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Characteristics Of The Co-Firing Brown Coals And Renewable Fuels – Contribution To The Decarbonization Process

Nihad Hodzic[1], Kenan Kadić[2]
[1] *University of Sarajevo - Faculty of Mechanical Engineering, Energy Department*
Vilsonovo setaliste 9, 71000 Sarajevo, Bosnia and Herzegovina
hodzic@mef.unsa.ba
[2] *Elektroprivreda BiH d.d. - Sarajevo Power utility, Power plant Kakanj - Kakanj*
72240 Kakanj, Bosnia and Herzegovina
ke.kadic@epbih.ba

ABSTRACT: *In addition to the necessary need to reduce the use of fossil fuels as a global measure to reduce CO_2 emissions, the decarbonisation strategy also includes the development and application of new technology in the field of electricity production. Technical-technological solutions imply the development and application of technologies for clean energy, which are those technologies that result in very low, zero or even negative emissions of CO_2 and other greenhouse gases. Further, such primary energy conversion technologies from fossil fuels do not include those that are not accompanied by CO_2 capture and storage technologies. The aim of the research is to assess the influence of the change in the composition of oxidants in the combustion atmosphere on the composition of flue gases produced by the combustion of solid fuels. The tests included changing the oxygen content in the oxidant in the range from 21% to 35%, changing the process temperature and changing the fuel composition. From the results, it is concluded that for all test fuels it is possible to establish highly efficient combustion, in which the composition of the flue gases changes significantly with the increase in the proportion of oxygen in the oxidant. This refers to pollutant emissions: CO_2, CO, NO_x and SO_2. In this context, it is also concluded that it is possible to achieve the desired effect of an apparent increase in the concentration of CO_2 in flue gases, which is the primary reason for applying this technology for further capture and storage of this gas.*

KEYWORDS: *coal, woody biomass, oxygen-enriched combustion, emissions.*

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I. INTRODUCTION

Climate change and the decarbonisation process are the cause of the reduction in fossil fuel consumption. Fossil fuels will be replaced by renewable or alternative fuels. However, the energy transition from fossil to renewables is happening gradually because the stability of the energy system must be ensured. According to the projection, the transition process will last for some time, especially in countries that have yet to enter the transition process of the energy sector on a larger scale, approximately two or three decades - Bosnia and Herzegovina (BiH) is such an example of a country. In order to replace fossil fuels and carry out the transition in a sustainable way, the focus of research is on environmentally acceptable fuels while increasing the efficiency of primary energy use. The category of promising renewable fuels primarily includes biomass, either as waste from agricultural, forestry or wood-processing activities. Co-firing of waste biomass with coal is characterized as a clean coal technology. The research of this technology provides a global scientific contribution aimed at mitigating climate change, including a contribution at the local and national level towards a cleaner environment, as defined by the goals of the United Nations Agenda for Sustainable Development 2030 [1], and the Green Agenda of the EU and the Balkans [2]. Accordingly, in BiH it is neither realistic nor fair to expect a drastic reduction in the use of the most important domestic energy resource, coal, in a short period of time. This is evidenced by long-term energy strategy of BiH, which clearly shows a commitment to the use of coal in the future as well [3]. On the contrary, the goals of the European Union (EU) are clear and defined by the European Green Deal initiative, which is a commitment to complete climate neutrality by 2050, which was also confirmed in the annual report of the International Energy Agency for last year [4]. BiH, on its way to the EU, must respect and adapt to the global market and trends that tend towards clean energy. The European Green Deal initiative and the trend of clean energy production is also a great opportunity for the energy transition of

Bosnia and Herzegovina, which was also discussed by regional experts in the subject area [5]. The trend of switching electricity production from coal to renewable energy sources is a rather slow and long-term process. Because of this, but also because of its current representation and especially because of the stability and reliability of production, including a stable price, coal will remain an important resource in the energy system as the primary energy source in thermal power plants in the coming period. At the same time, due to competition and increasingly strict requirements regarding the overall reduction of negative impact on the environment, coal-based electricity producers are forced to use new technologies. Therefore, in addition to a higher degree of beneficial effect, these plants should have significantly less environmental load with polluting components in flue gases. At the same time, this prolongs the use of fossil fuels for a certain period of time in which a further alternative or replacement for fossil fuels with other sources of energy should be found. New clean coal technologies also include technologies with additional renewable fuel/co-firing, e.g. with woody biomass (residues after felling and processing, small branches, sawdust). From the point of view, of the combustion process and the creation of carbon dioxide (CO_2), these fuels are considered renewable and neutral [6,7]. CO_2 emissions from conventional coal-fired thermal power plant boilers in Bosnia and Herzegovina are extremely high. Bosnian coals, generally belong to low-value and low-reactivity coals, and the ash from these coals is very prone to slagging/fouling of the boiler heating surfaces. In the short-term and medium-term plans of the EU, on whose path BiH is also, co-firing of coal with biomass and municipal waste is one of the most promising applications [8,9].

Renewable fuels in energy and industrial boilers must meet several criteria, such as availability preferably throughout the year, appropriate chemical composition and humidity to reduce transport costs and contribution to the heat value, and adequate price. Woody waste, as biomass, is a fuel that meets all these criteria. In addition to coal, whose balance and exploitation reserves according to the latest estimates amount to about $4.5 \cdot 10^9$ t, Bosnia and Herzegovina also has a significant biomass potential - the estimate is that the total annual technical energy potential of biomass residues amounts to more than 33 PJ, which is equivalent to more than 3 million tons of Bosnian lignite [10,11,12]. In the developed countries of the world, in addition to the use of biomass, the burning of waste for the purpose of obtaining electrical and thermal energy with minimal negative impact on the environment is very popular. Namely, the partial use of biomass replaces a certain amount of coal in the production of electricity and heat, reduces the amount of harmful gases, primarily CO_2, because about 98% of the total CO_2 emission at the world level originates from the burning of fossil fuels, and 30% to 40% from and CO_2 emissions are produced by burning coal [13]. Every year, burning coal produces more than 14 billion tons of CO_2, which is released into the atmosphere, most of which is generated during the production of electricity [14]. In the paper [15], it is stated that the negative greenhouse effect is mainly contributed by CO_2 with a share of over 55%. Therefore, obtaining specific scientific and socially useful data on the possibilities of such application of domestic resources (combination of the use of coal and waste woody biomass in the co-firing process) represents a more than sufficient motivational basis for research - see also [10,16,17].

II. FUEL TEST MATRIX, TEST REGIMES AND LAB-SCALE FURNACE

Fuel Test Matrix: Laboratory research pulverized-fuel combustion technology was carried out for mixtures primary fuels. Table 1 shows the designations of the basic fuels and their basic characteristics. Those primary fuels are:

- K1, a mixture of brown coals from Kakanj, Breza and Zenica mines in the ratio by mass of 70:20:10, respectively - the mixture was formed in laboratory conditions after drying and grinding the coal components.
- K2, brown coal mixture extracted from unit 6 plant at Kakanj Thermal Power Plant - grinds created by mixing several components of brown coals that are normally burned at Kakanj Thermal Power Plant, e.g. from mines: Kakanj, Breza, Zenica, Gračanica, Livno and Nova Bila.
- WB, waste woody biomass, sawdust - 50:50 mixture of beech and spruce.
- M, Miscanthus, fast growing energy crop. Miscanthus (M) and waste woody bio-mass (WB) were ground in a laboratory mill after drying.

Table 1. Basic characteristics of primary fuels, working/delivery condition [18].

Fuel	Brown coal, K1	Brown coal, K2	Woody biomass, WB	Miscanthus, M
Moisture, %	11.29	12.04	41.82	12.33
Ash, %	41.38	36.98	0.39	4.28
Volatiles, %	26.86	29.90	48.98	71.40
Fixed C, %	20.38	20.94	8.83	11.99

Combustible, %	47.32	50.98	57.80	83.39
Carbon, %	31.89	35.42	28.79	42.60
Hydrogen, %	2.71	2.64	3.54	4.79
Sulphur, total, %	2.47	2.46	0.09	0.15
Nitrogen, %	0.64	0.62	0.11	0.11
Net, LHV, kJ/kg	12,170	13,198	9,155	14,090

By mixing brown coal and some types of biomass in the appropriate ratio by mass, three fuel mixtures were formed, which, like brown coal mixtures, were subjected to combustion with defined conditions. These conditions include the appropriate process temperature, the total coefficient of excess air for combustion and the staged supply of that air to the combustion chamber (*air staging*), Table 2. In all tests, flue gas composition was continuously analyzed, and the mean value of pollutant emission was determined: NO_x, SO_2, CO_2 and CO - the emission of these components was expressed in relation to the reference content at O_2=6% dry. In addition, for certain test regimes, additionally analyzed samples of ash deposits in the furnace and samples of slag and ash at the exit from the furnace were excluded.

The formed and mixed fuel mixture is deposited in the bunker. Due to the different bulk density of the mixture, the operating characteristic of the dispenser is first determined and such fuel is supplied to the combustion chamber from the dispenser. As a reference fuel consumption, the consumption of brown coals K1 and K2 of 1 kg/h was taken. Based on this, the fuel consumption during co-firing tests was determined. Exam regimes lasted 2 hours each.

Table 2. Test fuel mixtures and settings of test regimes [18].

	Air staging, λ_1/λ=0.95/1.15	
	1250 °C	1450 °C
No.	Designation and composition of the fuel mixture by mass	
1.	K1	K2
2.	K1:WB:M=85:8:7	K2:M=93:7
3.	K1:WB:M=75:15:10	K2:WB=85:15
4.	K1:WB=75:25	K2:WB=75:25

Lab-scale furnace [10], Fig.1: Entrained electrically heated tube reactor, located in the laboratory of the Faculty of Mechanical Engineering Sarajevo is used for the tests. The lab-scale furnace allows testing the characteristics of combustion of various fuels at different technological conditions. In short, the plant is designed to operate at a wide temperature interval to 1560 °C and in conditions of different amounts and distribution of basic fuel and combustion air, including the ability to test reburning using basic fuel and additional solid or gasses fuels. The research provides data on combustion efficiency, the deposit intensity and the characteristics of deposits from the reaction zone are obtained, as well as slag and ash at the reactor outlet. The emissions of flue gas components are measured: O_2, CO, CO_2, NO, NO_2, NO_x and SO_2.

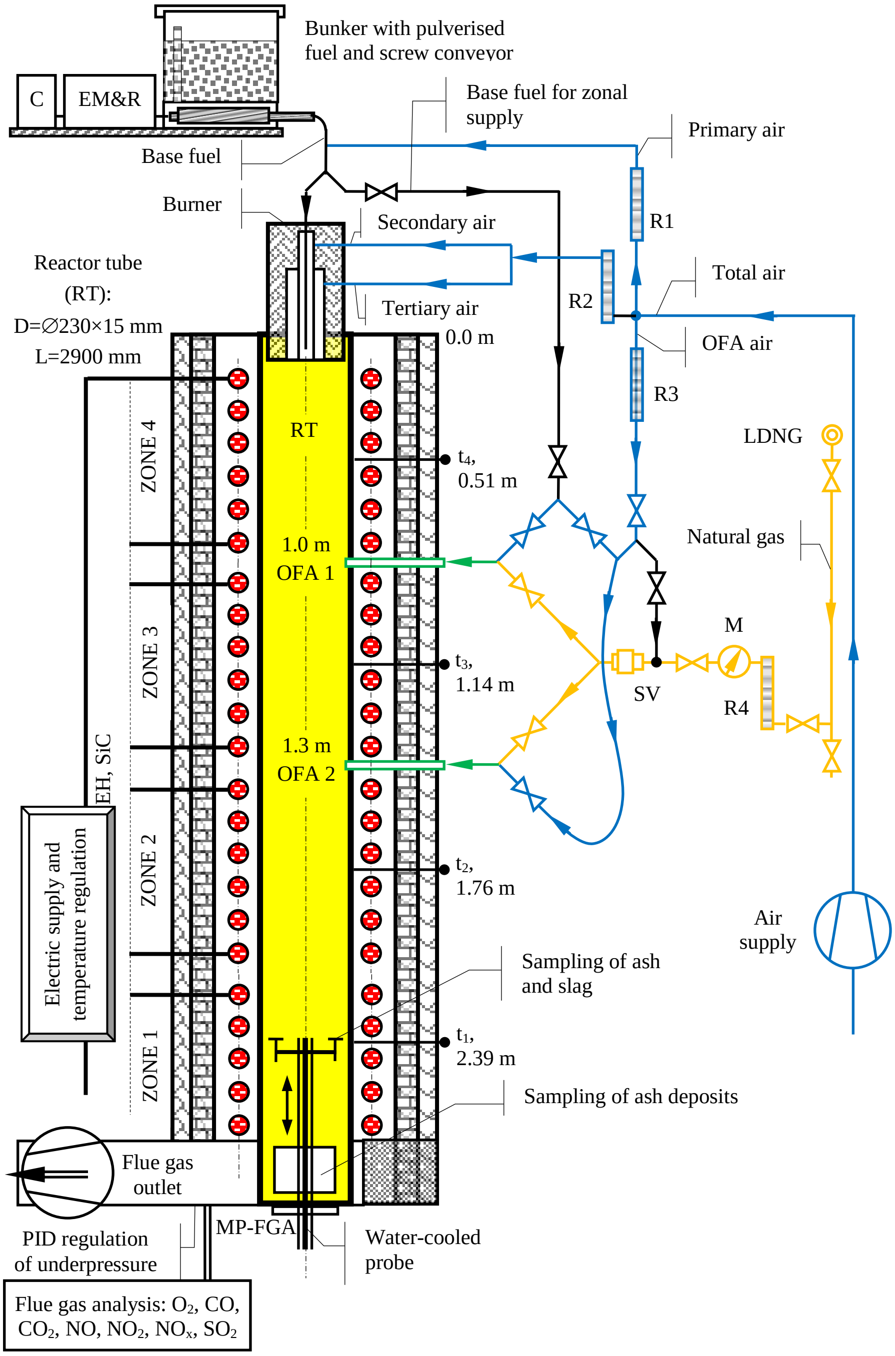

Figure 1. Principal scheme of part of the lab-scale furnace with indicated staging introduction of combustion air [10].

III. RESULTS AND DISCUSSION

III-1. Temperature 1250 °C

Basically, this process temperature corresponds to the pulverized-fuel combustion te-chnology with dry bottom furnace. Fig. 2 shows the results of NO_x and SO_2 emissions during the co-firing of different types and proportions of biomass with a mixture of brown coal K1. Due to the high content of sulfur in coal (S=2.47%) and the relatively low temperature of the process, which favors a better binding of sulfur to the alkali from the ash, the SO_2 emission is at the expected level in the range of 3,500 to 4,000 mg/m_n^3 at 6% O_2 dry. This is, due to the process temperature, a significantly lower SO_2 emission compared to the SO_2 emission in the regular operation of block 6 of the Kakanj Thermal Power Plant, where pulverized-fuel combustion technology with slag tab furnace (t>1300 °C) was applied and where this SO_2 emission is usually above 6,000 mg/m_n^3 at 6% O_2

dry. In addition, there is no significant change in SO_2 emission considering the change in the type and content of biomass in the mixture with coal.

The emission of NO_x during co-firing is at the emission level during the combustion of the K1 coal mixture, i.e. at the level of 670 mg/m_n^3 at 6% O_2 dry. Compared to the current NO_x emission at block 6 of the Kakanj Thermal Power Plant, this emission is also lower by 130 mg/m_n^3 on average, mainly due to the lower combustion temperature.

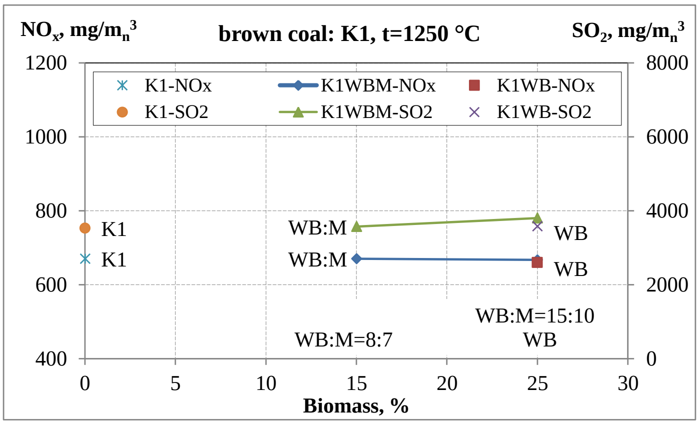

Figure 2. NO_x and SO_2 emissions for the brown coal K1, woody biomass and Miscanthus.

Primarily due to a relatively lower combustion temperature, but also due to a significant deviation in the quality of brown coal grinding K1 obtained in laboratory conditions, quite high CO emission values were measured, Fig. 3. In particular, this emission during the combustion of K1 coal is 238 mg/m_n^3 at 6% O_2 dry - the content of brown coal grinding fractions that passed through the 90 µm sieve is less than 26%, while the fraction of granulation fractions between 1 and 2 mm is 8.35%. The diagram also shows that the CO emission increases slightly with the increase in the proportion of biomass in the mixture with coal. This phenomenon can be explained by the higher proportion of volatiles in both types of biomass, as well as by the larger granulation of component fuels, milled coal and biomass. Namely, in such conditions, with an increasingly significant share of volatiles and larger fuel particles, for more complete combustion it is necessary to provide as long a path and as long combustion time as possible. However, this CO emission trend still corresponds well to the NO_x emission trend for all observed fuel mixtures - see also [19,20].

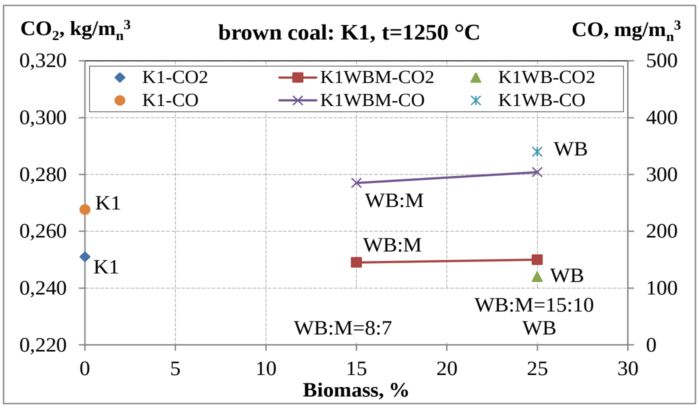

Figure 3. CO_2 and CO emissions for the brown coal K1, woody biomass and Miscanthus.

Figure 4 shows samples of ash deposits from the furnace as well as samples of slag at the exit from the furnace created during co-firing regimes of brown coal and different types and proportions of biomass in the mixture. All deposit samples from the furnace are loose and easily removed from the surface of the tablet due to gravity. And all the slag samples are in a loose state without the appearance of initial particles that have been fused. Taken together, in these conditions of co-firing, there is no appearance of ash flaking in the firebox. As a result of the above regarding the increased CO emission, an increased content of unburnt carbon in the slag was also detected, unburnt carbon content UBC<4%. With the possibility of achieving a better quality of milled fuel and more favorable combustion conditions in real operation, this deficiency in terms of combustion efficiency is reduced to a significantly lower level, especially in the case of combined pulverized-fuel combustion with an additional afterburner grid.

Figure 4. Samples of deposits and slag during co-firing of biomass with coal K1 - see also [21].

III-2. Temperature 1450 °C

In contrast to the previous case, this process temperature basically corresponds to the pulverized-fuel combustion technology with slag tab furnace. In this regard, Figure 5 shows the results of NO_x and SO_2 emissions during co-firing of different types and proportions of biomass with brown coal K2. Considering that the temperature of the process is high, consequently the binding of sulfur to the alkali from the ash is also lower, which with a rather high content of sulfur in the basic mixture of brown coal K2 (S=2.46%), generates SO_2 emissions at the expected high level and in the range of 6,000 to 6,400 mg/m_n^3 at 6% O_2 dry. Nevertheless, these are slightly lower SO_2 emissions compared to the same emission during the combustion of the K2 brown coal mixture, where this emission is at the level of around 6,800 mg/m_n^3 at 6% O_2 dry. As for the NO_x emission, it can be noted that this emission during co-firing is in the range between 700 and 740 mg/m_n^3 at 6% O_2 dry, which is somewhat lower compared to the NO_x emission measured during the combustion of a mixture of brown coals e_{K2}=750 mg/m_n^3 at 6% O_2 dry - in real terms in the operation of block 6 of the Kakanj Thermal Power Plant, that emission is in the range of 750÷850 mg/m_n^3 at 6% O_2 dry. Therefore, the co-firing of coal and biomass practically does not reduce the level of NO_x emissions, or the reduction is very slight compared to the combustion of only brown coal - see also [19,20].

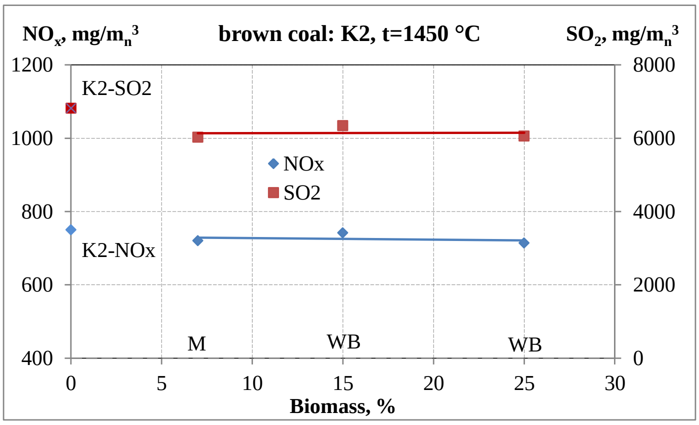

Figure 5. NO_x and SO_2 emissions for the brown coal K2, woody biomass and Miscanthus.

The fairly low CO emissions (<150 mg/m_n^3 at 6% O_2 dry) are due to the high combustion temperature expected in all test regimes, Fig. 6. At the same time, it is noticeable that the CO emission increases with the increase in biomass content in the mixture with coal. This phenomenon can be linked to a significantly higher content of volatiles in the biomass (WB has almost 50%, and M over 70%) compared to K2 coal (<30%), as well as to the grinding quality of certain primary fuels in the mixture - at both types of biomass have a significantly higher content of larger slag fractions compared to brown coal. E.g. the share of brown coal fractions that passed through the 90 µm sieve is 50.41%, while it is 13% for M and only 5% for WB. However, this emission trend also corresponds well to the NO_x emission trend for all test mixtures. Further, during co-firing with biomass, the net emission of CO_2 decreases, proportionally to the content of biomass in the mixture.

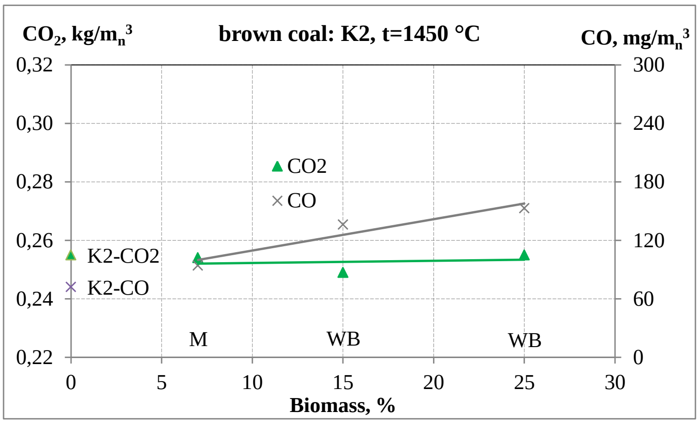

Figure 6. CO_2 and CO emissions for the brown coal K2, woody biomass and Miscanthus.

In this set of test regimes, samples of ash deposits from the furnace as well as samples of slag at the exit from the furnace were excluded, Fig. 7. In this case, the ash deposit is always in a molten state and upon cooling it creates a hard and hard-to-separate deposit from the surface of the ceramic tablet, which in laboratory research represents the uncooled surface in the furnace. In all samples of slag from the bottom of the hearth, a significant proportion of larger fused pieces is visible. From the above, it can be concluded that the fuel in question, from the aspect of ash properties, can be burned efficiently with unhindered removal of slag in a liquid state - the spill temperature of brown coal ash K2 is 1350 °C. It is clear that the appearance of flaking is possible in this case. The carbon content in the deposit is on average almost 0%, and in the slag below 0.5%.

Figure 7. Samples of deposits and slag during co-firing of biomass with coal K2 - see also [21].

IV. CONCLUSION

The obtained results and findings from this research clearly show that waste wood biomass and Miscanthus, as a fast-growing energy crop, are suitable and promising for application with the aim of decarbonizing the energy sector during the implementation of the energy transition. It has been shown that under defined combustion conditions it is possible to use both types of biomass practically without hindrance and up to 25% of the mixture with brown coal. As CO_2 neutral fuels, the use of these types of biomass generally reduces the net CO_2 emission in proportion to its share in the mixture. In this particular case, it was shown that the co-firing of these fuels can be performed in different temperature conditions that correspond to combustion technologies with different ways of removing slag from the furnace. In addition, the efficiency of the primary energy conversion process from fuel at a combustion temperature of 1250 °C in real conditions will be higher due to the existence or possibility of installing an afterburner grid. The contribution to the improvement of the efficiency of the co-firing process in real operation certainly enables a better quality of mechanical fuel preparation, i.e. the possibility of grinding fuel to a more favorable granulation compared to a laboratory mill. The emission of nitrogen oxides during co-firing, in both cases, is at the level of emissions during the combustion of a mixture of brown coal and practically does not depend on the content of biomass in the mixture. The SO_2 emission is generally high and depends significantly on the combustion temperature, and practically very little on the biomass content in the mixture with brown coal. Namely, the content of total and combustible sulfur in coal is quite high.

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