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The Effect of Fuel and Air Agitation on the Combustion Process in a Low-Emission Combustion Chamber

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Abstract—Methods for numerically simulating the working process in low-emission combustion chamber and for testing it are described. A method of using numerical simulation for predicting NO_x emission and combustion process stability in a low-emission combustion chamber is proposed.

Keywords: low-emission combustion chamber, burner device, fuel–air mixture, emission, air excess factor, amplitude, frequency, stability, pulsation, gradient

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Traditionally, diffusion combustion of fuel was applied in the combustion chambers (CCs) of gas turbine units (GTUs), with which the required reliability, stability, and economic efficiency of this process was achieved. However, such combustion method entails high emission of NO_x. Toughening the requirements imposed on the environmental characteristics of GTUs has led to the need to make a shift for firing a preagitated lean fuel–air mixture. The use of this method makes it possible to reach a considerably smaller yield of thermal nitrogen oxides. Setting up premixing of fuel and air and evaluating effectivity of this process became among the objectives to be pursued in developing CCs.

The use of such method for firing lean fuel–air mixtures often leads to the occurrence of vibratory or unstable combustion in certain operating modes of gas turbine units. Under such conditions, pressure fluctuations with significant amplitudes arise in the combustion chamber, which may lead to vibration and failure of engine parts [1]. Small variations in the composition of mixture may affect the stability of its ignition and give rise to fluctuations of heat release. Pressure pulsations can be generated under such conditions if a resonance with the acoustic wave in the CC takes place. In addition, since the flame in the combustion chamber is interrelated with the aerodynamic behavior of the recirculation zone, the flame front fluctuations depend essentially on the hydrodynamic processes in this zone [2–4].

The development and modification of existing combustion chambers up to the category of low-emission ones is a time- and money-consuming process. The expenditures of time and money for this work can be reduced by using modern software systems. These systems allow the user to calculate gas dynamic and combustion processes in a 3D space of any complexity and to evaluate the emission of NO_x and other combustion products. However, the results obtained from such calculations are still insufficiently trustworthy because there is too large degree of freedom in selecting the assumptions and simplifications used to describe the combustion process. To achieve successful application of calculation results, they should be identified with the use of experimental data obtained on model CCs.

In this article, we present the results obtained from experimental and numerical investigations of a model CC. By using the obtained ratios between the numerical and experimental data, it is possible to predict NO_x emission and stability of combustion process.

The numerical investigations were carried out using the domestically developed FlowVision software system [5] intended for numerical simulation of 3D laminar and turbulent, steady and unsteady flows of liquid and gas by numerically solving the Navier–Stokes equations describing a flow of fluid. This software system takes into account the influence of various physicochemical effects (combustion, turbulence, etc.). The combustion model assumes a single irreversible gross reaction.

The experimental investigations were carried out on the experimental rig of the All-Russia Thermal Engineering Institute (VTI). The schematic diagram of the experimental section with the model CC installed in it is shown in Fig. 1.

The values of NO_x emission at the flame tube outlet were measured by means of the chemiluminescence technique with a measurement error of less than 1% of full scale and using Testo350M and Infralight-11E gas analyzers. Pressure pulsations were measured at two points in the flame tube (see Fig. 1) by means of KISTLER sensors with the use of a MIC-300 instrument.

The design of the model CC is typical for modern combustion chambers employing the principle of fir-