Microwave solid fuel ignition

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Abstract. The article continues the study of the effect of microwave exposure on solid fuel. On the basis of the experimental studies, the dependences of changes in the temperature and humidity fields of the fuel on the time of microwave exposure, to arson, have been established. The possibility of using the microwave electromagnetic field to automate the process of burning solid fuel in a boiler plant, afterburning unburned fuel residues is considered. The mechanism and basic conditions of these processes are presented. The influence of this technology on the intensification of the fuel ignition process, its homogenization, an increase in energy characteristics and a change in the elemental composition, an increase in the efficiency of a boiler plant, a decrease in chemical, mechanical underburning and harmful emissions of a boiler plant is considered. The main conditions of the applied technology are: placement of the microwave generator on the combustion device of the boiler unit, the size of the solid fuel samples or its contacting pieces should be less than the wavelength of the microwave electromagnetic field (12.4 cm), the moisture content - within the range from 10 to 95%. The intensification of the process of burning solid fuel also depends on the type of fuel, its physical and chemical properties (various types of coal, wood fuel, including wood waste, peat, and others). Modernization of boiler plants using this technology is possible by unifying projects that take into account the correspondence of microwave generators to the thermal power of boiler units.

1. Introduction

In Russia, as in other developed countries of the world, the issue of saving fuel resources and energy conservation is the main issue in the country's heat and power complex. Especially, it has become relevant at the present time, in connection with the energy crisis that happened in countries with developed industry. This circumstance leaves its mark on the change in the balance of fuel resources. The bet on renewable energy sources, such as solar and wind power plants, turned out to be not as reliable as planned and did not withstand the confluence of circumstances, including natural ones. The absence of wind for a long time and the reduction of sunny days - had a negative impact. In this situation, TPPs are being restored using traditional types of fuel, such as fuel oil, various types of coal, peat, and wood fuel.

Once again, the need arose to improve technologies for their incineration. One of them, which helps to save fuel resources, is the combustion of solid fuel using microwave energy. This technology can be used not only to increase the energy characteristics of fuel, change its elemental composition, reduce harmful emissions that have a negative impact on the environment, but also to set fire to solid fuel and afterburning its unburned residues.
It allows: to increase the degree of automation of the processes of obtaining heat and electric energy, to eliminate the risks of the maintenance personnel associated with the ignition of the boiler unit, to save a significant number of flammable substances spent on the ignition of solid fuel. In connection with the above, this technology also allows to reduce the financial costs of operating solid fuel boiler plants.

2. Methods and materials
In previously published scientific works [1-12], the results of experimental studies on the effect of microwave radiation on wood fuel and peat of different fractions were considered, and they were heated to the ignition temperature. Under microwave action on solid fuel, the temperature of its inner layers rises, accompanied by excess pressure of water vapor. It, in turn, facilitates the transfer of steam from the inner - to the side of the outer fuel layers. This process is accompanied by the formation of new and the opening of existing cracks, pores and capillaries. In addition, counter-diffusion occurs at the boundary between the inner layer and the outer layer, which prevents dehydration of the material. In order to reduce its effect, the process of heating and convection of fuel with flue gases in the pre-combustion chamber of combined heating was used. At the same time, with their help, the following was carried out: preliminary heating of the fuel, drying of its outer layers and removal of moisture from the volume of the chamber. The use of combined exposure (microwave and flue gases) made it possible to obtain homogenized fuel from solid fuel with a high moisture content, which is not inferior in its energy characteristics to pellets, and to increase the efficiency of the boiler plant.

In continuation of the previous studies, we will consider the microwave ignition of solid fuel directly in the furnace of the boiler unit of the boiler plant. In this case, we will place the microwave generator on the combustion device of the boiler unit and use it for microwave exposure to solid fuel with a high moisture content in order to ignite it (ignite the boiler unit), as well as afterburning unburned fuel residues.

Let's consider the conditions of the processes occurring during this process.

1. One of the main conditions for the processes of microwave ignition of solid fuel is the "locking" of the microwave EMF waves inside the fuel. It occurs when the size of the fuel sample or its contiguous pieces is less than the wavelength of the microwave EMF. As a result of experimental studies, it was found that the penetration depth of microwave EMF into a dielectric material is less than 12.4 cm. Thus, under the condition that the length of the electromagnetic wave is less than this value, there is a maximum effect on solid fuel due to reflection from the boundary between the media "matter - air" and their multiple superposition, with an extremum in the centre of the fuel core;

2. The action of counter-diffusion, in this case, has a maximum value, since there is no convection of hot flue gases, which affects its reduction. The partial pressure of water vapor, with microwave radiation, will increase sharply - in proportion to the time of microwave exposure to solid fuel. The process is accompanied by the formation of deep cracks with cracking of the material, both along the length and in the cross section of the fuel sample. The outer surface of the fuel (mainly refers to peat and coal, which have a colloidal-porous structure) undergoes structural changes - in the form of the formation of roughness, swelling and bumps with crushing of large pieces into small components. These changes in the fuel wood, coal and peat, lead to a significant increase in the area of their oxidation and accompanied by intensive water vapor outlet (draining) of the inner layers of fuel. Microwave heating is carried out to ignition of fuel, accompanied by a torch undamped volatile hydrocarbon. Figure 1 shows graphs of fuel temperature and humidity of the microwave exposure time to the point of ignition. The efficiency of the process, in our case depends not only on time, but also the character (constant or intermittent) exposure to the microwave. With a constant - a process is intensified.
3. The process of microwave heating is carried out until the onset of stable combustion of volatile hydrocarbons emerging from the inner layers of the fuel (fuel core). At the same time, hydrogen combustion is present in the mechanism of ignition of the fuel sample, since the dissociation of water molecules with decomposition into hydrogen and oxygen components is carried out under microwave exposure:

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\begin{align*}
H_2O & \rightarrow H_2O^+; \\
H_2O^+ + M & \rightarrow H + OH^+ + M; \\
OH^+ + M & \rightarrow H + O^+ + M; \\
H_2 + e & \rightarrow H + H^+ - 17eV. 
\end{align*}
\]

4. After the end of the process of burning solid fuel, the microwave effect on it stops;
5. Afterburning of unburned fuel residues is also carried out under microwave exposure and leads to a decrease in chemical and mechanical under burning. This circumstance helps to reduce the negative impact on the environment when it is burned in a boiler plant.

3. Results and discussion

Microwave heating of solid fuel, before setting fire, depends on the type of fuel (different types of coal, wood fuel, including wood waste, peat), its structure, moisture content, wavelength and time exposure to EMF. The values of these dependencies vary widely and are revealed empirically, as a result of experimental studies. They are shown in tables 1 and 2. For each type of fuel, the optimal parameters and conditions for the microwave heating process can be set, before arson (figure 2). In the same way, the optimal parameters of the afterburning of unburned fuel residues under microwave exposure are revealed. The combination of the results of theoretical and experimental studies is the basis of the technology considered in the article. The economic efficiency of its application is due to low material and financial costs.
Table 1. Results of field experiments with microwave - impact on fuel samples.

| No. | Type of fuel                  | Fuel moisture, % | Fraction size, cm | Time to ignition of the sample, sec | Sample ignition temperature, °C |
|-----|------------------------------|------------------|-------------------|-------------------------------------|--------------------------------|
| 1   | Beech (wood chips)           | 48.6             | 3-5               | 323                                 | 296.9                          |
| 2   | Pellets                      | 11               | 1x5               | 222                                 | 324                            |
| 3   | Pellets                      | 15               | 1x5               | 187                                 | 324                            |
| 4   | Pellets                      | 39.6             | 1x5               | 211                                 | 324                            |
| 5   | Aspen (wood chips)           | 30.0             | 3-6               | 268                                 | 282                            |
| 6   | Cork                         | 45.7             | 5-8               | 186                                 | 266                            |
| 7   | Spruce                       | 43.8             | 7-10              | 146                                 | 289                            |
| 8   | Spruce                       | 70               | 7-10              | 259                                 | 289                            |
| 9   | Spruce                       | 91               | 7-10              | 342                                 | 289                            |
| 10  | Sawdust                      | 45               | менее 1           | 479                                 | 272                            |
| 11  | Peat                         | 81.3             | 7                 | 245                                 | 267                            |
| 12  | Coke peat                    | 72.2             | 9                 | 184                                 | 277                            |

In addition, an important positive aspect of its application is the reduction of fire and explosion hazard, personnel injury, in contrast to the standard method of ignition of a boiler unit in a solid fuel boiler house using flammable substances.

Protection of the operating personnel of a solid fuel boiler house from the effects of microwave radiation is carried out using protective screens.

Modernization of such boiler houses due to the use of this technology is possible with the unification of microwave generators mounted on combustion devices of boiler units in accordance with their capacity.

Table 2. Results of experiments with continuous and periodic action of the microwave field on fuel samples.

| No. | Type of fuel   | Fuel moisture, % | Fraction size, cm | Sample ignition time under continuous exposure to microwave radiation, sec | Sample ignition time under periodic exposure to microwave radiation (with a period of 40 seconds), sec |
|-----|----------------|------------------|-------------------|---------------------------------------------------------------------------|--------------------------------------------------------------------------------|
| 1   | Peat           | 63.5             | 7                 | 200                                                                        | 248                                                                          |
| 2   | Spruce         | 43.8             | 7-10              | 146                                                                        | 228                                                                          |
| 3   | Aspen (wood chips) | 30.0         | 3-6               | 268                                                                        | 349                                                                          |
Figure 2. A graph of the dependence of the temperature (before ignition) of the samples on the time of microwave exposure.

4. Conclusions
As a result of the use of microwave heating of solid fuel for its ignition and under burning of fuel residues, it was established:

1. The intensification of processes occurs in the inner layers of the fuel, before arson.
2. Due to the counter-diffusion processes and a sharply increasing fractional vapor pressure in the area located between the outer and inner layers, the internal structure of the fuel and its surface are destroyed. The process is accompanied by an increase in the area of oxidation. This circumstance, in addition to the intensification of the processes of drying the inner layers of the fuel, the release of volatile hydrocarbons from them, also has a positive effect on increasing the energy characteristics of the fuel and the efficiency of the boiler plant.
3. There is a homogenization of fuel, with homogeneous properties, evenly distributed throughout the volume of the material.
4. Microwave exposure reduces chemical and mechanical under burning of fuel.

Thus, the use of this technology automates the process of burning solid fuel in the boiler furnace, intensifies it, and reduces harmful emissions into the environment. At the same time, its application makes it possible to modernize boiler installations without significant material and financial costs. Modernization projects can be unified due to the compliance of microwave generators placed on furnaces with the power of boiler units.

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