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Catalytic ignition and autothermal combustion of JP-8 and its surrogates over a Pt/ γ -Al₂O₃ catalyst

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Abstract

With the aim of utilizing JP-8 fuel for small scale portable power generation systems, catalytic combustion of JP-8 is studied. The surface ignition, extinction and autothermal combustion of JP-8, of a six-component surrogate fuel mixture, and the individual components of the surrogate fuel over a Pt/ γ -Al₂O₃ catalyst are experimentally investigated in a packed bed flow reactor. The surrogate mixture exhibits similar ignition–extinction behavior and autothermal temperatures compared to JP-8 suggesting the possibility of using this surrogate mixture for detailed kinetics of catalytic combustion of JP-8. It is shown that JP-8 ignites at low temperatures in the presence of catalyst. Upon ignition, catalytic combustion of JP-8 and the surrogate mixture is self-sustained and robust combustion is observed under fuel lean as well as fuel rich conditions. It is shown that the ignition temperature of the hydrocarbon fuels increases with increasing equivalence ratio. Extinction is observed under fuel lean conditions, whereas sustained combustion was also observed for fuel rich conditions. The effect of dilution in the air flow on the catalytic ignition and autothermal temperatures of the fuel mixture is also investigated by adding helium to the air stream while keeping the flow rate and the equivalence ratio constant. The autothermal temperature decreases linearly as the amount of dilution in the flow is increased, whereas the ignition temperature shows no dependence on the dilution level under the range of our conditions, showing that ignition is dependent only on the type and relative concentration of the active species.

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1. Introduction

In order to meet the demand for high energy density portable power sources, research has focused on utilizing hydrocarbon fuels as an energy source to replace conventional batteries

[1–5]. The latter have low gravimetric and volumetric power densities, relatively short life cycles and are made of materials that are difficult to recycle and are environmentally hazardous. The high specific energy of hydrocarbon fuels (higher than traditional batteries by up to two orders of magnitude) [1,6] and the ability to recharge a hydrocarbon-fueled power source, by merely adding more fuel, are driving attributes of a future fuel-to-electricity technology. One approach to extract power from fuels is to reform the fuel into hydrogen that is eventually purified for PEM fuel cells [7–10]. The direct use of hydrogen in portable

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systems is not practical due to the requirements for high pressure tanks to store and transport the fuel and the energy required to store hydrogen. The alternative is to reform hydrocarbon fuels to hydrogen *in situ* or *onboard* by means of a fuel reformer [11–13] followed by a water–gas shift reactor and a purifier. Direct methanol fuel cells using methanol as the fuel are also being explored. However, the slow, compared to hydrogen, oxidation of methanol at the anode and the crossover of methanol from the anode to the cathode, result in markedly degraded performance compared to hydrogen PEM fuel cells [10].

An alternative approach to energy generation is the direct combustion of hydrocarbon fuels in microcombustors to produce heat and/or power. Efforts to utilize combustion of hydrocarbons in small scale devices have led to designs that are scaled down versions of large scale power generating devices [14–16]. However, the requirements for moving parts and the higher temperatures of homogeneous combustion in these devices challenge fabrication, insulation, and sealing. An alternative approach is to combust the fuel in microreactors, with minimal moving parts, to produce heat which can be converted into electrical power using energy conversion modules [2,17–19]. The increased surface to volume ratio of such small scale devices results in considerable heat losses and radical quenching leading to unsustainable homogeneous combustion [17,20–22]. Catalytic combustion in such small devices is preferred due to the reaction occurring at much lower temperatures and being sustained at much leaner fuel/air ratios compared to homogeneous combustion [23], thereby easing the design constraints of the system. In addition, fuel ignition occurs at much lower temperatures, and certain fuels (hydrogen and methanol) have been found to be self-starting and self-sustained negating the need for complex ignition systems [24,25].

The majority of research on microburners has exploited gaseous fuels. Obviously, this may be a suboptimal choice in many cases. Liquid hydro-

carbon fuels have preferred attributes in terms of storage, transportability, safety, and mass energy density. Of particular interest to the US military is the use of logistic fuels, such as JP-8, for portable power generation. Previous studies of JP-8 have mainly been focused on homogeneous combustion [26,27], combustion on porous media [28] and the development of prototype devices utilizing JP-8 to generate power [29]. However, there has not been any systematic analysis of the catalytic combustion of JP-8. There is a clear need to do so in order to determine the ignition–extinction characteristics, soot formation, and emissions.

In this paper, our first goal is to study the catalytic combustion of JP-8 over a Pt/ γ -Al₂O₃ catalyst. We determine ignition–extinction limits and autothermal temperatures that are important in integration of microcombustors with energy conversion devices. The chemical composition of JP-8 varies depending on the source of the fuel. The numerous compounds of JP-8 make detailed kinetic studies impractical. Kinetic studies using a surrogate fuel, which mimics the properties of JP-8, consisting of a small, known mixture of single fuels is possibly a viable approach to overcome the aforementioned challenges. Several such mixtures, ranging in composition from 2 to 12 components, have been suggested in the literature to match various properties of JP-8 [30]. However, the applicability of such surrogates fuels for capturing the catalytic combustion of JP-8 is unclear. Our second goal is then to assess the extension of the surrogate fuels concept to catalytic studies.

2. Experimental setup

A schematic of our experimental setup is shown in Fig. 1. In order to vaporize the fuel before being delivered to the catalyst bed, the fuel is injected, by means of a 2.5 ml syringe installed on a syringe pump, into a stainless steel capillary tube (0.25 mm inner diameter). The exit of the

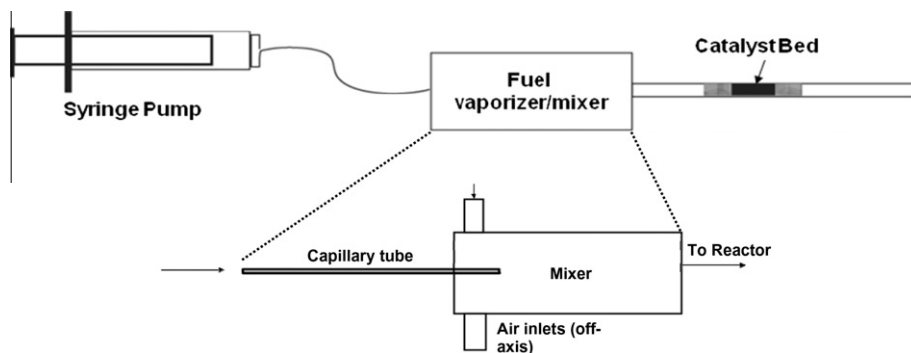


Fig. 1. Experimental setup.

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