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# Flame structure and laminar burning speeds of JP-8/air premixed mixtures at high temperatures and pressures

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ABSTRACT

Jet propellant 8 (JP-8)/air laminar burning speed was experimentally measured and its flame structure was studied at high temperatures and pressures using a high-speed camera. The experimental facilities included a spherical vessel, used for the measurement of burning speed, and a cylindrical vessel, used in a shadowgraph system to study flame shape and structure and to measure burning speed. A thermodynamic model was developed to calculate burning speeds using the dynamic pressure rise in the vessel due to the combustion process. The model consists of a central burned gas core of variable temperature surrounded first by a reaction sheet, then by an unburned gas shell with uniform temperature and lastly by thermal boundary layers at the wall and electrodes. Radiation from burned gases to the walls was also included in the model. Burning speeds of laminar flames of JP-8/air were calculated for a wide range of conditions. A Power law correlation was developed to calculate laminar burning speed at temperatures ranging from 500–700 K, pressures of 1–6 atm and equivalence ratios of 0.8–1. Flame structure and cell formations were observed using an optical system. Experimental results showed that pressure and the fuel–air equivalence ratio have a strong influence on flame structure.



## 1. Introduction

The United States Army and Air Force use JP-8 and Jet A-1 fuels as the main sources of energy for military land vehicles and aircraft [1,2]. The North Atlantic Treaty Organization (NATO) has decided to use the same fuel across all battlefields under the 'single fuel concept' [2,3]. JP-8 and Jet A-1 have similar chemical structures because JP-8 is created from Jet A-1 by using special additives to improve thermal stability characteristics [4]. JP-8 can be used as an alternative for diesel fuel because of their similar thermal and chemical properties. Due to its acceptable thermal stability parameters, such as its low freezing point of less than −60 °C and its dual application as both a coolant and an energy source, JP-8 is widely applied to aircraft engines and gas-turbines [1].

JP-8 is a complex chemical fuel composed of aromatics, *n*-paraffins, and cycloparaffins [2,5,6] which makes it difficult to develop any chemical kinetics mechanism for this fuel. Some researchers have tried to identify surrogates for JP-8 with similar thermo-physical and thermo-chemical properties [5–7]. Validation of the developed chemical kinetics mechanism requires some reliable experimental data. Laminar burning speed is one of the fundamental properties of a fuel which can be used to validate theoretical models. It can also be used to correlate turbulent burning speeds. Laminar burning speed is strongly affected by mixture characteristics such as equivalence ratio and diluent type and operational conditions such as temperature and pressure. Depending on the experimental facilities and design, there are various methods for measurement of laminar burning speed [8–15]. The flexibility of system to measure the laminar burning speeds at high temperatures and pressures is very important.

Ji et al [16] have measured the laminar burning speed of JP-8/air mixtures at atmospheric pressure, a temperature of 403 K, and various equivalence ratios using an atmospheric counter flow flame. They have also measured the laminar burning speeds of some other heavy hydrocarbons and have compared those with JP-8 laminar burning speeds. However, there are no published data about burning speed of JP-8 under conditions of combined high temperatures, high pressures, and varying equivalence ratios. In this study, the laminar burning speed of JP-8 has been measured at high temperatures and pressures. A thermodynamic model, described in Section 4, using the pressure rise method has been employed [17–19]. A shadowgraph optical system was used to observe the shape of the flames and ensure that they were laminar. Finally, a correlation was developed for laminar burning speeds of JP-8/air as a function of temperature, pressure, and equivalence ratio.

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## 2. Experimental facility

The experimental system includes a spherical chamber and a cylindrical vessel. Both the spherical and cylindrical vessels were used to measure pressure rise caused by the combustion process. The cylindrical vessel withstands a maximum pressure of 50 atm, while the spherical vessel was used for a maximum pressure of 425 atm. The cylindrical vessel was used in a shadowgraph system which took pictures of flame propagation. Both vessels were filled using a control system composed of valves, pipes connected to the air, and a vacuum pump. Liquid fuel was stored in a liquid fuel reservoir which was attached to a heated liquid fuel manifold. The heated liquid fuel manifold was equipped with two cartridge heaters used to evaporate the liquid fuel. The liquid fuel was heated until it was completely evaporated before it entered the combustion chamber. The temperature of the heated liquid fuel manifold was equal to the temperature of the combustion chamber and the oven. Ionization probes, screwed into the vessel's inner walls, were used to determine flame arrival time to vessel walls. A data acquisition system was used to capture the pressure–time data as well as the signals from the ionization probes. A computer driven system has been used to make the mixture with the required fuel and oxidizer and to initiate the combustion process. Fig. 1 shows a schematic of the experimental system.

### 2.1. Spherical vessel

The spherical vessel was constructed from two hemispheres, bolted together to form a sphere, with an inner diameter of 15.24 cm. The hemispheres were constructed from 4140 steel with a thickness of 2.54 cm in order to withstand internal pressures up to 425 atm. The vessel was evacuated and filled through a 6 mm tube on its bottom. The vessel was fitted with two extended spark plug electrodes which provided a central point ignition source for the chamber. The ignition energy was fixed at 15 mJ. The chamber was also fitted with a piezoelectric pressure transducer, two thermocouples for measuring internal temperature and outer wall temperature, and three ionization probes which detected when the flame had reached the wall. The entire vessel was contained within a large oven capable of elevating the vessel temperature to ~500 K.

### 2.2. Cylindrical vessel

The cylindrical vessel was constructed from 316 SS and measures 13.5 cm in diameter and 13 cm in length. The vessel is fitted with 3.5 cm thick Fused silica windows at both ends which are sealed to the chamber with o-rings. The windows limit the vessel's operation to a maximum pressure of 50 atm. The purpose of the windows is to provide a clear line of sight through the vessel for a shadowgraph setup which allows real time recording of the combustion event. The vessel is also fitted with band heaters which allow the vessel to be heated to a temperature of 500 K. The vessel is fitted with spark plugs that allow for central point ignition, similar to the sphere's, and thermocouples that measure the internal temperature of the chamber and the temperature of the vessel walls.

### 2.3. Shadowgraph system

Fig. 2 presents the layout of the shadowgraph system. The shadowgraph system is setup with the cylindrical vessel to take optical recordings of the combustion event. A CMOS camera, with the capability of taking pictures up to 40,000 frames per second, has been used for these experiments. The shadowgraph setup consists of five components which are shown in Fig. 2. Starting from the light source, the pinpoint source of light is captured by a spherical mirror 152.4 cm away which reflects the light in a 15.24 cm circular beam. This beam travels through the combustion vessel to the opposite spherical mirror. Once the circular pattern hits this second mirror it is again focused into a pin point 152.4 cm away onto the CMOS camera. The image that the camera receives from the shadowgraph system is very sensitive to density variations and has the ability see the changes in density of the mixture as the combustion takes place.

The goal of these experiments was to study the structure of JP-8 premixed flames and to find the affective parameters of the burn-

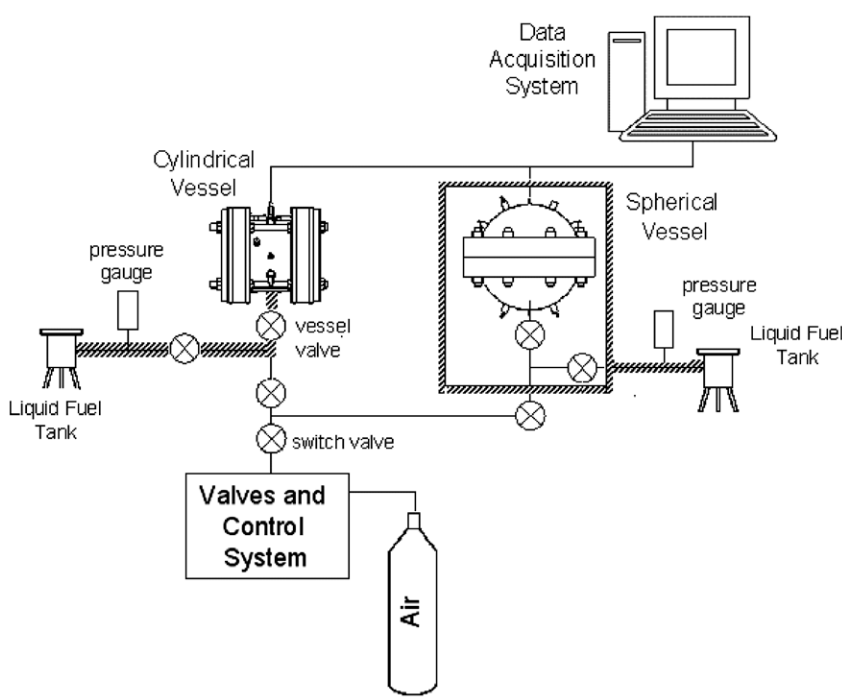


**Fig. 1.** Schematic diagram of experimental facilities.