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Utilization of Lignite and Waste Biomass As a Clean Energy Source by Carbonization

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ABSTRACT

Carbonization is the general name of the process of producing gas, liquid and solid products, especially from fossil fuels such as coal, by heating in an oxygen-free environment. Carbonization is one of the most important transformation processes to obtain high-quality solid (char), gas and liquid products. Fossil-based resources such as coal, petroleum and natural gas are not suitable for long-term use, as they are both limited and harm the environment. Therefore, for energy continuity, it is necessary to benefit from renewable energy sources such as biomass along with fossil fuels. By burning the char obtained from the carbonization of coal and biomass, it is possible to reduce the contents such as SO2 and NOx that pollute the atmosphere. In this study, carbonization experiments of lignite and pistachio shell at different mixing ratios (coal: biomass by weight 1:0, 0:1, 1:1 and 1:2) and temperatures (350, 450 and 550°C) was carried out. The higher heating values and C, H, N, S contents of the chars obtained from each experiment were determined. With the increasing temperature and biomass ratio, positive changes have been observed in the obtained clean fuel. At all temperatures, the C content increased and the S content decreased as the mixing ratio increased. The C content, which was 60.67% at a 1:1 mixture ratio at 550°C, increased to 73.55% at the ratio of 1:2, while the S content decreased from 1.87% to 0.94%. At a 1:1 mix ratio, the C content increased from 51.19% at 350°C to 60.67% at 550°C, while the S content decreased from 2.24% to 1.87%. Optimum test conditions were determined as a 1:2 mixing ratio and 550°C temperature.

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1. INTRODUCTION

One of the most important indicators of the development levels of countries is energy production. The fact that energy production is more than consumption is one of the important factors that cause the development of the industry and the increase of the national income. Energy production depends on finding the resources that provide it and making optimum use of these resources. In this respect, fossil fuels such as coal, bituminous shale, oil and natural gas, which are used as energy sources today, are of great importance.

Various gases such as carbon dioxide, carbon monoxide, sulfur oxides, nitrogen oxides, which are formed as a result of burning coal for energy production, cause air pollution. These pollutants, which are released into the atmosphere with combustion gases, react with the effect of sunlight or with other compounds in the atmosphere. As a result, secondary pollutants such as ozone, aerosol, nitrate, nitrite and various acids may be formed [1]. Therefore, the use of fossil fuels in energy production without passing through a transformation process such as carbonization, liquefaction, gasification creates environmental problems.

For energy to be sustainable, it is imperative to use new and renewable energy sources as well as fossil fuels. Biomass energy is one of the renewable energy sources that do not pollute the environment and are sustainable [2, 3].

All organic matter that can be renewed in less than a century, including plants growing on land and in water, animal residues, food industry and forest products and urban waste can be defined as biomass [4]. Biomass can be transformed into various energy sources such as hydrogen, ethanol, methanol, or methane by thermal, biological and physical processes. In this way, instead of decaying biomass, it can be brought into the world economy as a renewable alternative energy source.

Biomass is known to have higher H/C and O/C values compared to coal. The high hydrogen content in biomass can be used with coal as a source of hydrogen during carbonization [5]. H and OH radicals emitted from biomass during carbonization support the cracks in the aromatic rings of the coal [6-8]. In addition, by burning biomass with coal, it is possible to reduce the SO_2 and NO_x contents emitted into the atmosphere. Combustion of high sulfur bituminous coal mixed with 20% straw showed a net reduction in NO_x and SO_2 emissions [9]. CO_2 released as a result of the burning of hard coal can be reduced by approximately 93% in the case of using biomass [10].

In this way, both the negative environmental effects caused by the combustion are eliminated and the biomass (apricot kernel, pistachio shell, domestic waste, etc.) which is in the state of waste is utilized. To obtain clean and sustainable energy, it is very important to use biomass and low-calorie lignite together and bring them into the economy.

Many researchers have determined that low-quality coals and biomass easily form a good synergy during carbonization [11-14]. Recently, studies in which different fossil fuel types, different furnaces/reactors, different operating conditions and coal and biomass are used together have come to the fore [15-22].

In this study, yields of chars formed as a result of carbonization of Kangal lignite (KL) and pistachio shell (PS) separately and together were calculated. In addition, proximate and ultimate analyzes of the chars were also made. The effects of different mixing ratios (coal: biomass by weight 1:0, 0:1, 1:1 and 1:2) and different temperatures (350, 450 and 550°C) on clean fuel properties were determined.

2. MATERIAL AND METHOD

The lignite sample used in this research was acquired from Kangal-Sivas, which is located in the Internal Anatolia of Turkey. The lignite samples were prepared according to the ASTM standards (ASTM D3173, ASTM D3174 and ASTM D3175) for higher heating value (HHV), proximate and ultimate analysis. The pistachio shell used as biomass was obtained from the Gaziantep region of Turkey.

According to the ultimate analysis results on a dry basis (db), the lignite was found to be 22.81% C, 1.40% H, 0.36% N and 2.95% S; pistachio shell was determined to contain 47.37% C, 5.90% H and 1.74%N. The high carbon content in the structure has shown that pistachio shells can be suitable for clean fuel production.

Proximate analysis and HHV results on a dry basis (db) of lignite and pistachio shell are given in Table 1.

Table 1. Proximate analysis results of lignite and pistachio shell

	Lignite	Pistachio shell
Moisture (%)	5.83	9.16
Ash (%)	43.66	13.95
Volatile matter (%)	31.91	68.13
Fixed C (%)	18.60	8.76
Higher heating value (kcal/kg)	2860.31	4270.56

It is seen from Table 1 that lignite contains high ash (43.66%) and its higher heating value is approximately 2860 kcal/kg, whereas the pistachio shell contains low ash (13.95%) and its higher heating value is approximately 4271 kcal/kg.

Carbonization experiments were carried out using the Protherm PZF multi-zone tube furnace given in Figure 1. Carbonization was carried out at different temperatures (350, 450, 550°C) by keeping the 150 ml/min N_2 gas flow, 10°C/min heating rate and 60 min residence time constant.

Figure 1. Tube furnace used in carbonization experiments

The experiments were carried out in different mixing ratios (coal: biomass by weight 1:0, 0:1, 1:1 and 1: 2). The furnace was opened 24 hours later and the solid products (chars) were taken. Elemental analysis and higher heating values of the chars were calculated.

3. RESULTS AND DISCUSSION

Elemental analysis and calorific values of chars obtained at different mixing ratios and different temperatures are given in Table 2.

Table 2. Elemental analysis results of chars

Exp. No.	Mixing ratio (KL:PS)	Temperature (ºC)	C (%)	H (%)	N (%)	S (%)	HHV (kcal/kg)
1	0:1	350	49.56	5.89	1.74	-	4282.11
2	0:1	450	52.47	5.84	1.66	-	4299.03
3	0:1	550	55.01	5.62	1.64	-	4300.65
4	1:0	350	33.98	1.37	0.36	2.94	2853.01
5	1:0	450	37.24	1.33	0.33	2.61	2987.06
6	1:0	550	45.55	1.31	0.30	2.25	3204.16
7	1:1	350	51.19	4.39	0.65	2.24	4654.03
8	1:1	450	55.96	4.12	0.62	2.11	4771.65
9	1:1	550	60.67	4.08	0.56	1.87	4956.04
10	1:2	350	67.19	3.95	0.47	1.72	5263.66
11	1:2	450	69.26	3.64	0.39	1.33	5421.78
12	1:2	550	73.55	3.51	0.32	0.94	5816.44

It was determined from Table 2 that the C content increased from 49.56% to 55.01% with the increasing temperature as a result of pistachio shell carbonization (0:1). No significant change was observed in the higher heating value.

In lignite carbonization (1:0) it was determined that there was an increase in C content with increasing temperature. The C content increased from 33.98% at 350°C to 37.24% and 45.55% at 450°C and 550°C, respectively. As the temperature increased, the S content decreased from 2.94% to 2.25%. There was an increase of approximately 351 kcal/kg in the higher heating value.

It can be seen from Table 2 that in all mixing ratios there is an increase in the C content and higher heating values of the chars as the temperature increases. On the other hand, the contents of H, N and S decreased. Considering the mixing ratio, it was observed that at the same temperatures, C contents increased and S contents decreased with increasing biomass ratio. The C content, which was 51.19% at a 1:1 mixture ratio at 350°C, increased to 67.19% at the ratio of 1:2. S content has decreased from 2.24% to 1.72%. There was an increase of approximately 610 kcal/kg in the higher heating value of the char.

The C content, which was 60.67% at a 1:1 mixture ratio at 550°C, increased to 73.55% at the ratio of 1:2, while the S content decreased from 1.87% to 0.94%. The higher heating value of the char increased from 4956.04 kcal/kg to 5816.44 kcal/kg. These values are the optimum results obtained from experiments. Based on these data, it can be said that when working at the same temperatures, the increase in biomass in the mixture affects the char quality positively.

It has been observed that the increasing temperature causes positive changes in the quality of the char. At a 1:1 mix ratio, the C content increased from 51.19% at 350°C to 60.67% at 550°C, while the S content decreased from 2.24% to 1.87%. It has been calculated that there is an increase in calorific value of approximately 302 kcal/kg. As the temperature increased in the mixture ratio of 1:2, the C content from 67.19% increased to 73.55%, while the S content from 1.72% decreased to 0.94%. The higher heating value increased from 5263.66 kcal/kg to 5816.44 kcal/kg.

It was determined that as the temperature and mixing ratio increased, there was an increase of 22.36% in the C content and a decrease of 1.3% in the S content. An increase of approximately 1163 kcal/kg was observed in the higher heating value.

Based on all these results, it has been concluded appropriate to choose the carbonization char at a mixture ratio of 1:2 and 550°C as the optimum clean fuel.

4. CONCLUSIONS

When the carbonization results (1:0) were compared with the results (1:2), it was determined that there was a 28% increase in C content and a 1.31% decrease in S content at 550°C. It was determined that the higher heating value of the char increased by approximately 2612 kcal/kg. According to these results, it was determined that the combination of lignite and biomass (pistachio shell) had a positive effect on the characteristics of the char.

Since most of the coal deposits in Turkey are young lignite and therefore their higher heating values are low, it is not very economical to directly burn them and use them in energy production. In this respect, carbonization of lignite and biomass mixtures, finding energetic values of solid-liquid-gas components and characterization of these products gain importance.

As a result of the experiments, it was determined that it is possible to use the char obtained as a result of the carbonization of the mixtures of biomass and lignite in different proportions, as a clean fuel. With the low S content of the char obtained in this way, both the environmental pollution will be reduced and a part of the clean energy requirement of the country will be met. In the carbonization of lignite-biomass mixtures, the increase in C content and higher heating value and decrease in S content is an important result in terms of increasing the use of agricultural wastes in energy production. Energy values of char can be increased in the presence of a catalyst and by using different biomass. Therefore, it would be appropriate to carry out more detailed studies on the subject.

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