The effect of pressure pulsation on diffusion combustion

Agafontsev, M., Loboda, E., Klimentiev, A., Reyno, V.

M. V. Agafontsev, E. L. Loboda, A. S. Klimentiev, V. V. Reyno, "The effect of pressure pulsation on diffusion combustion," Proc. SPIE 11916, 27th International Symposium on Atmospheric and Ocean Optics, Atmospheric Physics, 119161K (15 December 2021); doi: 10.1117/12.2603896

Event: 27th International Symposium on Atmospheric and Ocean Optics, Atmospheric Physics, 2021, Moscow, Russian Federation

The effect of pressure pulsation on diffusion combustion

M.V. Agafontsev [1,2], E.L. Loboda [1,2], A.S. Klimentiev [1], V.V. Reyno [2],

[1] Tomsk State University, Russia 634050, Tomsk, Lenin Av., 36;
[2] Institute of Atmospheric Optics Russian by V.E. Zuyev, Russian Academy of Science, Russia, 634021, Tomsk, Academician Zuev Sq., 1
E-mail: kim75mva@gmail.com, loboda@mail.tsu.ru, aleksandr.klimentev.96@mail.ru, reyno@iao.ru

ABSTRACT

The paper presents the results of a study of diffusion combustion of gasoline in the presence of external pressure pulsations with small amplitude. It is found that external pressure pulsations lead to characteristic changes in the temperature field, which are expressed by an increase in the amplitude of the temperature pulsation for certain modes of pressure pulsations. Analysis of the spectra of temperature changes in the entire recorded area showed an uneven distribution of frequency maxima.

Keywords: combustion, hydrocarbons, acoustic oscillation, infrared diagnosis, FFT analysis

1. INTRODUCTION

Diffusion combustion mode of various types of combustible materials is the most common, due to the ease of implementation and use in practice. The processes in which this combustion mode is the most extensive are man-made and natural fires. The difficulty in their study is the chaotic nature of the combustion process, which is expressed in unpredictable behavior. Combustion in this mode is realized in conditions of developed turbulence. It is known that the movement of turbulent structures in a diffusion flame leads to temperature pulsations in the flame [1], which occur with a certain frequency related to the size and speed of movement of turbulent structures in the flame.

The flame plume pulsations observed during combustion are due to the formation of multiple vortices resulting from turbulent mixing in the primary combustion zone [2, 3]. Previous studies have shown that the steady-state component depends on the evaporation rate of the fuel, the geometrical characteristics of the flame, and the radiation intensity. The low-frequency components in the flame signal are due to changes in the geometry of the flame plume, aerodynamic, or convective effects. High-frequency pulsations reflect processes occurring during chemical reactions [4].

A review of the literature devoted to the study of the influence of acoustic waves on the combustion process of gaseous fuel is presented in [5]. The authors conclude that the use of acoustic waves is a possible way to control the combustion mode. In addition, they emphasize the fact that such an effect increases the efficiency of fuel combustion and reduces the amount of harmful gaseous combustion products [6-9]. They noted the promise of such studies for extinguishing fires.

Among the various methods of investigating pulsed combustion modes, we can distinguish methods based on the analysis of the sequence of images of the combustion process [10-12]. In a paper [10] was analyzed the behavior of the luminous zones of pool fires at the large-scale experiments performed in Japan, 1981 [13]. The source of the combustion was a 30 and 50-m diameter pool of kerosene. The authors obtained that the zone of maximum luminous is located in the central point of the average plume. At the same time, the authors observed a shift of the luminous zone upstream, with an increase in the diameter. The authors also obtained quantitative estimates of the flame pulsation frequency near the base. The authors [11] have developed an experimental setup to study the pulsation mode of combustion, which allows for real-time analysis. The authors of the work have shown that as the diameter of the burner increases, the frequency of flame pulsation decreases, which is consistent with the works [14,15]. The authors [11] conducted a study of flame pulsation during combustion of a premixed mixture of fuel and oxidizer with a known ratio. They obtained frequency spectra that show that the high-frequency components of the flame radiation increase with a decrease in the equivalence ratio, which

27th International Symposium on Atmospheric and Ocean Optics, Atmospheric Physics,
edited by Gennadii G. Matvienko, Oleg A. Romanovskii, Proc. of SPIE Vol. 11916,
119161K · © 2021 SPIE · 0277-786X · doi: 10.1117/12.2603896

leads to an increase in the measured flicker (the flicker has a maximum value at an equivalence ratio of 1.38). In the article [16], a study of flame pulsation during flow swirling was carried out. The authors used a beam deflection method based on the Schlieren principle as a sensor that registers flame pulsations. The authors [16] recorded 4 discrete peaks in the obtained flame pulsation spectrum. Of these, the first peak corresponds to the natural frequency of flame pulsation, which is determined by the burner geometry and the fuel-air mixture. The remaining peaks are harmonic frequencies.

This paper presents the results of an experimental study of gasoline combustion under the influence of low-amplitude external pressure pulsations. Noncontact IR thermography methods were used for the studies.

2. DESCRIPTION OF EXPERIMENTAL SETUP

Gasoline with a mass of 10 g was used as a combustible material. The combustible substance was diffusively combusted in a tin container, which diameter was 0.15 m and the side walls height was 0.02 m. As recording equipment was used infrared camera JADE J530SB with narrow-band filter with a bandwidth of 2.5 - 2.7 microns wavelength. The infrasound generator was a 25-GD-26 low-frequency loudspeaker, to which was applied a sinusoidal signal generated by a signal generator of a special form G6-28, preamplifier using an amplifier LV 103. Additionally, the temperature in the flame was monitored by a thermocouple of K type to find the effective radiation coefficient of the flame. The distance from the source of oscillations to the flame was 0.3 m. The scheme of the experiment is shown in figure 1.

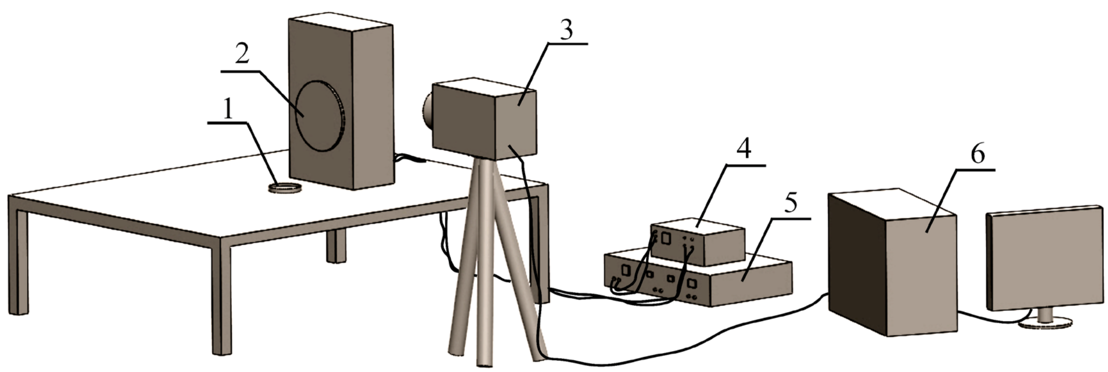
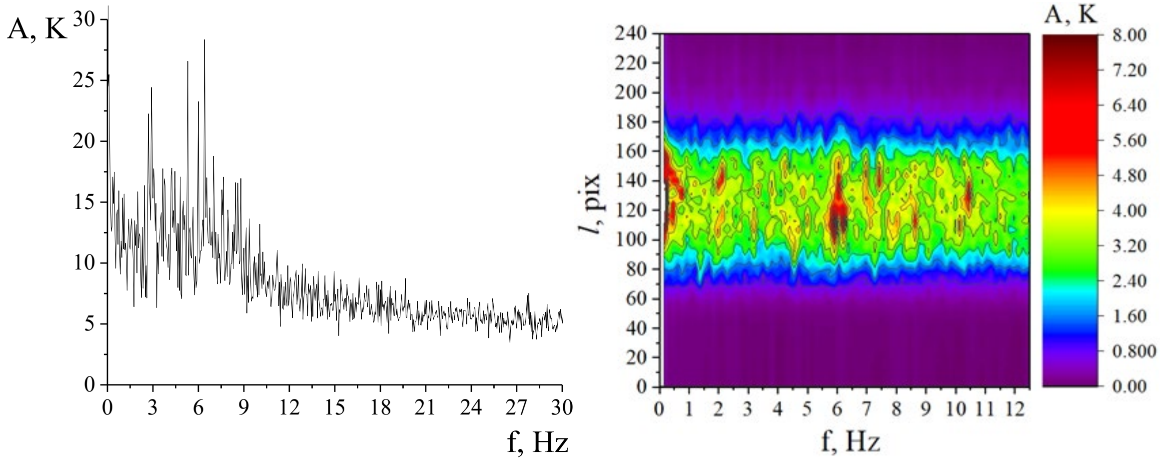


Fig. 1. Schematics of the experimental setup: 1 - tank with the fuel; 2 - 25-GD-26 loudspeaker; 3 - Jade J530SB thermal imaging camera; 4 - LV 103 amplifier; 5 - G6-28 generator; 6 - personal computer

The thermograms obtained as a result of the survey were processed using "Altair" software. To find the spectrum of temperature changes in the whole recorded area, the algorithm of the program "TempSpectrum-v.1" [17] was modified.

Figure 2 shows the spectrum of temperature change in the flame during gasoline combustion, in the absence of external influences. The temperature change spectrum shown in Figure 2a is obtained in the central section of the flame, and the number of analyzed points in the thermogram corresponds to 30. The temperature change spectrum shown in Figure 2b is obtained for the entire working area of the thermogram.

3. RESULTS AND DISCUSSION

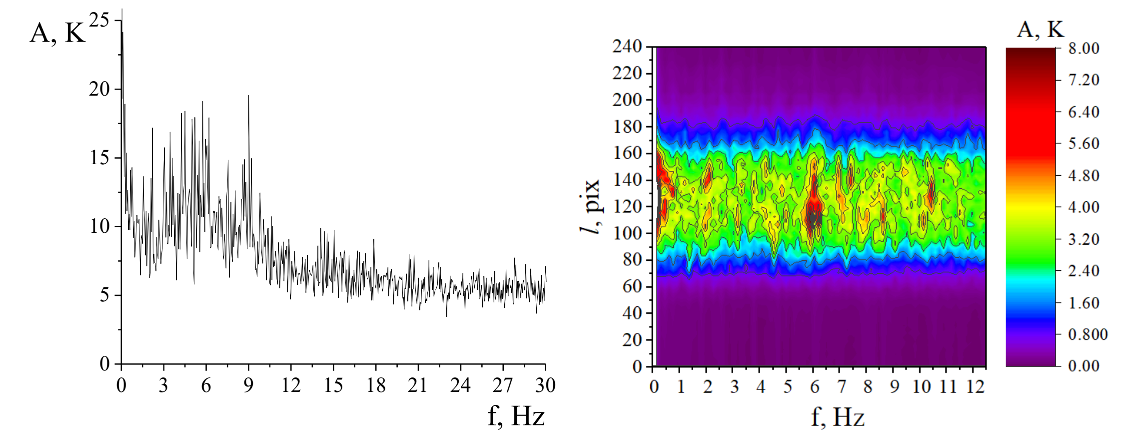


a

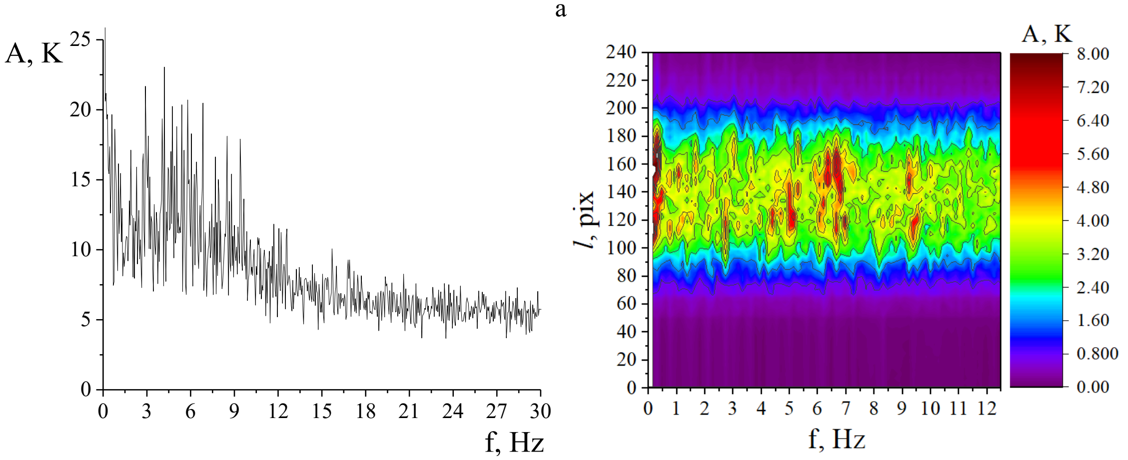
b

Fig. 2. Spectrum of temperature changes in the flame produced by the diffusion combustion of gasoline without external influences: a - in the central section of the flame plume, b - in the entire operating area of the thermogram

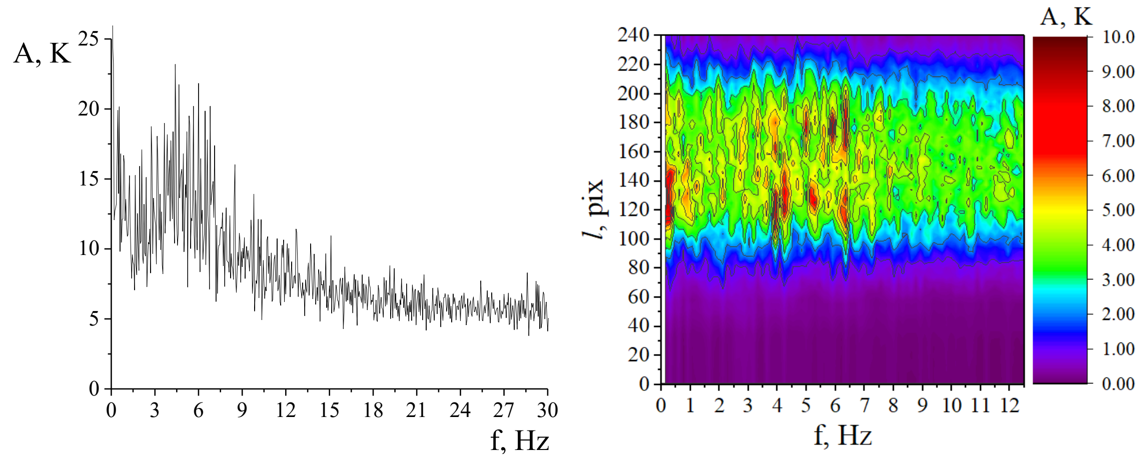
Figure 3 shows the spectra of changes in the temperature of the flame when exposed to sound vibrations with frequencies of 2 Hz, 4 Hz, 6 Hz, 8 Hz.



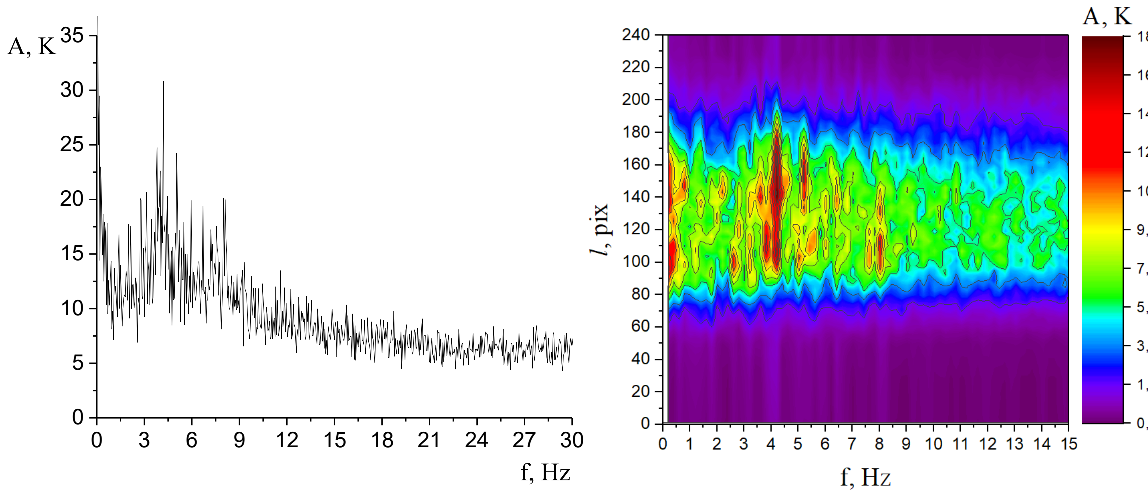
a



b



c



d

a - 2 Hz, b - 4 Hz, c - 6 Hz, d – 8 Hz. The figure on the right is obtained for the central section of the flame plume, on the left - for the entire working area of the thermogram.

Fig. 3. The spectrum of temperature changes in the flame formed by the diffusion combustion of gasoline in the presence of external influences of pressure pulsations with different frequencies

From the analysis of Figures 2 and 3, we can conclude that, at certain frequencies of exposure, there is an intensification of fuel combustion, which is accompanied by an increase in the amplitude of temperature pulsations in the flame with frequencies close to the frequency of exposure. This phenomenon can be explained as an intensification of combustion in individual turbulent structures due to improved mixing of volatile combustible components with the oxidizer from the external atmosphere, and due to the appearance of mechanical resonance. Comparing the spectra of temperature changes obtained for one section and the entire operating region, it can be concluded about the heterogeneous distribution of the foci of amplitude maxima. In addition, we can notice a discrepancy in the maximum values of the pulsation amplitude, which is caused by averaging over 320 points, which were used to obtain the spectrum. The presence of pulsation amplitude maximums at the edges of the flame plume is probably associated with the area of greatest intensity of mixing the ambient air (oxidizer) with the upward flow of combustible gases.

Acknowledgment

This work was supported by the Ministry of Science and Higher Education of the Russian Federation (V.E. Zuev Institute of Atmospheric Optics of Siberian Branch of the Russian Academy of Sciences).

REFERENCES

[1] Loboda E.L., Matvienko O.V., Vavilov V.P., Reyno V.V. Infrared thermographic evaluation of flame turbulence scale, Infrared Phys. Technol., 2015, V. 72, pp. 1–7. DOI: 10.1016/j.infrared.2015.07.001.

[2] Portscht R. Studies on characteristic fluctuation of the flame radiation emitted by fires, Combust. Sci. Technol., 1975, V. 10, Iss. 4, pp. 73–84. DOI: 10.1080/00102207508946659.

[3] Khesin M. Demonstration of new frequency-based flame monitoring system, Proc. Amer. Power Conf., Chicago, IL, 1996, V. 58-II, pp. 1010–1013.

[4] Jones A.R. Flame failure detection and modern boilers, J. Phys. E Sci. Instrum., 1988, V. 21, Iss. 10, pp. 921–928. DOI: 10.1088/0022-3735/21/10/001.

[5] Il'yushonok A.V., Goncharenko I.A., Leshenyuk N.S., Kuleshov V.K., Tereshenkov V.I. O vliyanii zvukovykh voln na protsessy goreniya, Vestnik Universiteta grazhdanskoy zashchity MCHS Belarusi. 2017. V. 1, Iss 1. pp. 26–34.

[6] Krivokorytov M.S., Golub V.V., Volodin V.V. Vliyaniye akusticheskikh kolebaniy na diffuzionnoye goreniye metana, Pis'ma v Zhurnal tekhnicheskoy fiziki, 2012. Iss. 38 (10). pp. 57–63.

[7] Golub V.V., Baklanov D.I., Golovastov S.V., Ivanov K.V., Ivanov M.F., Kiverin A.D., Volodin V.V. Vozdeystviye akusticheskogo polya na razvitiye plameni i perekhod v detonatsiyu, TVT, 2010, Iss. 48:6. pp. 901–907.

[8] Volodin V.V., Korobov A.Ye., Golovastov S.V., Golub V.V. Vliyaniye otrazhennykh akusticheskikh vozmushcheniy na uskoreniye fronta plameni, Pis'ma v zhurnal tekhnicheskoy fiziki, 2015. V. 41, Iss. 21, pp. 60–65.

[9] Golub V.V., Ivanov M.F., Volodin V.V., Blagodatskikh D.V., Golovastov S.V. Vliyaniye akusticheskikh voln na zonu vosplameneniya i perekhod goreniya v detonatsiyu: eksperiment i raschet, TVT, 2009, Iss. 47:2, pp. 315–316.

[10] Takahashi N., Suzuki M., Dobashi R., Hirano T. Behavior of luminous zones appearing on plumes of large-scale pool fires of kerosene, Fire Safety, 1999, V. 33, Iss.1, pp. 1–10. DOI: 10.1016/S0379-7112(99)00009-0.

[11] Huang Y., Yan Y., Lu G., Reed A. On-line flicker measurement of gaseous flames by image processing and spectral analysis, Meas Sci Technol, 1999, V. 10, pp. 726–733. DOI: 10.1088/0957-0233/10/8/307.

[12] Chen J., Bao Q. Digital image processing based fire flame color and oscillation frequency analysis, Procedia Engineering, 2012, V. 45, pp. 595–601. DOI: 10.1016/j.proeng.2012.08.209.

[13] Japan Society for Safety Engineering. The Report of the Oil Pool Fire Experiment. J. S. S. E, Yokohama, Japan, 1981.

[14] Cetegen B.M., Ahmed T.A. Experiments on the periodic instability of buoyant plumes and pool fires, Combustion and Flame, 1993, V. 93, Iss. 1–2, pp. 157-184. DOI: 10.1016/0010-2180(93)90090-P.

[15] Hamins A., Yang J.C., Kashiwagi T. An experimental investigation of the pulsation frequency of flames, Twenty-fourth symposium (international) on combustion, 1992, V. 24, Iss. 1, pp. 1695–1702. DOI: 10.1016/S0082-0784(06)80198-0.

[16] Gotodaa H., Uedaa T., Shepherdb I.G., Cheng R.K. Flame flickering frequency on a rotating Bunsen burner, Chemical Engineering Science, 2007, V. 62, Iss. 6, pp. 1753–1759. DOI: 10.1016/j.ces.2006.11.012.

[17] Agafontsev M.V., Kasymov D.P., Reino V.V., Loboda E.L. RU Patent No.№ 2018660618 «TempSpectrum-v.l.», 28.08.2019.