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Control of an air siphon nozzle using hydrogen and gases other than air

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ABSTRACT

Air siphon nozzles are a simple device commonly used to transport liquid fuel to a combustor. Recent research in dual fuel combustion demonstrates benefits to using gas and liquid phase fuels in the same system. This paper demonstrates the use of hydrogen and other gases other than air to control liquid fuel flow through the siphon nozzle. It is shown mathematically that the two major variables controlling liquid flow rate are the specific heat ratio and upstream pressure of the gas. Since diatomic gases have similar specific heat ratios ($k = 1.4$ at 300 K), a mixture of hydrogen and air can control liquid flow using only pressure, regardless of mixture composition. At relevant gas pressures, it is analytically shown that the error from changing k is small for $1.1 < k < 1.67$. The analytical work was verified experimentally by measuring the suction pressure on the fuel line. Tests using air, hydrogen, argon and helium showed good agreement between gases. However, the deviation begins to increase with the use of propane. This flexibility with gas selection enables liquid flow control with gas mixtures such as hydrogen rich reformate.

Introduction

Air siphon nozzles use pressurized air to draw liquid fuel from a reservoir to a combustor. This research demonstrates that when using a gas other than air, the important variable determining liquid flow rate is the upstream gas pressure. This is shown analytically and experimentally, including limitations based on pressure range and gas type. This has valuable applications in the control of dual fuel combustion. The present nozzle research developed from tests burning JP-8 and hydrogen through an air-siphon nozzle. To simplify logistics, the US Military has mandated that only one fuel, JP-8, be taken to the battlefield since 1988. The increased capability of soldier-carried electronic devices includes increased power demand without increasing weight. Due to the weight of diesel engines, portable power under 1 kW requires innovative, fuel efficient power sources.

This need presents an opportunity for Stirling engines, thermionic generators, thermoelectric generators, and thermo-photovoltaic generators which would not be able to compete directly with internal combustion engines at higher power levels. These power sources can all produce power of 250 W–2000 W, and all use an external combustion heat source. Techniques improving the combustion of heavy liquid hydrocarbon fuels, and hence JP-8, to provide energy to these systems would fill this power gap. Coombe [1] examined the effect of oxygen enriched air on the combustion of JP-8 in small combustors.

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DuBois [2] studied autothermal catalytic reforming of JP-8 for solid oxide fuel cell applications and allowed the generation *in situ* of hydrogen on the application site from JP-8. Due to this availability of hydrogen, the possibility and advantages of dual firing hydrogen and JP-8 was previously investigated by the authors [3].

Previous work in hydrogen enriched combustion has shown success in other areas. Schefer [4] added hydrogen to methane-air flames and found that it improved lean flame stability and reduced NO_x emissions. Kumar [5] added hydrogen to liquefied petroleum gas flames which lowered NO_x emissions while increasing CO. Experiments in an LPG fired inverse diffusion flame showed improved flame stability with hydrogen addition [6]. Fundamental combustion bomb experiments examining the flame characteristics of hydrogen-LPG flames determined that hydrogen increased laminar burning velocity and reduced flame thickness. Miao et al. attributed this in part to improved thermal diffusivity [7].

Hydrogen research in diesel engines can be divided into two categories: 1) using hydrogen as an additive in conjunction with EGR to reduce NO_x and particulates and 2) using hydrogen as the main fuel with diesel fuel used for ignition.

Kumar et al. used hydrogen to improve the performance of a vegetable oil fueled compression ignition engine [8]. They found improvements in CO, hydrocarbon, and smoke emissions, but increased NO_x emissions. Exhaust gas fuel reforming shows that hydrogen for diesel engines can be produced on board while only carrying one fuel [9,10]. Using hydrogen in conjunction with exhaust gas recirculation (EGR) provides a path around the NO_x-particulate trade-off [11].

Karim outlines an approach using hydrogen as the primary energy source with diesel injected for ignition [12]. He identified the potential to use a wide range of gaseous fuels, but noted that better understanding of the combustion process is necessary to effectively control a dual fuel engine. Fang et al. compared hydrogen, ethanol and gasoline as fumigants with diesel ignition [13]. Hydrogen increases ignition delay, but decreases the required time for combustion, which is consistent with [14].

Banerjee et al. provide a thorough review of hydrogen and EGR as an approach to meet competing requirements in particulates, NO_x and fuel efficiency [15]. Verhelst et al. examine work done in hydrogen combustion as a pathway to hydrogen fueled engines [16].

Research on kerosene fueled gas turbine combustors shows improved flame stability with hydrogen addition. Decreasing the lean blow out limit allows lean operation, reducing NO_x without increasing CO [17,18]. Further research shows the same flame stability improvement using hydrogen rich reformer gas which can be produced from jet fuel on board [19].

The use of hydrogen or hydrogen-rich reformate presents a variable composition gas mixture as the motive fluid for an air siphon nozzle. In support of dual fuel combustion, this research studied the use of gases other than air as the motive fluid in air siphon nozzles. It is found that the upstream gas pressure is the dominant variable controlling liquid flow, regardless of gas composition. An analytical explanation is demonstrated with experimental support. This flexibility in nozzle control will be an asset to implantation of dual fuel combustion using hydrogen or hydrogen-rich reformate with liquid fuels.

Experimental apparatus

The present research began with combustion experiments using an air siphon nozzle to dual fire JP-8 and hydrogen, as shown in Fig. 1. Pressurized air is used both to move the JP-8 from the reservoir to the nozzle and to atomize the liquid. Dynamic pressure of the high speed gas creates a suction which draws the fuel from the reservoir to the nozzle. The two major variables affecting liquid fuel flow rate are the suction created by the high speed gas and the height difference between the liquid in the reservoir and the nozzle. The height difference is held constant with a constant level oiler, leaving gas flow as the only variable.

Since quantity of gases is important for combustion studies, gas flow to the nozzle is controlled by laminar flow, pressure-based mass flow controllers. Adding hydrogen to the gas is observed to change the liquid flow rate differently than adding air. For example, at 20 cm elevation change, 10 slpm air produces 8.7 g/min liquid flow and 15 slpm air produces 11.2 g/min; however, 10 slpm air and 5 slpm H_2 produces only 9.6 g/min. After observing changes to fuel flow based on hydrogen addition, the effect was measured more directly.

Fig. 2 shows the nozzle liquid and gas flow paths. The fuel line was replaced with a pressure transducer (Omega PX309-030A5V). When pressurized air flowed through the nozzle, the indicated absolute pressure was below atmospheric. This is the pressure difference which drives fuel flow. The suction pressure is defined as atmospheric pressure minus the absolute pressure measured on the fuel line. A higher suction pressure corresponds to a higher liquid fuel flow. Gas flow through the nozzle was adjusted by mass flow controllers and mixed in a T connection 30 cm below the nozzle. Gases and liquid are supplied through ¼″ (6.35 mm) O.D. tubing. Hydrogen flow was controlled by Alicat MCR-100SLPM-D mass

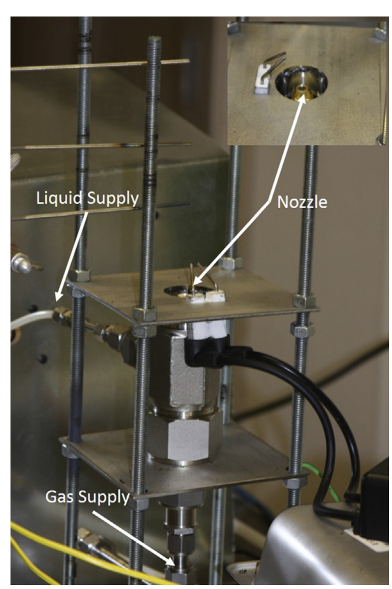

Fig. 1 – Combustion test stand.