Review of Ongoing Chemical Kinetics Studies at Laboratory for Hypersonic and Shock Wave Research, IISc

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ABSTRACT Growing interest in high-speed propulsion has fueled increased efforts to develop supersonic combustion ramjet (Scramjet) engines for hypersonic flight applications (Segal, 2009). Scramjet engine development encompasses a wide range of fields of study, and fuel is one of them. For long-duration hypersonic flight, liquid hydrocarbon fuels are considered advantageous over other fuels as they have higher density and small storage requirements. In the development of liquid hydrocarbon-fueled Scramjet, chemical kinetics play a critical role not only in fuel combustion but also in the cooling of the engine. The idea is to use liquid hydrocarbon fuel to cool down the walls of an engine, where, along with sensible heating of the fuel, it will undergo a thermal cracking, an endothermic reaction resulting in increased heat sink. Then, the cracked fuel will be injected into the engine for combustion (Wang, 2012). Therefore, the characterization study of liquid hydrocarbon fuels for Scramjet involves the thermal cracking of base fuel at operating conditions relevant to the engine's cooling and fuel supply system. It also includes the oxidation study of base fuel and thermal cracking products at engine-relevant operating conditions, including property measurements such as Ignition Delay Time and Laminar Flame Speed.

This paper reviews ongoing chemical kinetics studies at the Laboratory for Hypersonic and Shock Wave Research (LHSR), IISc. Our work primarily aims to characterize different fuels to check their compatibility with the Scramjet engine and provide valuable design insights. To study the behavior of fuel in the cooling channels of a Scramjet engine, the Plug Flow Reactor (PFR) has been designed and fabricated. The design of PFR was carried out using CFD, considering n-decane as a fuel, and a validation study from previous work was used to choose an accurate numerical setup (Bhoir, 2023). Presently, experiments are being carried out for supercritical pyrolysis of RP-1 as it is a potential fuel for the Scramjet engine due to its low aromatic content. In these experiments, the operating conditions such as pressure, heat flux and fuel residence time are kept equivalent to that of the cooling channels of the Scramjet engine. The primary objective of this study is to find out heat sinks, coke formation, and products of decomposition of RP-1 under those conditions and develop a surrogate for the cracked products.

In the studies related to fuel combustion, chemical shock tubes (CST-1 and CST-3) are being used. CST-1 and CST-3 are single pulse shock tubes with well-defined test times as shown in Figure 1. In LHSR, fuel combustion is being studied in three steps. Since the pyrolysis of fuel molecules is the first step of fuel combustion, the pyrolysis of many pure species has been carried out. Recently, the pyrolysis of methyl cyclopentane was carried out in CST-1, and the decomposition products were collected and analyzed in a Gas Chromatograph (GC) with a Flame Ionized Detector (FID). This experimental data helps validate the pyrolysis steps of the chemical kinetic mechanism of fuel combustion. In the next step, the oxidation of the fuel-air mixture at different equivalence ratios is carried out. This data helps in validating the complete chemical kinetic mechanism of fuel combustion with the concentration of CO and CO_2 . In the last step, the properties of the fuel-air mixture, such as Ignition Delay Time (IDT) and Laminar Flame Speed, are targeted. Apart from validating chemical kinetics mechanisms, these properties also provide valuable design inputs for scramjet combustors. Recently, the IDT of various fuels and pure species, such as RP-1 and ethylene, have been measured. Figure 2 shows the IDT measurement signal for RP-1 and air mixture. For the measurement of laminar flame speed, the shock tube (CST-3) test section has been facilitated with a quartz window, and these experiments will be carried out very soon.

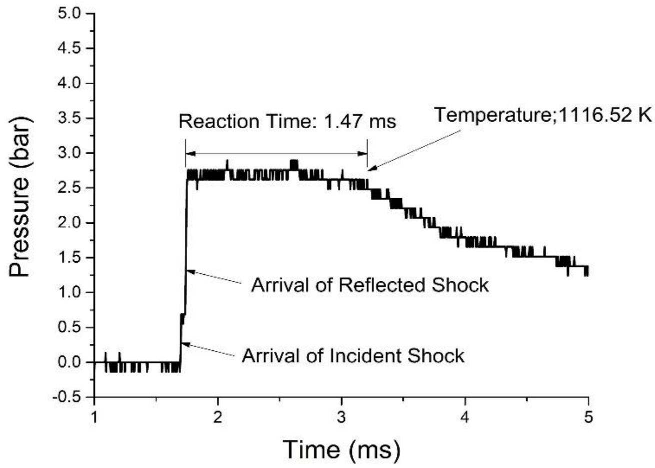

Figure 1. Pressure Trace at 5 mm from end flange.

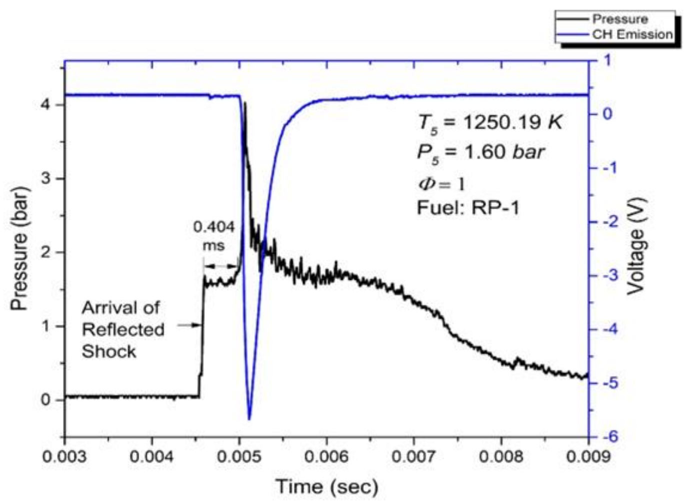

Figure 2. Ignition Delay Signal of RP-1 and air mixture.

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