

## Preventing circulating fluidised bed agglomeration and deposition during biomass combustion

ŁUKASZ DUNAJSKI\*  
WOJCIECH KRUK  
WOJCIECH NOWAK

Department of Heating, Ventilation and Air Protection, Faculty of Environmental Engineering and Biotechnology, Częstochowa University of Technology, J.H. Dąbrowskiego 73, 42-200 Częstochowa, Poland

**Abstract** According to a fuel flexibility, fluidized bed boilers are considered as appropriate for biomass combustion as cofiring. But the burning of fuels such as forest and agricultural biomass raises a number of operational problems. Most important of these problems are bed agglomeration and deposition. Deposition appears when biomass contains significant amounts of alkali elements, such as sodium and potassium. The purpose of the work is to select a fuel additive to overcome these operational problems. Investigations were conducted in two stages at a pilot scale 0.1 MW<sub>th</sub> laboratory circulating fluidized bed reactor. As the fuel, the mixture of biomass contained forest residues, sunflower husks, straw and wood pellets from mixed woods was selected. In the first stage biomass was burnt without any additives, while in the second one the fuel was enriched with some additive. The additive (liquid mixture of chemicals) was added to the fuel in amounts of 1 dm<sup>3</sup> per 5–10 Mg of fuel. The following operational parameters were examined: temperature profiles along the height of the circulating fluidised bed column, pressure profiles, emissions. After the tests, the laboratory reactor was inspected inside. Its results enables expression of the following conclusions: there was no agglomeration during fuel additive testing, and the deposition was reduced as well. Moreover, the parts (heating surfaces, separator) of the laboratory reactor were coated with a protective layer. The layer covered microcracks and protected the parts from deposition for a long period after the operation.

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\*Corresponding Author. E-mail: lukasz@dunajski.com

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## 1 Introduction

Over the last few years, the global power industry set itself new challenges in achieving maximum of the efficiency, while taking care of the environment. Efforts are being made to the production of electricity, which uses renewable fuels (straw, wood, waste from agricultural production, etc.) as the greatest contribution. However, this trend brings unexpected difficulties in conducting continuous boiler. Many power plants are based largely on the boilers which were designed 10–15 years ago. The solutions used during their design and the construction processes, did not predict that the combustion will change to other kind than those they were designed for. This causes frequent complications associated with their proper work. In turn, the newly designed units prepared to burn multiple fuels, such as circulating fluidised bed (CFB) boilers, observed symptoms of erratic operation. Combustion of biomass more widely in several percent share, may cause fluctuations in the structure of ash, which in turn may result in stopping the boiler, due to the agglomeration of the fluidized bed. This phenomenon certainly contributes to lowering the efficiency of energy production. This is because in the biomass there are large amounts of sodium and potassium, which are released during combustion to fluidized bed, where it reacts with the quartz sand, which consists mainly of  $\text{SiO}_2$ . Softening temperature of this compound is 1996.15 K, and produces an eutectic mixture, which has a softening point 1420.15 and 1310.15 K respectively. While the time passes and the alkaline compounds are delivered to the fuel, local amount of agglomerates increases and it begins to interact with each other, forming agglomerates of substantial weight and size. This state of affairs is relevant to the correctness of circulating fluidized bed, and this is directly related to the efficiency of the boiler. Another factor, which influences the process of formation of agglomerates in the bed is the impact on large temperature gradient in the layer. This happens when the coat of fluid bed circulated improperly, the fuel related is not sufficiently mixed. Effect of fuel type on the distribution of temperature in the fluidized bed is shown in Fig. 1.

Power engineering companies search for an effective way of countering the negative aspects of the use of ‘green energy’. The result of presented papers is the awareness of the need for the biomass segregation and matching the proportion in this a way that the barrier of 250 mg/kg of alkaline

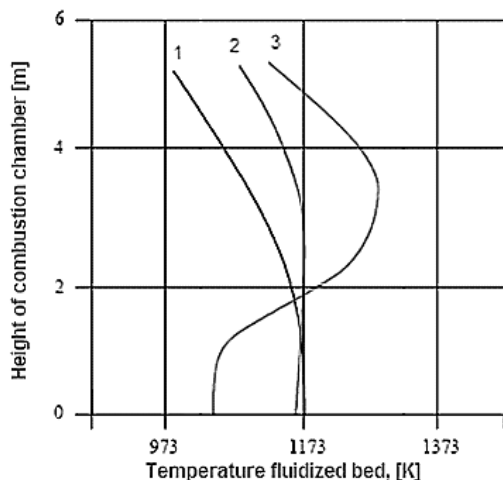


Figure 1. Effect of fuel type on the temperature distribution along the height of fluidized bed combustion: 1 – wood, 2 – brown coal, 3 – coal.

compounds in the dry mixture of fuel has not been exceeded. The major disadvantage of this solution is the availability of the fuel for these parameters, which remain balance the economic. Today the biomass market in Europe has a huge demand for raw materials, often customer expectations become too high, relative to production. This situation forces us to buy a biomass which is currently on the market, and does not meet certain parameters. Also, economic considerations weigh in favor of buying cheaper biomass, which directly translates into a deterioration in the quality and characteristics of combustion.

## 2 Experiment

There is another direction of improving the quality of biomass burning, i.e., chemical interference in the structure of ash, using an appropriate additive. An important advantage of this solution is the necessity of its application in continuous movement of the boiler, to observe its operation in real time. Usage of well-chosen product enables combustion of difficult fuel, without being exposed to unplanned boiler disconnection. The test described above on the real object, was conducted following to the series of experiments on a laboratory stand  $0.1 \text{ MW}_{\text{th}}$  with circulating fluidized bed. This is a modeling of CFB boiler (a position in a pilot-scale) of 6.25 m a column height

and 0.10 m of diameter of column. Inside, there is about 8 kg circulated fluidized bed composed of sand with a diameter of 0.1 mm. Fluidization layer provides air supplied under the grate, in an amount of 16 m<sup>3</sup>/h, and 3 m<sup>3</sup>/h with fuel. Schematic of the test stand is shown in Fig. 2.

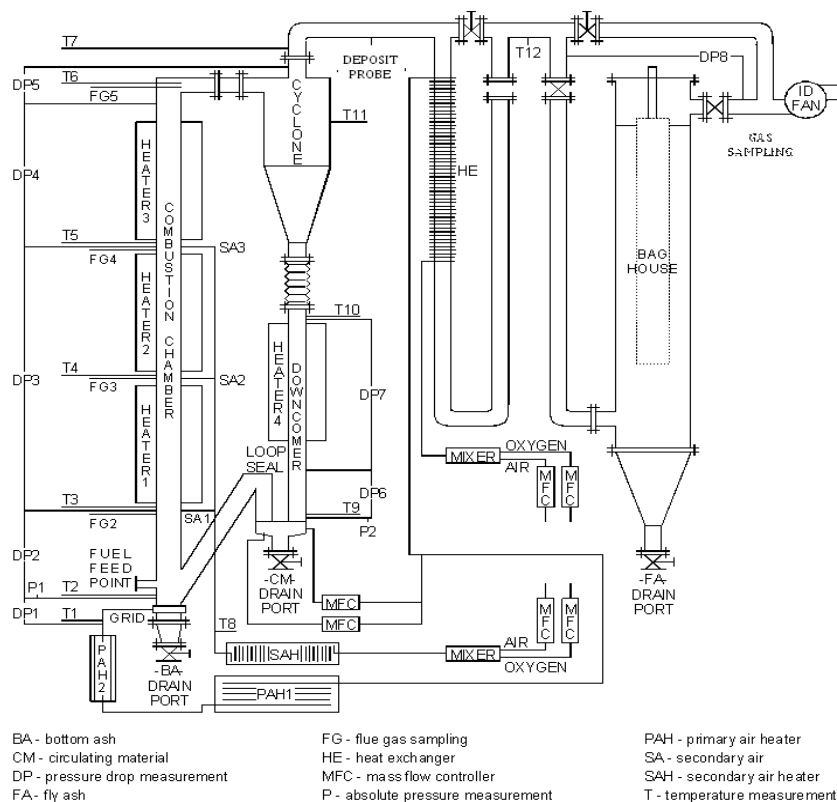


Figure 2. Scheme of laboratory position with circulating fluidized bed.

During the test cycle, which started at the initial phase, coal from PGE Turow Power Plant was burned. During the experiment, conducted for seven days, there were no fluctuations in the work stand, which indicates a fair reflection of the ratio with the actual CFB boiler. Therefore it was decided to change the research methodology in order to accelerate the processes in the combustion chamber, i.e., using only biomass as fuel. Such concept of research, helped to obtain deposits and agglomerates fluidized bed after seven days of work positions. The survey was conducted in two stages, without the use of the additive, and in the second stage with using

the additive preparation EKOSTABIL. At each stage position fuel mix consisting of 20% wood pellets and 80% sunflower husk was used to power the fuel mix. The first stage lasted 7 working days, during which the biomass burning was carried out in a 3-shift system, with minor interruptions of work positions for technical reasons. This was to simulate the process of formation of deposits in the boiler on a real scale. The second stage also lasted seven days, during which the fuel was treated with the addition of EKOSTABIL. This experience was to show cleaning of heating surfaces of the real object. In the second stage of the study, with an unchanged composition of fuel, additional preparation EKOSTABIL was given in quantity  $0.1 \text{ dm}^3$  on 5-10 Mg fuel. On the real object different proportions are being used, i.e., one liter of the preparation is added to the 10 tons of coal (fuel). The ratio was changed to the following reasons:

- Fuel composition of co-incinerating biomass boilers is not more than 10% of the biomass (Energy supplied on the basis of gross calorific value) the remaining 90% is lignite. Therefore, the concentration of elements has a negative impact on the boiler is also much lower.
- Realised accelerated test (it was not technically possible carry on the experiment for a month), therefore expected to accelerate clean surface so it was obtained by increasing the amount of the product, per unit mass of fuel. According to the scale, size and geometry there is usually a bit worse combustion efficiency (high CO) compensates for this by increasing the amount of additive.

## 3 Results

### 3.1 Changes of temperature

Figures 3a and 3b show the changes of temperature in the test stand, 0.29 and 5.38 m above the grate, during the two sessions of measurement. The data compiled in Figs. 3a and 3b show that both the first and second stage of the temperature was maintained at a similar level, characteristic of the boilers with circulating fluidized bed (1073.15–1123.15 K). First two hours of measurements are showing the process of warming up the position after the break at night.

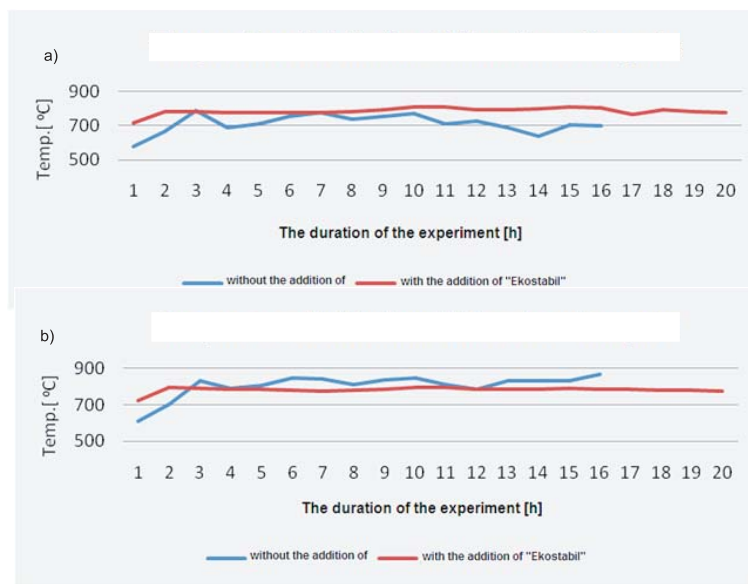


Figure 3. Temperature change during the two session, with and without EKOSTABIL, at the measuring point above the grate: a) 0.29 m, b) 5.38 m.

### 3.2 Changes of pressure and density of the fluidized bed relative to atmospheric pressure

Figures 4 show the pressure changes in the combustion chamber (column), during the two test sessions. Also in the case of registered pressure, despite the fact that they exhibit considerable fluctuations, it is clear that the process of combustion in the fluidized bed was carried out in similar conditions.

Figures 5 show the distributions of pressure in the tube precipitation. Also in the tube precipitation, especially at the height of 1.252 m above siphon the pressure distributions were similar during both phases of the study. Pressure at a height of 0.95 m are different, but their variations are within the scale of measurement error.

The average density of the fluid bed in individual sections of a fluidized column was calculated on the basis of these measurements. Densities are summarized in Figs. 6 and 7.

In plots a change in average density of the layer with the height of the column is seen. It is typical for circulating fluidized bed – diversification of a dense layer immediately above the grate and then going to the layer of low density at the top of the column. Density distribution shows the

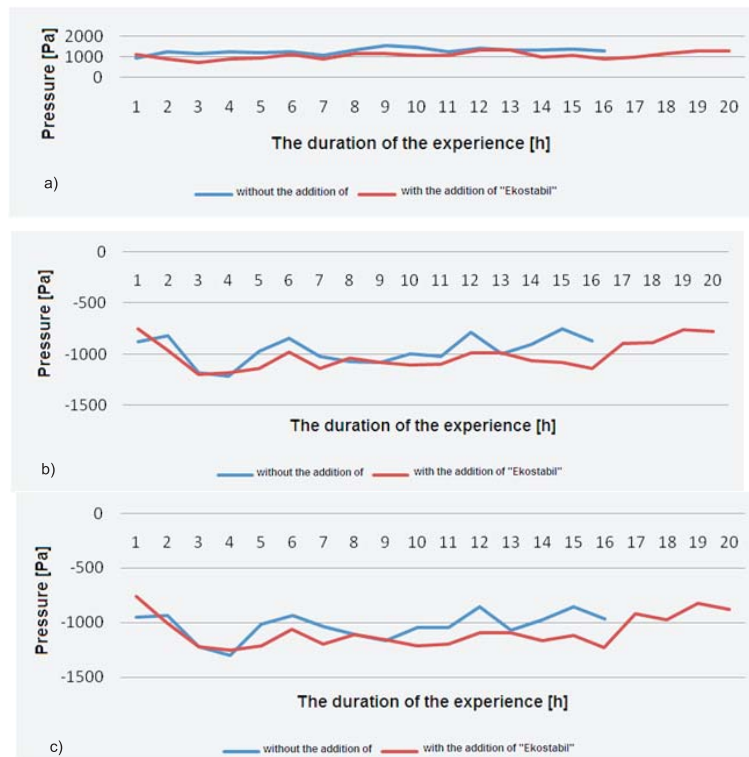


Figure 4. Pressure change in the column during the two runs, with and without EKOSTABIL, above the grate at a height of: a) 0.05 m, b) 2.55 m, c) 4.75 m .

proper conduct of the fluidization process. One may also notice that there are larger fluctuations in average density during the measurement session without the use of the additive. The observed differences can be explained in several ways, the first possible reason is better combustion of large quantities of volatiles, e.g., the combustion of biomass with EKOSTABIL. Another likely, also likely is the contamination of the separator, settled by deposits. It is expected that the separation process deteriorated, especially the small grains.

#### 4 Microscopic analysis of the material layer

After sampling fluid layer material, it was subjected to analysis with an optical microscope. Microscopic analysis of the circulating material show that the combustion of biomass, resulted in agglomeration of the bed material.



Figure 5. Pressure change in the pipe precipitation, during two measurement series, with and without EKOSTABIL, above the siphon: a) 1.25 m, b) 0.95 m.

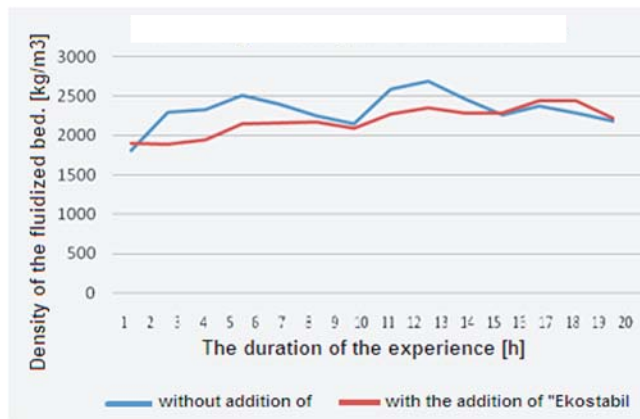


Figure 6. The average density of the fluidized bed, during the two runs with and without EKOSTABIL for the entire height of the column.

Figure 8 shows the resulting agglomerates at a x16 magnification.

Prior to the second stage of research the material fluidized bed has been replaced by a new one. Also in the second stage of tests, the samples were taken, but there was no agglomeration of the material. Note that the combustion process of biomass was carried out with less EKOSTABIL, however use of the additive is not conducive to allowing the agglomeration



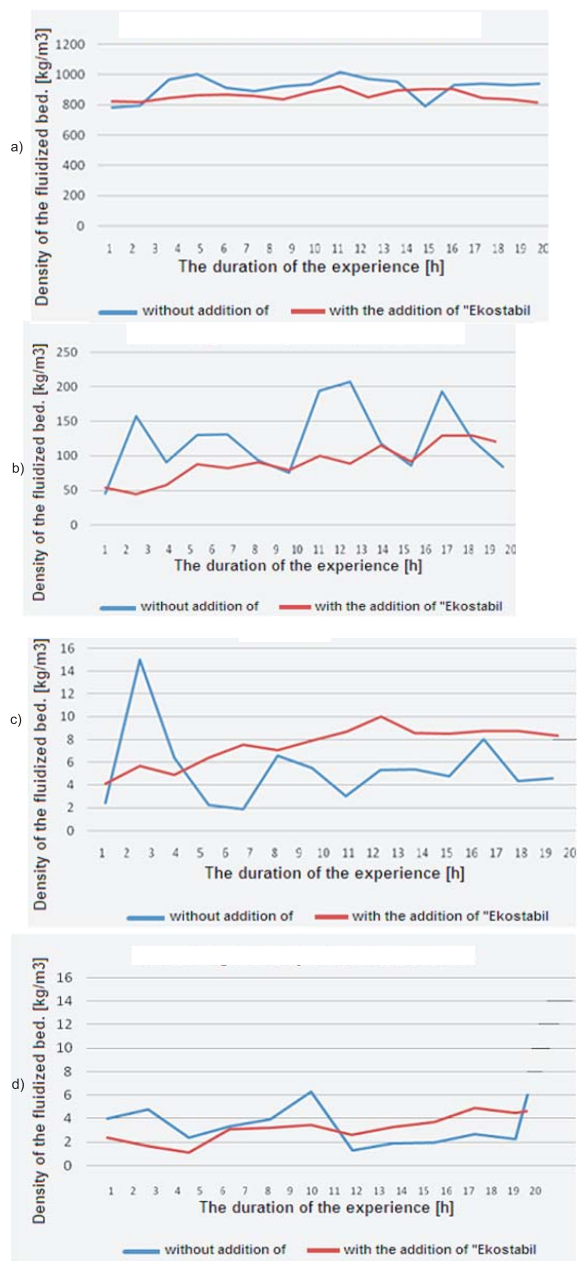


Figure 7. Average density of the fluid bed, at the time of two runs with and without EKOSTABIL, on the section above the grate: a) 0.05 m to 0.25 m, b) 0.25–0.55 m, c) 0.55–2.55 m, d) 2.55–4.75 m.

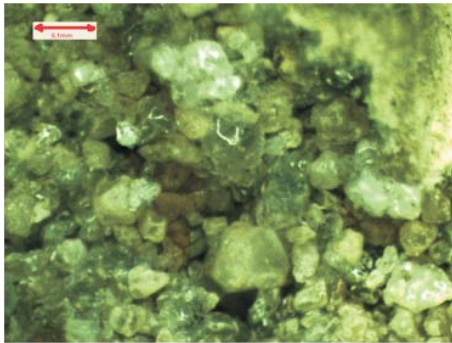


Figure 8. Agglomerates resulting from biomass burning. The sample was taken on the last day of the first phase of research (only biomass burning).

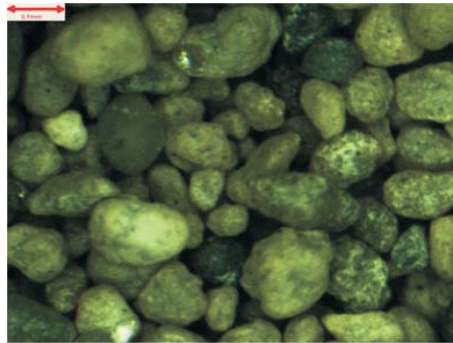


Figure 9. Macroscopic pictures of samples of material layers, taken during the combustion of biomass with EKOSTABIL. The sample was taken in the last hour of the second stage.

of the material layer (Fig. 9).

#### 4.1 Visual inspection

After the first stage of testing – biomass burning, a visual inspection of internal components position was carried out, which revealed intense formation of deposits, mainly within the separator and the downcomer, in case of combustion of biomass (Figs. 10 and 11).



Figure 10. View of junction between the fluidization column and separator.



Figure 11. Output of the cyclone to the downcomer pipe.

As one can see in the pictures, there is a layer of sintered material in junc-

tion. In addition, on the exit of the cyclone the sediment deposited on the downcomer pipe preventing the further flow of material layers. The surface inside the cyclone is also overgrown and there is only a small gap that the material comes out of the cyclone. These deposits are impossible to further investigate, blocking the way recurrence circular material; presumably they were caused by the decrease of temperature in the combustion zone.

Because blocking deposits it was not possible to continue research under such conditions, some deposits were removed mechanically, but parts of them were left to see the effects of EKOSTABIL. Figure 12 shows the deposits left inside the position of the test. During the second measurement



Figure 12. Deposits left in the position, before serving additive EKOSTABIL.



Figure 13. The interior of the position purified of the deposits after the application of EKOSTABIL. The picture was taken in the identical spot where the picture of Fig. 12.

session, biomass was burned with addition of EKOSTABIL. 120.4 kg of fuel and 2.25 dm<sup>3</sup> of additive were used. The duration of the experiment was 20 h. The position did not require stopping, operating parameters did not deviate from the norm. After the second stage of the study inspection was also conducted (Figs. 13 and 14).

Comparing Figs. 12 and 13 it can be said that deposits have been largely removed. In Fig. 14 it can be seen that the cyclone has been cleared from deposits. From the inside of the laboratory stand sampled deposits were taken, after that the chemical composition was analyzed. The analysis of the chemical composition of deposits made X-ray fluorescence (XRF)



Figure 14. The interior of the cyclone in its upper part.

technique, and the results are summarized in Tab. 1. The XRF method involves the use of X-rays in chemical analysis based on secondary emission spectrum. Analyzer MiniPAL Pal's Analytics was used.

Table 1. The chemical composition of deposits formed during biomass burning.

Chemical compound	Weight % mass
Na <sub>2</sub> O	47.0
Al <sub>2</sub> O <sub>3</sub>	4.0
SiO <sub>2</sub>	9.0
P <sub>2</sub> O <sub>5</sub>	19.7
SO <sub>3</sub>	1.8
K <sub>2</sub> O	11.4
CaO	4.7
TiO <sub>2</sub>	0.1
V <sub>2</sub> O <sub>5</sub>	0.01
Cr <sub>2</sub> O <sub>3</sub>	0.04
MnO	0.1
Fe <sub>2</sub> O <sub>3</sub>	1.9
NiO	0.02
ZnO	0.05

As one can see a 47% of sample contains sodium oxide, which is typical for the type of agro biomass, with high content of alkali metals. At the

same time attention is returned to the high concentration of alumina up to 4%, due to the physical structure of the deposit it is highly probable that a layer of sodium oxide was covered with a small thickness of the metallic layer. According to the manufacturer's declaration of the preparation, such phenomena may have occurred. Confirmation of this hypothesis is in Fig. 15, which shows a passivation layer at the gas inlet to the cyclone.

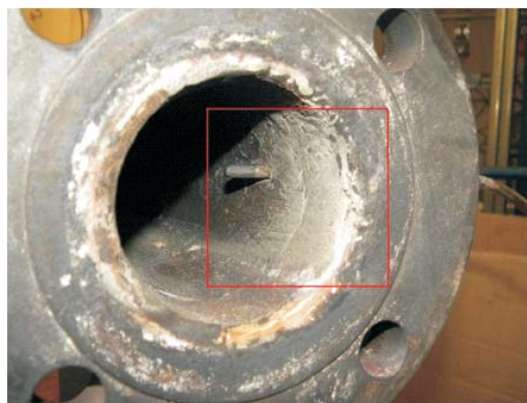


Figure 15. Passivation layer at the entrance gas to the cyclone.

## 5 Industrial test

Results of tests on a laboratory scale proved to be so promising that it was decided to carry out industrial tests. Operation test preparation called 'regenerator bed' was carried out in one of the leading power plant in Poland, having considerable experience in the field of biomass cofiring in CFB boilers. The starting point trials were visual inspection of the boiler: furnace chamber, and the bottom of the nozzle – cross channel. During the inspection it was observed that heating surface in the combustion chamber (Fig. 16) and the second one in the cross channel (Fig. 17), did not show significant changes. Inspection of the bottom of the nozzle has brought results in the form, the observed retention of agglomerates between the nozzles (Figs. 18 and 19).

After the power unit started working, we began to gather the reference material, aiming to determine the degree of suitability of the product. The photographic documentation of the structure of fluidized bed has been made by portable microscope (Fig. 20).



Figure 16. Heating surface, combustion chamber, CFB boiler.



Figure 17. Heating surface of cross channel, the second string.



Figure 18. The bottom nozzle CFB boiler, the residual material.

Dosage takes place in a continuous manner (Fig. 21). In the case of CFB boiler, it is injected in the center of an aerosol into the scraper feeder, on the surface of the carbon in quantities of  $1 \text{ dm}^3$  for the preparation of up to 9 tons of lignite.

The regenerator bed in a manner was continuously provided 24 h a day during 8 days. During this cycle macroscopic images of the material layer were taken. Figure 22a shows the structure of the fluidized bed after 3 days of dosing, and Fig. 22b shows the structure of the layer after 8 days.



Figure 19. Fluidized bed material.

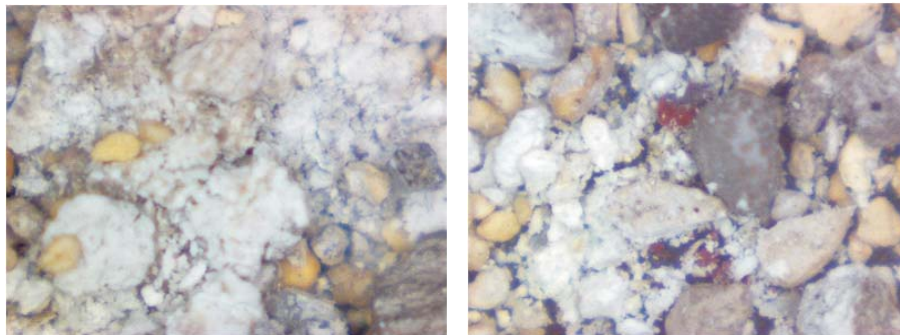


Figure 20. Microscopic photographs of fluidized bed material before using the additive.

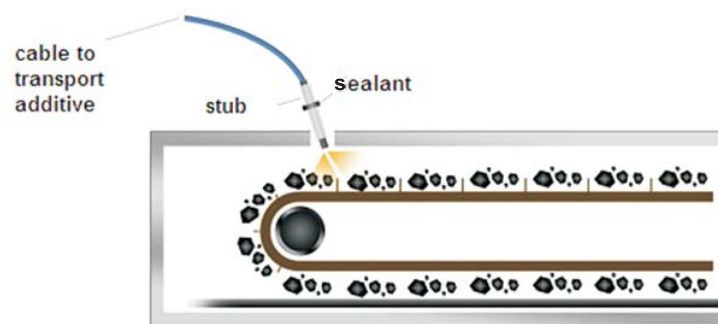


Figure 21. Method of administration of the regenerator bed on the scraper coal feeder.

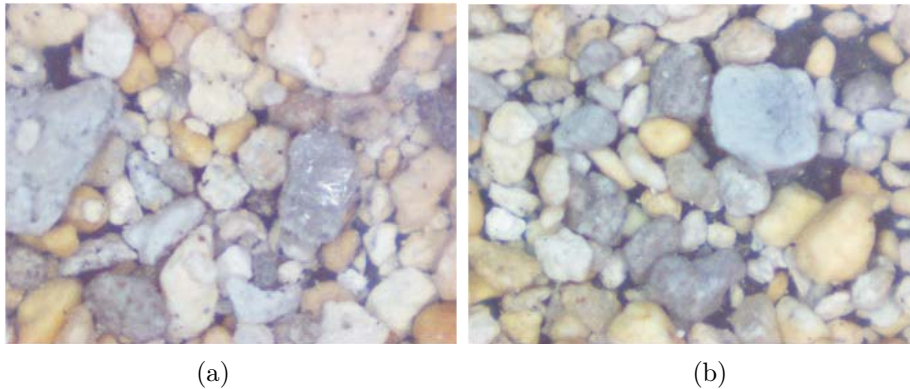


Figure 22. Structure of fluidized bed after 3 days (a), and 8 days (b) of dosing additive.

## 6 Conclusion

Summarizing, it can be concluded that the use of a regenerator bed has an effective impact on the fluidized bed material deagglomeration. In addition, during the entire cycle of dosing, there was no significant variation of greenhouse gases or other parameters of the boiler. Acknowledging the effectiveness of the additive, is to extend the operation of the boiler by about 11%, compared to the normal working hours.

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