

# Experimental Research on The Co-firing of Mixtures of Lignite, Waste Woody Biomass and Miscanthus in The Direction of Energy Sector Transition

Nihad Hodzic and Kenan Kadic

## ABSTRACT

Decarbonization of the energy sector is a necessary but long-term process. It includes at least partial substitution of fossil fuels using renewable and alternative fuels. However, this substitution, apart from not always being possible, is often accompanied by limitations and unknowns. Those unknowns are dominantly related to the possibility of establishing stable, highly efficient and low-waste combustion as a fundamental process of primary energy conversion from fuel. Such situations are very common considering the necessity of decarbonization in a very large number of fossil fuel-based energy plants, especially coal-based ones. The possibility of establishing an energetically, economically and environmentally acceptable combustion process is a function of a number of variables, of which the collective properties of the fuel, including the ash from that fuel, are dominant in this sense. With the motive of a scientific contribution to the energy transition, and with the aim of obtaining new knowledge about the characteristics of the combustion of lignite coals with different types of biomass, a set of laboratory research was carried out. Various mixtures of lignite, waste woody biomass and Miscanthus as a fast-growing energy crop were subjected to combustion. With a change in the composition of the fuel mixture, the tests were performed at a process temperature of 1250 °C and with a staged supply of combustion air. With these combustion conditions, the emission of undesirable components into the environment, the efficiency of combustion and the ash estimated tendency of fouling of the boiler heating surfaces were determined. It has been shown that even with co-firing at a temperature of 1250 °C, it is possible to establish an efficient process with an acceptable content of unburnt carbon in the slag (unburnt carbon content, UBC<4%) as well as CO emissions ( $e_{CO} \leq 340 \text{ mg/m}_n^3$ ), a relatively low emission of nitrogen oxides  $e_{NOx} \leq 670 \text{ mg/m}_n^3$ . Also, the process proved to be well controlled from the aspect of possible ash slagging in the furnace. The net emission of CO<sub>2</sub> decreases in proportion to the share of biomass in the mixture, while the emission of SO<sub>2</sub> is high, at the level of  $e_{SO2} \leq 2500 \text{ mg/m}_n^3$ .

**Keywords:** Ash, biomass, coal, combustion, emissions.

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## I. INTRODUCTION

Decarbonization of the energy sector is a necessary imperative. Substitution of fossil fuels with renewable and alternative fuels is one of the ways to meet the increasingly expensive demands of the market. This need is particularly pronounced in the field of thermo-energetics, which is still based on the use of coal as a carrier of primary energy. Due to the pronounced complexity of the implementation, the energy transition from fossil to renewable fuels is happening gradually because it is primarily necessary to ensure the stability of the energy system at every moment of operation. Complexity is caused by frequent technical but also limitations related to legal and professional legislation, unknowns in the development of the overall process and the economic aspect. According to the projected dynamics, the transition process will continue for some time, especially in countries

that have yet to enter the transition process of the energy sector on a larger scale, approximately two to three decades - Bosnia and Herzegovina (BiH) is such an example of a country. In order to replace fossil fuels in the foreseeable future, and to carry out the transition of the energy sector in a sustainable manner, the focus of research is on environmentally acceptable fuels with a further increase in the efficiency of the use of primary energy. The category of abundant and promising renewable fuels primarily includes biomass, either as waste from agricultural, forestry or wood-processing activities. In this regard, research into the possibility of co-firing of coal and biomass is very current throughout the world. The development of such combustion technologies belongs to the new Clean Coal Technologies (CCT), which provides a global scientific contribution aimed at mitigating climate change, as defined by the goals of the United Nations Agenda for Sustainable Development 2030 [1], and the

EU Green Agenda and of the Balkans [2], [3]. In connection with the above, including taking into account the fact that the energy system of BiH is based predominantly on domestic coal (about 2/3 of the total electricity produced in BiH is produced as part of thermal power plants on lignite and brown coal), in BiH it is neither realistic nor it is fair to expect a drastic reduction in the use of the most important domestic energy resource, coal, in the near future. This is also discussed in the long-term energy strategy of BiH, where the commitment to the use of coal in the future is clearly shown [4]. On the other hand, the goals of the 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 [5], [6]. On the way to the EU, BiH must respect and adapt to the global market and trends that tend towards clean energy. The European Green Deal initiative is also a great opportunity for the energy transition of BiH, i.e. monitoring the trend of clean energy production, which was also discussed by regional experts in the subject area, [3]. 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 the representation and reliability of production, including a stable price, coal as the primary energy source in thermal power plants will remain an important resource in the energy system 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 monitor and adopt new technologies. Therefore, in addition to a higher degree of utilization, these plants should also be classified as plants with a significantly lower environmental load based on the polluting components in the 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. Technologies with additional renewable fuel/cofiring, e.g. with waste woody biomass (residues after felling and processing, small branches, sawdust) are included in CCT. These fuels are considered renewable and neutral fuels from the point of view of the combustion process and CO<sub>2</sub> production [7], [8]. The emission of CO<sub>2</sub> from conventional coal-fired thermal power plant (TE) boilers in BiH is extremely high - on average above 950 kg/MWh. 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 bio-mass and municipal waste is one of the most promising applications [9]-[11]. 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, BiH 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 [9], [12]. In the developed countries of the world, in addition to the use of bio-mass, the burning of waste for the purpose of obtaining electrical energy with minimal negative impact on the environment is very popular. Substitution of coal with biomass during the combustion process also reduces the amount of harmful gases, primarily CO<sub>2</sub>, because about 98% of the total CO<sub>2</sub> emission at the world level originates from the burning of fossil fuels, and 30-40% of that emission is caused by the burning of coal [13], [14]. Every year, burning coal produces more than 14 billion tons of CO<sub>2</sub>, [15], [16]. In the paper [17], it is stated that the negative greenhouse effect is mainly contributed by CO<sub>2</sub> with a share of over 55%. Therefore, obtaining scientific data on the possibilities of such application of domestic fuels (combination of the use of lignite, waste woody biomass and/or energy crops in the co-firing process) represents a more than sufficient motive for research - see also [12], [13], [16] and [18].

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

### A. Fuel Test Matrix

Different mixtures of lignite coals and two types of wood biomass were subjected to laboratory research on combustion in flight. In addition, these component fuels - Table I:

- L1 - a mixture of two lignite coals from the Šikulje and Dubrava mines and a mixture of brown coals from the Banovići and Đurđevik mines (all mines are in BiH). At the same time, the mass fraction of lignite from the Šikulje mine is 40%, lignite from the Dubrava mine is 35%, and the mixture of brown coals - a total of 25%, i.e. the mass ratio in lignite L1 is:  
L1=Šikulje:Dubrava:(Banovići+Đurđevik)=40:35:25.  
Mixture L1 was formed in laboratory conditions after drying and grinding the coal components.
- L2 - a mixture of two lignite coals from the Šikulje and Dubrava mines (BiH) in a ratio by mass of 50:50 - and this mixture was formed as well as L1.
- WB - waste woody biomass, sawdust - a mixture of beech and spruce sawdust in a ratio of 50:50.
- M - *Miscanthus*, a fast-growing energy crop from an experimental planting plot in Butmir (BiH). M and WB were ground in a laboratory mill after drying.

TABLE I: BASIC CHARACTERISTICS OF PRIMARY FUELS [19]

Fuel	L1	L2	WB	M
Moisture, %	3.39	3.27	41.82	12.33
Ash, %	41.67	38.28	0.39	4.28
Volatiles, %	30.90	33.64	48.98	71.40
Fixed C, %	23.90	24.79	8.83	11.99
Combustible, %	54.94	58.45	57.80	83.39
Carbon, %	36.69	38.72	28.79	42.60
Hydrogen, %	3.07	2.95	3.54	4.79
Sulphur, total, %	1.65	1.57	0.09	0.15
Nitrogen, %	0.79	0.86	0.11	0.11
Oxygen, %	13.31	15.02	25.29	35.78
HHV, kJ/kg	14,688	14,870	10,846	15,361
LHV, kJ/kg	13,977	14,187	9,155	14,090

L1, L2 - lignite, the data was obtained after partial drying.

WB - woody biomass, M - *Miscanthus*, the data refer to the fresh state.

The main characteristics of L1 and L2 lignite mixtures are high moisture and ash content in the fresh state, low reactivity

vity and low heating value. The key characteristics of both types of biomass are significant moisture content in the fresh state, especially in the case of waste woody biomass, a relatively low ash content and a significant share of volatiles and total combustible substances. A particularly favorable feature of this biomass is its very low content of sulfur and nitrogen.

### B. Lab-scale furnace

Entrained electrically heated tube reactor, located in the laboratory of the Faculty of Mechanical Engineering Sarajevo is used for the tests, Fig. 1 - see and [12], [16], [20], [21].

The lab-scale furnace allows testing the characteristics of combustion of various fuels at different ambient and technological conditions. In short, the plant is designed to operate at a wide temperature interval (from ambient temperature to 1560 °C) and in conditions of different amounts and distribution of basic fuel and combustion air, including the ability to test reburning using both basic and additional solid and gasses fuels, for example natural gas. During the research, data concerning the efficiency of combustion, 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 emission of flue gas components are measured: O<sub>2</sub>, CO, CO<sub>2</sub>, NO, NO<sub>2</sub>, NO<sub>x</sub> i SO<sub>2</sub> - [12], [16].

### C. Test regimes

By mixing lignite coals (L1 or L2) and a certain type of biomass (WB and/or M) in the appropriate ratio by mass, three fuel mixtures were formed, which, like the lignite coal mixtures, were subjected to combustion under appropriate technical and technological conditions. These conditions are primarily related to the appropriate process temperature (1250 °C), which basically corresponds to the pulverized-fuel combustion technology with dry bottom furnace, the total coefficient of excess air for combustion ( $\lambda$ ) and the staged supply of that air to the furnace (air staging,  $\Delta\lambda = \text{OFA} = \lambda - \lambda_1$ ), Table 2. In this way, in the actual operation of the blocks, in TPP Tuzla (BiH) lignite mixtures L1 and L2 are burned, [19].

TABLE II: TEST FUEL MIXTURES AND SETTINGS OF TEST REGIMES [19]

Temperature 1250 °C, Air staging $\lambda_1/\lambda=0.95/1.15$		
No.	Designation and composition of the fuel mixture by mass	
1.	L1	L2
2.	L1:WB=93:7	L2:WB=85:15
3.	L1:WB=85:15	L2:WB:M=80:13:7
4.	L1:M=93:7	L2:WB:M=75:15:10

L1, L2 - lignite, WB - woody biomass, M - Miscanthus

In all tests, flue gas was continuously analyzed, on the basis of which the emission of key flue gas components was determined: NO+NO<sub>2</sub>=NO<sub>x</sub>, SO<sub>2</sub>, CO<sub>2</sub> and CO - the emission of all flue gas components was expressed in relation to the reference content O<sub>2ref</sub>=6% in dry flue gases. In addition, samples of ash deposits in the furnace and samples of slag and ash at the exit from the furnace were excluded and additionally analyzed. Considering the different bulk density of the fuel mixtures, for each of them the characteristic of the dispenser was previously determined so that the measurement results obtained during the research could be correlated with fuel consumption (kg/h), i.e. with the thermal load of the furnace based on the fuel entered (kW), [19].

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 lignite coals L1 and L2 of 1 kg/h was taken. Based on this, the fuel consumption during co-firing tests was determined. Exam regimes lasted 2 hours each.

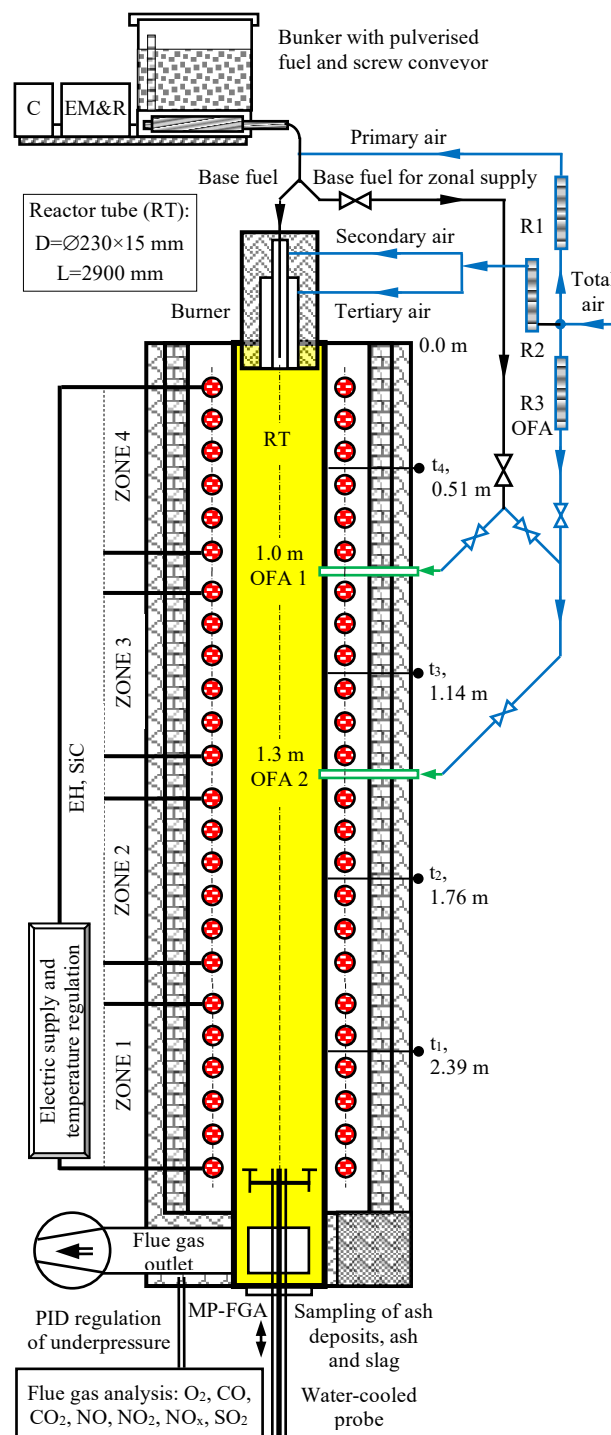


Fig. 1. Principal scheme of part of the lab-scale furnace with indicated staging introduction of combustion air [12].

## III. RESULTS AND DISCUSSION

Research on the characteristics of co-firing on the macro principle of *input - output*, that is, *reactants - products*, was carried out at a process temperature of 1250 °C. During the test, flue gas analysis was continuously performed with the aim of determining the level of emissions of key flue gas components, and samples of ash deposits from the reaction zone, as well as samples of slag and ash at the exit from the furnace, were taken. These samples were subjected to visual, chemical (CA) and ash fusion temperature (AFT) analysis.

## A. Emissions

**Lignite L1** Fig. 2 shows the results of NO<sub>x</sub> and SO<sub>2</sub> emissions during co-firing of different types and proportions of biomass with L1. The emission of NO<sub>x</sub> during co-firing is at the emission level during the combustion of L1, i.e. at the level of 320 mg/m<sup>3</sup> and with small variations depending on the type and content of biomass in the mixture with L1 - this fact has been scientifically known for a long time and was also confirmed in these studies. Additionally, compared to the current NO<sub>x</sub> emission at unit 5 in TPP Tuzla, these emissions are at the same level, which is additional evidence of the adequately established key settings of research at the laboratory plant in relation to real operation. These are, first of all, the mean process temperatures, the coefficient of excess air for combustion and the application of the primary measure of staged supply of air in the furnace. Considering the content of total and combustible sulfur in lignite ( $S_{\text{tot}}=1.65\%$ ,  $S_{\text{com}}=1.08\%$ ), the relatively lower temperature of the process, which favors a better binding of sulfur to alkali from the ash, the SO<sub>2</sub> emission is at the expected level, in the range of 2,300 to 2,500 mg/m<sup>3</sup>. This is a completely comparable emission with the emission in the actual operation at unit 5 in TPP Tuzla. In addition, it can be seen that there is no significant change in SO<sub>2</sub> emission with regard to the type and content of biomass in the mixture with coal - the emission decreases very slightly with the increase in the proportion of biomass in the fuel. So, for example, SO<sub>2</sub> emission during co-firing with 15% of woody biomass in a mixture with L1 is 200 mg/m<sup>3</sup> lower (or only 8%) compared to the emission during combustion of L1 - see also [22]-[24].

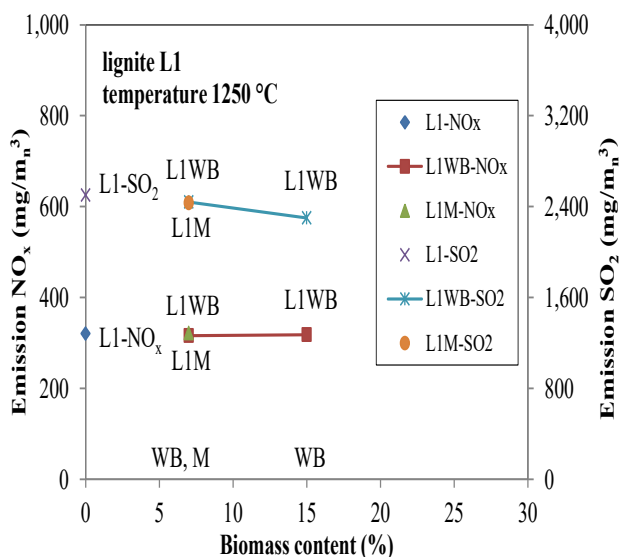


Fig. 2. Emission of NO<sub>x</sub> and SO<sub>2</sub> during co-firing of lignite L1, woody biomass and Miscanthus.

Primarily due to the relatively lower temperature, but also due to the better quality of ground L1, which is extracted behind the drive mills at unit 5 in TPP Tuzla, higher values of CO emissions were measured during co-firing, Fig. 3. That emission during the combustion of L1 is 142 mg/m<sup>3</sup>, while the same emission during co-firing with 15% of waste woody biomass in the fuel is 300 mg/m<sup>3</sup>. At the same time, the content of fractions of ground L1 that passed through the 1 mm and 90 µm sieves is 100% and 26.5%, while this content for fractions of waste woody biomass is 98.9% and 5%, respectively. For this reason, the CO emission increases with the increase in the proportion of biomass in the mixture with L1 - see also [20], [23], [25]-[27].

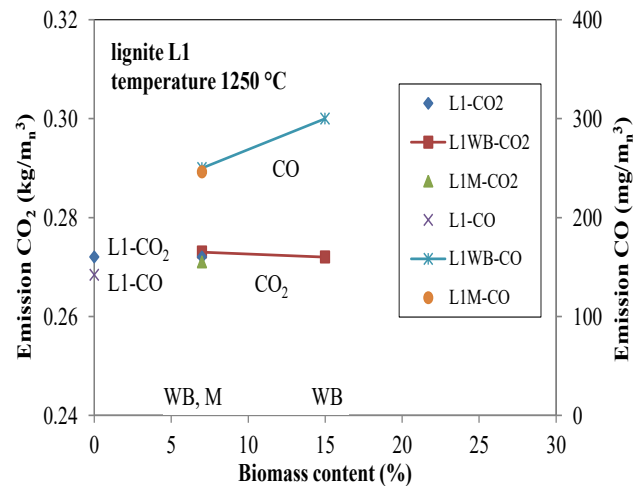


Fig. 3. Emission of CO<sub>2</sub> and CO during co-firing of lignite L1, woody biomass and Miscanthus.

This phenomenon is linked to a higher proportion of volatiles in both types of biomass. In these conditions of an increasingly significant share of volatiles and larger fuel particles, for more complete combustion it is necessary to provide as long a path and time as possible for combustion. However, in this case, the CO emission trend still matches the NO<sub>x</sub> emission trend well for all fuels [26], [27].

**Lignite L2** Analogously to the previous one, Fig. 4 shows the results of NO<sub>x</sub> and SO<sub>2</sub> emissions measured during the co-firing of L2, waste woody biomass and Miscanthus. In this case too, the NO<sub>x</sub> emission during co-firing is at the level of the measured emission during the combustion of the L2 lignite mixture, i.e. at the level of 310 to 320 mg/m<sup>3</sup> and also with small variations depending on the type and content of biomass in the mixture with lignite. Specifically, the NO<sub>x</sub> emission during L2 combustion is 320 mg/m<sup>3</sup>, while the average NO<sub>x</sub> emission during co-firing is 315 mg/m<sup>3</sup>. The total content of sulfur and the content of combustible sulfur in L2 ( $S_{\text{tot}}=1.57\%$ , i.e.  $S_{\text{com}}=0.90\%$ ) with a relatively lower process temperature result in SO<sub>2</sub> emission at the level of 2,360 to close to 2,500 mg/m<sup>3</sup>, which is comparable to the emission in a real operation when burning L2. It has been shown that there is no significant change in SO<sub>2</sub> emission with regard to the type and content of biomass in the mixture with coal - the emission decreases very slightly with the increase in the proportion of biomass in the mixture. So, for example, SO<sub>2</sub> emission during co-firing with a total of 25% biomass (15% woody biomass and 10% Miscanthus) is only



150 mg/m<sup>3</sup> lower (6%) compared to the emission during combustion of L2 for same conditions,  $e_{L2-SO_2}=2490$  mg/m<sup>3</sup>.

As expected, even higher CO emissions were measured during the co-firing of L2 fuel, Fig. 5 - see CO emission values at biomass content in the mixture of 20% and 25%: 320 mg/m<sup>3</sup> and 346 mg/m<sup>3</sup>, respectively. The reason for this is the mentioned less favorable granulation of both types of biomass compared to fuels L1 and L2, and the even higher content of biomass in the mixture with L2 (max. content of biomass in this case is 25%).

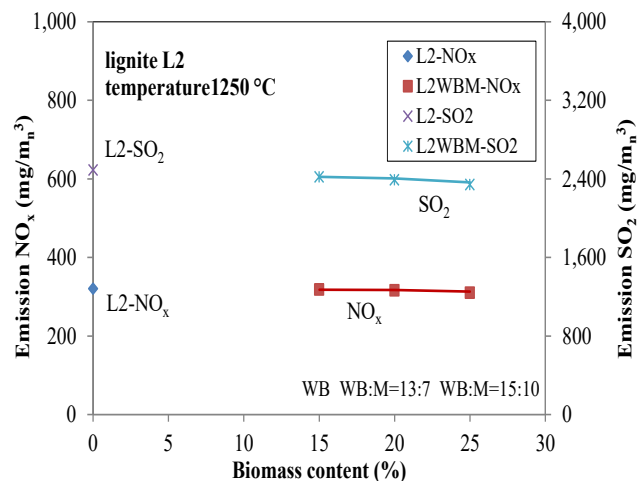


Fig. 4. Emission of NO<sub>x</sub> and SO<sub>2</sub> during co-firing of lignite L2, woody biomass and Miscanthus.

This is certainly connected with slightly lower NO<sub>x</sub> and CO<sub>2</sub> emissions in co-firing tests with a proportion of bio-mass in the mixture  $\geq 20\%$ , Fig. 5. More specifically, during co-firing with 25% of biomass in the fuel (15% of waste woody biomass and 10% of Miscanthus are from char), the emission of NO<sub>x</sub> and CO<sub>2</sub> is 310 mg/m<sup>3</sup> and 0.253 kg/m<sup>3</sup>. It should also be emphasized here that the structure of the Miscanthus grind, compared to the woody biomass grind, is different, it is more needlelike, and that its residue on the 1 mm sieve is 0.83%, while 14.03% of the Miscanthus fraction passed through the 90  $\mu$ m sieve, [19].

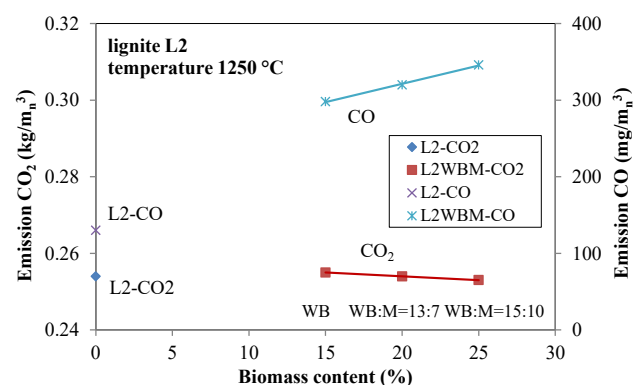


Fig. 5. Emission of CO<sub>2</sub> and CO during co-firing of lignite L2, woody biomass and Miscanthus.

### B. Deposit, Slag and Ash

It is of crucial importance to know the properties of ash from fuel when choosing a concept and designing a furnace in accordance with the appropriate combustion technology for that ash. These findings are also equally important for existing plants in cases where there is a need to change or

expand the type of fuel. In this regard, Fig. 6 shows the results of the chemical analysis of the composition of ash from lignite (L1=100), and the composition of slag resulting from the co-firing of L1 with 7% Miscanthus (L1:M=93:7) and with 15% waste woody biomass (L1:WB=85:15). In general, biomass in a mixture with lignite not only changes the total ash content in the mixture (reduces it), but also changes the chemical composition of that ash. In addition, there is an additional overcomposition of the ash components in terms of location and structure of the solid sample during the combustion process. So it is evident that Miscanthus contributes more to the increase of SiO<sub>2</sub>, while WB increases the Fe<sub>2</sub>O<sub>3</sub> component more - [12], [16], [28]-[30].

As a result of the change in the chemical composition of the ash by adding biomass to the mixture with lignite, the physical properties of the ash and the characteristic ash fusion temperatures also change. In this case, the SiO<sub>2</sub> content, which significantly determines the mentioned ash temperatures, is 54% in lignite, while in WB it is slightly below 7%, and in Miscanthus almost 68% - [12], [19], [31]-[34].

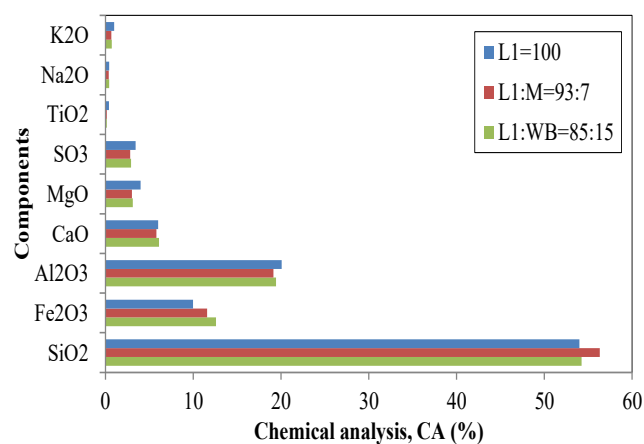


Fig. 6. Chemical composition of ash from fuel L1 and slag during co-firing with different types and content of biomass in the mixture.

In addition, there is also a significant difference in the content of Fe<sub>2</sub>O<sub>3</sub> in the component fuels - this content is almost 10% in lignite, only 1.10% in WB, and 4% in fuel M. The difference in Al<sub>2</sub>O<sub>3</sub> content is even more pronounced - in lignite it is about 20% and in both types of biomass it is significantly below 0.5%. On the contrary, biomass ash has a significantly higher content of CaO, MgO, Na<sub>2</sub>O and K<sub>2</sub>O compounds, especially in WB. All this generally contributes to the reduction of the ash fusion temperatures in the fuel mixture. In particular, a practically equal influence of 7% Miscanthus and 15% of waste wood biomass can be observed - practically equal ash fusion temperatures were obtained for the slag samples, Fig. 7, [19], [34].

Regardless of the type and content of biomass in the mixture with lignite, all samples of ash deposits from the furnace formed during co-firing tests in the given process settings are loose - the deposit is easily removed from the sampler when it is tilted, due to gravity, Fig. 8. And all slag samples are in a loose state and without the appearance of initial fused particles - the slag grains are somewhat larger during co-firing compared to lignite combustion. Overall, under these conditions of burning, there is no fear of ash slagging in the furnace, Fig. 8, [19], [35].

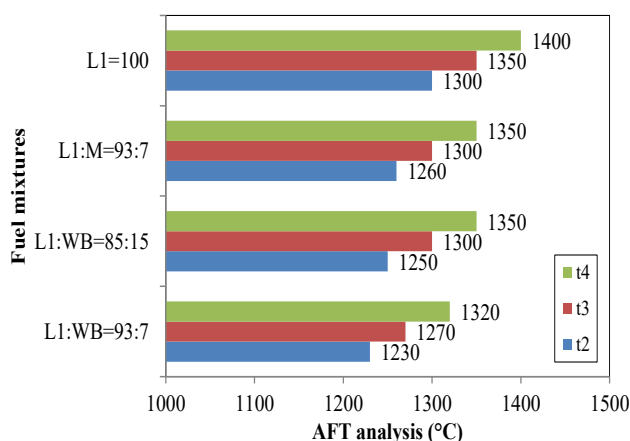


Fig. 7. Ash fusion temperatures (AFT) from lignite L1 and slag during co-firing of lignite with different types and content of biomass in the mixture; t<sub>2</sub> - softening, t<sub>3</sub> - hemisphere, t<sub>4</sub> - flowing.



Fig. 8. Samples of deposits and slag during co-firing of lignite with different types and content of biomass in the mixture - see also [26] and [29].

Regarding the efficiency of the combustion process, viewed through the content of combustible materials in the slag and ash samples at the exit from the furnace, the research results show that it is possible to establish a practically acceptable combustion, Fig. 9. This primarily shows the measured very low carbon content, or even zero, in deposit samples from the furnace.

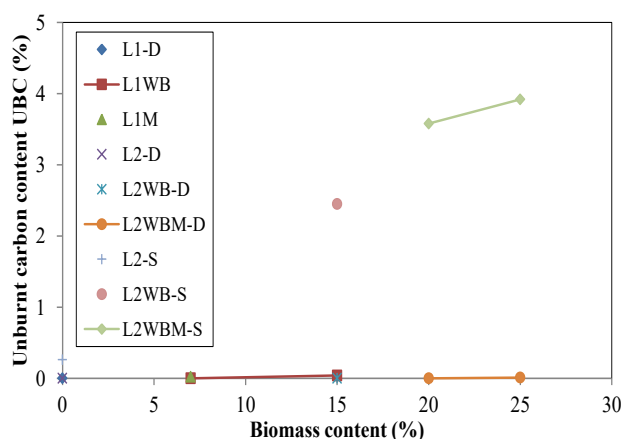


Fig. 9. Unburnt carbon content (UBC) for samples of deposits and slag during co-firing of lignite with different types and content of biomass in the fuel mixture.

Somewhat higher values of carbon content measured in slag during co-firing tests with  $\geq 20\%$  biomass in the mixture indicate that in the treated combustion conditions the combustion path is insufficiently long for larger fuel particles, specifically biomass, i.e. that the afterburning phase is not efficient enough. In real operation conditions, this lack of the process can be solved, e.g. with an additional grate for afterburning process.

#### IV. CONCLUSION

The knowledge obtained and the results of these studies clearly indicate that renewable and CO<sub>2</sub> neutral fuels: waste woody 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 conditions of co-firing, the unhindered use of both types of biomass and up to 25% of the mixture with lignite is possible. As CO<sub>2</sub>-neutral fuels, the use of these types of biomass generally reduces the net CO<sub>2</sub> emission in proportion to its share in the mixture. In this case, it was shown that the co-firing of these fuels can be carried out smoothly with an acceptable energy efficiency at a process temperature that basically corresponds to the pulverized-fuel combustion technology with dry bottom furnace, which is widely used (1250 °C). 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. An additional contribution to improving the efficiency of the co-firing process is related to the level of quality of mechanical fuel preparation, i.e. the fineness of grinding solid fuels into smaller fuel fractions. The emission of nitrogen oxides during co-firing is at the level of emissions during the combustion of the basic lignite mixture and does not depend on the type and content of biomass in the mixture. The SO<sub>2</sub> emission, although relatively high, is favorable and dominantly depends on the combustion process temperature and sulfur content, especially combustible, in the basic fuel - in lignite, and practically insignificantly on the type and content of biomass in the mixture with lignite. Namely, the content of total and combustible sulfur in coal is quite high. Although the biomass content in the mixture with lignite directly changes the chemical and physical properties of the total ash in the mixture, the research results clearly show that the co-firing of these fuels can be carried out smoothly under the established conditions and from the aspect of the behavior of the ash from the mixture in the process. The presence of these two types of biomass does not worsen the process in terms of slagging/fouling of the boiler heating surfaces. More precisely, all solid samples of ash deposits removed from the combustion zone, as well as all samples of slag and ash at the exit from the furnace, are in a loose and highly dispersed state without initial fused particles, which are a pre-requisite for the intensification of unwanted contamination of heating surfaces.

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- *Waste to energy in Adria region for sustainability improvement*,

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## CONFLICT OF INTEREST

Authors declare that they do not have any conflict of interest.

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