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Physical and chemical transformations under the thermal action on coal-water fuel made of low-grade coal

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Abstract
Experimental and theoretical investigations of the laws of physical and chemical transformations in the process of thermal action on the coal-water fuel depending on the raw characteristics of the fuel and the main parameters of influence were carried out. It has been shown that the preliminary thermal effects on the coal-water fuel at a temperature range 150-200 °C leads to the change of properties and composition of the fuel with the formation of intermediate flammable compounds. This improves fuel ignition and enhances combustion efficiency of the coal-water fuel in the further thermal treatment.
Key words: COAL-WATER FUEL, LOW-GRADE COAL, THERMAL ACTION, THERMOGRAVIMETRIC RESEARCH, PHYSICAL AND CHEMICAL TRANSFORMATIONS, STAGE OF METAMORPHISM, STEAM-GAS PHASE

The use of coal-water fuel in various electric power plants is one of the promising directions of coal-fired power industry. The coal-water fuels production from low-grade coals, watered coal fines, wet slimes, concentration plants wastes, which are not used at the present time, and the use of them in power industry may produce significant economic and ecological effect [1-3]. For example, there are more than 120 million tons of slimy waste coals in waste and slime ponds, in the form of waste piles in Ukraine, which waste utilization is relevant objective of the reduction of negative impact on the environment. The effective processes of coal-water fuel preparation and processing development should be based on science-based laws of the physical and physical-chemical effects on fuels considering their properties and composition. However, the coal-water fuel combustion in various electric power plants is wide spread in recent times; there are a lot of outstanding questions, primarily connected with the physical and chemical transformations and processes, especially at the initial stage of the thermal action on the coal-water fuel. These processes are important for all the thermal methods of fuel

recycling. Since various coal and waste coal grades may be used when coal-water fuel preparing, the properties of the resulting fuel and, therefore, mechanisms of physical-chemical reactions and kinetics under the thermal and thermochemical effects are quite different.

Furthermore, during coal-water fuel operation, its preliminary heating, which affects the rheological properties and fuel stability significantly, is used. According to paper [5], the temperature of coal-water fuel preheating of up to 50 °C recommended by many authors causes the stability reduction and fuel solid phase; only more than 80 minutes processing prevents this. Therefore, it is advisable to consider fuel heating higher temperature range before use. When heating, the coal-water fuel viscosity is also reduced (if the fuel temperature is increased by 10 °C, the viscosity is reduced to 1.5-2%) [6].

The investigations of the laws of physical and chemical transformations in the process of thermal action on the coal-water fuel made of coals of various stages of metamorphism will allow establishing of rational parameters of heat treatment, which leads to desirable and controlled changes of fuel properties and composition, and finally leads to increase of fuel processing energy efficiency. The important indicators of thermal action are the temperature of a steam-gas phase formation beginning and an area of its maximum formation, steam-gas phase formation rate, quantity and composition of a steam-gas phase depending on fuel initial characteristics and action basic parameters (temperature, pressure, time).

The experimental and theoretical researches of thermal action on the water-coal fuel obtained from the coals of metamorphism different stages characterized by high concentration of mineral impurities were carried out. The results of thermogravimetric researches of temperature and thermal action time effect under atmospheric pressure on the steam-gas phase formation dynamics from water-coal fuel are presented on the example of the water coal-fuel obtained from anthracite (Fig. 1).

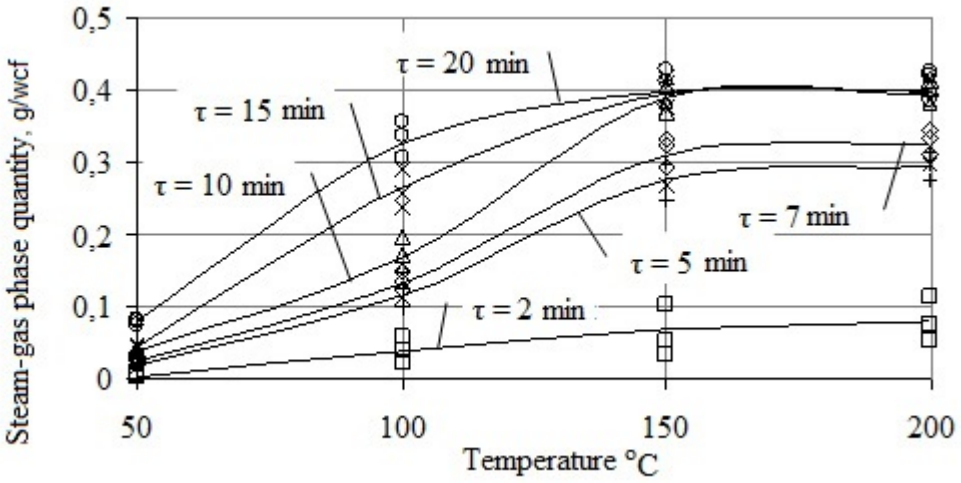

Figure 1. Dynamics of steam-gas phase formation from water-coal fuel under the thermal action on the water-coal fuel: - theoretical dependences; - experimental dependences: □- 2 min., ✦ - 5 min., ◇ -7 min., △ - 10 min., × - 15 min., ○ - 20 min.

The presented results show that at a temperature over 50 °C, the steam-gas phase, which quantity increases with temperature increasing, is intensively formed. At temperatures of 50-100 °C, the steam formation process is dominating, therefore the water steam diffusing into coal particles activates coal particles surface that causes increasing in the evolution rate and quantity of water-coal fuel gaseous components. Further temperature increase leads to chemical bond plentiful opening and numerous thermochemical reactions implementation.

As is evident from the obtained data, the divergence of theoretical researches results (solid lines) obtained by means of a program complex for thermodynamic calculation of equilibrium composition and multicomponent heterogeneous systems properties [7], and experimental thermogravimetric researches results is no more than 5-10%. The divergence is reduced in the area of long temperature effect as at such thermal action parameters, the quantity and composition of a steam-gas phase are closer to thermodynamic equilibrium. Thus, this program complex allows rather adequate describing of thermochemical transformation processes in water-coal fuel. Under an atmospheric pressure, the composition of the formed steam-gas phase at thermal action on water-

coal fuel is given in Fig. 2 on the example of the water coal-fuel obtained from anthracite.

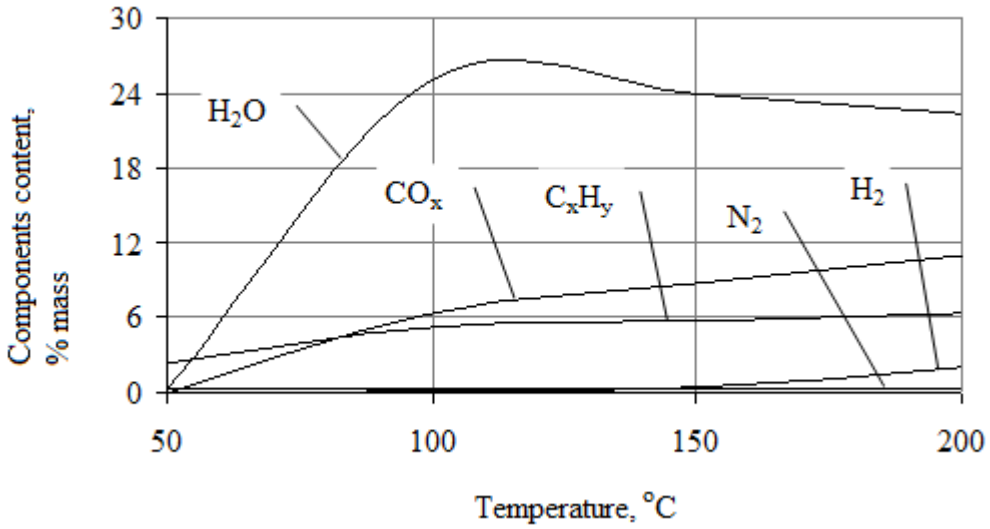

Figure 2. The main components concentration in a steam-gas phase under thermal action on water-coal fuel

As the researches have shown, the chemical interaction of water with carbon begins at temperatures of 30-40 °C; this is caused by coal machining, which is one of stages of water-coal fuel preparation. Mechanical coal activation is followed by evolution of the volatile and soluble low-molecular products, which are the products of mechanochemical transformations of organic substances of coals [8]. This is conductive to chemical interaction of coal substance and water in lower temperature range in comparison with coal. With temperature increase of more than 50 °C, the reaction speed of carbon with water (water steam) considerably increases. This interaction proceeds through the steam adsorption on a coal surface with formation and evolution of H_2, CO, CO_2, C_xH_y in a gas phase.

As thermal action under atmospheric pressure proceeds with considerable steam formation in temperature range of up to 100 °C which causes rheological properties deterioration, it is recommended to carry out the preliminary thermal action on water-coal fuel under the pressure of 0.5-1.5 MPa. The conducted researches have shown that under the pressure of 0.5-1.5 MPa, the formation dynamics and composition of steam-gas phase under the thermal action on water-coal fuel are similar to the processes under atmospheric pressure; thus, the access activity of steam-gas phase is shifted to the area of higher temperatures which is due to increase in saturation temperature under higher pressures. The researches have shown that after thermal action (at temperatures of 150-200 °C), the water-coal fuel is of more homogeneous character; viscosity reduction and stability increase are observed. What is more, water-coal fuel is saturated with fuel components after thermal action which improves the indicators of its ignition and increases the efficiency of burning under further thermal processing.

The stage of coal metamorphism, from which the fuel is made, is one of the important parameters, which affect the regularities of physical and chemical transformations during thermal action on water-coal fuel, as it is known that the metamorphism stage significantly affects the coals properties due to the change of their molecular structure [9]. The results of experimental thermogravimetric researches of temperature and thermal action time effect under atmospheric pressure on the steam-gas phase formation dynamics from water-coal fuel obtained from the coals of different grades are presented on the Fig. 3.

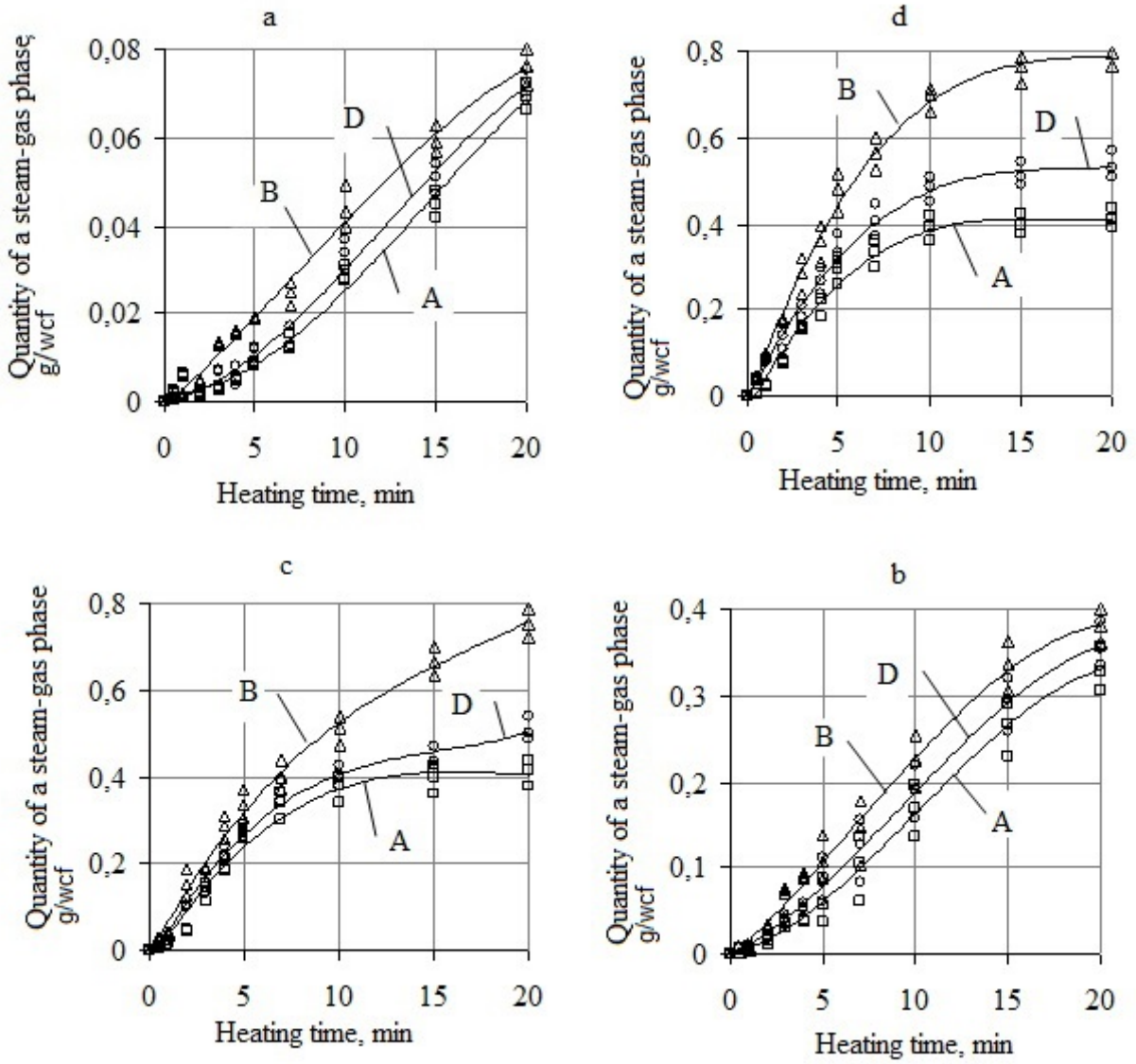

Figure 3. The steam-gas phase formation dynamics at thermal action on the water-coal fuel obtained from coals of various grades at temperatures of 50 °C (a), 100 °C (b), 150 °C (c) и 200 °C (d): △ - B (water-coal fuel from brown coal); ○ - D (water-coal fuel from long-flame coal); □ - A (water coal fuel from anthracite)

The obtained results analysis of thermogravimetric researches shows that the formation speed and quantity of steam-gas phase is the greatest for the water-coal fuel made of brown coal, which belongs to a low stage of metamorphism. Whereas, the formation speed and quantity of steam-gas phase for the water-coal fuel obtained from anthracite is the smallest. As it is seen from the data presented, under thermal action on water-coal fuel in temperature range of 50-100 °C, the quantity of a steam-gas phase constantly increases for all the samples of water-coal fuel.

At thermal action temperature increase of up to 150-200 °C, more intensive output of a steam-gas phase in the same time span is observed; and physical and chemical transformations dependence during thermal action from initial coal characteristics is shown more considerably. At thermal action of more than 15 min, the steam-gas components quantity is not practically changed for all the samples of water-coal fuel; this does not mean that there are no chemical reactions and assumes intermediate chemical components formation, which is carried out without gas generation. Physical and chemical transformations laws during thermal action are similar for water-coal fuel samples obtained from other coal grades. The composition analysis under thermal action on water-coal fuel samples made from different coals grades showed that the fuels steam-gas and solid phase ratio is 39-79% and 21-61% depending on initial raw materials and action parameters, which are quite various. However, the steam and gas components ratio in a steam-gas phase is almost identical for all the water-coal fuel samples obtained from coals of a different stage of

metamorphism despite the different quantity of the steam-gas phase under the thermal action. When heating of water-coal fuels up to 50 °C under atmospheric pressure, the steam content in a steam-gas phase is 12-14%, and gas components are 86-88%. The further increase in fuels heating temperature up to 100 °C causes substantial increase of steam phase content up to 66-68%. When increasing of water-coal fuel heating temperature up to 150-200 °C, the steam amount in a steam-gas phase is reduced to 56-61%. This is explained by steam interaction with fuel carbon with the subsequent formation of combustible components and intermediate radicals. At that, gas components content in a steam-gas phase is 38-44%. As the researches have shown, the pressure increase, at which there is a thermal action on water coal fuel, causes steam-gas phase output maximum shift to the area of temperatures. At that, the ratio of steam and gas components as a part of a steam-gas phase is not changed.

The conducted researches have shown that during thermal action on water-coal fuel, the quantity of gas components is 80-85% more than the quantity of the gas components, which are formed under direct effect on the coal samples, from which water-coal fuel is made. It is caused by interaction of the most part of fuel carbon and significant amount of water steam with formation of CO and C_xH_y. Thus, the water phase in water-coal fuel under preliminary thermal action improves the fuel burn-out process and reduces the necessary fuel-residence time and, therefore, overall dimensions of furnace chambers for water coal-fuel processing [10].

Conclusion

Experimental and theoretical investigations of the laws of physical and chemical transformations in the process of thermal action on the coal-water fuel obtained from the coals of metamorphism different stages were carried out. The results of thermogravimetric researches of thermal action on the coal-water fuel showed that at a temperature over 50 °C, the steam-gas phase, which quantity increases with temperature increasing, is intensively formed. At temperatures of 50-100 °C, the steam formation process is dominating, therefore the water steam diffusing into coal particles activates coal particles surface that causes increasing in the evolution rate and quantity of water-coal fuel gaseous components H_2, CO, CO_2, C_xH_y.

Further temperature increase leads to chemical bonds plentiful opening and numerous thermochemical reactions implementation and physical and chemical transformations dependence during thermal action from initial coal characteristics (metamorphism stage, mineral impurities content, etc.). The steam and gas components ratio in a steam-gas phase is almost identical for all the water-coal fuel samples obtained from coals of a different stage of metamorphism despite the different quantity of the steam-gas phase under the thermal action.

The conducted researches have shown that under the pressure of 0.5-1.5 MPa, the formation of dynamics and composition of steam-gas phase under the thermal action on water-coal fuel are similar to the processes under atmospheric pressure; thus the access activity of steam-gas phase is shifted to the area of higher temperatures which is due to increase in saturation temperature under higher pressures.

The obtained researches results show that the preliminary thermal effects on the coal-water fuel at a temperature range 150-200 °C leads to improvement of its rheological properties, fuel organic substance structure change with the formation of intermediate flammable compounds. This improves fuel ignition and enhances combustion efficiency of the coal-water fuel in the further thermal treatment.

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