EFFECT OF AN H₂O₂ ADDITIVE ON HYDROGEN IGNITION AND COMBUSTION IN A SUPERSONIC AIR FLOW

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The effect of small amounts of inert and reacting additives (such as hydrogen peroxide, its decomposition products, CO₂, etc.) on the ignition and combustion of hydrogen in a high-temperature supersonic air flow was studied experimentally. It is shown that direct doping of the fuel has little effect on the combustion of H₂, whereas injection of hydrogen peroxide or small amounts of pure hydrogen ahead of the nozzle decreases suddenly the ignition delay, indicating the profound effect of the reaction products. Comparative experiments with inert additives showed that these additives only lead to a decrease in the air-flow temperature.

It is known [1-6] that the addition of chemically active agents to an oxidizer or fuel can have a significant effect on the ignition delay and the time of chemical reactions for some parameters of the medium. In particular, Golovitchev et al. [1] showed numerically that the addition of 10% (by volume) hydrogen peroxide to a methane-air mixture or a CH₄-O₂-air mixture at initial temperatures of 1200-2025 K decreases the ignition delay considerably. The addition of hydrogen or propane to a CH₄-O₂-Ar mixture also leads to a decrease in the ignition delay [3]. Golovitchev and Bruno [4] showed that the ignition of H₂ in a concurrent supersonic air flow (M = 2 and T ≲ 1400 K) can be achieved by burning part of the hydrogen in a precombustion chamber or by introducing 10% H₂O₂ with the fuel. Pure hydrogen did not ignite under these conditions. In this case, OH and H radicals have a strong effect on the acceleration of chemical reactions, as noted in [1, 4]. Furthermore, it was found that the NO concentration changes with the addition of H₂O₂ just as with the addition of H₂ in [7].

Hydrogen peroxide, unlike many other chemically active agents (for example, those containing fluorine or silanes, which can also be used [5, 6]) is far less toxic under normal conditions, because its decomposition products are H₂, O₂, and water. In addition, H₂O₂ is used in many other fields of technology and is produced on the commercial scale. A disadvantage of H₂O₂ is its chemical instability at volume concentrations higher than 37.4%, which imposes certain limitations on the transportation and the shelf life of highly concentrated hydrogen peroxide.

The goal of the present work is to verify experimentally the possibility of using H₂O₂ and its decomposition products (H₂ and H₂O) to improve hydrogen ignition and to control its combustion in a hot supersonic air flow.

A diagram of the experiment and the setup used are shown in Fig. 1. Air heated in an arc heater passed through a precombustion chamber and then into a supersonic axisymmetric nozzle with a diameter of 50 mm. Hydrogen was fed to an injector 10 mm in diameter located along the nozzle axis. In the hot air jet, it self-ignited and burned. The flame structure and combustion intensity were studied by recording the radiation-intensity distribution of OH radicals [8], and the flame shape was recorded by a video camera. We used the basic regime with steady H₂ combustion and a distinct ignition delay. The air-flow Mach number was M = 2.2, the pressure was p₀ = 7.2 atm, the stagnation temperature was T₀ = 2000 K, and the air and
Fig. 2. Oscillograms of the radiation intensity of OH radicals versus flame length with supply of only H\textsubscript{2} (a), H\textsubscript{2} + H\textsubscript{2}O (b), and H\textsubscript{2} + H\textsubscript{2}O\textsubscript{2} (c) to the injector.

hydrogen flow rates were 580 and 4.6 g/sec, respectively. Hydrogen peroxide or another liquid to be studied was placed in a 16-cm\textsuperscript{3} vessel closed by a piston from above.

During the experiment, air was initially fed to the precombustion chamber, and the main hydrogen was then fed to the injector. The arc heater was started, and the required regime was attained and recorded for subsequent comparison. After that, the valve in the H\textsubscript{2}O\textsubscript{2} feeding line opened, and the hydrogen pressure from the main line was transferred to the piston. Hydrogen peroxide from the vessel was supplied through a diaphragm to the hydrogen main line, in which it was mixed with hydrogen and injected through the injector. The flow rate of H\textsubscript{2}O\textsubscript{2} was usually 0.5 g/sec. In the experiments, we used hydrogen peroxide of stable (3 and 37.4%) and unstable (65%) concentrations. For comparison, we also used distilled water instead of H\textsubscript{2}O\textsubscript{2}.

The experiments performed showed that in the basic regime (supply of H\textsubscript{2} alone), the ignition delay (for distance) was \( x = 230 \text{ mm} \) from the injector cutoff (Fig. 2a). With the addition of water, the ignition delay increased to \( x \approx 340 \text{ mm} \) (Fig. 2b). With supply of H\textsubscript{2}O\textsubscript{2} at 3 and 37.4% concentrations, essentially no differences from the case of water supply were observed.

With the addition of 65% hydrogen peroxide, the ignition delay decreased insignificantly (\( x \approx 320 \text{ mm} \)). It should be noted that this effect is within the accuracy of recording and maintenance of regime stability. The fact that at an \( \sim 65% \) H\textsubscript{2}O\textsubscript{2} concentration, the change in ignition delay does not exceed 6% as compared with the addition of water can be considered reliable.

A more significant effect is observed with supply of H\textsubscript{2}O\textsubscript{2} to the precombustion chamber. The basic regime of air and H\textsubscript{2} supply to the injector was the same. The supply system was somewhat different, because hydrogen peroxide was supplied by a separate line and was injected by air. The site of supply was at 130 mm from the nozzle throat (at \( 220 \text{ mm} \) from the injector cutoff). In these experiments, we used only 65% hydrogen peroxide. Recording of the OH radiation by an optico-mechanical scanner, direct observation, and video recording showed that, with supply of H\textsubscript{2}O\textsubscript{2}, the ignition delay immediately vanished.

In the experiments with H\textsubscript{2}O\textsubscript{2}, the hydrogen-ignition delay increased with increase in water-flow rate. As the flow rate reached 5 g/sec, the total combustion intensity decreased markedly. Visual observations and color video recording showed that the water did not completely evaporate, and part of it entered the combustion zone as very fine droplets. With a prolonged water supply (more than 5 sec) at this flow rate, the flame was no longer stable. It was recorded for a short time in the region of the fourth and fifth “barrels” of the air jet, and then extinguished spontaneously.

A similar increase in ignition delay followed by flame extinction was also observed with supply of