The active centers that carry the process of combustion at atmospheric pressure are usually recorded by methods of optical spectroscopy. The absorption spectrum of hydrogen atoms lies in the region of the vacuum ultraviolet, and their recording in flames involves great difficulties. Therefore, indirect methods are used, requiring the introduction of various additives [1]. The ESR method was used earlier for rarefied flames to detect hydrogen atoms at pressures below 10 torr [2]. Usually the ESR spectrum in the gas phase can be detected only at low pressures as a result of the strong broadening of the absorption lines when the pressure is increased. In [3], however, it was shown that the width of the ESR line of atomic hydrogen varies little with increasing pressure. The possibility of measuring the concentration of hydrogen atoms with an ESR spectrometer in the combustion of methane- and hydrogen-air mixtures at atmospheric pressure was first demonstrated in [4], where estimates of the H concentration in the flame front were made.

Fig. 1. Profiles of the concentrations of hydrogen atoms along the height of diffusion hydrogen-air flames for various coefficients of excess air $\alpha$: 1) 0.2; 2) 0.3; 3) 0.4; 4) 0.8; 5) 1.0; 6) 2.0.

Fig. 2. Comparison of the measured hydrogen atom concentrations with the corresponding equilibrium H concentrations, calculated for an adiabatic temperature of the flame [15]: 1) maximum H concentrations; 2) H concentrations measured at a distance of $\sim$10 cm from the stabilizer; 3) curve of the equilibrium H concentrations.

We studied the distribution of the hydrogen atom concentration along the length of the combustion zone in sufficiently extensive diffusion flames of hydrogen with air in a broad range of variation of the initial composition of the mixtures, as well as in certain flames of preliminarily mixed hydrocarbon–air mixtures. An advantage of the ESR method is the fact that the measurement procedure does not disrupt the conditions of combustion and permits a determination of the absolute concentrations of atomic hydrogen. In this case the possibility of simultaneous measurement of other parameters of the flame (optical spectra, temperature of the flame, ionization currents, and others) is retained.

**EXPERIMENTAL METHOD**

The experiments were conducted on a burner placed directly in the resonator of an EPR-2M type spectrometer. The burner consists of two coaxial tubes 14 and 6 mm in diameter, through which the fuel and oxidizing agent were delivered separately. In an investigation of the combustion of hydrocarbon–air mixtures, preliminarily mixed mixtures were delivered through the inner tube. The gas consumption was monitored with manometers and rotameters, and in work with preliminarily mixed mixtures, the mixture entering the burner was additionally analyzed on a Khrom-3 type chromatograph. In the case of separate delivery of the fuel and oxidizing agent, the stencil tube ended in a conical stabilizer, into the cavity of which the fuel gas was delivered. In addition, preliminary preheating of the gases to ~200° was provided. The burner can easily be displaced along the resonator, which permits recording of hydrogen atoms along the height of the tube at various stages of combustion, as well as in the combustion products. Measurement of the temperature in the combustion zone and combustion products was performed with a PP-1 thermocouple 0.2 mm in diameter, protected with a thin layer of quartz. Standardization was carried out according to the C-line of molecular oxygen, passed through the burner at 1.5 torr and ~20°. In a measurement of the absolute concentrations of H atoms under conditions of combustion, the dependence of the absorption signal on the temperature was considered. The values obtained for \([H]\) are somewhat elevated, since the gas temperature along the cross section of the burner is nonuniform, and a consideration of the dependence of \([H]\) on \(T\) was performed for the maximum measured values of \(T\).

**DISCUSSION OF RESULTS**

Figure 1 presents the results of a measurement of the hydrogen atom concentration along the height of the diffusion flames of hydrogen–air mixtures for various initial compositions and a total consumption of ~640 liter/h. From the data cited it is evident that the maximum H concentrations are reached in the combustion zone close to the stabilizer, and then drop smoothly along the height of the burner. An analysis of the dependence of the H concentration on the initial ratio of hydrogen and air in the combustion zone shows that the maximum of \([H]\) increases with enrichment of the initial composition of the mixtures.

It is interesting to compare the data obtained with the equilibrium values of the hydrogen atom concentrations in the flame of hydrogen–air mixtures, calculated in [5]. This comparison is presented in Fig. 2. The maximum hydrogen atom concentrations in the combustion zone are approximately an order of magnitude greater than the equilibrium concentrations close to the stoichiometric initial composition of the mixture and two to three orders of magnitude greater than those far from the stoichiometry, both on rich and on poor mixtures. Concentrations of H above the equilibrium values are also maintained far from the combustion zone. Thus, at a distance of ~10 cm from the stabilizer (see Fig. 2), on rich and poor mixtures, large concentrations of H, significantly exceeding the equilibrium values, still remain. We should note that close to the stoichiometric initial composition of the mixture at a distance of ~10 cm from the stabilizer, the hydrogen atom concentrations approach the equilibrium values.

The rate constant of recombination of hydrogen atoms in triple collisions \(H + H + M \rightarrow H_2 + M\) was estimated according to the drop in the hydrogen atom concentration at the end of the combustion zone and in the combustion products for one of the curves of Fig. 1 (\(\alpha = 0.8\)). Its value, \(3 \cdot 10^{-33} \text{ cm}^6 \cdot \text{molecule}^{-2} \cdot \text{sec}^{-1}\) at \(T = 1000°K\), proved close to that known from the literature [6, 7] in the temperature range under consideration. The temperature dependence of the rate constant of recombination \(K \sim T^{-1.3}\) also is in satisfactory agreement with the known data [6].

An investigation of the H concentration in the combustion zone and in the combustion products of preliminarily mixed mixtures of air with hydrocarbons (especially pure methane and propane) was conducted at a flow rate of the mixtures ~150 liter/h. To expand the limits of combustion the mixtures were preheated to ~150°. The maximum concentrations of hydrogen atoms recorded in the combustion zone of rich methane– and propane–air mixtures reached \(10^{18} \text{ cm}^{-3}\), which is an order of magnitude below the maximum H concentrations detected in the zone of combustion of hydrogen with air. As the hydrocarbon–air mixtures become...