Combustion of composite fuel "coal-sawdust"

Artem Kuznetsov*

Kutateladze Institute of Thermophysics, 630090 Novosibirsk, Russia

Abstract. The article deals with the processes associated with the production and combustion of composite powder fuel from coal and woodworking waste, pulp and paper production and agriculture. The relationship between the structure and properties of solid fuels obtained under various conditions of preliminary mechanical processing of components, and physicochemical processes occurring during combustion in a combustion chamber has been studied. As a result of experiments, it was found that the composite material burns better than a mixture of its components, combustion begins earlier, the combustion zone is shifted to the center, and the combustion temperatures are higher, which contributes to more complete combustion of the fuel. It was also found that in the case of a stationary combustion process, the temperatures when using composite fuel are higher than when burning a mixture of components. The difference in temperature is 100-400 °C, depending on the stage of combustion.

1 Introduction

According to experts forecasts, by 2050 mankind will be able to use up to 38% of the consumed fuel and up to 17% of electricity obtained from biomass. Processing and recycling of unused resources, such as constantly renewable waste from the forestry and agricultural industries (barks, lignin, substandard wood, sawdust, shavings, as well as cereal straw, bagasse, sunflower shells, rice and buckwheat), will help solve some social problems and problems environment [1].

To date, there are new concepts that allow the full use of renewable plant materials for the production of second-generation biofuels [2]. For example, the carbohydrate content of lignocellulose can be used to produce liquid forms of biofuels such as bioethanol. And the residues containing a large amount of lignin can be used for the production of solid biofuels [3]. However, obtaining solid biofuels is still a difficult task, and at the moment, the main production is limited to the creation of fuel pellets and briquettes from wood waste at high temperatures. Deep modification of lignocellulose in order to improve its thermophysical properties is not given sufficient attention.

Among the methods for controlling the physicochemical properties of plant materials, mechanochemical processing is a simple and environmentally friendly method. Mechanochemical treatment can increase the rate of subsequent chemical processes, such as combustion, by increasing the specific surface of particles and changing the structure of polymers, including lignin and cellulose.

To date, there has been progress in the engineering field of designing burners, which is ahead of the technology for producing fuel for various power plants. For example, there is efficient equipment that is capable of burning finely dispersed fuel in an environmentally friendly mode and utilizing lignin, the most large-tonnage and problematic waste from pulp and paper industries. However, fuel conditioning technologies can only offer ultra-fine grinding or calorific enhancement by adding fuel oil, waste oil, or micronized coal, which are often energy inefficient.

In this case, a promising process of burning coal and biomass together, known as co-firing, is being discussed. This process is widely used in EU countries and allows the use of some agricultural waste without significant changes in energy installations. The efficiency of combustion of biomass alone is 16 to 20%, while co-combustion with coal achieves an efficiency of 35 to 40%. Adding only 5–10% of biomass to coal fuel does not require a major modification of power plants [4], and this method is used at plants with a capacity of less than 700 MW to improve the environmental friendliness of energy production [5]. Despite claims that it is possible to burn large amounts of biomass, in practice this is associated with some difficulties, such as low calorific value and low ash melting point. However, already more than 150 coal-fired power plants with a capacity of 50 to 700 MW have experience in co-firing coal and biomass [6].

The use of biomass in pulverized coal boilers requires additional fuel preparation, including drying, grinding and mixing, before it is fed into the boiler. An important factor is the size and shape of biomass particles, which have a significant impact on the combustion process in a dust boiler [7, 8]. It must be taken into account that the particle size of biomass must be larger than that of coal particles due to the low density and high volatile matter release rate during combustion. However, if the particle size is too large, then this can lead to an increase in unburned carbon residue. At the

* Corresponding author: temkansu@yandex.ru

moment, these parameters are often determined empirically.

To increase the intensity of fuel combustion and improve a number of kinetic, energy and economic indicators of combustion, the use of mechanical activation is promising. It allows increasing the reaction surface by creating uncompensated bonds, radicals, mobile active centers and a certain orientation of deformed fuel molecules, as well as reducing the fuel ignition activation energy. Preliminary mechanical treatment reduces the activation energy and increases the reactivity of the fuel [9].

To improve coal combustion technologies and improve environmental performance, the global energy industry has previously used co-combustion of coal and plant residues. This paper explores a new technological direction - the creation and use of "composite" powder fuels, which have a number of advantages over powdered coal, vegetable powder fuels and their mixtures, including technical, technological and environmental ones.

2 Experimental part

2.1 Composite fuel preparation

According to the set of parameters: maximum calorific value 21.1 MJ/kg and lignin content 31.4%, minimum ash content 2.06%, high content of carbon and hydrogen, the main object of further research was chosen - a composite of long-flame coal of the Kuznetsk deposit and pine sawdust, Western Siberia. To obtain composite particles, mill-type equipment was used, a roller mill - RM-20.

The pine sawdust-charcoal mixture was machined to create composite materials. In these materials, small particles of coal (7-15 microns) are fixed on larger particles of sawdust (100-150 microns). Images of composite parts under a microscope show that when coal and sawdust are ground together, they do not grind in the same way as separately. As a result, the aggregation of components and the formation of larger particles occur. Photographs, Figures 1-3, obtained using various types of microscopy, show light luminescent particles of sawdust and dark coal particles.

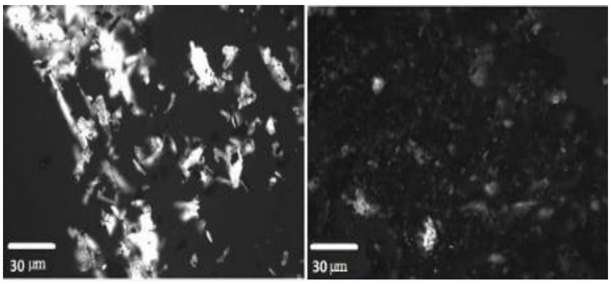

Fig. 1. Photo on a fluorescent microscope of a mixture of components (left) and a composite of the same composition (right). Light luminescent particles are pine sawdust, dark particles are coal. Sawdust particles are covered with coal particles.

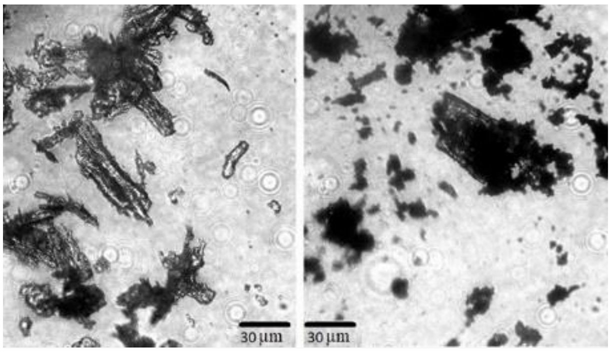

Fig. 2. Photographs using a transmission microscope, left - original sawdust, right – composite.

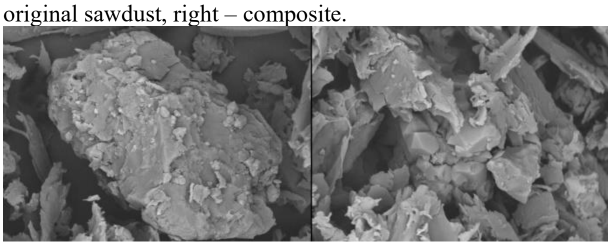

Fig. 3. Electron microscopic images of the composite at different magnifications.

On them you can see that large particles of sawdust are covered with smaller particles of coal. Meanwhile, in the photographs taken with a transmission microscope, it can be seen that small particles of coal have the shape of polyhedra, and large particles of sawdust have a layered structure. Electron microscopic images of the composite at different magnifications show that small particles of coal are fixed on the surface of large particles of sawdust.

The phase contrast of sawdust and coal in electron microscopy, in contrast to luminescence and transmission optical microscopy, is approximately the same, but the particles of sawdust and coal have a different morphology. Small particles of coal have the shape of polyhedrons, large particles of sawdust have a layered structure. As in the case of transmission micrographs, it can be argued that the structure of the composite includes large particles of sawdust, on the surface of which smaller particles of coal are located.

2.2 Combustion of composite fuel

To determine the optimal ratio of components in the composite, samples were prepared containing 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100% carbon. The burning time and three temperature characteristics were measured - the ignition temperature (the appearance of a visible flame), the maximum temperature and the smoldering temperature. It turned out that with an increase in the coal content to about 70%, the ignition temperature increases, judging by the values of the combustion time, the composite composition of 70% coal, 30% sawdust has the optimal combustion time. The maximum combustion temperature and smoldering temperature change to a much lesser extent.

Combustion of composite solid particles containing patches of plant material and coal occurs in two main stages, as well as the combustion of individual particles. At the first stage, the release and combustion of gaseous products occurs, and at the second stage, carbon, which was formed at the first stage, is oxidized. With an increase in the coal content in the mixture, the maxima of the rates of decomposition steps shift to higher temperatures. In addition, an increase in the carbon content in the composite leads to a decrease in the contribution of the first stage and an increase in the contribution of the second stage to the total mass loss during the combustion of the composite. As a result, the contribution to the weight change of the combustion stage of the carbon obtained in the first pyrolysis stage also increases. The mass of ash formed during the combustion of mixtures increases with an increase in the coal content in the mixture and amounts to 4–17% of the initial mass of the sample. The paper considers studies of the combustion of composite fuels, including coal and vegetable raw materials, as well as a separate combustion of each of the components. For this purpose, experimental setups were used: a tunnel vortex-type stand with a power of 50 kW and a laboratory furnace for burning fuel in the form of pressed pellets, equipped with a thermocouple and a data digitization system, which makes it possible to determine the burning time and flash point.

During combustion of the studied samples, the maximum temperature in the furnace was 1220–1320°C. At the exit from the combustion chamber, the concentrations of gases were: O_2 - 14.9-16.1%, CO - 0.3-0.8%, H_2 - 0-0.1%, CO_2 - 4.5-5.5 %, NO - 32.0-55.4%. With an increase in the spectral size of pine sawdust particles, an elongation of the flame is observed, followed by an increase in the number of unburned particles. The efficiency of the process of formation of combustible gases from coal at the first stage of combustion of activated fuel in a stationary mode in the presence of moisture has been studied. It was found that the addition of steam to the burning mixture in the amount of 0.4 kg per 1 kg of fuel increases the formation of hydrogen by 2-2.5 times and increases the degree of conversion from 0.49 to 0.72. It was found that the combustion temperatures of the mixture and composite fuel are higher than those of sawdust. The composite burns better than a simple mixture of components - combustion starts earlier, more volatile substances are formed and less ash is produced. Composite fuel has an increased calorific value compared to coal, which can be provided by increasing the completeness of fuel combustion. The composite composition of 70% coal and 30% sawdust has the optimal combustion parameters. The study of co-ignition, gasification, flare combustion of mixtures of coal and vegetable raw materials on an experimental bench of a tunnel vortex type with a power of 50 kW in a stationary mode of operation found that in almost all areas of the combustion of the composite, the temperature distribution along the length of the experimental bench is higher for composite fuel. When burning a composite fuel, as compared with the combustion of a mixture of components of the same composition, the first stage begins approximately 100 seconds earlier than when using a mixed fuel and occurs at temperatures 50–100°C higher. Combustion in the second stage occurs approximately simultaneously for both the mixture of components and the composite fuel, but the combustion of the composite provides temperatures 100–400°C higher. The difference in combustion temperatures increases towards the exit from the furnace.

3 Conclusions

A new type of powder fuel was obtained by mechanical processing of a powder fuel mixture to the stage of formation of a mechanocomposite, that is, encapsulated particles from vegetable raw materials with sizes less than 100 μm and a deposited layer of individual coal particles with sizes of the order of 1 μm and differing from the mixture of particles by a large phase contact surface (from units of % in a conventional mechanical mixture of particles to 90% in a mechanocomposite). An increase in the phase contact area opens up new possibilities for controlling the particle combustion kinetics due to the combination of the combustion processes of contacting particles of coal and biomass. For the first time, the lower concentration limits of ignition of composite particles of various compositions in mixtures with air were determined, and it was shown that the maximum decrease in the value of the concentration limit of ignition is observed for the composition "70% coal-30% sawdust".

At the first stage, combustible gases are released from the less stable internal component of the composite particle - vegetable raw materials. Combustion of combustible gaseous products of thermal decomposition is initiated by radical centers on the surface of coal particles, the number of which is significantly higher than the number of centers on particles of plant materials. An increase in temperature leads to decomposition of the surface layer of coal particles. At the second stage, the combustion of carbon occurs, which is formed during the decomposition of plant materials and coal.

The study of the thermal decomposition process was carried out at the expense of the Russian Science Foundation (Project No. 22-29-20280) and the Government of the Novosibirsk Region.

References

1. V.P. Tynkkynen, Russian Energy and Security up to 2030. Routledge, London. (2014)
2. N. Gaurav, S. Sivasankari, G.S. Kiran, A. Ninawe, J. Selvin, Renewable & Sustainable Energy Reviews **73** (2017)
3. O. Lomovsky, A. Bychkov, I. Lomovsky, V. Logvinenko, A. Burdukov, Thermal Science, **19** (2015)
4. S. Van Loo, J. Koppejan, Handbook of Biomass Combustion and Co-firing. – UK: Earthscan, (2008)
5. P. Molcan, G. Lu, T. Bris, Fuel **88** (2009)
6. D. Thran, J. Witt, K. Schaubach, J. Kiel, M. Carbo, et al., Biomass and Bioenergy **89** (2016)

7. A. Demirbas, Progress in Energy and Combustion Science **30** (2004)
8. V. Ganesan, K. A. Rosentrater, K. Muthukumarappan, Biosystems Engineering **101** (2008)
9. A. P. Burdukov, V. I. Popov, T. S. Yusupov, O. I. Lomovsky, Chemistry for Sustainable Development **17(5)** (2009)