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Pulsating burning of petroleum coke in the Rijke tube

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Abstract. In this paper, the combustion of petroleum coke is investigated. It is established that fluctuations of gas in the Rijke tube excited when petroleum coke burns with propane-air mixture. It is shown that over time the mixture supply can be significantly reduced due to the intensification of coke combustion by oscillations.


1. Introduction

Utilization of petroleum coke is an actual environmental problem. One of the solutions to this problem is the use of petroleum coke as a fuel for thermal power plants. Due to the high ignition temperature and low combustion rate, coke-coal or natural gas mixtures are used [1, 2]. It is known [3-5, 7] that gas oscillations significantly accelerate the combustion of solid fuels. There are a number of Rijke tube type plants that implement pulsed combustion of coal, wood and other industrial waste. The purpose of this work is to assess the possibility of pulsation combustion of petroleum coke in the Rijke tube.

2. Experimental result

The experimental setup is shown in Fig. 1. A quartz tube with a length of 0.87 m and an internal diameter of 56 mm was used. One layer of coke particles (average diameter 3.5 mm, average mass 2.64 g) was placed on a steel mesh ring. The ring was fixed on the gas supply pipe and was at a distance of ¼ of the length of the resonance tube from the lower end. The flame of the pre-prepared Propano-air mixture was evenly distributed along the ring and heated the coke layer to the combustion temperature. In the beginning when the coke is cold, the fluctuation of the gas was maintained Propano-air flame. When the coke starts to burn, the consumption of the mixture gradually decreased. In this case, the gas oscillations were maintained mainly due to the thermal energy of the burning layer. On the other hand, gas oscillations intensify heat and mass transfer processes in the layer. In the result of the coke particles burn faster and it becomes possible to self-maintenance of coke combustion.
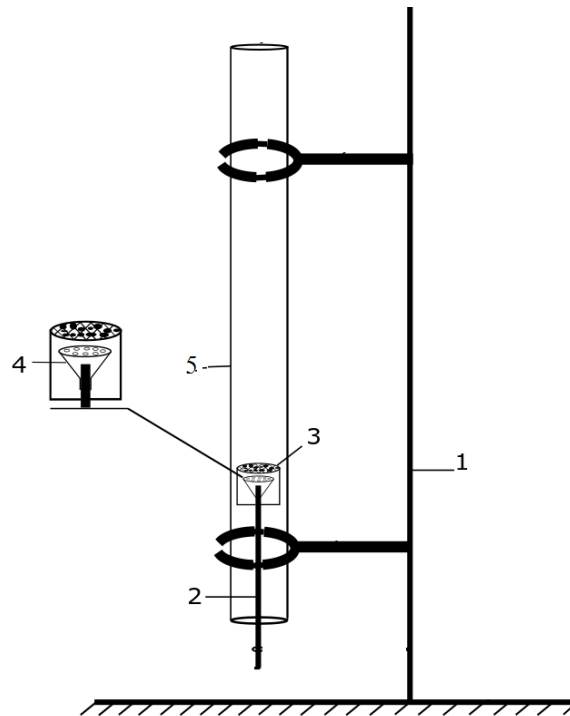
Figure 1. Experimental set-up.
1 - tripod, 2 - tube for supplying air-gas mixture to petroleum coke, 3 - steel mesh with petroleum coke, 4 - flame distributor, 5 - quartz glass tube.

Initial heating of the coke layer was carried out under the following conditions: propane consumption – $0,3\ l/min$, air consumption – $60\ l/min$. In this case, fluctuations of the gas with the frequency $229\ Hz$ was observed. After reducing the air flow to $10\ l/min$ it became necessary to increase the flow of propane to $0,5\ l/min$. Under such conditions, the measured frequency is $214\ Hz$. If the propane and air flows are equal $1\ l/min$, the oscillation frequency of the gas is equal to $223\ Hz$.

3. Calculation of the frequencies of the gas oscillations

From the acoustic point of view, the considered combustion chamber is a tube - resonator with open ends. If the average temperature of the gas T_0 in the tube does not change, the speed of sound will be constant, because:

$$c_0 = const\sqrt{T_0}, \tag{1}$$

In this case, as it is known [6], gas oscillations in a tube of length l have the frequencies:

$$f_n = \frac{c_0 n}{2l}, \quad n = 1, 2, 3, \ldots \tag{2}$$

In the case under study, the gas flow in the tube is inhomogeneous. At the bottom of the moving atmospheric air. Behind the fuel layer, the flow has a higher temperature and consists of combustion products of petroleum coke and stimulating gas. Typically, the speed of sound in combustion products is calculated by the formula (1), in which the value of the constant is the same as in the air flow [6]. Using table values of sound velocity $c_0 = 344\ м/с$, at air temperature $T_0 = 293K$, it is easy to calculate sound velocity at any temperature of combustion products T

$$c(T) = c_0\sqrt{T/T_0}$$

The peculiarity of the studied gas flow is that after increasing the temperature in the combustion zone, the gas is gradually cooled due to heat transfer to the walls of the tube. As a result, the speed of sound is variable.

In this paper, we propose to use the average speed of sound. As an initial approximation, we take the arithmetic mean of the sound velocities at the ends of the tube:

$$\bar{c} = (c_0 + c_l)/2, \quad c_l = c_0\sqrt{T_l/T_0}$$

In the tube opened at the ends, the vibration frequencies of the gas having a constant speed of sound are determined according to (2) by the formula:

$$f_n = \frac{\bar{c}n}{2l}$$

The table shows the results of measurements of the oscillation frequency of the gas, the gas temperature at the exit of the tube, the calculated values of the speed of sound at the exit of the tube and its average value, the calculated value of the oscillation frequency of the gas.

Table.

$f_э, Hz$	$t_l, °C$	T_l, K	$c_l, m/s$	$\bar{c}, m/s$	f_T, Hz
229	265	538	465	403	232
214	140	413	407	375	216
223	208	481	439	391	225

Comparison of the calculated and measured values of the gas oscillation frequency shows that they are consistent with a high degree of accuracy.

4. Conclusion

As a result, the principal possibility of the pulsating combustion of petroleum coke in the Rijke tube is proved. It is found that the frequency of gas oscillations corresponds to the lowest possible frequency of oscillations in the tube with open ends. With high accuracy to calculate frequencies, it is possible to use a known formula for a gas with constant sound speed equal to the arithmetic mean value of the sound speed at the ends of the tube.

Acknowledgements

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