Study of the combustion process of liquid off-design fuel in a spray burner device with a controlled supply of primary air

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Abstract. This work studies the process of combustion of liquid off-design fuel (using waste oil as an example) in a jet of superheated water vapor in a spray burner device with a controlled supply of primary air. The average temperature along the vertical axis of the burner device was measured, the composition of intermediate and final combustion products, and heat release were studied when the parameters in the gas generation chamber were varied. It has been shown that changing the primary air flow rate when spraying liquid off-design fuel with a jet of superheated water vapor can additionally influence the flame structure and the level of emissions. And the technology itself can be used to create low-emission burner devices.

1 Introduction

One of the urgent tasks is the inclusion of accumulated substandard fuels and combustible waste (used lubricating fluids, waste from oil production and oil refining, etc.) into the fuel and energy balance, which is directly related to the development of the Waste-to-Energy trend [1-3]. These types of cheap energy resources are not widely used today due to the lack of a universal, effective and environmentally friendly technology for their disposal. If such energy sources are used correctly [2], they can be an alternative to high-quality fuels, while simultaneously solving the environmental problem of the accumulation of combustible waste and its safe storage. Thus, for the successful development of this area and ensuring its sustainable development, it is necessary to create and develop highly efficient and environmentally friendly technologies and equipment [4].

In IT SB RAS, a method of burning liquid hydrocarbon fuel sprayed by a heated stream of air or superheated steam is being studied [5]. A distinctive feature of this method from traditional approaches is that it is based on the interaction of a high-speed gas jet with a drop of fuel, which ensures high-quality dispersion of various types of fuel [6], and can even be used for burning liquid combustible waste. Works [5,6] show that the use of superheated steam can significantly reduce the content of harmful emissions in combustion products compared to heated air. Thus, the use of superheated steam allows for partial steam gasification when interacting with a fuel drop. In addition, it ensures a reduction in the concentration of nitrogen oxides in exhaust gases by up to 50% with high combustion

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efficiency of hydrocarbon fuels. In the works, this effect is associated with a decrease in the flame temperature, due to which the formation of "thermal" NOx is reduced. However, all the results of previous work were obtained on burner devices with an unregulated supply of primary air, which does not allow us to provide optimal parameters that provide the greatest reduction in harmful emissions while maintaining high combustion efficiency.

The purpose of this work is to obtain new experimental data on the influence of operating parameters in the gas generation chamber of a burner device, namely, the amount of excess air when spraying liquid off-design fuel with a jet of superheated steam, on the content of harmful emissions in combustion products.

2 Introduction

To obtain experimental data on the influence of parameters in the gas generation chamber of a burner device on the content of harmful emissions in combustion products, studies were carried out on an experimental fire bench [7], the main elements of which are: a spray burner device, an adjustable fuel and compressed air supply system, and measuring equipment. As a burner device, a laboratory sample of a spray burner device with an adjustable supply of primary air was used, the diagram of which is shown in Figure 1. The main elements of the device are: a body with holes for controlled air supply; a steam nozzle connected to a superheated steam supply system; fuel supply system; measuring and control instruments. Fuel atomization in the device is carried out due to its interaction with a high-speed gas stream. A more detailed description of the burner and the principle of its operation is given in [7].

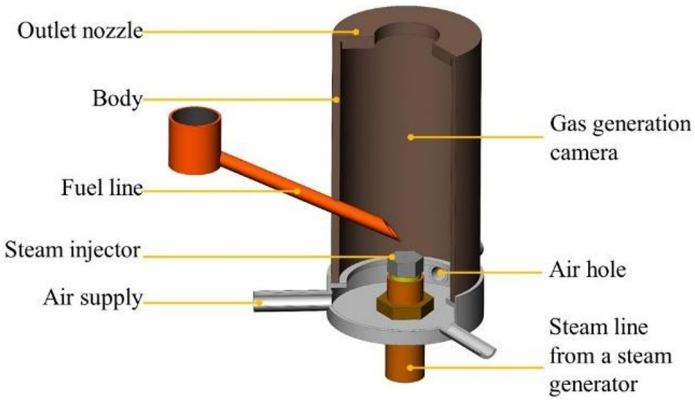

Fig. 1. Diagram of a spray burner device with controlled supply of primary air.

In this work the combustion of used automobile oil (gross formula $C_{12}H_{23,04}N_{0,084}O_{0,156}$) is investigated as an example of off-design fuel. The atomizer is superheated steam with a degree of superheating of ~100 ºC. A series of experiments was carried out to measure the temperature and composition of intermediate combustion products in a flame when burning waste oil using a platinum-rhodium-platinum-rhodium thermocouple type B and a TEST-1 gas analyzer. Also, using a flow calorimeter, the completeness of fuel combustion was assessed; the Testo 350 gas analyzer obtained the dependences of the content of carbon monoxide and nitrogen oxides in the flue gases. The measurement techniques are described in more detail in [7]. For the study, a mode with a constant fuel consumption of 0.95 kg/h and a spray (superheated steam) consumption of 0.65 kg/h was chosen. The primary air flow varied in the range of 4.5-12 kg/h. This fuel/steam mode was selected from previously obtained data on the combustion of diesel fuel in a burner device with an unregulated air supply into the gas generation chamber: it showed a low content of carbon monoxide and

nitrogen oxide in the exhaust gases of 20 and 95 mg/kWh, respectively. Table 1 presents the parameters and designations of the studied modes.

Table 1. The modes of study.

Mode	Fuel consumption, kg/h	Steam consumption, kg/h	Air flow rate, kg/h
O10S6A4.5	0.95	0.65	4.5
O10S6A7	0.95	0.65	7
O10S6A9.5	0.95	0.65	9.5
O10S6A12	0.95	0.65	12

3 Results and discussion

During the experimental study, the following indicators of the combustion process were determined: flame temperature profiles, amount of heat released, composition of intermediate and final products of fuel combustion. Figure 2 shows typical flame photographs for the modes under study, taken with a Nikon D780 digital camera (ISO – 2200, shutter speed – 1/200 sec.). It can be noted that with an increase in the primary air flow rate, the visible size of the flame decreases, and also the level of "inhomogeneities" in the edge of the torch visually decreases, which indicates an increase in the rate of exit of the combustible mixture from the gas generation chamber of the device, thereby possibly shifting the maximum value of the flame temperature to the burner nozzle.

Fig. 2. Typical photographs of flames at different primary air flow rates.

Figure 3 shows the average temperature profiles measured along the vertical axis of the burner device. It can be seen that with an increase in air flow, the position of the maximum temperature shifts towards the nozzle of the burner device, which is consistent with the assumption made earlier from characteristic photographs of the flame. Thus, the flame goes inside the combustion chamber, which indicates that the main combustion begins to occur in the burner device. In this case, with a decrease in the amount of supplied air, a decrease in

the maximum flame temperature is observed, due to which it is possible to expect a decrease in the formation of nitrogen oxide and its content in the final combustion products.

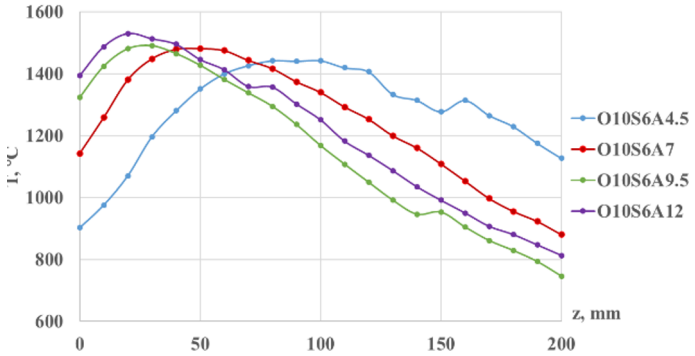

Fig. 3. Average temperature profiles along the axis of the burner device.

Figure 4 shows profiles of some intermediate combustion products measured using the TEST-1 gas analyzer [7] along the axis of the device.

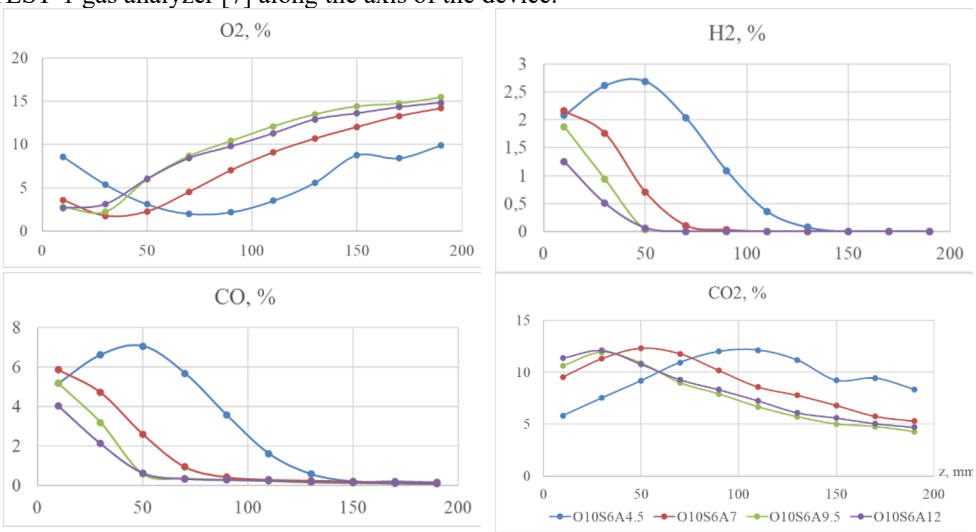

Fig. 4. Profiles of the content of intermediate combustion products in the flame along the axis of the burner device.

The profiles of CO and H_2 (products of incomplete combustion) show that the position of the maximum of their content decreases closer to the outlet nozzle of the burner device with an increase in the amount of supplied air, which confirms the conclusion that combustion moves closer to the base. It is also clear that with a significant decrease in the amount of air supplied to the gas generation chamber, a high oxygen content is observed at the outlet of the device, which may indicate a significant decrease in the degree of oxidation of the fuel in the chamber with a possible shift towards its gasification (the average temperature at the base of the external flame does not exceed 1000 °C), thus we can expect low levels of carbon monoxide in combustion products, despite high intermediate values.

Figure 5 shows the results of measuring the content of toxic combustion products (CO, NOx), obtained for the studied modes using a Testo-350 gas analyzer [7]. The figure shows that with an increase in primary air flow, an increase in the level of emissions is observed. Thus, it was found that the amount of air supplied into the gas generation chamber when spraying liquid off-design fuel with a jet of superheated steam also, in addition to steam

consumption [7], also affects the content of harmful emissions in combustion products and makes it possible to select optimal modes for the operation of the device depending on the type of fuel . It is worth noting that reducing the air to less than 4.5 kg/h (corresponds to α=0.375 in the figure 5) led to flame pulsation, probably due to the fact that the amount of heat received from partially oxidized fuel in the gas generation chamber is not sufficient for further ignition of the combustible mixture.

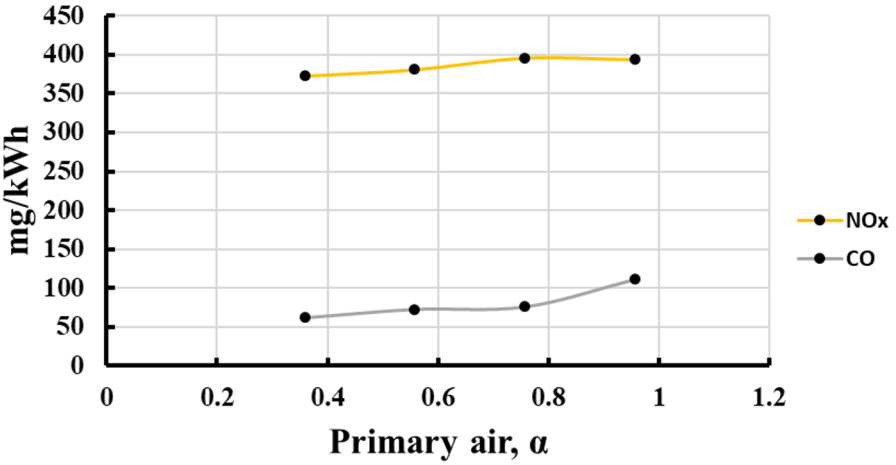

Fig. 5. Content of toxic combustion products: α - excess air coefficient in the gas generation chamber.

For the mode that demonstrated the best performance in terms of the content of carbon monoxide and nitrogen oxides, O10S6A4.5, a study of the fuel combustion heat was carried out. The results are presented in Table 2. It was found that the amount of heat released per 1 kg of burned fuel is close to the higher specific heat of combustion of waste oil (45.0 MJ/kg), thus reducing the amount of air supplied to the gas generation chamber does not reduce the degree of completeness of fuel burnout while simultaneously reducing emissions of harmful substances (CO and NOx).

Table 2. The modes of study.

O_2, %	1.9
CO, ppm (mg/kWh)	51 (61.82)
NOx, ppm (mg/kWh)	187 (372.82)
Flue gas temperature, °C	26.56
Calorific value, MJ/k	44.21

4 Conclusion

During the experimental study, the following indicators of the combustion process were determined: flame temperature profiles, amount of heat released, composition of intermediate and final products of fuel combustion. It has been shown that varying the primary air flow rate can influence the flame structure and emissions level. An increase in primary air flow leads to a decrease in flame due to the fact that the combustion reaction occurs earlier (inside the burner device). At the same time, there is an increase in the level of harmful emissions. The studied method of burning substandard fuel by spraying with superheated steam makes

it possible to reduce the level of emissions of harmful combustion products (such as CO and NOx) while finding optimal modes and can be used to create burner devices for the purpose of recycling substandard fuels (within the framework of Waste-to-Energy technology).

The research was carried out with funding from the Russian Science Foundation (project No. 23-79-10029).

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