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Impact of biomass co-firing on selected parameters of a 225 MW power unit

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Abstract

The issues surrounding the co-firing of coal-biomass in pulverized-coal boilers, facilities originally designed for coal firing, are receiving considerable attention. Basic issues are discussed in this paper, as are the results from tests conducted in 225 MW power plant units prior to the implementation of co-firing technology. The data collected before and after implementation were compared. The comparison and analysis were limited to the most important characteristic parameters of the power unit. An economic/financial analysis of the implemented co-firing technology will be presented in a separate publication.

Keywords: biomass co-firing in power plants, technical effects of co-firing

1. Introduction

Increased use of renewable energy in the fuel and energy market is generating significant benefits in terms of reduced greenhouse gas emissions. Directive 2009/28/EC set a 20% target for the overall share of energy from renewable sources in the European Union by 2020 [1, 2]. Waste wood derived from forestry residues and wood products industries, cereal straw from the processing of leguminous and oleaginous plants, and biomass from crops grown for energy are the most common materials that make up biomass fuels. Other biomass sources include organic waste not mentioned above, sewage sludge from pulp and paper plants, sugar refineries and flax dryers, and biogas [1–7].

The properties of biomass are significantly different from those of coal, with greater variability of physical and energy parameters, the most important being chemical composition, non-combustible mass ratio and moisture [1, 3, 7]. Moisture content is one of the basic parameters determining the suitability of the fuel for energy use, as it significantly decreases the fuel calorific/heating value and affects the combustion process [1, 3, 7]. High and highly variable moisture content is the major disadvantage of biomass. Moisture causes an increase in flue gas volume and may reduce combustion temperature, which hinders direct combustion and may reduce overall system efficiency through incomplete combustion-related losses [1, 3–5, 7].

Solid biofuels are also characteristic in that they contain approximately 70÷80% volatile matter versus 10÷50% volatile contents in coal [3, 4]. The predominant form in co-firing is the combustion of gas as volatiles, producing about 67% total heat [1, 4]. Higher combustion temperatures and level of biomass milling intensify this process. For effective combustion of biomass, special design options have to be considered for combustion chambers to be able to supply air above the fuel bed at the locations of volatiles release [4, 7]. Co-firing of biomass with hard coal is particularly problematic due to significant differences in volatile matter content, a lot higher in the case of biomass [1, 4, 6, 7].

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Ash is a secondary product of combustion, produced as a result of high temperature action on mineral substances present in biomass. The ash content is considerably lower in biomass than in coal [1, 3, 4, 6]. Biomass ash has relatively high alkaline metal contents, particularly sodium and potassium, which lower the ash melting point. The softening temperature of biomass ash (750÷1000°C) is also lower than that of coal (over 1000°C). Lowered melting temperature, even at a relatively small mass share of co-fired biomass, is responsible for fouling on heat transfer surfaces due to the lower softening temperature of the coal-biomass mixture. This leads to a rise in the temperature of the exhaust flue gas, affecting the efficiency of the boiler – compared with boiler efficiency in coal-only operation [1, 4–7].

Considering these technical challenges, prior to making a decision about the implementation of coal-biomass co-firing technology in the pulverized-coal boilers of a GDF SUEZ Energia Polska S.A. power plant in Połaniec, substantial testing was carried out in order to establish the optimal technical parameters and fuel composition (coal and biomass) for the pulverized coal boilers [8, 9].

2. Tests characteristics and results

The objectives of the tests [8, 9] included the evaluation of the possibility of powder preparation and biomass co-firing in existing coal burners, identification of potential equipment operation problems and, for safety reasons, determination of operating conditions for biomass transport via the existing coal feeding system. The testing program helped examine the impact of coal-biomass co-firing on energy efficiency and changes in the composition of dust-flue gas pollutant emissions and included tests of coal mill and pulverized-coal boiler performance to check the effect of biomass feeding on the electrical energy production technology and cost, as well as on the environmental protection cost.

All the parameters that might influence the biomass combustion process in the boiler or the operation of the equipment and systems involved in pre-treating the fuel fed to the boiler were recorded, in particular: flue temperature, steam temperature in the boiler and changes in the composition of harmful compounds contained in the flue.

Two groups of tests were performed [8, 9]:

- Co-firing of the biomass at 5% to 20% by mass in one mill/pulverizer set, at a temperature of the fuel mixture leaving the mill of 100÷115°C. These tests were designed to provide general data concerning the possibility of biomass combustion using existing burners and powder preparation, and the identification of potential technical hazards.
- Co-firing of the biomass at 20÷30% by mass ratio in five out of the six mill sets in one power unit, at a temperature of the biofuel-coal mixture of approx. 120°C.

These tests were designed to determine the maximum achievable capacity of the power unit. The results showed that the power unit was able to reach the maximum capacity of 210÷215 MW at the set parameters of the boiler and normal combustion stability. No significant changes in flame temperature or stability were observed.

The test results confirmed the feasibility of coal-biomass co-firing in the existing facilities. The boilers maintained the required operating parameters. Combustibles in the slag and ash were within the limits, which proved the regularity of the combustion process; the operation of electro filters was failure-free. The tested method of biomass co-firing did not indicate any reduction in nitrogen oxide emissions [8, 9].

Following the trials, the mills and coal feeding systems were inspected, as was the condition of the bunker walls. The condition of the installations gave no cause for concern. No significant changes were observed in the performance of the mill sets or in the temperatures of the flue gas, live steam or vapors that might be due to the switch to a different fuel. No significant differences in nitrogen dioxide emissions were found. By contrast, sulfur dioxide and dust emission levels after exhaust fans decreased [8, 9].

Compositions of biomass and coal derived from different locations were tested and proved to give variable results due to the different chemical characteristics of the coal [3].

3. Selected operating parameters of power units for co-firing technology

This section presents operating data of 225 MW power units modified to permit biomass co-firing with hard coal. These data, collected for three years of operation leading to a successful implementation of the co-firing technology, were compared with those gathered from the hard coal only combustion period. The year of operation preceding the full implementation of the technology was denoted as year zero.

Table 1: Share of electricity generated from biomass co-firing in consecutive years of power plant operation

Year of operation	Electricity share
	%
0	0.0
1	6.3
2	5.4
3	6.5

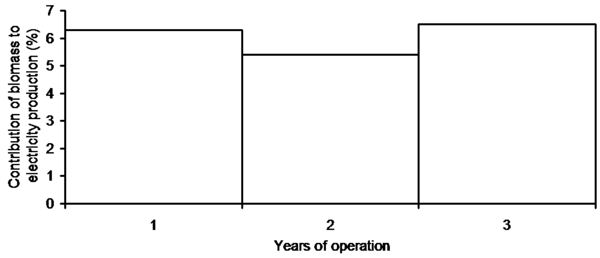

Figure 1: Relative (percentage) share of electrical energy obtained from biomass combustion in consecutive years of power plant operation

Table 1 and fig. 1 illustrate the percentage share of energy generated from biomass co-firing in subsequent years of operation.

As shown in the table above, the share of electricity from the chemical energy contained in the biomass was about 6%.

Further on in this paper, the values of various quantities characteristic of the operation of the power plant (8 power units) are presented, together with the relative values of these quantities expressed as a percentage, in relation to the values from before the implementation of coal and biomass co-firing technology, determined from

$$\Delta x_{i\%} = \frac{X_i - X_0}{X_0} 100\% \quad (1)$$

where: $\Delta x_{i\%}$– the relative value of the analyzed quantity expressed as a percentage, in relation to the value before the implementation of coal and biomass co-firing technology, X_i – the value of the analyzed quantity in the i-th year of the power plant operation with biomass co-firing, $i = 1, 2, 3$, X_0 – the value of the analyzed quantity in year zero, leading up to the implementation of biomass co-firing technology in the power plant.

Table 2 shows average values and relative changes in average capacity of the power units in consecutive years of operation with biomass co-firing. The results obtained are illustrated in fig. 2.

Table 2: Average capacity of the power unit and relative (percentage) change in average capacity in consecutive years of biomass co-firing

Year of operation	Average capacity of a power unit	Relative change in average capacity of a unit
	MW	%
0	164.3	-
1	157.3	- 4.26
2	167.1	1.70
3	165.7	0.85

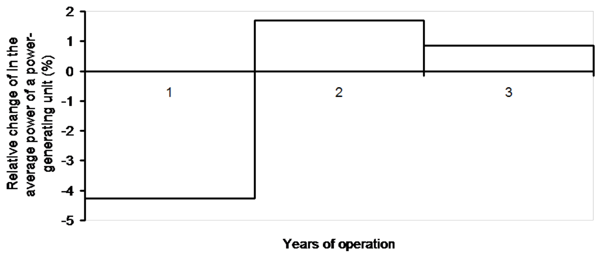

Figure 2: Relative (percentage) change in the average capacity of the power unit in consecutive years of biomass co-firing

As the data and calculations indicate, in the initial period of operation the losses in power unit output were due to downtime caused by necessary inspections, more frequent than before. The average power unit capacity increased in the following years and exceeded the capacity achieved before the implementation of the biomass co-firing technology.

Table 3: Average value of the power unit operating time and relative (percentage) change in the operating time of power units in consecutive years of biomass co-firing

Year of operation	Power unit operating time	Relative change in the power unit operating time
	h	%
0	5185	-
1	3951	- 23.80
2	5017	- 3.28
3	4777	- 7.87

The downtime due to more frequent inspections is reflected in the average values of the power unit operating time and the relative operating time change in subsequent years of co-firing, as shown in table 3 and fig. 3.

Also, the values of average output obtained from one

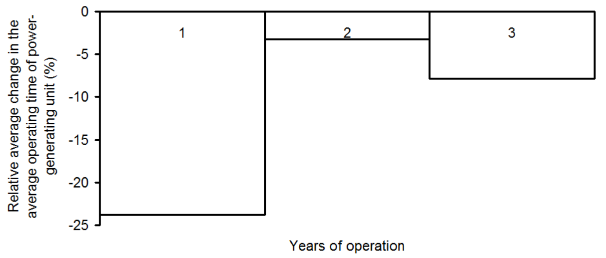

Figure 3: Relative (percentage) change in generating unit operating time in consecutive years of biomass co-firing

Table 4: Average power unit capacity from one set of mills and relative (percentage) change in power unit capacity from one set of mills in consecutive years of biomass co-firing

Year of oper-ation	Average power unit capacity from one mill set	Relative change in average capacity of a power unit, obtained from one mill set
	MW	%
0	40.7	-
1	37.8	- 7.13
2	39.6	- 2.70
3	38.6	- 5.16

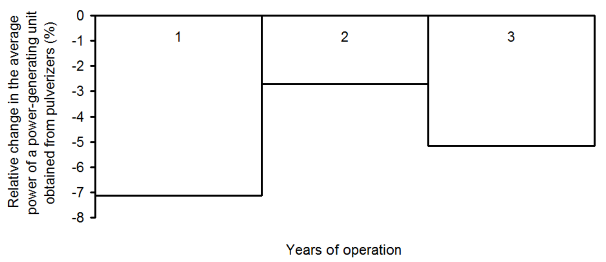

Figure 4: Relative (percentage) change in the power unit capacity from a mill set in consecutive years of biomass co-firing

mill set and relative change in the power unit capacity based on one mill set decreased in consecutive years of biomass co-firing. The analysis indicates that to provide the required capacity of the power unit, a larger number of mills have to operate concurrently. The results from the analysis are shown in table 4 and fig. 4.

The reduction in the average output from one mill set resulted in an increased number of mills working simultaneously to provide enough fuel for generating the expected quantity of electricity. Data concerning this issue are shown in table 5 and illustrated in fig. 5.

Table 5: Average number of pulverizers in one power unit and relative (percentage) change in the number of pulverizers in one power unit in consecutive years of biomass co-firing

Year of opera-tion	Number of pulverizers in the power unit	Relative change in the number of pulverizers
	mills/power unit	%
0	4.0	-
1	4.2	5.00
2	4.2	5.00
3	4.3	7.50

Figure 5: Relative (percentage) change in the number of pulverizers in the power unit in consecutive years of biomass co-firing

Table 6: Table 6. Pulverizers' operating time and relative (percentage) change in pulverizers' operating time in consecutive years of biomass co-firing

Year of opera-tion	Pulverizers' operating time	Relative change in pulverizers' operating time
	h/power unit	%
0	20989	-
1	16460	- 21.58
2	21177	- 0.90
3	20469	-2.48

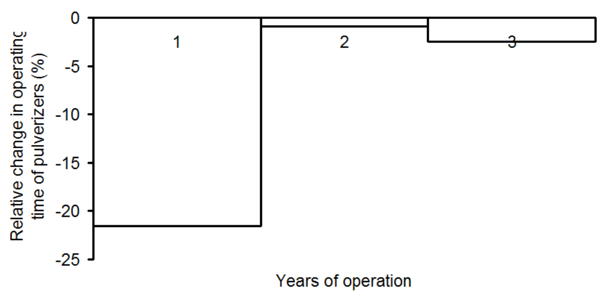

Figure 6: Relative (percentage) change in pulverizers' operating time in consecutive years of biomass co-firing

Average change in the number of mills increased by 5% but due to technical issues demanding more frequent inspections and overhauls, the time of their operation decreased, as shown in table 6 and fig. 6.

Table 7: Average fuel stream in mill sets and relative (percentage) change in the stream in mill sets in consecutive years of biomass co-firing

Year of operation	Average stream of ground fuel	Relative change in fuel stream
	Mg/h	%
0	19.2	-
1	18.8	- 2.08
2	18.7	- 2.60
3	18.7	- 2.60

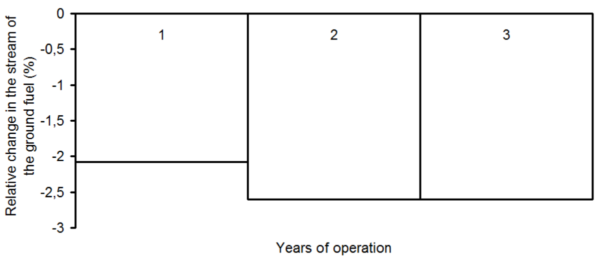

Figure 7: Relative (percentage) change in stream in mill sets in consecutive years of biomass co-firing

Average stream of fuel being pulverized also decreased, slightly, as shown in table 7 and fig. 7.

Table 8: Energy consumption per 1 Mg fuel in pulverizers and relative (percentage) change in specific energy consumption in consecutive years of biomass co-firing

Year of operation	Energy consumption per ground/pulverized fuel mass unit	Relative change in energy consumption
	kW·h/Mg	%
0	29.2	-
1	32.6	11.64
2	33.0	13.01
3	34.5	18.15

The difficulties described earlier in the paper cause an increase in specific energy consumption for grinding/pulverizing 1 Mg of fuel (coal and biomass). According to data in table 8 and in fig. 8, the increase in energy unit consumption (kW·h/Mg) is considerable.

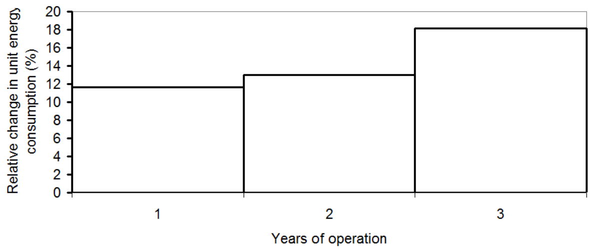

Figure 8: Relative (percentage) change in specific energy consumption of mills in consecutive years of biomass co-firing

Table 9: Cost of energy used to grind 1 Mg of fuel in pulverizers and relative (percentage) change in unit cost of energy used in consecutive years of biomass co-firing

Year of operation	Energy consumption by mass unit of the ground fuel	Relative change in energy consumption
	zł/Mg	%
0	2.98	-
1	3.32	11.41
2	3.37	13.09
3	3.52	18.12

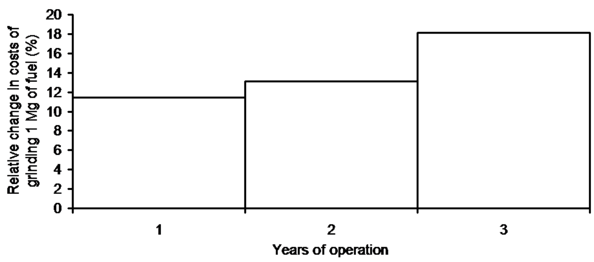

Figure 9: Relative (percentage) change in unit cost of energy used for a ground fuel mass unit in consecutive years of biomass co-firing

This translates into higher cost of energy used to grind 1 Mg of fuel in the mills, as shown in table 9 and fig. 9.

Changes in combustion products were substantive and reached more than 200% of the composition, compared with those from the combustion of coal.

Tables 10÷12 and fig. 10÷12 compare combustible contents in the slag and ash, and the incomplete combus-

Table 10: Change in the combustible content in the slag and relative (percentage) change in the combustible content in the slag in consecutive years of biomass co-firing

Year of operation	Combustible content in the slag	Relative change in combustible content in the slag
	%	%
0	2.0	-
1	4.0	100.0
2	6.4	220.0
3	5.4	170.0

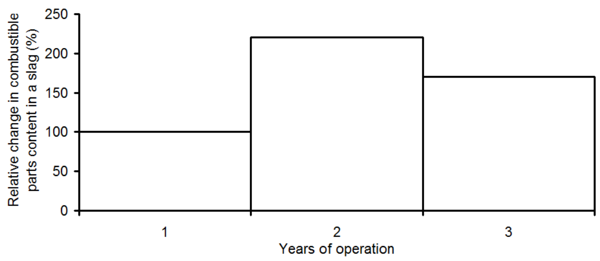

Figure 10: Relative (percentage) change in the combustible content in the slag in consecutive years of biomass co-firing

Table 11: Change in the combustible content in the ash and relative (percentage) change in the combustible content in the ash in consecutive years of biomass co-firing

Year of operation	Amount of combustible content in the ash	Relative change in combustible content in the ash
	%	%
0	1.2	-
1	2.7	125.0
2	3.6	200.0
3	3.7	208.0

Figure 11: Relative (percentage) change in the combustible content in the ash in consecutive years of biomass co-firing

Table 12: Change in incomplete combustion loss and relative (percentage) change in incomplete combustion loss in consecutive years of biomass co-firing

Year of operation	Incomplete combustion loss	Relative change in incomplete combustion loss
	%	%
0	0.31	-
1	0.79	154.8
2	1.07	245.2
3	1.16	274.2

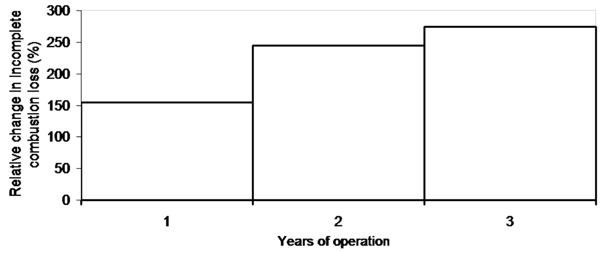

Figure 12: Relative (percentage) change in incomplete combustion loss in consecutive years of biomass co-firing

tion loss in the biomass co-firing products relative to the products of coal-only combustion.

There is a higher content of combustible matter in the slag and ash, and the increase in the incomplete combustion loss in co-firing reduced the efficiency of electrical energy generation, but as the carbon dioxide (CO_2) emission decreased markedly, the economic impact should be regarded as satisfactory.

4. Summary

The increase in the share of renewable energies for the purpose of reducing greenhouse gas emissions is a requirement imposed by EU regulations. The technology of biomass co-firing with coal generates a number of essentially technical difficulties and, as presented in this paper, at times fails to bring the expected results.

In their attempt to match these requirements, in 2012 GDF SUEZ Energia Polska S.A. opened a 205 MW power unit in the Połaniec power plant, with a fluidized bed boiler entirely powered by biomass fuel. It is the biggest and the most groundbreaking project now being implemented in Poland. The energy the power unit generates constitutes 25% of the domestic biomass only electricity production.

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