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On a porous medium combustor for hydrogen flame stabilization and operation

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ABSTRACT

In this study, the characteristics of hydrogen flame stabilization in porous medium combustor were investigated. The flame was observed in a quartz tube. The porous medium was oxide-bonded silicon carbide (OB-SiC) or aluminum oxide (Al_2O_3) with 60 PPI and 30 PPI pore size distributions. The results indicated that under a low equivalence operation, the flame would transform from surface combustion to interior combustion with an increased heating value. Under a high equivalence ratio, both interior combustion and flashback transition existed at the same time. The thermal conductivity of silicon carbide is higher than that of aluminum oxide. Thus, interior combustion region was more extensive under a low equivalence ratio operation with a high premixed gas velocity. Flashback was apparent for Al_2O_3 under high an equivalence ratio with low a premixed gas velocity. Consequently, hydrogen flame stability could be controlled by the pore size distribution and thermal conductivity of the porous media, input heating value and input equivalence ratio.

Introduction and literature review

During past decades, human acquired energy from fossil fuel resources and produced greenhouse gas (e.g. carbon dioxide and methane) into the environment. Global climate change was possible due to fossil fuel combustion. Besides, natural energy resources will vanish soon. For example, coal supply can only last 200 more years. The global oil crisis and carbon dioxide reduction make energy research an important issue in the world. Energy technologies have been an important issue since nineteenth century when industrial revolution started. Solid fuel such as coal and wood were commonly employed on steam engine and boiler. Nevertheless, the major breakthrough of energy usage was transited from solid fuel to gas and liquid form gradually. Gas fuel (hydrogen and methane) has the chance to become one of the main energy sources for human beings in the low carbon emission age [1]. Because of soaring petroleum price, renewable energy, such as hydrogen, wind, solar and bio energy applications are rapidly developed. These new clean energy technologies will not only prompt efficiency but also reduce carbon emission in the future.

Hydrogen molecular is the smallest and lightest of all elements, thus it is difficult to exist in pure form in the universe.

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The hydrogen resources could be obtained in many ways, with, for example the steam reforming reaction on hydrocarbon fuel being able to produce large quantity of hydrogen. Besides, several new hydrogen production technologies were developed, such as petroleum refined procedure and water electrolysis, etc. As a fuel, the advantages of hydrogen are its highest adiabatic flame temperature (2390 K), its widest flammability limit (Φ = 0.1–7.1, *Vol*% = 4–75%) and highest heat release per mass in kilogram (*LHV* = 119.7 MJ/kg) [2]. Moreover, the major emission after hydrogen combustion is water vapor. It won't cause any green house gas (GHG) emission. Nevertheless, some abnormal combustion phenomena, such as auto-ignition and flashback, could attribute to the natural properties of hydrogen. As the results of minimum ignition energy (0.02 mJ) and laminar flame velocity (S_L = 290 cm/s, Φ = 1.0) of hydrogen, flame holding would be a problem for hydrogen combustion applications [3]. Besides, in hydrogen enriched combustion [4–6], the flow field in combustor would be affected due to the high laminar flame velocity and non-equidiffusion phenomena (preferential diffusion and non-unity Lewis number). When higher hydrogen content, flame structure would be distorted due to high diffusion and eddy formation near the entrance. Therefore, the stability of combustion (burning rate and flame structure) will different from normal premixed flame of hydrocarbon fuels [7]. It is thus necessary to carefully design the fuel parameters and combustion chamber geometry for applications of hydrogen as a fuel.

The exhaust gas of vehicle is one of the major sources of carbon dioxide. Many studies aimed to apply hydrogen to replace gasoline in internal combustion engines since hydrogen combustion won't produce nitric oxides or involve carbon molecular. However, there are still many problems in hydrogen storage and transportation need to be overcome in automobile applications. Especially under high pressure operation in cylinder, abnormal combustion phenomena would induce high pressure condition, e.g. knocking or backfire. Therefore hydrogen flame stability studies play an important role that could assist the development of hydrogen internal combustion engine [2]. Hydroxyl radical (OH^*) and vapor (H_2O) are the major species on hydrogen flame. By chemiluminescence, the wavelength of vapor is around 600–900 nm which is close to that of red light. The wavelength of OH^* radical emission is about 295–325 nm. The ultraviolet wavelengths below 400 nm are not visible to human eyes so that H_2 flame could not be seen [8–10] (Fig. 1). Flame observation is important for combustion study. Ciatti et al. [8] analyzed hydrogen flame temperature in cylinder by chemiluminescence method. An optical system with laparoscope and optic fiber was used to transfer the light wavelength in a combustion chamber to a spectrograph. The light information collected was employed to analyze combustion temperature in the cylinder. The chemiluminescence intensity of hydroxyl radical (OH^*) depends on the equivalence ratio (Φ), and the flame temperature is also a function of equivalence ratio. The optical system used in Ciatti et al. [8] could be used to monitor the ultraviolet emissions of the OH^* radical. It is also possible to calculate the combustion gas temperature based on the spectrographic signal. Schfer et al. [9] studied flame color of premixed and diffusion flame of hydrogen combustion. Flame colors vary with reactant gas purity. Fig. 2, shows that the upstream flame is bluish either due to CH^* radical formation from carbon dioxide pyrolysis which is commonly present in atmosphere, or due to trace amounts of hydrocarbon contaminants in hydrogen fuel source. Moreover, the reddish flame of downstream was due to the vapor of product in hydrogen combustion. The premixed flame light of hydrogen has two regions in Fig. 2, the bluish and reddish part in high equivalence ratio (Φ = 1.0, 0.8). Decreasing the equivalence ratios, the reddish part transited to invisible gradually in the leaner conditions (Φ = 0.7, 0.62). The concentration of vapor and CH^* was higher in fuel richer combustion, so temperature and light emission would be increased. Thus, flame was brighter and flame length was longer under high equivalence ratios.

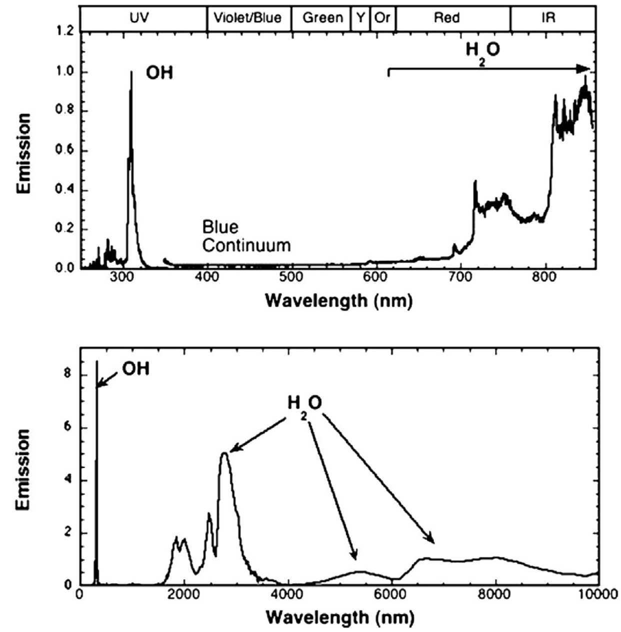

Fig. 1 – Emission spectra in typical hydrogen–air flame [9].

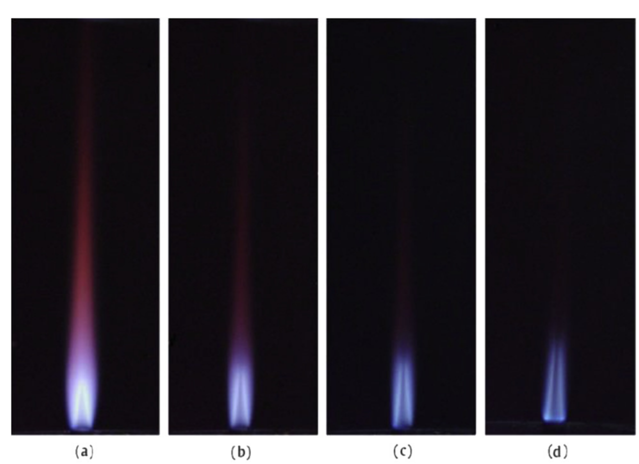

Fig. 2 – Flame luminescence photographs of turbulent, premixed H_2–air jet [9]. (a) Φ = 1.0, (b) Φ = 0.8, (c) Φ = 0.7, (d) Φ = 0.62.