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Original Research

Experimental-Energy Combustion of Biomass Combined with Coal in Thermal Power Plants

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Abstract

Approximately 11,000 industrial facilities from 30 European countries are being monitored within the trading scheme for the European Union's Emissions Trading System (ETS). They have released into the atmosphere 1.88 billion tons of CO_2 emissions in 2011, of which a considerable portion is coming from thermal power plants. Additional power plant-generated waste like ash, slag (slag-ash mixture), oxides, sulfur, and nitrogen components present an environmental burden in closer and wider surroundings of thermal power plants.

This article synthesizes the results of scientific research, experimentation, and practical examination of environment-energy optimal biomass combustion of semianthracite with black coal. Experimentation was performed under practical conditions in Vojany Power Plant (EVO), the largest thermal power plant using fossil fuels in Slovakia.

Keywords: environment, biomass, efectiveness, combustion

Introduction

According to EU legislation from 2008, they have approved the energy sector goal for 2020 of providing 20% of energy from renewable sources [1]. One of the ways to achieve this goal can also be coincineration of biomass. Under the shared combustion of biomass and coal there is a reduction or, more accurately, partial elimination of the environmental impact due to low content of sulfur and nitrogen in the biomass, resulting in a reduction of CO, SO_2, and NO_x, as well as reducing emissions of heavy metals [2].

Coincineration of biomass energy willows and other biomass plants with coal in the near future and in the present is currently considered one of the most promising methods for the provision of energy production in general. Despite the availability, and technological and environmental benefits proclaimed by this system on a larger scale, it has failed to be applied in Slovakia and globally. The biggest problem appears to be increased costs associated with the production and logistics of biomass assurance. Coincineration of biomass with coal significantly increases the clean energy ratio, defined as the ratio of produced electricity to the total consumption of fossil energy. When substituting a certain percentage of coal with biomass it is primarily reducing the greenhouse gas emissions from mining, transportation, and combustion of coal [3]. In practice, coincineration of willow chips with wood waste is being used in biomass power stations. In Sweden for, example, it plays an important role in the local energy supply [4]. Studies of environmental impact of coal combustion from a power plant exist in many counties, including Poland [5, 6].

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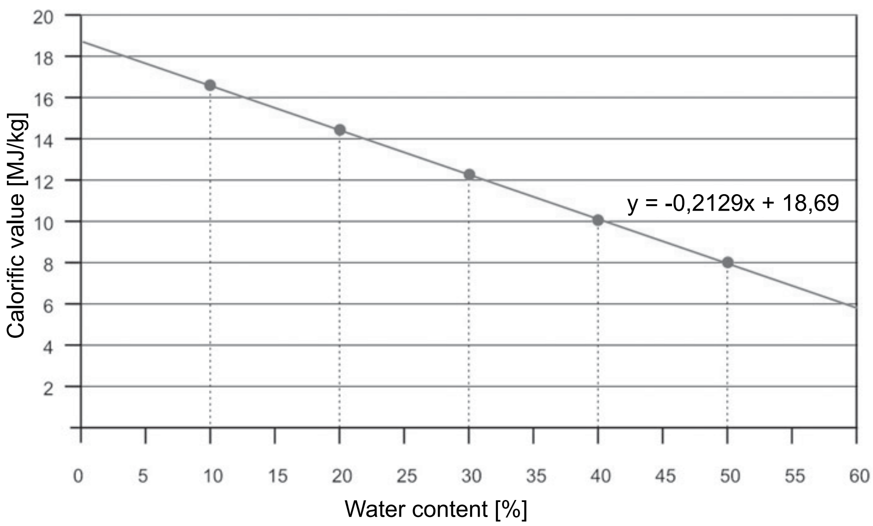

Fig. 1. Dependency of the calorific value of wood chips on water content [10].

In line with the above trends, Vojany power plant started in collaboration with the authors of the paper in 2009, in the form of scientific research complex project combustion of black coal with biomass in fluidized boilers, including the provision of (growing) plant biomass in the pond area surrounding the facility, gaining a self-made slag-ash mixture. Coincineration of biomass, mainly wood chips mixed with black coal in a 4% ratio, produced its first positive results in the reduction of emissions by 40 kg per MWh produced, and operational savings associated with the consumption of limestone, the creation and disposal of ash, steam, and water consumption. The project's next phase was experimentally realized coincineration of biomass with a share of 7% and then 15%. Research focused on the potential provision of biomass showed that the surrounding of the facility has good power potential for fast-growing energy crops like willow. In connection with this research we initiated specific purposeful cultivation of biomass on a large pond containing slag-ash mixture, about 56 ha [7]. The area of Vojany is one of most burdened areas in eastern Slovakia [8].

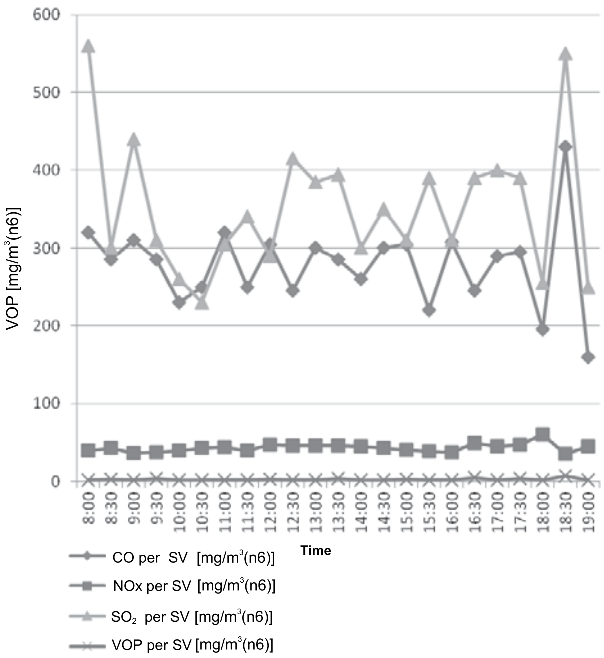

Fig. 2. Time course of measured concentrations of pollutants, coal fuel.

The Combustion Process in the EVO Facility before the Experiments

Coincineration of biomass in EVO boilers began in 2007. For the first tests woodchip forest biomass was chosen. To achieve the same thermal input necessary to deliver instead of one cubic meter of black coal, six cubic meters of biomass to the boiler, due to the different density and heating value of wood chips and black coal calorific value, could not be replaced by any amount of coal with biomass. Coal has a density of about 1 t/m^3 and heating value of 25 MJ/kg. Wood chips have a density of 0.3 t/m^3 and calorific value 10 MJ/kg.

Calculations based on the time proved that the added mixture of wood chips containing about 4% of the heat energy mix does not negatively affect dynamic characteristics of the power plant units. Tests in 2007 also proved that it is possible to smoothly combust biomass (wood chip) in fluidized boilers in Vojany power plant. It turned out that wood chips have a positive impact on the boiler combustion mode, because of lower ignite temperature and a higher proportion of volatile matter than coal. Therefore, there is more efficient combustion of irradiated fuel, which results in a decrease in the concentration of carbon monoxide in the exhaust gas [9].

These partial positive results have initiated the launch of scientific-research activities aimed at a complex solution for the issue of environmental energy-biomass combustion optimization processes.

Table 1. Average values of concentration of pollutants, fuel black coal.

Parameter	66 [MW]	88 [MW]	110 [MW]
SO_2 [mg.m^{-3}(n6)]	328,13	366,67	371,8
NO_x [mg.m^{-3}(n6)]	37,03	40,97	46,83
CO [mg.m^{-3}(n6)]	286,03	279,13	259,07
VOP [mg.m^{-3}(n6)]	5,9	5,9	6,3

Experimentation and Modeling of Coincineration

Coincineration of Wood Chips with Coal (Stage I)

Replacement of a share of combusted black coal in thermal power EVO with biomass-based fuels was carried out with priority to maximize the reduction of emissions, especially carbon oxides sulfur, by providing the required energy performance and therefore ultimately in increasing competitiveness to improve economic indicators, and manufacturing and energy-production companies.

The experiment was performed by the coincineration of black semi-anthracite coal wood biomass in fluidized FK5 boilers in the examining facility.

The average heating values of black coal in the experiment ranged from 25.4 to 28.1 MJ·kg^{-1}, and the wood chips ranged from 8.0 to 8.65 MJ·kg^{-1}. The course, depending on the heating value of wood chips from their moisture, is graphically illustrated in Fig. 1.

Manufacturer-guaranteed emission limits for dry combustion converted at 6% O_2 are: SO_2 400 mg·Nm^{-3}, NO_x 300 mg·Nm^{-3}, CO 250 mg·Nm^{-3}, and dust 50 mg·Nm^{-3}.

Measurements within the experiment were carried out on the three different power level blocks of 66, 88, and 110 MW at:

a) Combustion of of black coal alone
b) With 1.91% ratio of wood chips to total power input in the boiler
c) With 3.91% ratio of wood chips on the total input to the boiler

The Values of Emissions of Pollutants in the Combustion of Black Coal Alone

During the course of experimentation, the concentration values of pollutants (VOP) in the exhausts were monitored. The process and the results are shown in Fig. 2, and average values of concentration of the individual VOP are shown in Table 1. For 1.91% share of wood chips the process and the results are shown in Fig. 3 and average values of concentration of the individual VOP are shown in Table 2 and for 3.91% share of wood chips in Fig. 4 and Table 3.

From presented continuous forms of concentrations of pollutants (the individual VOP) it is significant that:

– During testing, legislative-allowed emission limits for SO_2 were preserved and there has been an increase in performance and in values
– With increased performance there was a decrease in the concentration of carbon monoxide in coincineration ratio of wood chips
– Other values of VOP are also below the the individual emission limits

Simultaneously the efficiency of boiler and coincineration of coal itself and the coincineration of biomass are presented in Table 4.

Taking into account the partially different characteristics or better quality of supplied and combusted coal and wood chips, it can be stated that the coincineration of a mixture of coal and wood chips can lead into a slight reduction in boiler efficiency, which is negligible compared to the achieved environmental safety effects.

Based on these tests and partial results of experimentation, we have proceeded to implementation of Phase I in plant biomass coincineration in the power plant at block No. 6 in July 2009. To support experiments a landfill with open capacity of 400 tons was built and customized with technology (crusher-sorter) and transport (conveyor belts) biomass.

The Total Share Ratio of Wood Chips on Final Boiler Input 1.91%

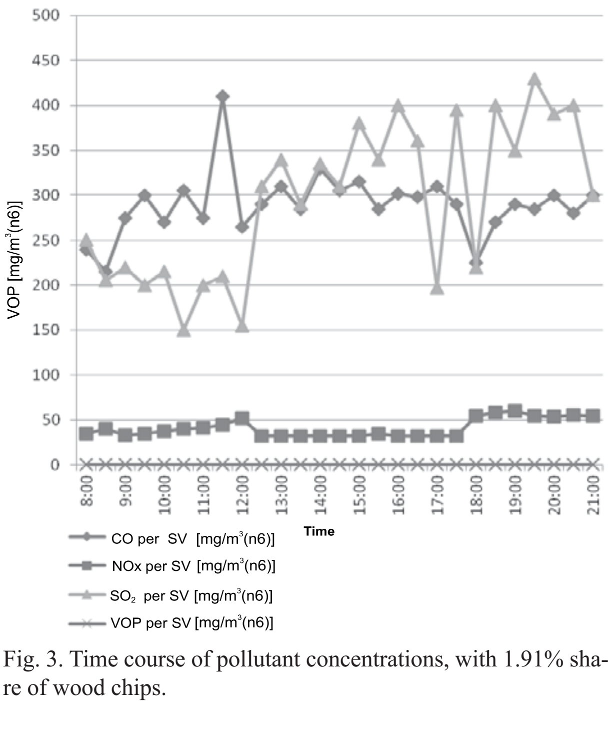

Fig. 3. Time course of pollutant concentrations, with 1.91% share of wood chips.

Table 2. Average value concentration of individual pollutants with 1.91% share of wood chips.

Parameter	66 [MW]	88 [MW]	110 [MW]
SO_2 [mg.m^{-3}(n6)]	215,9	336,17	387,93
NO_x [mg.m^{-3}(n6)]	31,73	41,03	53,23
CO [mg.m^{-3}(n6)]	309,17	278,87	280,43
VOP [mg.m^{-3}(n6)]	6,1	6,3	6,3

The Total Share Ratio of Wood Chips on Final Boiler Input 3.91%

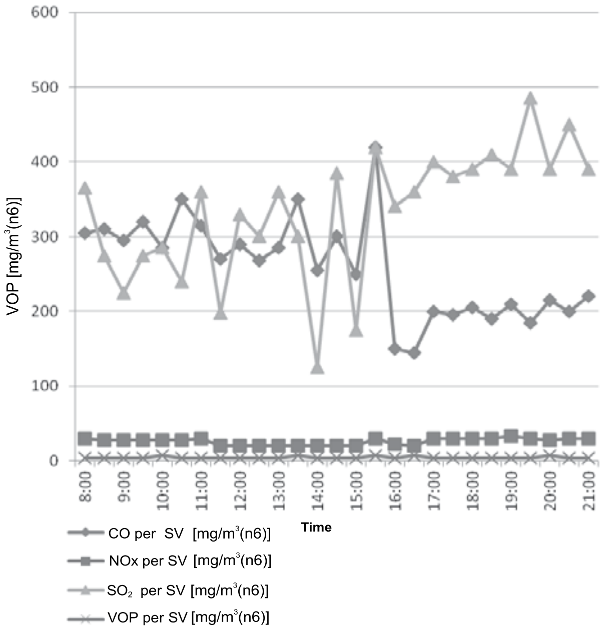

Fig. 4. Time course of of concentrations of pollutants, with a 3.91% share of wood chips.

Table 3. Average value concentration of individual pollutants, with a 3.91% share of wood chips.

Parameter	66 [MW]	88 [MW]	110 [MW]
SO_2 [mg.m^{-3}(n6)]	264,03	312,93	402,77
NO_x [mg.m^{-3}(n6)]	27,63	21,17	32,2
CO [mg.m^{-3}(n6)]	318,40	272,03	206,63
VOP [mg.m^{-3}(n6)]	6,5	6,6	6,6

A mechanized system was used for wood chips, to transport them over a conveyor belt and coal through the other one, and a rated power of conveyor belts was set to properly balance mutual ratio. Use of raw wood chips (softwood and hardwood) and their share was gradually increased to 5.3%.

The share of 5.3% was not achieved by increasing the weight, but by coiniceration of better quality of the combusted wood chips with a higher calorific value than previously considered biomass, which was considered in the project. This means over 11 MJ/kg compared to the projected calorific value 9.5 MJ/kg. This ratio has proved to be best possible to maintain the maximum dynamic properties of the boiler and in the execution of transporting the fuel mixture into the boiler. Subsequently, in relation to the achieved results it was determined on the implementation of Stage II of the biomass project coinicineration, which consisted of the construction of independent mechanized access to the boiler, especially for biomass.

Table 4. The effectiveness of fluidized boiler K5 in the holdings surveyed.

Electrical performance	Black coal	Share of wood chip 1,91%	Share of wood chip 3,91%
[MW]	[%]	[%]	[%]
66	93,81	93,47	92,30
88	93,55	93,32	92,91
110	93,52	92,57	93,20

Capacities of coal lines remained clear and the new path was used to transport a higher volume of wood chips into the boiler.

The combustion of one ton of biomass eliminated approximately one ton of carbon dioxide emissions (Table 5).

Coincineration of Wood pellets with Coal (Stage II)

Within the next experiments in 2010 forest wood chips were replaced by wood pellets. Their advantage was that the bulk density was about 0.6 to 0.7 t/m^3 – approximately twice as much as the density of chips. Pellets additionally possessed a 1.5-times higher calorific value than wood chips. Energy parameters of wood pellets are approaching coal properties. Their addition allowed us to increase the proportion of biomass without compromising the energy operation of the power unit. Testing showed that it is possible to increase the share of biomass heat to almost 30% without any negative impact on the energy operation of the power unit.

Monitoring and measuring individual power levels when burning a mixture of coal and biomass was determined in intervals of three hours. Stabilization of the boiler after the change of power level was one hour. The dependency of the calorific value of wood pellets from moisture is displayed graphically in Fig. 5.

Measurements during the experiments were conducted at three individual power levels of block 50, 80, and 100 MW at:

a) 6.64% share of biomass in total power consumption of the boiler
b) 14.8% share of biomass in total input to the boiler

Measuring and coiniceration of coal and biomass took place at the volume ratio of 1/3 mixture of wood chips and 2/3 pellets. The share of biomass in the total heat input of the boiler was 6.64%, according to the parameters of Table 6.

Table 5. The amount of CO_2 saved by coincineration of biomass.

Year	Wood chip share [t]	CO_2 - eliminated [t]
2009	8 311	9 600
2010	19 987	24 784
2011	21 443	25 673

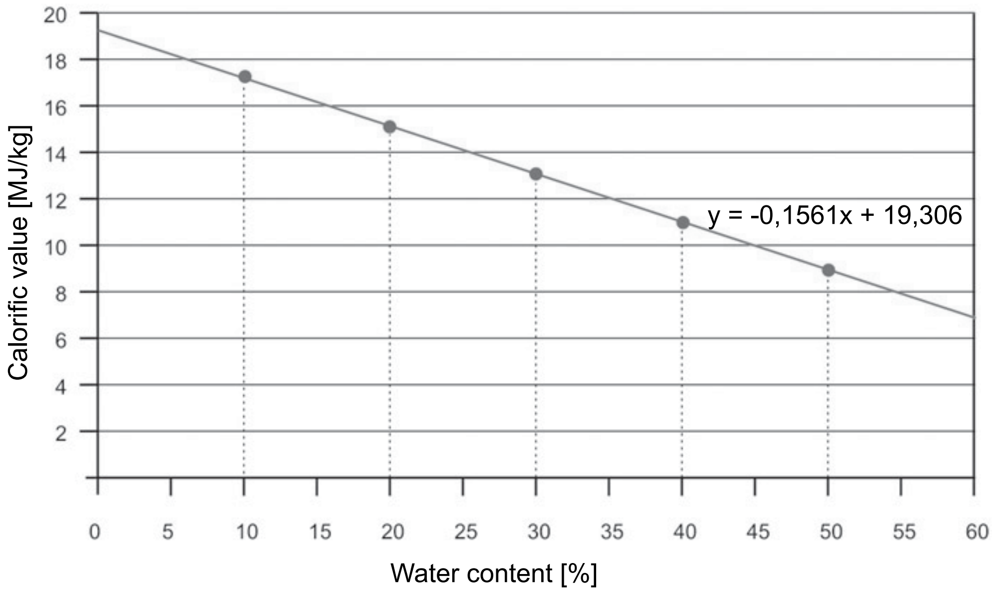

Fig. 5. The dependency of calorific value of pellets on water content [10].

Table 6. Characteristics of wood chips and pellets.

Type	Water content [%]	Calorific value [MJ/kg]
Wood chip	30,02	12,30
Pellets	5,50	18,45

The Share of Total Biomass Boiler Input 6.64%

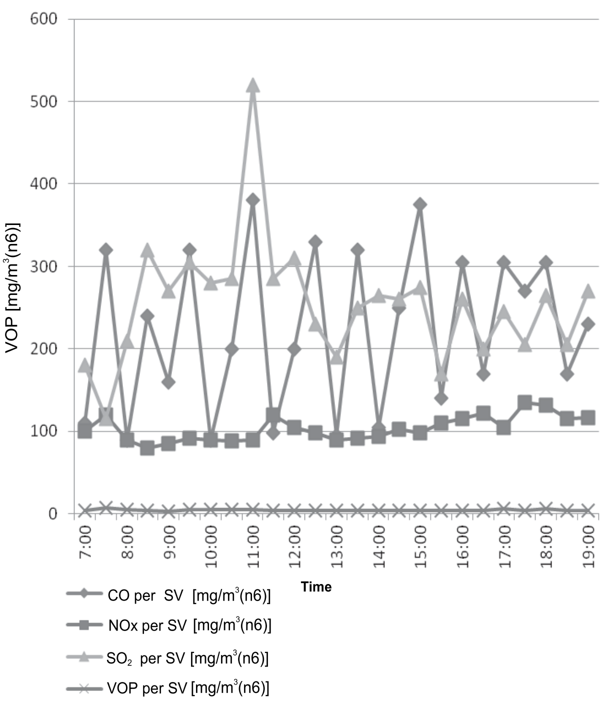

Fig. 6. Time course of pollutant concentrations with a share of 6.64% of pellets.

During the experiments and measurements concentrations of pollutants in the exhaust gases were simultaneously monitored. In Fig. 6 the time course of the concentrations of pollutants in the exhaust gas is shown.

The average concentrations of individual pollutants are shown in Table 7.

During the measurements we continuously monitored the concentrations of pollutants in the exhaust gases (Fig. 7).

The average concentrations of individual pollutants are shown in Table 9.

During the experiment, the combustion of wood chips with an average calorific value of 12.30 MJ/kg and pellets with an average calorific value of 18.45 MJ/kg with the share of biomass at 6.64% and calorific value of 18.48 MJ/kg of biomass ratio of 14.8% on boiler input (Table 8).

Wood pellets in terms of calorific value and volume density are significantly suitable types of biomass, which can increase its share in the fuel mix for EVO-fluidized boilers.

Table 7. The average concentrations of individual pollutants, FK 6 EVO.

Parameter [Measure]	Performance 50 MWe	Performance 80 MWe	Performance 100 MWe
Concentration SO_2 [mg/m^3(n6)]	284,97	241,97	239,7
Concentration NO_x [mg/m^3(n6)]	77,53	93,73	128,7
Concentration CO [mg/m^3(n6)]	187,0	217,9	234,5
VOP [mg/m^3(n6)]	1,43	2,93	6,37

Table 8. Pellet properties.

Type	Water content [%]	Calorific value [MJ/kg]
Pellets	5,43	18,48

Table 9. The average concentrations of individual pollutants, FK 6 EVO.

Parameter [Measure]	Performance 50 MWe	Performance 80 MWe	Performance 100 MWe
Concentration SO_2 [mg/m^3(n6)]	348,4	446,3	363,1
Concentration NO_x [mg/m^3(n6)]	71,15	71,10	77,35
Concentration CO [mg/m^3(n6)]	188,3	222,7	214,6
VOP [mg/m^3(n6)]	3,05	3,4	6,25

The facility is obtaining its biomass currently from six local suppliers. The surrounding wetlands around the facility provide good conditions for rapidly growing trees (poplar, willow), and the EVO facility is a promising purchaser and will be their regular customer in the future as well. With self grown cultivation of biomass in surrounding areas of the plant or in the wetlands there is potential for increasing employment in the region for people with lower qualifications.

Share of Biomass on Total Boiler Input of 14.8%.

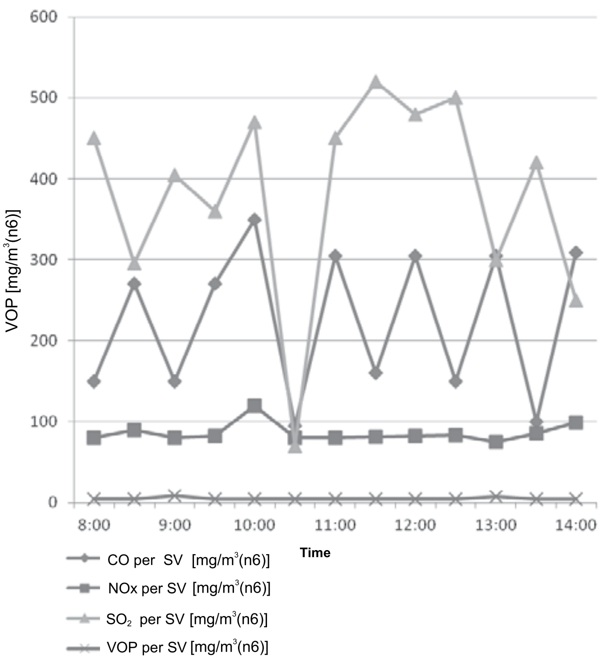

Fig. 7. Time course of pollutant concentrationswith a share of 14.8% of pellets.

Conclusions

The results of our previous experiments focused on the eco-energy optimization of biomass coiniceration with coal proved that:

– After the implementation of technological changes it is possible to improve homogenization of a mixture of coal and wood chips in a long-term combustion of this fuel mixture in thermal power SE a.s. and in general. The significant increase in the ratio of coinicerated biomass allows us to build a separate route for mechanized transport of biomass from the surrounding area of the plant and pond slag-ash mixture directly into the boiler.
– Legislation required emissions of pollutants were met at a 6.64% share of biomass on total power input of the fuel into the boiler, while the fuel had an average sulfur content of only 0.17%. The 14.8% share of biomass had two-times the sulfur content in the fuel and the SO_2 emissions were above the limit.
– Beneficial effect was observed by reduction of the CO concentration with increasing quantity of biomass at lower boiler output.

Production of biomass and incineration of coal in fluidized boilers, of thermal power stations SE, a.s., as well as other power plants is in terms of environmental benefits reflected in a significant reduction in emissions and production of solid waste generated by burning coal only.

The use of biomass is an environmentally adequate way of power generation and has a a positive impact on the environment. In cooperation with the EVO we have our own knowledge of this technology with four years experience. Daily in terms of an experiment-based model, about 80 tons of wood chips are coincinerated. Implementation of research results into practice, thus contributing to the European Union's commitment to continually increase the use of renewable energy to 20% by 2020.

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