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MODELING OF COAL-BASED COMPOSITE BRIQUETTES IN ORDER TO REDUCE SULFUR EMISSIONS INTO THE ATMOSPHERE

Rusmir Razić[1], Nedzad Alić [2]

ABSTRACT

The tendency to abolish, to obtain heat from coal in order to reduce atmospheric pollution, leads to the closure of coal deposits. The alternative for obtaining heat, especially in the category of heating smaller residential buildings, with wood pellets, although acceptable from an ecological point of view, has its drawbacks, if one takes into account the scale of the required amount of energy and the role of the forest in purifying the air. Wood pulp and coal as basic energy carriers have hydrocarbon compounds. So, in both cases COx and NOx gases appear as gaseous products. The difference is in their scale. Unlike wood, coal also contains sulfur compounds, which makes it an environmentally unacceptable fuel. By adding a certain amount of wood pulp and additives to the coal mass, in this work, pyrophyllite shale, the impact on the energy and ecological aspects of heat release of such a complex fuel mixture was investigated. The ecological aspect is accentuated through the release of sulfur from coal. The mixture was subjected to the briquetting process, and the obtained samples were tested with relevant parameters, primarily the obtained lower heat value and sulfur content (SOx) in these products. The obtained results are very optimistic with both parameters mentioned above and can be a guide for further research for this idea.

Key words: coal, wood sawdust, briquette, calorific value, sulfur, ecology.

1. INTRODUCTION

The basis of the research problem is reflected in the question: does stopping (banning) the use of coal in a specific group of consumers completely solve the problem of air pollution at the local and global level. Coal, as an energy source, is used repeatedly, and among other things, in less developed countries, a significant amount is used to heat smaller residential units. On the other hand, there is an expressed tendency to abolish, to obtain heat from coal in order to reduce atmospheric pollution, which in turn leads to the closure of coal deposits. The alternative for obtaining heat, especially in the category of heating smaller residential buildings, with wood pellets, although acceptable from an ecological point of view, has its drawbacks, if one takes into account the scale of the required amount of energy and the role of the forest in purifying the air.

The most common solution offered as a replacement for coal in the aforementioned category is biomass, primarily wood or its pellets as a finished energy product. Although this mass during combustion has a significant reduction in the emission of primary gases that affect the reduction of air pollution, it is necessary to take into account the fact that the primary improvement can consequently and in the long term have a completely different result. Namely, the excessive exploitation of wood mass reduces the total amount of forest wealth, which in turn represents a natural "filter" of air, so the forest is said to be the lungs of the Earth. Therefore, the hypothesis of replacing the type of energy source put forward in this way does not give certainty in obtaining a good result of reducing pollution and impact on general climatic conditions.

The topicality of the research problem is the consideration of one of the possibilities of using coal as an energy source with reduced environmental risk (impact on the environment).

[1] MA in mining engineering, RMU Gračanica, Bosnia and Herzegovina
[2] Associate professor, Faculty of mining, geology and civil enginering University of Tuzla nedzad.alic@untz.ba

The aim of the research is:
- Obtain a composite coal pellet with a reduced emission of pollutants into the atmosphere,
- Reduce the consumption of wood mass for the heating needs of smaller consumers,
- Ensure the continuation of coal exploitation with acceptable ecological standards,
- By modulating the content and type of coal additives when making briquettes, it can significantly influence, during combustion, the reduction of emission gases into the atmosphere.

2. BASICS, METHODS AND MATERIALS

The basic postulates of the hypothesis are related to two processes: the burning of solid fuels and the preparation or physical form of the combustible mass.

The equipment used for all actions during the research and the applied standard are as follows: - Preparation of input components and preparation of briquettes: crushing of materials: jaw and hammer laboratory crusher, balance of accuracy 0.01 gram, type dryer, laboratory shaker with a series of sieves with square opening (mm), laboratory homogenizer and laboratory extruder press for making briquettes.
-Measuring procedures and devices for establishing the parameters of the obtained experimental briquettes: elemental analysis of input components and experimental briquettes was done with an elemental analyzer EA3000, and the heat value was determined with a calorimeter system C 5000 (tables 2, 3, 4 and 5).

Coal sample: the sample was taken from the "Kotezi" coal deposit in the north-western part of the Bugojan coal basin, in a total amount of 60 kg, in the field, from the layer on the surface of this deposit, and was subjected to comminution while at the same time determining the parameters of coarseness reduction on individual laboratory devices, up to a grain size of 1 mm. Sample of sawdust: a sample of pine sawdust weighing 20 kg was taken from the sawmill "Bunta" in Bugojno. Pyrophyllite sample: a crushed sample of the purple variety of pyrophyllite shale from Parsović was used for the tests in the amount of 5000 g. The binder suspension used to make all experimental types of briquettes in this research was a 10% starch solution, type H, manufactured by Helios Domžale, R. Slovenia, in water.

2.1 Research methods

The research model is based on the following principle:
- determination of characteristic or representative (key) indicators in research;
- determination of sample processing methods, namely:

a) method of preparing samples for tests,
b) selection of methods of laboratory tests,

- interpretation and processing of research results,
- research conclusion.

2.1.1 Representative research indicators

Representative indicators of the research are: the lower heating value of briquettes without moisture, the content of total, fuel and darkness in the ash.

2.1.2 Test procedure

For the previously described materials, the elements of the composition of individual briquettes and the procedures for obtaining them in laboratory conditions have been set. In accordance with the aim of the research, it was decided to produce five briquettes with different content, in which the emphasis is on the variable content of additives, while maintaining the same amount of fuel constituents. In this connection, the following relations were formed, with the associated markings: briquette A1: whose content is 100% coal, weight 2000 g, briquette A2: whose content is coal in a mass of 1400 g and wood sawdust in a mass of 600 g, briquette A3: whose coal content in the mass of 1400 g and wood sawdust in the mass of 600 g and pyrophyllite in the mass of 40 g, briquette A4: whose content is coal in the mass of 1400 g and wood sawdust in the mass of 600 g and pyrophyllite in the mass of 120 g, briquette A5: whose content is coal in the mass of 1400 g and wood sawdust weighing 600 g and pyrophyllite weighing 200 g, and the sample of coal used in making these briquettes is marked with the code A0. In the procedure of making individual briquettes, the total mass content of the components is given in table 1.

Table 1. Mass content of individual components in the total sample of individual briquettes

No.	Type of input component	Mass, g				
		A1	A2	A3	A4	A5
1.	sawdust	0	600	600	600	600
2.	coal	2000	1400	1400	1400	1400
3.	pyrophyllite	0	0	40	120	200
4.	starch	1,89	1,28	1,49	1,57	1,65
In total		2001,89	2001,28	2201,65	2121,57	2201,65

The added amount of suspension enabled the next stage, briquetting in an extruder press with a single hole diameter of 6 mm. The obtained green briquettes were air-dried, which completed the laboratory procedure of obtaining briquettes.

The very appearance in the outer shell, but also in the cross-section of the pellet, reflects the characteristics of the components from which it is built. Briquettes obtained from coal give a finer, smoother structure on the outer shell of the briquette cylinder, they are more homogeneous, as can be seen in the general physical sense in Figure 1. Observing, the cross-section of individual briquette mixtures, which is also shown in Figure 1, clearly in the structural characterization, individual parts of the various components that make up this composite can be observed.

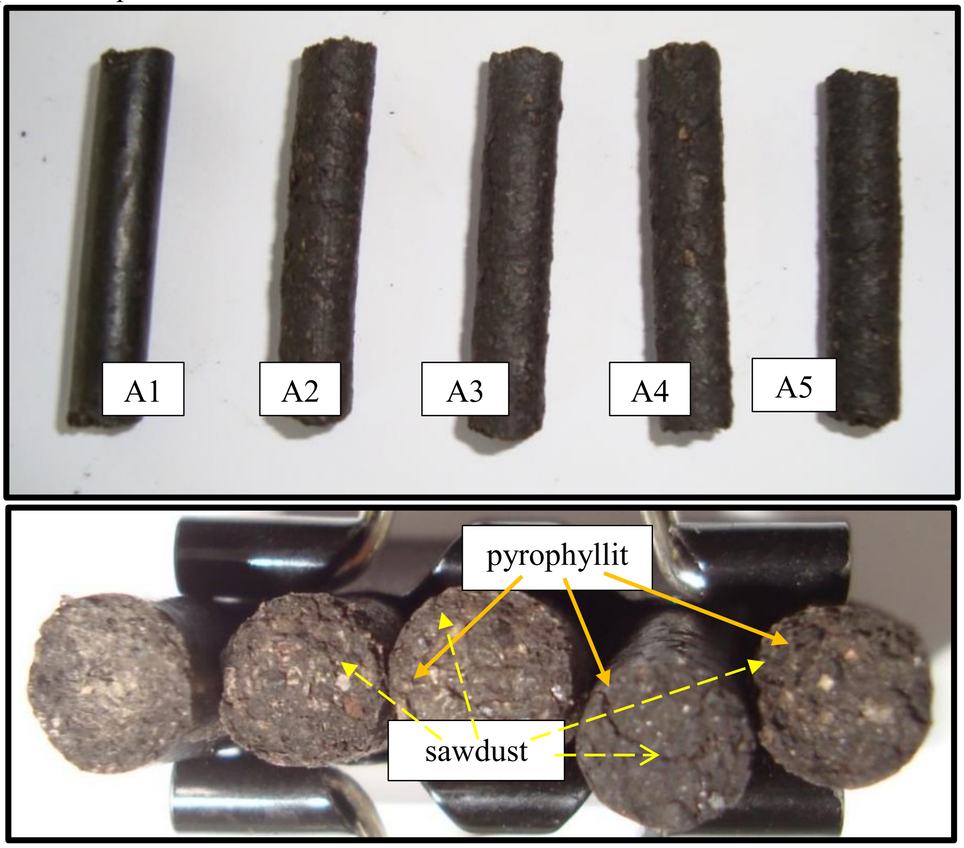

Figure 1. Structural appearance of the briquette and its cross-section

In a general physical sense, the obtained briquettes have satisfactory strength, which can satisfy all conditions of manipulative operations in their use. It is also clear that the briquettes are very hydroscopic, and that they significantly lose their mechanical characteristics when the humidity increases, up to their complete destruction.

3. RESEARCH RESULTS

Table 2, shows the summary results of elementary and technical analysis of coal, and pine sawdust, used as a supplement to coal, used in this research to make briquettes.

Table 2. Results of technical and chemical analysis of coal (sample A0) and pine sawdust, used in making briquettes and tested in RGH Kakanj, without moisture

Type of analysis	Units	Method	without moisture	
			COAL A0	SAWDUST
Ash	%m/m	BAS ISO 1171:2012	29,56	8,04
Combustible substances	%m/m	INS 80625200:2019	70,44	91,96
Volatile substances	%m/m	BAS ISO 5071-1:2014 ; BAS ISO 562:2012	44,87	78,99
Coke	%m/m	INS 80625201:2019	55,13	21,01
Cfl_x	%m/m	INS 80625201:2019	25,56	12,95
Total carbon	%m/m	BAS ASTM D 5373:2016	46,17	48,96
Hydrogen	%m/m	BAS ASTM D 5373:2016	2,92	7,2
Nitrogen	%m/m	BAS ASTM D 5373:2016	0,8	0,15
Oxygen	%m/m	ASTM D 3176:2015	18,91	35,62
GTV	kJ/kg	BAS ISO 1928:2010	17402	18588
DTV	kJ/kg	BAS ISO 1928:2010	16800	17473
Sulfur total	%m/m	BAS ISO 334:2015	3,06	0,02
Sulfur in ash	%m/m	ASTM D 1757:1996	1,42	0
Sulfur fuels	%m/m	INS 80625211:2019	1,64	0,02

The value of the characteristic parameters of the solid residue (ash) of coal combustion and wood sawdust tested in the laboratory of RGH Kakanj and the silicate analysis of pyrophyllite schist are given in table 3.

Table 3. Results of chemical analysis of pyrophyllite schist and coal ash and sawdust

Type of analysis	Method	Units	Coal A0	Sawdust	Pyrophophyllite schist
Content SiO_2	BAS 1009:2003	%m/m	36,58	55,88	65,10
Content Fe_2O_3	BAS 1011:2003	%m/m	16,5	2,69	1,65
Content Al_2O_3	BAS 1013:2003	%m/m	11,64	8,61	18,38
Content CaO	BAS 1014:2003	%m/m	12,54	13,89	2,70
Content MgO	BAS 1015:2003	%m/m	5,34	8,44	1,49
Content SO_3	BAS 1018:2003	%m/m	15,60	1,14	0,58
Content TiO_2	BAS 1012:2003	%m/m	0,22	0,16	0,08
Content Na_2O	ASTM D 6349:2013	%m/m	0,29	5,11	0,23
Content K_2O	ASTM D 6349:2013	%m/m	1,29	4,09	1,77
Content MnO	-	-	-	-	0,02
Content P_2O_5	-	-	-	-	0,06
Content CO_2	-	-	-	-	4,04
Content KH_2O	-	-	-	-	3,90
		Suma	**100,00**	**100,00**	**100,00**

Table 4. Results of technical and chemical analysis of briquettes from experiments, without moisture

Type of analysis	Units	Method	Samples of briquettes without moisture												
			A1	A2-1	A2-2	A2-3	A3-1	A3-2	A3-3	A4-1	A4-2	A4-3	A5-1	A5-2	A5-3
Ash	%m/m	BAS ISO 1171:2012	25,36	20,73	20,63	20,77	21,25	21,24	20,94	24,89	24,62	24,95	25,92	25,58	25,86
Combustible substances	%m/m	INS 80625200:2019	74,64	79,27	79,37	79,23	78,75	78,76	79,06	75,11	75,38	75,05	74,08	74,42	74,14
Volatile substances	%m/m	BAS ISO 5071-1:2014 ; BAS ISO 562:2012	45,28	54,3	54,17	54,42	54,39	54,41	54,23	53,1	53,1	53,12	51,37	51,94	51,74
Coke	%m/m	INS 80625201:2019	54,72	45,7	45,83	45,58	45,61	45,59	45,77	46,9	46,9	46,88	48,63	48,06	48,26
Cfl_x	%m/m	INS 80625201:2019	29,36	24,96	25,21	24,81	24,36	24,35	24,83	22,01	22,28	21,93	22,7	22,48	22,4
Total carbon	%m/m	BAS ASTM D 5373:2016	49,1	50,89	50,93	50,79	50,31	50,31	50,48	47,99	48,14	47,95	49,76	49,95	49,61
Hydrogen	%m/m	BAS ASTM D 5373:2016	3,13	3,31	3,32	3,32	3,29	3,3	3,31	3,13	3,16	3,13	3,11	3,12	3,1
Nitrogen	%m/m	BAS ASTM D 5373:2016	0,87	0,92	0,92	0,92	0,93	0,93	0,93	0,87	0,88	0,87	0,87	0,87	0,88
Oxygen	%m/m	ASTM D 3176:2015	19,73	22,61	22,66	22,57	22,53	22,55	22,61	21,54	21,59	21,55	19,22	19,34	19,38
GTV	kJ/kg	BAS ISO 1928:2010	18605	18958	18978	18945	18769	18776	18851	17884	17967	17861	18803	18868	18704
DTV	kJ/kg	BAS ISO 1928:2010	17961	18276	18295	18261	18091	18097	18169	17239	17316	17216	18163	18226	18065
Sulfur total	%m/m	BAS ISO 334:2015	3,29	2,2	2,21	2,29	2,49	2,48	2,53	2,71	2,77	2,69	2,53	2,55	2,57
Sulfur in ash	%m/m	ASTM D 1757:1996	1,47	0,66	0,67	0,67	0,81	0,8	0,8	1,14	1,15	1,14	1,41	1,4	1,4
Sulfur fuels	%m/m	INS 80625211:2019	1,82	1,54	1,54	1,62	1,68	1,68	1,73	1,57	1,62	1,55	1,12	1,15	1,17

For all briquettes obtained according to the described procedure and recipes, measurements of indicators of elemental and immediate analysis were performed. Both analyzes were performed on three separately taken samples from each mixture made according to the recipe, i.e. type of briquette, for samples with gross moisture, with moisture in the analytical sample and without moisture, the results of which are given in table 4, in table 5 are the results of the silicate analysis of briquette ash.

Table 5. Results of chemical analysis of briquettes

Type of analysis	Method	Units	Chemical analysis of ash of briquette samples												
			A1	A2-1	A2-2	A2-3	A3-1	A3-2	A3-3	A4-1	A4-2	A4-3	A5-1	A5-2	A5-3
Content SiO_2	BAS 1009:2003	% m/m	37,64	49,43	49,59	49,37	41,85	41,51	41,65	47,07	47,16	46,88	38,59	38,22	38,47
Content Fe_2O_3	BAS 1011:2003	% m/m	13,57	16,37	15,97	15,97	15,57	15,78	15,57	13,17	13,38	13,13	15,77	15,58	15,57
Content $A1_2O_3$	BAS 1013:2003	% m/m	14,34	10,84	11,16	10,84	11,48	11,79	11,79	9,56	9,88	9,88	14,03	13,38	13,7
Content CaO	BAS 1014:2003	% m/m	13,4	10,25	10,2	10,3	12,1	12,05	12,05	11,6	11,4	11,65	12,2	12,55	12,4
Content MgO	BAS 1015:2003	% m/m	4,3	2,95	2,9	3	6,8	6,9	6,7	3,6	3,7	3,6	3,05	3,25	3,1
Content SO_3	BAS 1018:2003	% m/m	14,72	8,22	8,31	8,18	9,68	9,79	9,74	11,73	11,66	11,7	13,94	14,03	13,86
Content TiO_2	BAS 1012:2003	% m/m	0,25	0,3	0,27	0,28	0,21	0,23	0,21	0,25	0,23	0,25	0,21	0,24	0,22
Content Na_2O	ASTM D 6349:2013	% m/m	0,331	0,281	0,266	0,271	0,255	0,261	0,249	0,364	0,333	0,341	0,247	0,259	0,239
Content K_2O	ASTM D 6349:2013	% m/m	1,291	1,279	1,265	1,277	1,207	1,211	1,205	1,305	1,297	1,242	1,202	1,218	1,199

4. DISCUSSION OF THE OBTAINED RESULTS

The analysis of the obtained test results in this paper must take into account the statements of expected deviations in the calculations of the obtained and experimentally measured values of the relevant research indicators. In addition, the following two processes that have a significant impact on the process of obtaining the sample in its final form (briquettes) in the different variants provided for in this research should be mentioned:

- the first refers to standardized methods of determining the parameters of representative quantities of materials that enter the composition of the target composite, for example from the total quantity obtained by homogenization of the material sample, the heat value in the calorimeter (as well as all other indicators) is determined at the quantity of 1 gram, knowing that the materials used are extremely inhomogeneous,
- the second, although accurately measured quantities of constituents in the final form of briquettes (coal, sawdust and pyrophyllite) are introduced into the process, it is almost impossible to distribute these components, regardless of their dosing and mixing method, evenly, in such a way that they are present in each part of the obtained briquette and in all the obtained briquettes.

The problem arises when one wants to define parameter values in measuring devices, which generally take the minimum amount of mass in the analysis. This minimum amount is actually obtained through the laboratory procedure of determining a representative sample. Considering the physical characteristics of the briquettes (shape, state of dimensions, etc.), it is very difficult to obtain a relevant representative sample. The problems just mentioned lead us to first perform a theoretical analysis of the indicators of the obtained products of the agglomeration process, with the fact that we included in the analysis experimentally determined values of the parameters of the input components.

4.1 Analysis of sample contents taken in measuring procedures

It is impossible to establish the aforementioned statement about individual amounts of applied substances in the sample taken for instrumental analysis in absolute terms, neither by analytical nor instrumental methods. For this reason, in this research, a model was applied that has undoubtedly acceptable accuracy in determining the participation of certain substances in the measuring sample (1 gram). Deviations from the absolutely correct proportions of this model, given in the following text, will not be relevant at all in order to significantly change the attitude about the influence on the relevant indicators in the research. The calculation model has the following conditions: that the samples were (and are) taken from individual experiments in which the mass of coal and sawdust was maintained, and the mass of pyrophyllite was changed, and ultimately these samples belong to a set of exactly defined briquettes. For this reason, an analysis of the content of the samples subjected to testing was carried out.

To begin with, the elemental composition of the obtained briquettes was calculated according to the recipes and the characteristics of the input components in the briquettes. All other briquette parameters in the total mass of added components were calculated in the same way. The calculation model is the same for all indicators, and in the following text the general principle of the model for calculating the values of these briquette parameters is given using the example of ash content:

$$P_B = \frac{(P_u \cdot m_u) + (P_D \cdot m_D) + (P_p \cdot m_p)}{m_u + m_D + m_p};\%$$

where is:

- P_p - pyrophyllite ash, (%),
- m_p - mass of pyrophyllite in the mixture, (g),

- P_u - coal ash for briquettes, (%),
- P_D - wood sawdust ash, (%),
- m_u - total mass of coal in mixture A2, (g,
- m_D - total mass of sawdust in mixture A2, g).

It is clear that the total fuel mass in the briquette consists of combustible components of coal and wood, because pyrophyllite does not contain combustible elements in its composition. From this fact, from the total mass introduced into the mixture, the share of combustible materials from sawdust coal in the briquette can be calculated from the following ratio:

$$S_{mb} = \frac{m_{Smu} + m_{Smd}}{m_{Smb}}; (\%) \text{ respectively, } S_{mb} = \frac{m_{Smu}}{m_{Smb}} + \frac{m_{Smd}}{m_{Smb}}; (\%)$$

So, in the briquette, the total quantity of combustible materials, in relative amounts, consists of combustible materials from coal and sawdust, the sum of which gives 100%, as given in the following form.

$$S'_{mu} + S'_{md} = 100\%$$

Therefore, taking the previous ratios, i.e. the relative shares of coal and sawdust in the combustible mass, and the established value of the combustible matter of briquettes, we can calculate the share of individual components in the combustible matter, from the following relationship:

$$S'_{mu} = \left(\frac{m_{Smu}}{m_{Smb}}\right) \cdot 100; \% \text{ and, } S'_{md} = \left(\frac{m_{Smd}}{m_{Smb}}\right) \cdot 100; \%$$

The absolute participation of individual components can then be obtained by multiplying this relative participation with the value of combustible materials in each of the briquette samples.

$$S_{mu} = S'_{mu} \cdot \left(\frac{S_{mb}}{100}\right); \text{ respectively, } S_{md} = S'_{md} \cdot \left(\frac{S_{mb}}{100}\right); (\%)$$

where is:

- m_{Smu} - mass of combustible materials from coal in the briquette, (g),
- m_{Smd} - mass of combustible materials from sawdust in briquettes, (g),
- m_{Smb} - mass of combustible materials in the briquette, (g),
- Sm_b - proportion of combustible mass in the briquette, (%),
- Sm_u - proportion of combustible mass of coal in briquette, (%),
- Sm_{ud} - share of combustible wood mass in the briquette, (%),
- $S'm_u$ - relative share of the combustible mass of coal in the briquette, (%),
- $S'm_{ud}$ - relative share of combustible wood mass in the briquette, (%).

With this condition, it is possible to determine the content of combustible mass from coal in each measured sample of briquettes according to the following formula:

$$SM_U = \left(\frac{S_{UKB}}{S_{UKU}}\right) \cdot SM_B, (\%)$$

where is:

- SM_U - combustible mass of coal in briquettes for sample, (%),
- SM_B - combustible mass of the ith briquette, (%),
- S_{UKB} - total sulfur of the ith briquette, (%),
- S_{UKU} - total sulfur from the coal of the i-th briquette, (%).

By obtaining the value of the combustible mass of coal, it is easy to calculate the combustible mass of sawdust as the difference between this stated value and the total value for an individual sample. This model based on the example of calculating the content of combustible mass of coal and sawdust, and on that basis determining the participation of these two materials through the compilation of theoretically and experimentally obtained parameters is given in the example of A4 briquettes (ie A4-1, A4-2 and A4-3) in table 6.

Table 6. Analysis of briquette content according to combustible materials

Briquette		SM	Suku	Spu	Sgu	Coal	Sawdust
Analytical	A4	75,65	2,18	0,97	1,21	49,51	26,14
Experimentally	A4-3	75,05	2,69	1,14	1,55	61,00	14,05
Experimentally	A4-1	75,11	2,71	1,14	1,57	61,46	13,65
Experimentally	A4-2	75,38	2,77	1,15	1,62	62,82	12,56

Further analysis of the content of these samples taken from the briquettes according to this model that we present was done using ash, again approximating the results obtained from the analytical model, and the results of this analysis for sample A4 are given in table 7.

We obtained individual amounts of ash according to the following forms:

$$P_U = \left(\frac{P_{Bt}}{P_{Be}}\right) \cdot P_{Ut}\,,\ P_D = \left(\frac{P_{Bt}}{P_{Be}}\right) \cdot P_{Dt}\,,\ P_p = \left(\frac{P_{Bt}}{P_{Be}}\right) \cdot P_{pt}\,, (\%)$$

where is:

- P_U - coal ash in the ith briquette, (%),
- P_{Bt} - amount of ash in the analytical sample of the i-th pellet, (%),
- P_{Be} - amount of ash in the measuring sample of the i-th pellet, (%),
- P_{Ut} - amount of ash in the theoretical (analytical) sample of coal in the i-th pellet, (%),
- P_U - coal ash in the i-th briquette, (%).

Table 7. Analysis of briquette content according to ash in the measurement sample

Briquette	P	Coal	Sawdust	Pyrophyllite
A4	24,35	16,82	2,29	5,25
A4-3	24,95	17,23	2,34	5,38
A4-1	24,89	17,19	2,34	5,36
A4-2	24,62	17,01	2,31	5,30

The remaining samples from individual experiments were determined in the same way, and by adding the combustible mass and ash from coal, wood sawdust and pyrophyllite shale, we obtained the essential ratios of these substances, which were entered into the analysis, i.e. measurement in the instrument (e.g. for the heat value in the calorimeter 1 year). The analysis for sulfur was carried out in the same way and the results are given in table 8.

4.2 The effect of pyrophyllite on reducing the emission of sulfur gases in composite briquettes

It is clear that the introduction of materials that have a significantly lower amount of sulfur in their composition, such as wood sawdust and pyrophyllite, reduces the total amount of sulfur in the briquette. According to the tests of the basic components, and it was emphasized in the earlier text, that coal contains both forms of sulfur, and sawdust and pyrophyllite only one form of sulfur. According to this statement, the reduction of sulfur in the briquette results from the mass distribution of the briquette maker. At the same time, the mass distribution must be proportional to the total values entered by the briquette manufacturer and the values established by measuring in the instrument, for all types of sulfur (total, fuel and ash).

Another form or mechanism that can have an influence on the behavior of the mentioned form of sulfur is reflected in the content of pyrophyllite schist. The carbonates present in this shale change to Ca and Mg oxides when burning coal, which have a significant reactive power towards sulfur. In this way, the process of desulphurization with quicklime in coal-fired thermal power plants essentially takes place. During this, as a result of a chemical reaction, the mineral gypsum is formed, which turns into ash. The presence of a larger amount of sulfur in the ash than that obtained from the mass distribution speaks in favor of the fact of the conversion of fuel sulfur into sulfur in the ash. This statement is also observed in the TG analysis, where a loss of mass can be seen at temperatures of 850 ^{o}C, which would correspond to the loss of CO2 from the present carbonates (Ca and Mg).

This fact, in turn, indicates part of the response of the mechanism of action of pyrophyllite in the briquette during combustion to the effect on the behavior of sulfur from coal. Released sulfur from coal and calcium and magnesium oxide from carbonates are reactive, and as a result of their reaction, gypsum is formed. In this way, in addition to the sulfur in briquette ash that comes from non-combustible coal compounds, sulfur is also found that is released by burning. This mechanism can be seen in the research results through an increased amount of sulfur in the ash and a reduced amount of fuel sulfur, i.e. sulfur that is released into the atmosphere during combustion. The fact of the release of crystalline water from the pyrophyllite schist minerals and the possible reactions at the molecular level of these events should not be forgotten either. In addition to all of the above in terms of stating the possibility of reducing the amount of sulfur gases during the combustion of these and similar substances, the structure of the pyrophyllite mineral, which has the power to adsorb certain values into itself due to its fine, open porosity, should be emphasized.

So, the indicator of the influence on the atmosphere from the aspect of this kind of mixture in the briquettes is the mass reduction of the amount of sulfur in the fuel and the mutual relative relationship of the sulfur released after burning the briquettes. Based on the test results from the table, the total reduction of sulfur in relation to briquettes made of coal is calculated in the following table.

Table 8. Total sulfur reduction compared to coal briquettes

Briquette	Coal	Sawdust	Pyrophyllite	DTV , kJ/kg	Suk %	Sp %	Sg %	Reduction Suk, %
A1	100	0	0	17961	3,29	1,747	1,82	-
A2-3	73,06	18,8	8,14	18163	2,53	1,41	1,12	30,04
A2-2	73,94	17,95	8,12	17065	2,57	1,4	1,17	28,02
A2-1	73,31	18,66	8,03	18226	2,55	1,4	1,15	29,02
A4-3	75,05	19,57	5,38	17239	2,71	1,14	1,57	21,40
A4-2	75,11	19,53	5,36	17316	2,77	1,15	1,62	18,77
A4-1	75,38	19,32	5,3	16271	2,72	1,58	1,14	20,96
A3-3	73,6	24,62	1,78	18091	2,49	0,81	1,68	32,13
A3-1	73,36	24,86	1,78	18097	2,48	0,8	1,68	32,66
A3-2	74,25	23,99	1,76	18169	2,53	0,8	1,73	30,04
A5-3	68,27	31,73	0	18295	2,21	0,67	1,54	48,87
A5-2	70,21	29,79	0	18261	2,29	0,67	1,62	43,67
A5-1	72,25	27,75	0	16448	2,23	0,67	1,56	47,53

Let's look at the impact of individual briquette manufacturers on the total, fuel and sulfur in the ash. Figure 2 shows this dependence for coal, Figure 3 for sawdust and Figure 4 for pyrophyllite.

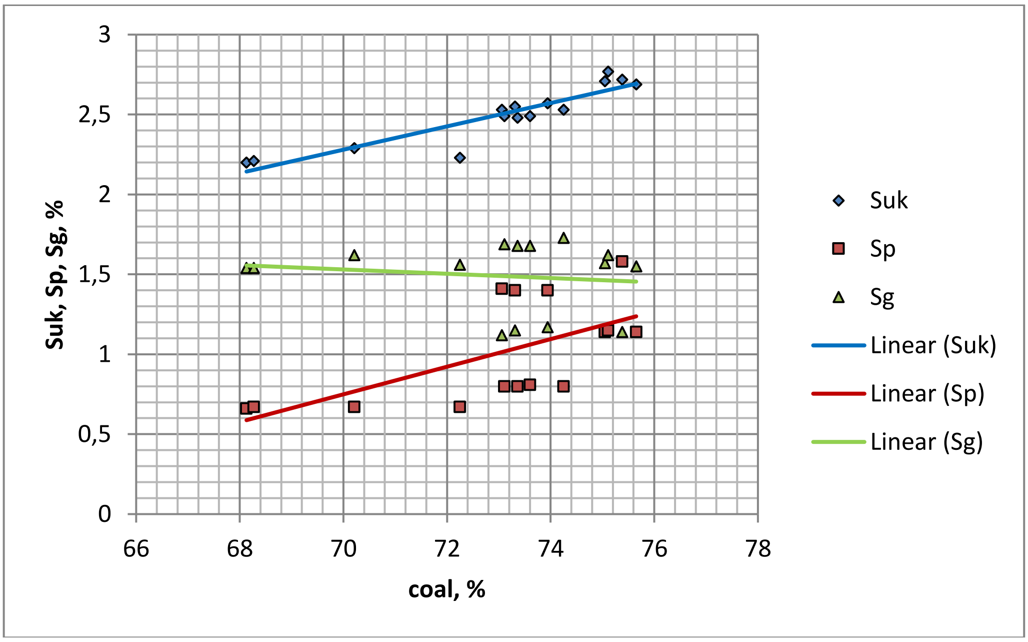

Figure 2. Influence of coal from briquettes on sulfur

According to this figure, coal affects the total sulfur in such a way that with its increased participation in the mixed briquette, the total sulfur and sulfur in the ash increase, while the fuel sulfur decreases very little.

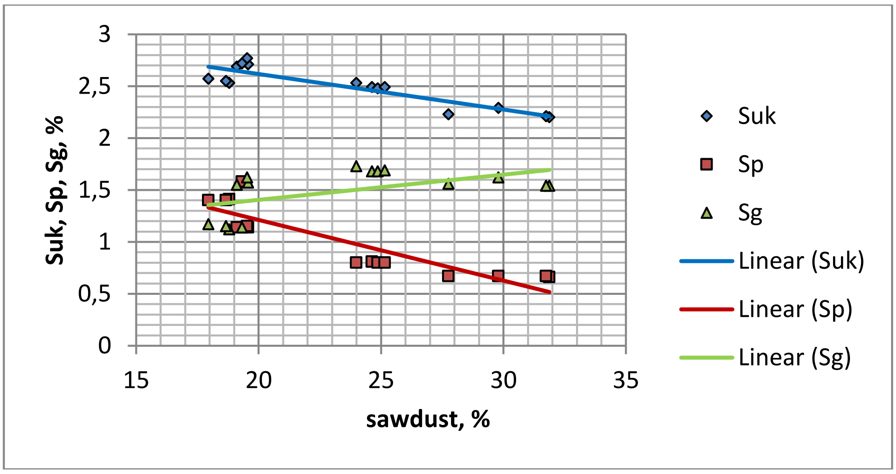

Figure 3. Effect of briquette sawdust on sulfur

From this relationship, it is evident that with the growth of sawdust in the briquette, the total amount of sulfur decreases, as well as the amount of sulfur in the ash, while the amount of fuel sulfur increases.

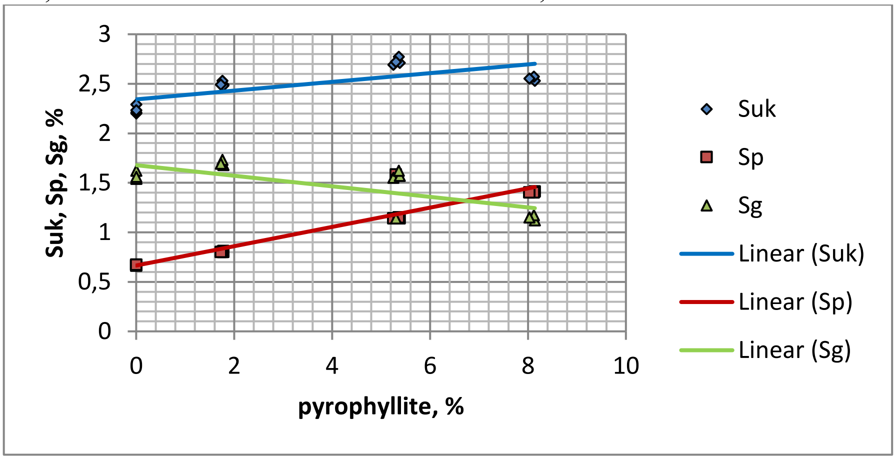

Figure 4. Effect of pyrophyllite from briquettes on sulfur

Increasing the content of pyrophyllite shale in the briquette leads to a slight increase in total sulfur, but a significant trend in the change of sulfur in ash, which is rapidly increasing, and a significant decrease in fuel sulfur. The reduction of the total and individual amounts of fuel and sulfur in the ash is also related to the "dilution" of the same in the coal through the addition of wood sawdust and pyrophyllite, which contain significantly less sulfur. This mass dilution of sulfur is calculated and given in table 9, with the fact that the results of the measured values of the same indicators obtained from the experimental samples are given in comparison.

Table 9.

			Due to dilution			Experimentally		
Briquette	**Coal in briquettes average %**	**Pyrophyllite schist**	Sukt	Sp	Sg	Suk	Sp	Sg
A1	100,00	0,00	3,29	1,470	1,820	3,290	1,470	1,820
A2	70,24	0,00	2,31	1,033	1,278	2,243	0,670	1,573
A3	73,74	1,77	2,43	1,084	1,342	2,513	1,003	1,510
A4	75,18	5,35	2,47	1,105	1,368	2,563	1,063	1,500
A5	73,44	8,10	2,42	1,080	1,337	2,550	1,403	1,147

The ratio of the reduction of all forms of sulfur in briquettes to mass dilution with the addition of wood sawdust and pyrophyllite are given in the diagram of figure 5 for total, figure 6 for fuels and figure 7 for sulfur in ash.

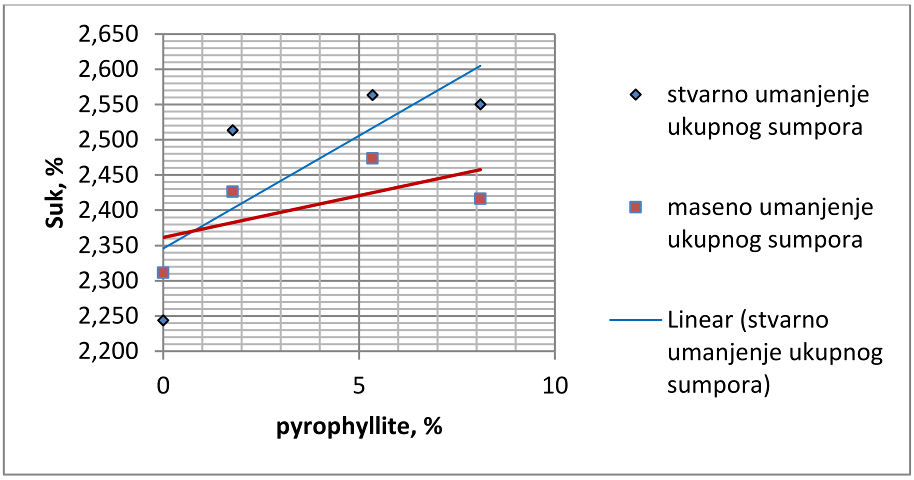

Figure 5. Relationship between mass and experimentally determined total sulfur according to the amount of pyrophyllite shale in the briquette

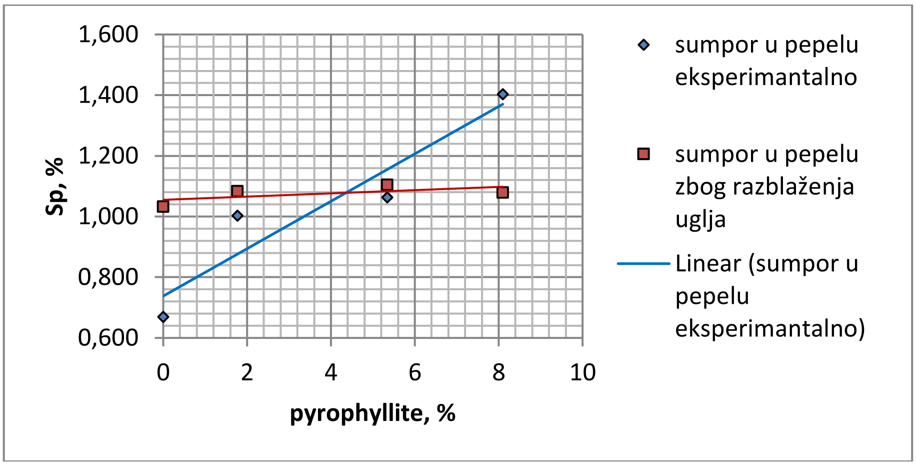

Figure 6. Relationship between mass and experimentally determined total sulfur according to the amount of pyrophyllite shale in the briquette

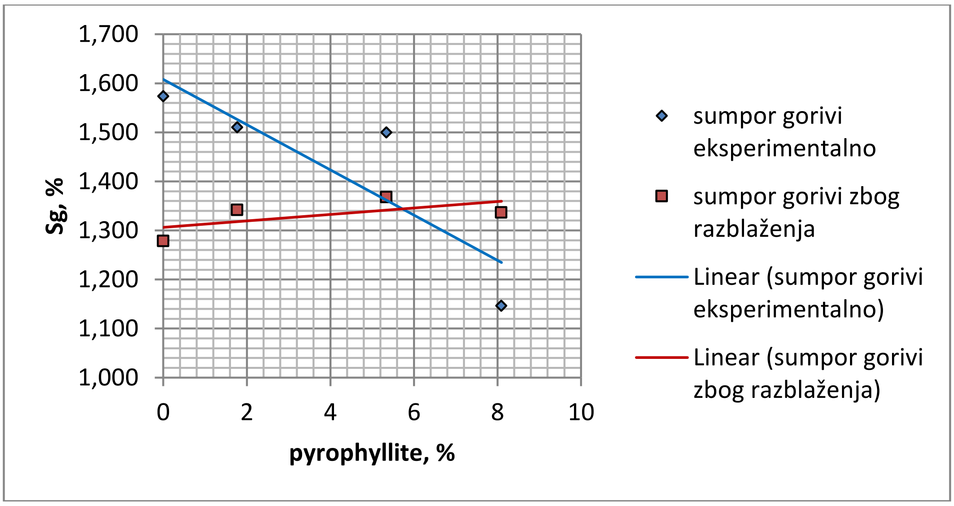

Figure 7. Relationship between mass and experimentally determined total sulfur according to the amount of pyrophyllite shale in the briquette

CONCLUSION

The hypothesis itself is based on the environmental impact of burning coal, primarily on the atmosphere. For this reason, the majority of research is devoted to the emission of gases released during this process. The focus is on sulfur as the primary environmental problem in coal combustion and it is investigated in detail. The recipe of the experimental briquette samples was set in such a way that the fuel materials coal and wood, pine sawdust, always reflected the same meaty part, and pyrophyllite was added to different briquettes with variable mass. A total of five different combinations of this mixture were made in individual quantities of approx. 2.00 kg. For the initial experimental sample, a briquette with 100% coal content was made, and the other four constantly had 1400 grams of coal, 600 grams of wood sawdust and 40, 120 and 200 grams of pyrophyllite shale. Briquettes are made in laboratory conditions. So the analysis required two interdependent steps. In the first step, the analysis of the obtained indicators had a two-fold task: analytical calculation of relevant research indicators based on the given recipe and tested indicators of input components, and analytical calculation of the content of the samples subjected to measurements.

The key indicator of the research and the answer to the set hypothesis of the work is reflected through the analysis of sulfur gases in the process of burning experimental briquettes. In this case too, the present inhomogeneities can be noticed, emphasized as in the previously described conclusion. These inhomogeneities can be approximated by observing the trend of set dependencies in analytical and instrumental measurement of experimental briquettes. Namely, it is logical that the analytical finding itself shows a reduction of all forms of sulfur depending on a kind of "dilution" of coal matter (the main sulfur carrier) with sawdust and pyrophyllite shale. From this aspect, the obtained results show certain deviations, but the trend of these indicators observed for analytically obtained and results obtained in instrumental measurement methods for total sulfur is similar. However, the distribution of total sulfur in the fuel and in the ash in the context of observing the results obtained due to the mass reduction of coal in the briquette for the analytical model and the experimental results is significantly different.

On the diagram of picture number 6, a slight growth trend is visible with a change in the content of pyrophyllite schist in the briquette with analytical and sudden growth of sulfur in the ash. On the contrary, and it is visible in the diagram of picture number 7, that the trend is similar in the analytical model, and completely opposite in the experimental model.

These diagrams are the indicators that can be used to confirm the working hypothesis, the addition of pyrophyllite shale to the coal mass reduces the impact of sulfur gases obtained from the combustion of this mixture on the atmosphere.

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