# New Method for Controlling Combustion in a Grate Boiler

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**Abstract:** The control of disturbances due to fuel quality variation is important development area in the grate combustion technology. Main challenges in the control of the grate combustion are inhomogeneous fuel, variation in fuel moisture content, non-uniform distribution of fuel on the grate area and high percentage of combustibles in ash. Information on events which occur in the furnace plays an important role in controlling of the grate combustion process. As the direct indicators of the combustion efficiency are not usually available, efficiency estimation reveals an important and challenging problem.

In this article we propose a new measurement method to estimate combustion on the grate and consider aspects of its application. The purpose was to find regularities in the behaviour of the measurements and to analyse the reliability and the utilization of the measurements. The method is based on combining information obtained from the fuel bed pressure signals and the grate temperature measurement signals. Furthermore, besides information of the new measurements, the normal combustion measurements at the power plant were also taken into account. Online aspect of the new measurements receives special emphasis as the estimates of combustion efficiency should be available in real-time for the control purposes. The share of biomass (e.g forest residue and agro biomass) increases in the power plants due to their environmentally friendly and domestic character. It means that there will be a high importance to develop new effective methods to control the combustion process in the future.

The method was tested at a combined heat and power plant 17 $MW_{th}$ combusting spruce bark. The new measurements give useful information on combustion on the grate. Especially by studying the pressure difference it was possible to notice variation in fuel quality. Combustion and ignition front location could be estimated by analysing simultaneously both pressure difference and temperature measurements. Changes in fuel bed height and combustion rate in the outermost circles of the grate were easy to spot.

***Keywords:*** grate combustion, measurement, control

## 1. INTRODUCTION

The remote control of small scale power plants has become more common due to financial savings. The option tends to however cause problems since the conditions in the furnace cannot be observed visually. For instance the locations of either ignition or combustion zones on the grate are unknown for remote operators due to lack of measurements. Substantial savings in operation costs could be achieved if the remote control systems would work properly.

With grate boilers, over 90% of problems in combustion control consist of fuel quality fluctuations. Also jamming of fuel feed system causes problems especially with screw based systems. Obtaining the necessary amount of power from highly fluctuating low quality fuel is challenging. Problems are also reflected to the fact that the fuel feed controller does not always work optimally due to the lack of information on accurate measurements of the fuel bed. Because the control system is a typical integrated system, the majority of problems affecting the air feed are also reflected in the fuel feed.

With wood-based fuels, fuel quality correlates strongly with its moisture content. These moisture variations could be easily measured with a reliable online measurement system. There are several different methods for moisture content measurement, but unfortunately, investment price restricts their use in large-scale boilers (<100MW). In addition, uneven fuel flow, frozen fuel in winter, the calibration requirements and delays, set specific requirements for the system. (Ruusunen 2008)

The objective of this study was to test and analyse a new measurement method for a grate of a full scale power plant. The fuel bed pressure difference and grate temperature measurements were installed in the boiler to test their usability, reliability and durability. Besides information obtained with new measurements, information from the existing measurements was also utilised in the analyses of the combustion process.

## 2. METHOD DESCRIPTION

### *2.1. Test environment*

The measurement method was tested at a grate fired power plant producing 2.9 $MW_e$ electricity and 13.7 $MW_{th}$ heat. The live steam values for the boiler are 450 $^0$C and 50 bar. Object boiler is based on BioGrate technology which allows combustion of biomass with high moisture content. The main fuel is spruce bark with moisture content between 35 - 65%. If the moisture content is higher than 65%, sawdust can be added to make the combustion process more stable and efficient. Biopower flow chart is presented in Fig. 1 showing the main components of the boiler plant (MW Power, 2010).

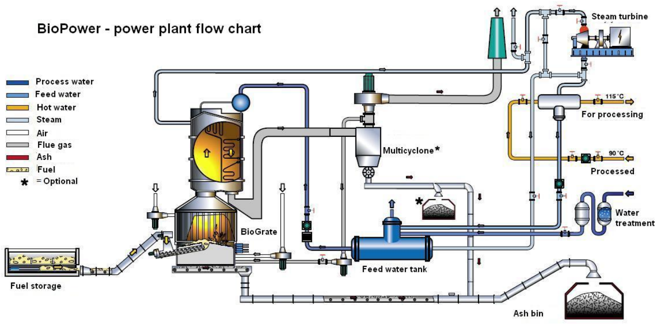


*Fig. 1. Flow chart of Biopower plant (*MW Power, 2010*).*

*Fig. 2. BioGrate - Grate firing boiler (*Wärtsilä, 2010*).*

BioGrate is a mechanical underfeeding grate, meaning that the fuel is fed from below the grate by a screw conveyor to the middle of the grate. The grate consists of circular rings, half of which are fixed and the other half is moved by a hydraulic system following a circular motion. With this slow rotating movement the fuel spreads evenly on the grate and moves forward. Fig. 2 shows the structure of BioGrate furnace. Stoker screw is on the right side, primary air is fed through the blue pipes (Wärtsilä, 2010).

The fuel dries in the beginning of the grate by the effect of heat radiation from the flames and refractory lining bricks. After drying, the pyrolysis and combustion of pyrolysis gases begin. The last zone is for combustion of carbon residue. After the combustion of residual carbon is completed, ashes fall from the edge of the grate to an ash basin filled with quenching water (MW Power, 2010). Fig. 3 shows a cross-section from the structure of BioGrate and the combustion zones.

With BioGrate boiler the ignition is assumed to take place near the grate surface. This is a result of fuel high moisture content and heat radiation from the hot grate. This way the combustion front propagates from down to up and as reaching the surface of the fuel bed, the next wave of combustion propagates from top to down. However, information from previously illustrated behaviour is uncertain for example due to the fact that primary air is not pre-heated and cools the fuel bed (Bin et al. 2005, Elliot 1989, Raiko 1995).

The air feed is divided into two phases: primary and secondary air. Primary air is fed from below through the grate, and secondary air is fed tangentially from above the grate and both of the air feeds are not pre-heated. Secondary air is fed tangentially to ensure as perfect mixture of combustion gases as possible. Primary air is divided into three zones; First zone is for drying, second zone for pyrolysis and third zone for combustion of carbon residue (Bin et al. 2005, MW Power 2010, Elliot 1989, Raiko 1995).

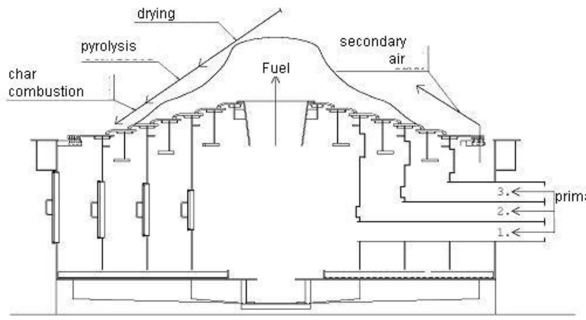


*Fig. 3. Cross-section of BioGrate and combustion zones* (Laitinen 2010).

### *2.2. The new measurements*

Six temperature sensors and eight pressure sensors were installed under the grate. Figure 4 illustrate the location of the sensors: green dots represent pressure sensors and red dots represent temperature sensors. The reference pressure sensor is located in the furnace.

The purpose of the grate temperature sensors was to locate the combustion zones on the grate by measuring the grate temperature. A direct measurement of the fuel is very difficult because the sensors located on the bed are deteriorated. In addition, the sensors interfere with both primary air flow and fuel flow on the grate and, preventing access to receive valid results. Single point measurements of the fuel can only indicate the temperature of a very limited area of the fuel bed. The temperature of the grate irons provides information from a wider area and also filters the fastest temperature variations. Measurements can be affected because of primary air cooling or warming effect. In the studied case, the cooling effect, because the primary air is not preheated. On the other hand, the grate is not water-cooled, so this does not interfere with the measurements.

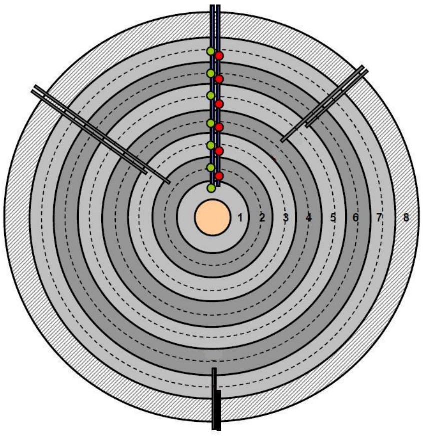


*Fig. 4. Location of the new measurements on the grate.*

The temperature measurement of grate sections have been previously tested in several types of grate-fired boilers, however, there is no current control system that can use this information. Measurements are performed with thermocouples, the only suitable measurement sensors, given the relatively high temperature values that the grate can reach. Thermoelements are also relatively inexpensive and they provide sufficiently accurate results in connection with the needs.

The pressure difference over the grate and fuel bed depends on the primary air flow, thickness of the fuel bed and structure of the grate. Estimation for the fuel bed thickness by following pressure difference and gas flow through the bed (primary air + circulating flue gas) on different sections of grate can be done after pressure difference over the grate is known. The problems for this method consist of primary air staging and variation of fuel particle size. However, the method gives information on the fuel bed density and thickness.

## 3. RESULTS

Process data with sampling rate 45 seconds was collected during a period six months and was analysed by using Matlab. The purpose was to find regularities in measured parameters. Some of the abnormal situations were written down by the operator, which helped considerably the analysis and gave confirmation for certain types of events.

If the pressure difference increases when the air feed is constant, fuel bed thickness or density increases. This, in turn means that, the temperature of the grate decreases because the insulating layer on the grate increases. In normal operating conditions of the boiler, the temperature is ~400 °C in the inner circles of the grate and pressure difference ~300 Pa (Fig. 5). The middle chart in Fig. 5 presents a situation after the fuel moisture content is increased. The temperature is lower and pressure drop higher than in normal conditions. However, here the moisture content is still almost the same and it does not have an important effect on the combustion. Power rate is still easy to maintain. In the lowest chart the fuel moisture content is higher than in other charts. The difference in moisture content is still not very significant; nevertheless, it is easy to spot the behaviour of the grate temperature. The temperature on the inner circles decreases and fuel bed is thick on circles eight and ten, fact easily perceived in the pressure difference. Despite this situation, the full power rate remains unaffected. These figures give valuable information about the measurement behaviour and as it is illustrated, some smaller variations in fuel quality are possible to spot.

If the velocity of the primary air becomes exceedingly great, primary air can pierce holes through the fuel bed and, therefore, cause escape of the combustion air directly to furnace. This causes increase to flue gas $O_2$ content and affect back to fuel feed. This is possible to observe by means of the new measurements and, in order to avoid such situations, fuel feed and movement of grates should be corrected. Fig. 6 presents a situation in which the fuel bed resistance is high and primary air can make holes through the bed. This has occurred during remote use of the power plant because no visual information was available from the furnace. As a result, the grate was full of fuel thus providing possibilities for many problems.

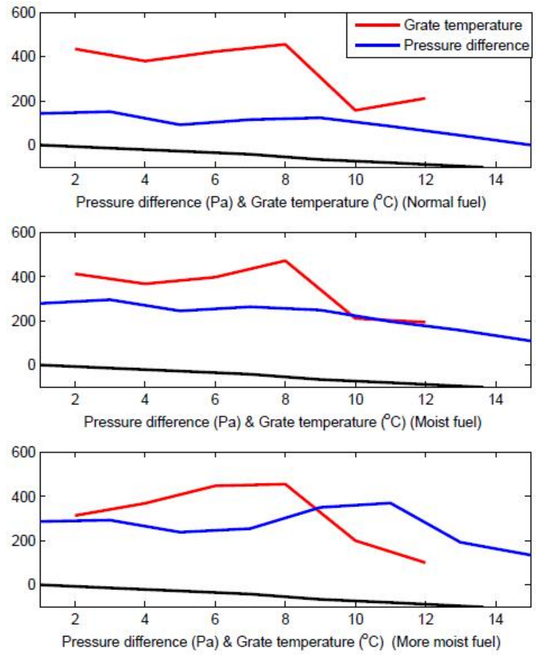


*Fig. 5. Fuel bed pressure difference and grate temperature with normal, moist and very moist fuel, respectively*

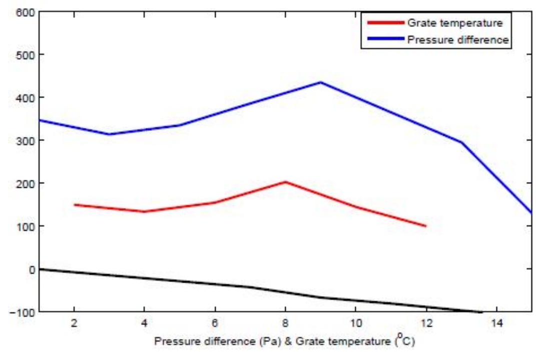


*Fig. 6. Fuel bed pressure difference and grate temperature when fuel bed is very thick.*

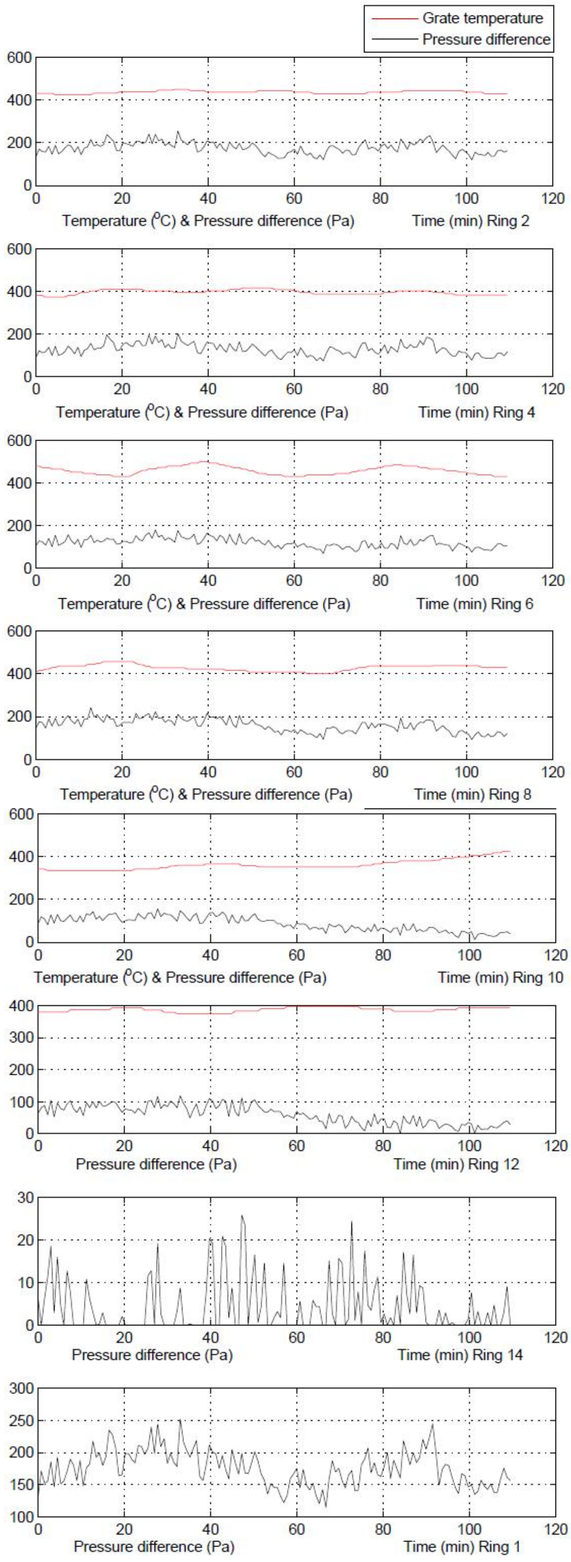


*Fig. 7. Grate temperatures and pressure drop over grate and bed when outer circles are empty.*

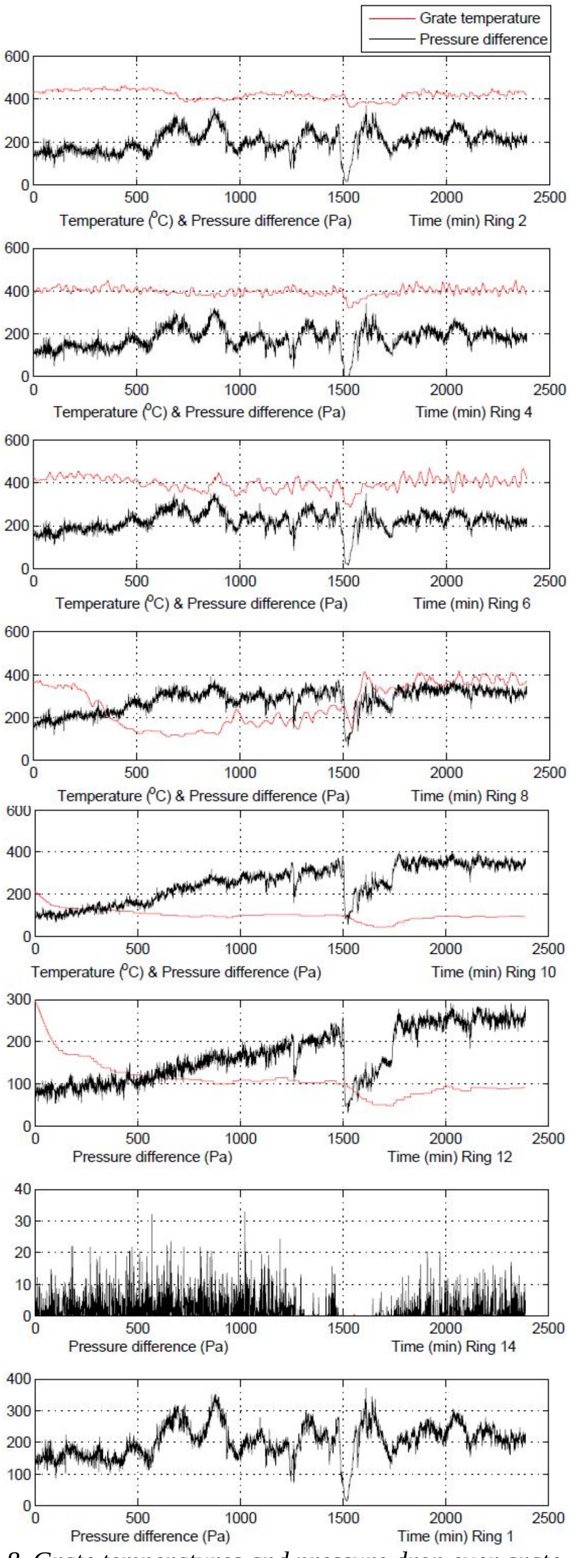


*Fig. 8. Grate temperatures and pressure drop over grate and bed when outer circles are full.*

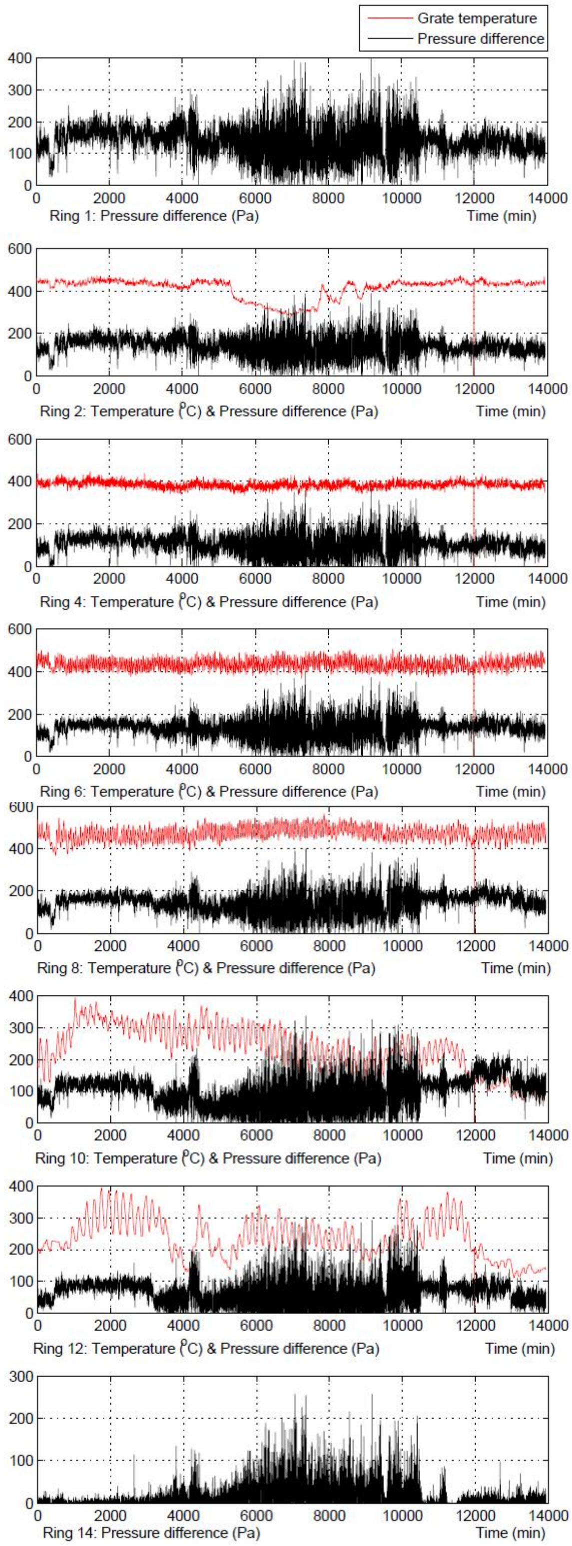


*Fig. 9. New measurements behaviour with very wet fuel (4500 min and 10500 min).*

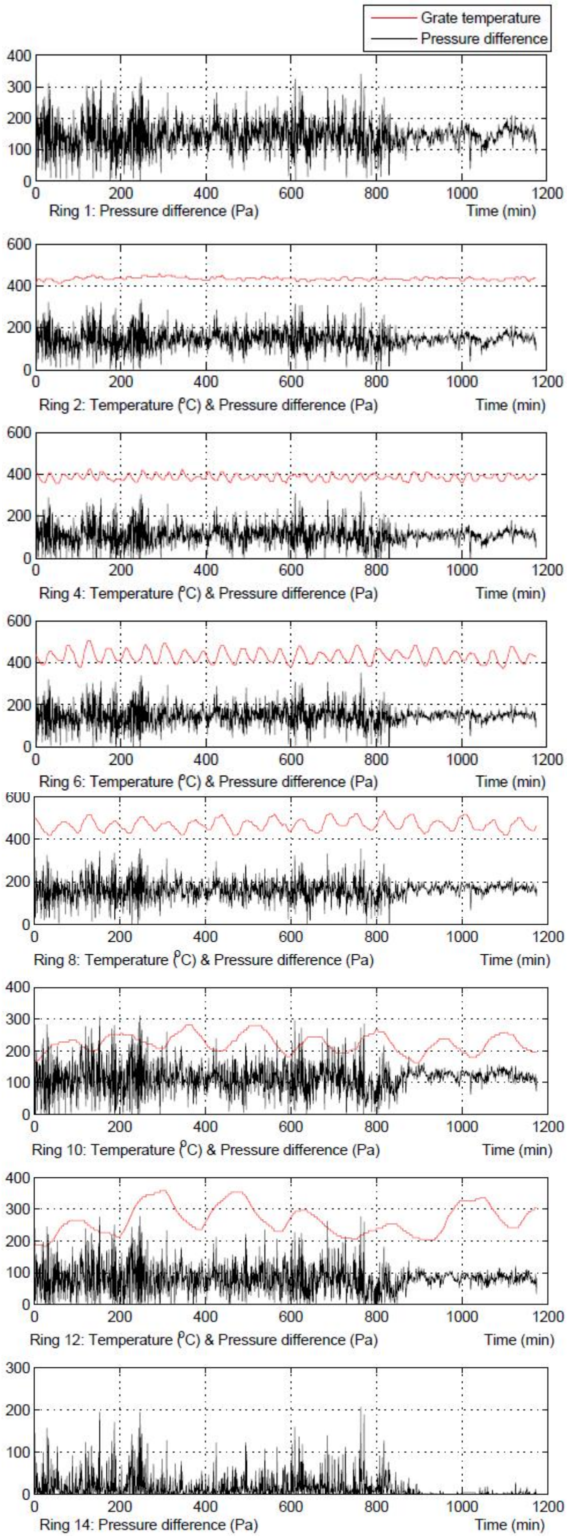


*Fig. 10. Cyclic temperature variation on grate shown by the temperature measurements.*

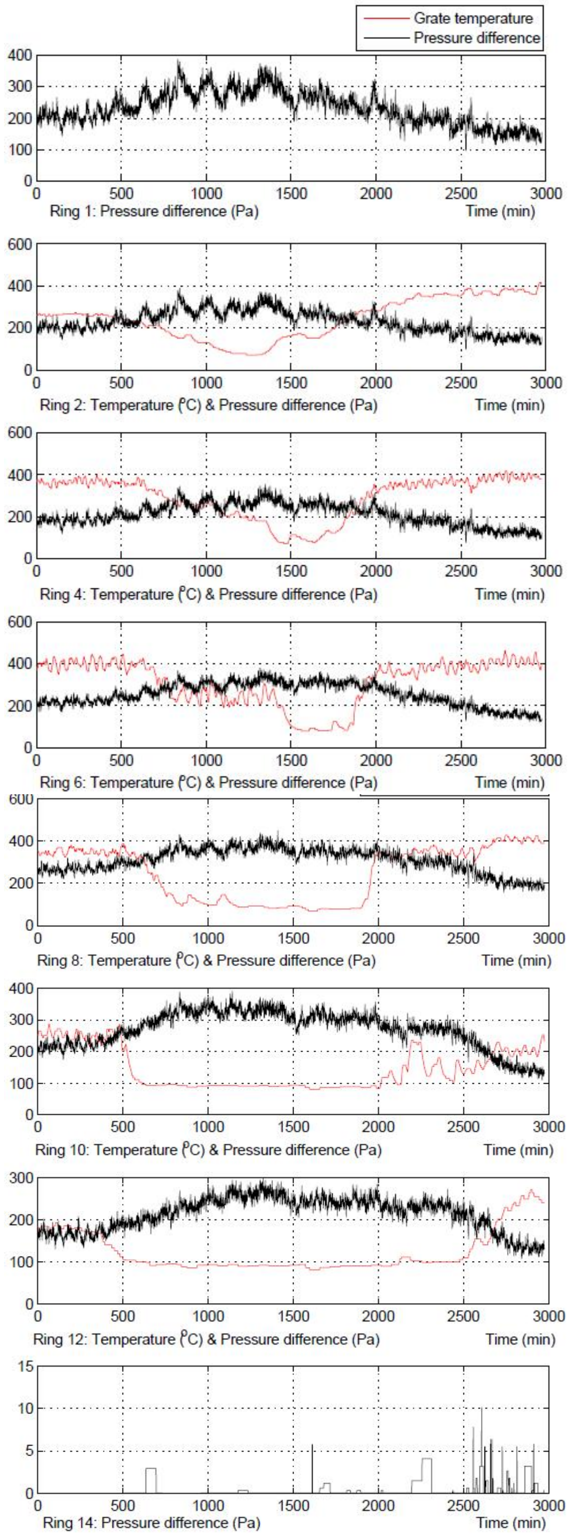


*Fig. 11. Primary air pressure difference relation with grate temperature measurements.*

Fig. 7 presents a situation in which the outer circles of the grate are almost empty. Images also show that values of the pressure difference measurements decrease, but as moving from the inner to outer circles, pressure difference drop is more radical on the outer circles. This event often intensifies as the fuel moisture content changes from high to low, when the combustion rate increases. If both inner circles temperature and furnace temperature increase, the situation may be analysed because it can indicate the location of empty spots on the grate. However, the furnace temperature does not necessarily rise if the primary air bypasses the grate without participating in the combustion and cools the furnace. Nevertheless, if the primary air pressure difference reflects a more severe reduction of fuel, combustion may be restricted by reducing the primary air. This situation arises when the moist fuel dries and begins to burn intensively.

On the contrary, a situation opposite to the above occurs, when the moist fuel blocks the grate, especially the outer circles (Fig. 8). Blocking of the grate is also perceptible in grate temperature measurements because the decrease in temperature is caused by the insulating property of the fuel bed. Such situations are repeated several times, especially with moist fuel.

There is a major problem area when the boiler is operated by remote access: situations in which operators feed excessive amount of fuel. This leads to many problem situations. The first problem is that combustion of moist fuel takes a long time, and if the feeding is excessive, at worst, the flames can be extinguished. If the fire does not extinguish, nevertheless, gaining full thermal output of the boiler is difficult. However, when this large amount of fuel dries and begins to burn, it is hard to control the combustion. Then combustion rate is restricted by reducing the amount of air feed, which causes additional emissions and fouling.

One purpose of the new measurements was to identify such situations and help to predict them before the amount of fed fuel is too big. It is easy to deduce from Fig. 8, when the amount of fuel on the outermost rings is high. However, detecting these situations before the fuel has already been fed in excess is difficult. The disturbance sensitivity of pressure difference is significantly higher compared to the new grate temperature measurements. Disturbances appear especially with partial loads, particularly in situations where the fuel moisture content increases rapidly. However, this sensitivity brings advantages, because disturbances caused by the fuel moisture variation provide information about fuel quality. Fig. 9 illustrates a situation (4500 min and 10500 min) in which the fuel changes from a normal to high moisture content.

Occasionally it was possible to detect certain types of cycles in grate temperature measurement. Fig. 10 shows that the cycles can last over 200 minutes in the outer part grate rings, while the corresponding cycles in the inner part of the grate last under 50 minutes. This kind of behaviour causes stress in the grate structure and can cause cracks in the grate. The main reason for large fluctuations of the grate temperature is a thin fuel bed and fuel movements resulting from the rotating grate. One obvious reason for differences in temperature fluctuation times is difference of fuel moving rate between in the inner and outer part of grate rings. The fuel flowing rate is slower on the outer circles compared to inner circles for two reasons: 1. in radial direction fuel flow rate is higher because fuel flows throughout surface is smaller in the inner grate rings, 2. in the outer part of grate rings fuel mass flow has decreased because of more proceeded drying and pyrolysis of fuel. The strong cyclical behaviour of the outer rings is also a result of the furnace structure, because the heat radiated from the bricklayer is more intense in the outer circles than in inner ones. In this case, temperature fluctuations are also larger since the thick embedding stores and release the heat slowly.

The temperature decreases faster on the outer grate circles compared to inner circles due to greater grate surface area and partly combusted fuel which cause lower fuel bed height than in the inside grate circles (Fig. 11). The temperature also remains low for a longer period in outer circles. The rapid decreasing of temperature can be explained by saying that the outer circles insulating fuel layer has greater density and the fuel gathers on the outer circles. This gathering also explains the fact that the temperature remains low for a longer period.

Figures also reflect the fact that, by using exclusively the grate temperature measurements it would be really difficult to figure out what really happens on the grate. A differential pressure, however, provide the necessary information to confirm this issue.

The analysis of the new grate temperature measurements confirmed the fact that, together with primary air pressure difference, it is possible to have information about the combustion occurring on the grate without the need of looking into the furnace. It is also possible to detect the combustion zones and estimate the ignition timing. Since the temperature sensors were installed in grate irons, measurements are relatively slow and, therefore, larger disturbances are filtered automatically.

## 4. CONCLUSIONS

The task of the power plant is to generate a sufficient amount of steam in correct pressure and temperature for electricity and heat production. The operation of the plant is guided, monitored and controlled with an effective control system. Effective implementation and operation of the control system requires extensive knowledge of the process in advance. The purpose of this work was to give results and information of the new installed measurements of fuel bed pressure difference and grate temperature, and by this means develop boiler operation.

To achieve as smooth and efficient combustion as possible, control system must react fast enough to the fuel quality changes or other preventable disturbances that may occur. The fuel feed and secondary air controls are based partly on flue gas oxygen content and, therefore, the detection of a fluctuation of fuel quality and the boiler control occur with a delay. The purpose of the new measurement is to give this information faster and confirm some specific uncertain situations. The measurement of flue gas oxygen level is not a totally reliable indicator, because the concentration may increase or decrease for several reasons.

The new measurements consist of the installation of devices to measure the temperature of the grate structure and the pressure difference that indicates the differential pressure caused by the primary air flow, the grate structure and the fuel bed. Supplied primary air is divided on the grate very evenly, so the pressure difference reflects quite accurately the fuel bed behaviour. Disruptions like noise were relatively low with the temperature measurement, but the pressure difference measurements were rather vulnerable for disruption. This problem was solved by using a suitable filtering method to reduce the amount of noise in the measurements. However, during the analysis it was possible to notice that the noise gives information about the fuel moisture content so no hardware filtering was necessary.

Analysis showed that the new measurements provide a lot of useful information, most of which was quite reliable given its regularity. With the new measurements, it was possible to detect when the amount of fuel on the grate was not optimal.

New measurements also gave confirmation about changes in fuel moisture content as well as in other variations in fuel quality.

The first step in further studies could be to implement the trend line drawing for the plant automation system. The purpose of it is to give better visual information for the operator of the installed measurement sensors. Therefore, the verification of their validity is even more reliable. It is also possible to add alarm limits to the trend line, so that the operator is informed as soon as possible. The next step, therefore, is carrying out a testing procedure, which would consist of step testing. By this step testing it is possible to study how the boiler behaves with fuel that has specific moisture content. The functionality of the controllers should be studied more carefully; an accurate model would facilitate the analysis and provide opportunities to test fuzzy logic.

The next step after modelling is to construct a fuzzy logic system for the power plant. At the beginning, the purpose of fuzzy logic should be to support the operator by offering advices for certain situations. When the structure of this fuzzy logic system would be tested and found to be functional, it would be possible to attach this system to be a part of automation system and, by this means, to control the boiler automatically. The idea of fuzzy logic in this case is to pay attention to the new measurement and by this way provide guidance for how to control the fuel feed and combustion air feed. It could also give instructions for air distribution. This includes both the primary and secondary air ratio and primary air distribution on the grate.

As a final result of this study, it is noticed that the installation of similar measurement system for different grate-fired power plants is profitable and the amount of information compared to price is very high. Measurements give versatile information and are particularly useful for the power plant operator. By taking all the benefit of the new measurements, it would also be possible to build a new even more functional control structure, which would facilitate the remote use of the power plant and improve the operation in case of disruptions.


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