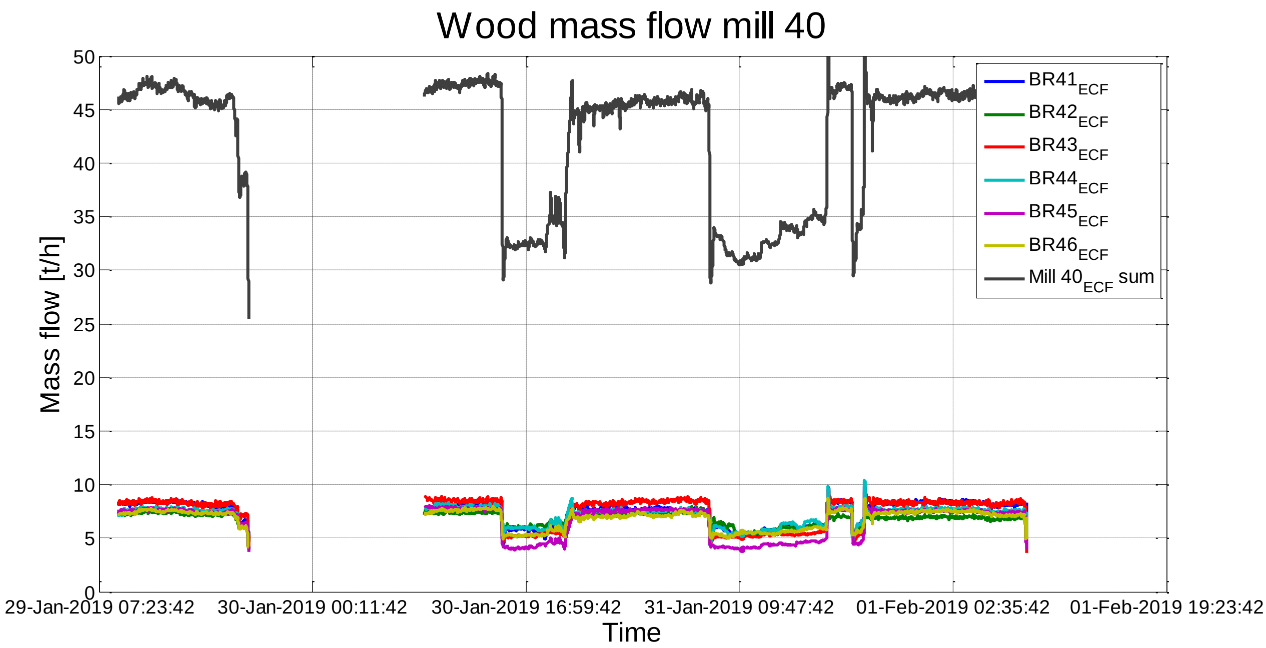

Figure 8: Single pipe and total mill mass flow over the complete measurement campaign

3.2 WOOD FLOW BALANCE

With respect to the main impact of mill load on the test results. The following figures are classified by mill load parameter during the tests.

Figure 9 displays the average mass flow values for each pipe (BR41 – BR46) during the test time for all the tests with a mill load set point of 100% mill load. Since parameter variations during test M40V3 failed and M40EU6 is a validation test with same parameters as M40V1, these tests show the same mass flow distribution, as expected. Quite good results regarding balance deviations can be seen in the outcome of test M40EU1 (enhanced primary air flow) and M40V2 (ash injection is switched off). Figure 10 shows the deviation from mean values over all pipes (BR41 – BR46), regarding the specific test time ranges. In both figures, a clear pattern difference between BR41-BR43 and BR44-BR46 is visible.

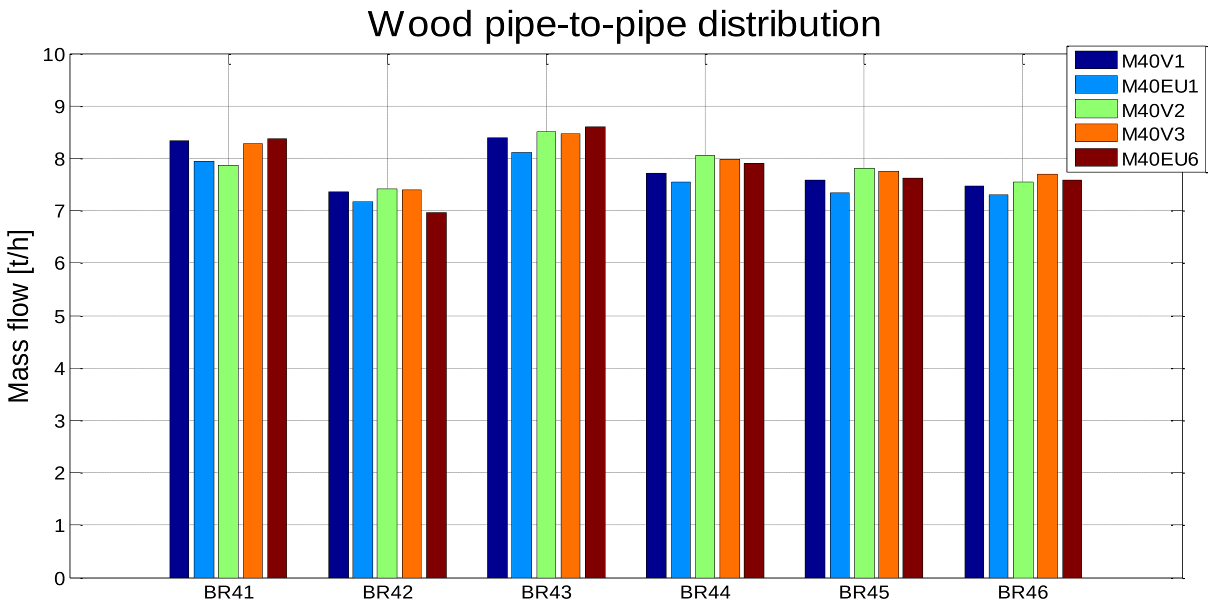

Figure 9: Wood mass flow distribution at 100% load

Except for test M40EU6 the wood flow shows a pipe-to-pipe relative deviation within ±7% (cf. Figure 10). These values are in line with best practice standards (even for coal operation) for optimal combustion that define a fuel line flow balance within ±10% deviation from the mean or better.

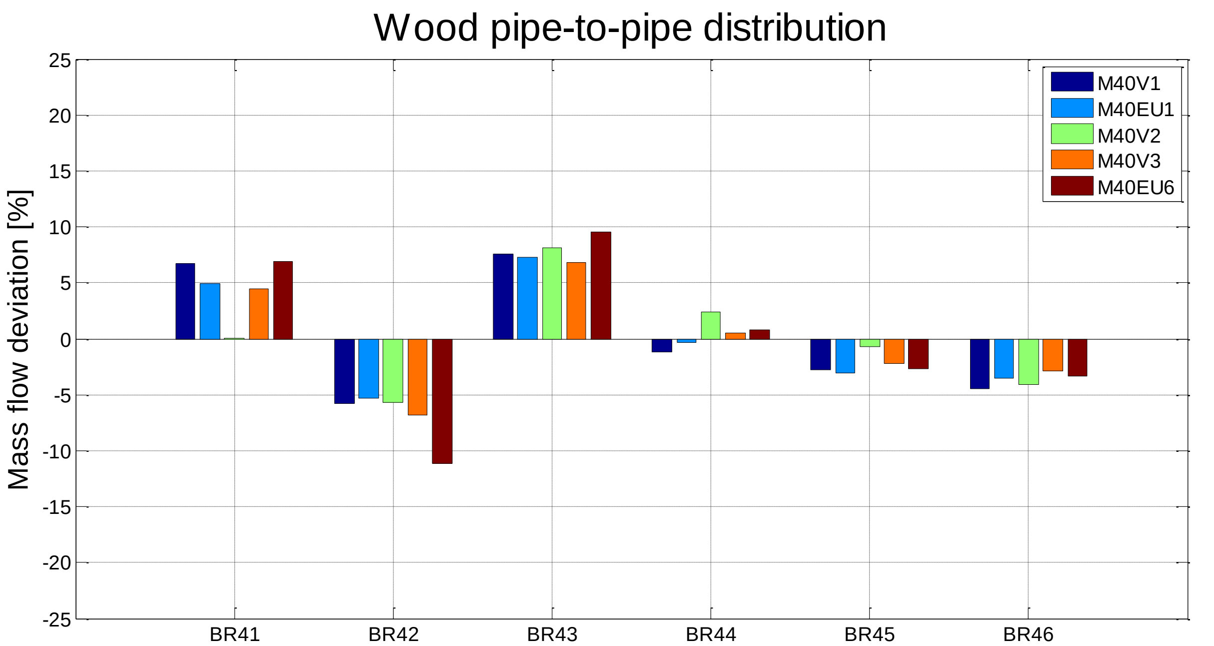

Figure 10: Relative pipe-to-pipe wood mass flow distribution at 100% load

At a mill load with set point of 80% and 60%, a side change of the mass flow distribution pattern is conspicuous, as mass flow of BR41 to BR43 is constantly decreasing instead of BR43 to BR46, as visible in Figure 11. Furthermore, compared to mill load set point 100%, the relative mass flow deviation between the pipes increased to up to ±20% at mill load 80% and about ±20% at mill load 66% due to the high deviation at PF pipe BR45 (see Figure 12). Observations of changing flow condition in the pipes (Figure 6, Figure 7) suit the change of mass flow distribution pattern and may reason the increasing deviation with lower mill load.

By comparing tests M40V4 and the validation M40EU7 against M40V5, where classifier speed is increased from 20 to 35 rpm, it can be seen, that it is possible to counteract against imbalances at lower mill loads by applying appropriate control strategies.

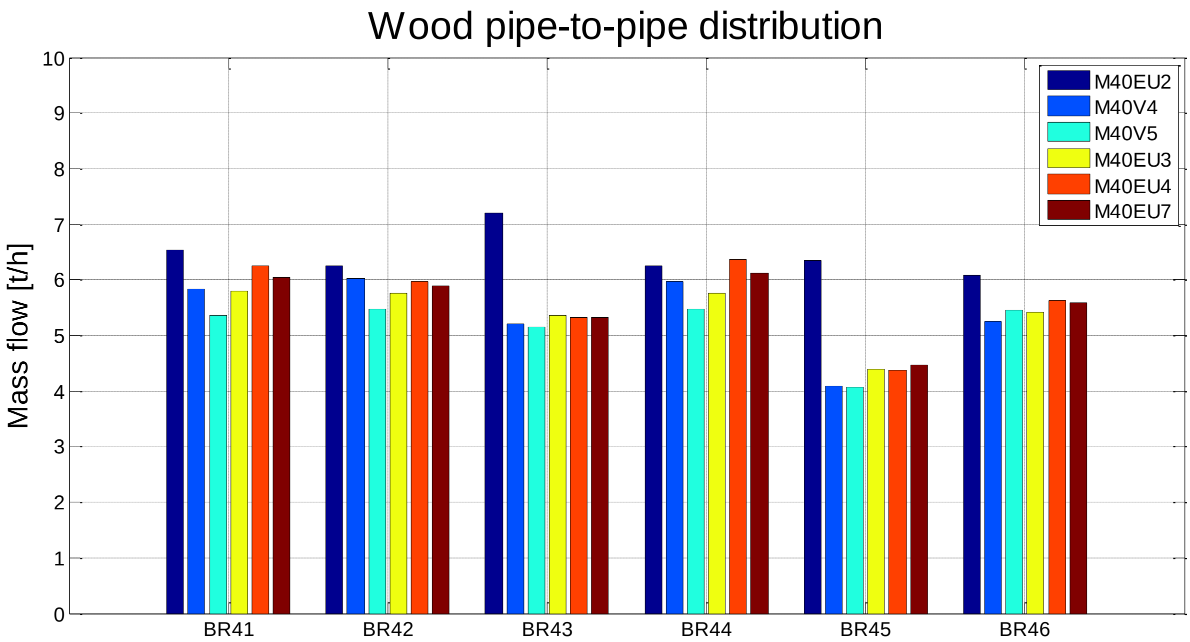

Figure 11: Wood mass flow distribution at 66% load

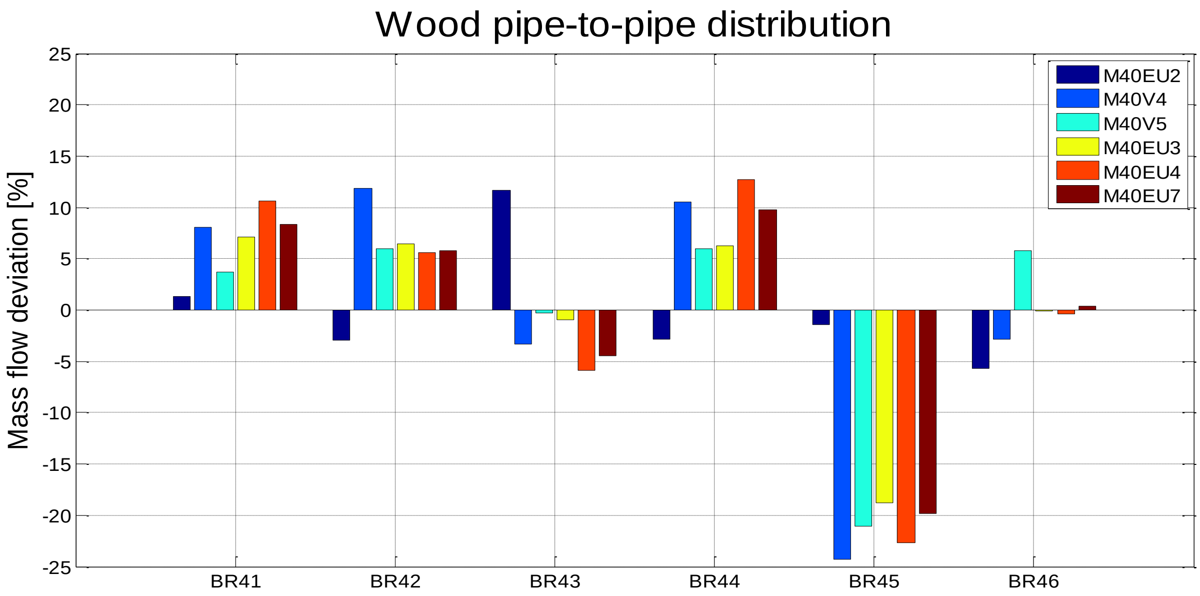

Figure 12: Relative pipe-to-pipe wood mass flow distribution at 66% load

3.3 DYNAMIC BEHAVIOR

The high sensitivity of the ECF sensors allows continuous monitoring of the dynamic flow in each pipe. Figure 13 shows short-term release or shortage of fuel due to load changes. A characteristic, which is not always possible to find in the DCS feeder data. During steady-state load condition, the sum of ECF signals of the six single PF-pipes correlate very well with the feeder signal.

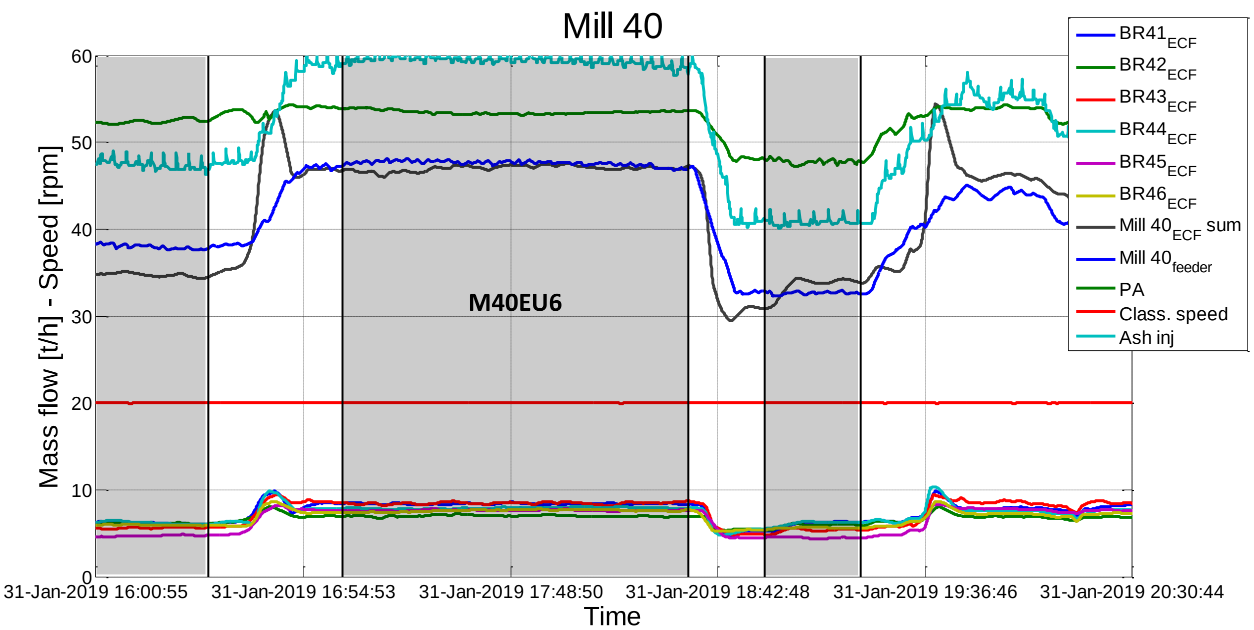

Figure 13: Dynamic mass flow and pipe-to-pipe distribution behaviors at different loads and during transient phases (load changes: from 80% to 100% and back to 66%)

3.4 MEASUREMENT ACCURACY & VALIDATION

High measurement accuracy as well as the capability to represent absolute values are fundamental requirements for the proper usage of an on-line mass flow measurement system. The EUcoalflow system has demonstrated these capabilities during the complete measurement campaign, also in comparison to the coal feeder signals, as depicted in Figure 14. The ECF sum signal correlates well with the feeder signal. Additionally, the system allows to assess and analyze the coal flow in each single pipe at the same time.

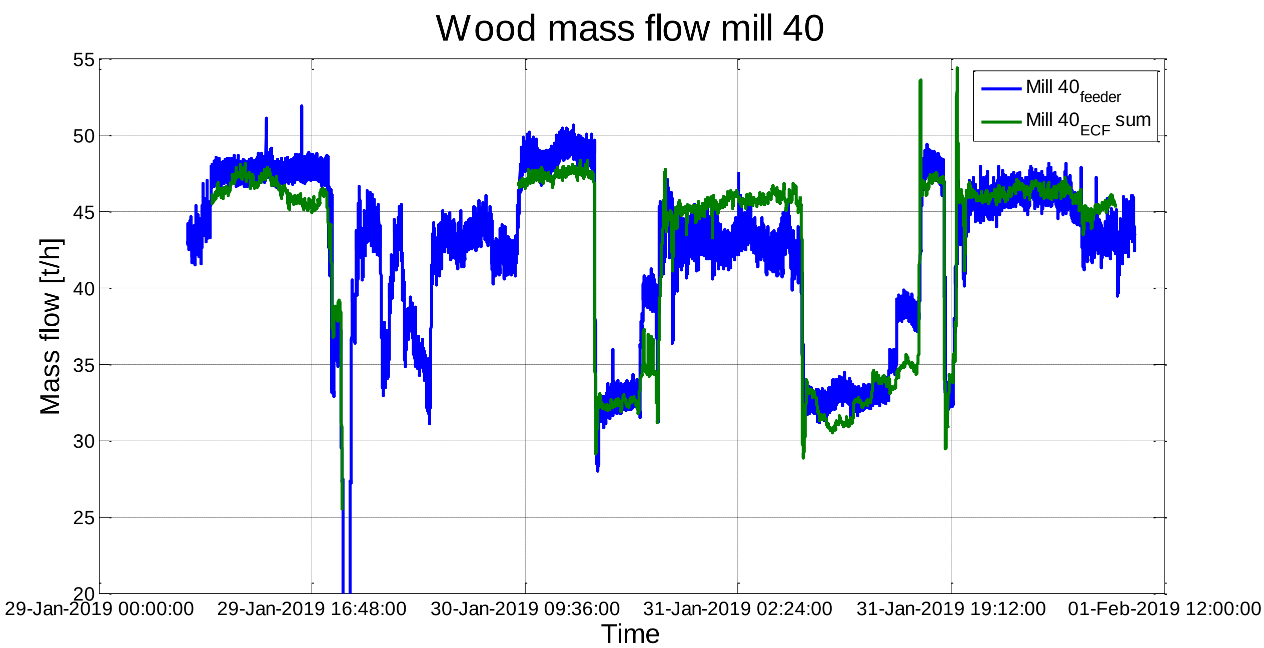

Figure 14: Fuel mass flow of feeder and sum of EUcoalflow single pipe measurement

Comparing the pipe specific mass flow data, acquired during isokinetic sampling in the tests M40V1, M40V2, M40V3, M40V4, M40V5 with the results of the simultaneous conducted ECF online measurements, an overall absolute deviation, regarding relative pipe-to-pipe mass flow deviation, of up to 8 % can be calculated.

Especially when pipe-to-pipe mass flow differences are high (66% load, M40V5), both measurement principles show similar mass flow patterns (Figure 15).

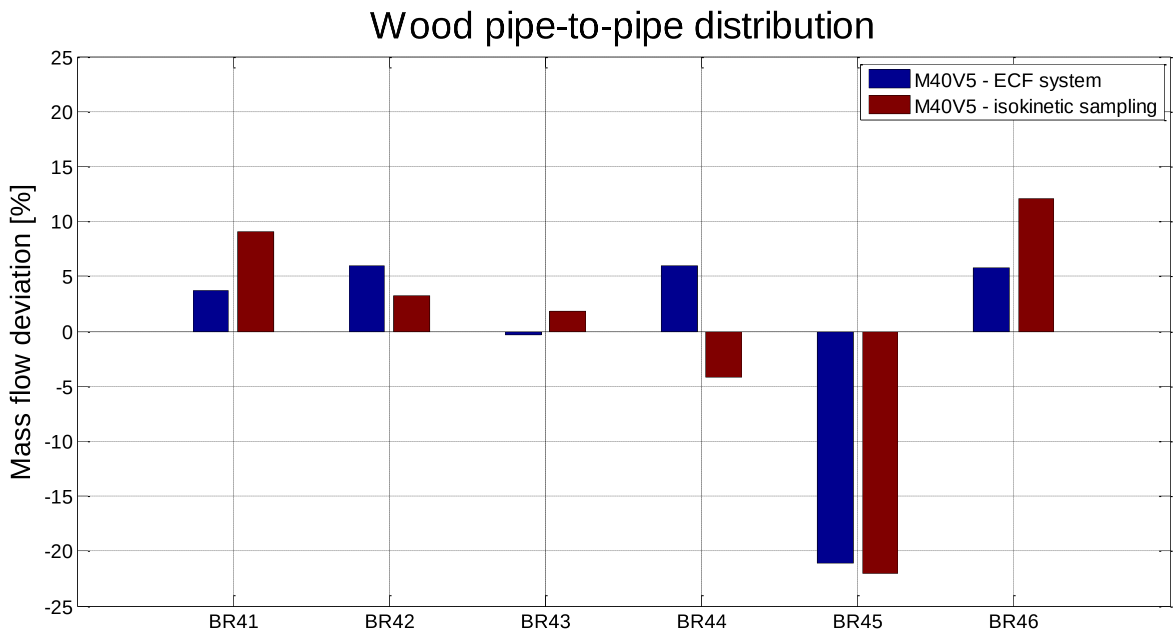

Figure 15: Comparison between relative pipe-to-pipe mass flow distribution, resulting from isokinetic suction and ECF system

In complex flow conditions, the online ECF measurements provided a clear picture of the behavior of all of the pipe mass flows at the same time, before, during and after the single measurements with isokinetic sampling. Due to this, systematic measurement errors can be avoided.

The amount of measurement data during the measurement campaign is enough to gain good statistical certainty. The ECF system showed capabilities to evaluate the measurement campaign itself.

4 SUMMARY AND OUTLOOK

The EUcoalflow (ECF) mobile system was successfully installed and commissioned to perform a measurement campaign at Strudstrup in Q1 2019. With the system in operation, the real-time fuel mass flow and distribution of all the six PF pipes at one mill, operating on wood pellets under different operating conditions, was shown. The findings can be summarized as follow:

- Measurement data at all the coal pipes are consistent and plausible
- The ECF system allowed direct monitor of wood mass flow and pipe-to-pipe distribution
- The ECF system provided stable and reproducible signals at all tested mill settings
- The results show a good correlation between EUcoalflow mass flow signals, feeder flow and isokinetic sampling

- The measurement results show a stable pipe-to-pipe distribution within ±7% at 100% mill load and different parameter settings
- At partial mill load (e.g. 66%) the results show pipe-to-pipe imbalances of wood flow of about ±20%The highest deviation has been measured for PF pipe BR45
- The high dynamic behavior of the ECF sensors allows direct detection of transient operating conditions
- The ECF allows detection of local flow phenomena within the pipes cross section (e.g. roping in BR42, BR43, BR46)
- Increased classifier speed could be identified as a possibility to counteract against the imbalances at lower mill loads

Enhancing online measurement systems with data management and analytics (EU-MDM), more useful information out of the data can be derived. Combined with continuous measurements, online SOH and overall performance of the underlying process and following condition based- or predictive maintenance of the related components (mill, etc.) can be implemented. Regarding this, EUtech experienced a necessity for early detection of evolving clogging in the PF pipes for biomass firing systems, to avoid larger damages due to pipe fire.

Furthermore, the highly reliable mass flow signals can be used for online optimization of the process. Control measures on the basis of online measured pipe-to-pipe imbalances or detected critical flow conditions (roping) can be continuously conducted. Furthermore, control system actions can be initiated for the case of the detection of faults.

5 References

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[2] Wiatros-Motyka, M.: Optimising fuel flow in pulverised coal and biomass fired boilers. In: IEA-CCC (2016).

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