Shock-Tube Ignition of Hydrocarbon Fuels in Air at Lower Temperatures and Higher Pressures

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1 Introduction

Experiments are ongoing in the authors' laboratory to study the ignition kinetics of hydrocarbon-air mixtures behind reflected shock waves at conditions representative of those seen in gas turbine and other engine applications. Some recent examples for methane-based fuel blends include the studies of de Vries and Petersen [1] and Petersen et al. [2, 3]. Engine conditions imply elevated pressures (10 atm and higher) and undiluted fuel-air mixtures. Lower temperatures (less than 1100 K) are also of interest in recent years for several reasons, including the possibility of autoignition in premixed systems prior to entering the main combustor [1] and in the validation of chemical kinetics models at low-to-intermediate temperatures.

Shock tubes are commonly utilized for ignition delay time experiments at higher pressures and higher temperatures, but in recent years, other groups in addition to the authors' have been extending shock-tube ignition experiments to temperatures less than 1200 K. Some examples of these studies include Fieweger et al. [4], Cadman and Thomas [5], Herzler et al. [6], and Huang et al. [7], among others. In most cases, the reflected-shock ignition times are faster than what is predicted by current chemical kinetics models, particularly for temperatures less than about 1000 K and pressures greater than 10 atm.

The current paper describes some ongoing experiments in the authors' laboratory for propane and methane-based fuel-air ignition times at lower temperatures and higher pressures that show similar trends both quantitatively and qualitatively to those seen in other shock-tube facilities over the same range of conditions. Such comparisons are important because they represent experiments conducted on at least four different facilities amongst different laboratories.

2 Experiment

The ignition tests are conducted in a high-pressure shock tube with the capability of achieving reflected-shock pressures as high as 100 atm. This facility, described in more detail by Petersen et al. [8], has a 16.2-cm driven section that is 10.7 m long. Ignition delay times are obtained behind the reflected shock tube using a combination of OH* or CH* chemiluminescence and pressure measurements [3]. However, for the undiluted fuel-air mixtures of interest herein, ignition times can be defined reliably using pressure measurements from a high-speed piezoelectric transducer located at the shock-tube endwall due to the rather large pressure increase that occurs at the time of ignition [1, 2, 3]. Using the special driver-gas tailoring techniques described by Amadio et al. [9], the test time behind the reflected shock wave can be extended beyond 10 ms for studying ignition at lower temperatures, where the slower chemical kinetics lead to longer ignition delay times than what are commonly seen at temperatures greater than about 1200 K.

Test mixtures currently being studied include a propane-air mixture with a fuel-to-air equivalence ratio (ϕ) of 0.5 and several methane-based blends including CH_4, C_2H_6, and C_3H_8. The propane-based mixture was chosen for direct comparison with the studies of Cadman and Thomas [5] and Herzler et al. [6], wherein the same mixture was employed. Likewise, the methane-based fuel-air mixtures were selected for direct comparison to the results of Huang and Bushe [10]. The air was a mixture of research-grade N_2 and O_2 at a molar ratio of 3.76, and the fuel components were from research-grade sources. All mixtures were prepared manometrically in high-pressure mixing tanks.

3 Results

A typical result of the experiments is shown in Fig. 1 for the fuel-lean propane-air mixture. The results represent a pressure of 30 atm and temperatures between about 900 and 1300 K. Also shown in Fig. 1 is a comparison with the data of Herzler et al. [6] for the same range of conditions. The agreement between the two sets of data is excellent. In both cases, a noticeable reduction in temperature sensitivity (i.e., slope or ignition activation energy) is seen for temperatures less than about 1100 K. The present data also agree with the propane-air data of Cadman and Thomas [5].

Similar agreement is seen between our experiments for methane/ethane/propane mixtures at higher pressure and lower temperature and the experimental results of Huang and Bushe [10]. Both sets of data display significant shifts in ignition activation energy for temperatures less than about 1100 K. These results agree with the methane-blend autoignition data of de Vries and Petersen [1], which were obtained near a specific combination of temperature and pressure (800 K, 18 atm).

While the present experiments are ongoing, some useful and important conclusions can be drawn. One of these conclusions is that the ignition delay times for temperatures below about 1000 K disagree with current chemical kinetics models, in some cases by an order of magnitude or more. Another observation is that there seems to be a consensus amongst shock-tube experiments for ignition delay times of hydrocarbon-air mixtures at the conditions of the present study (i.e., low-to-intermediate temperatures and higher pressures). Four different laboratories are showing the same basic trends at temperatures below 1100 K, and as shown in Fig. 1, the results are also quantitatively the same when identical mixtures and test conditions are utilized for the comparisons.

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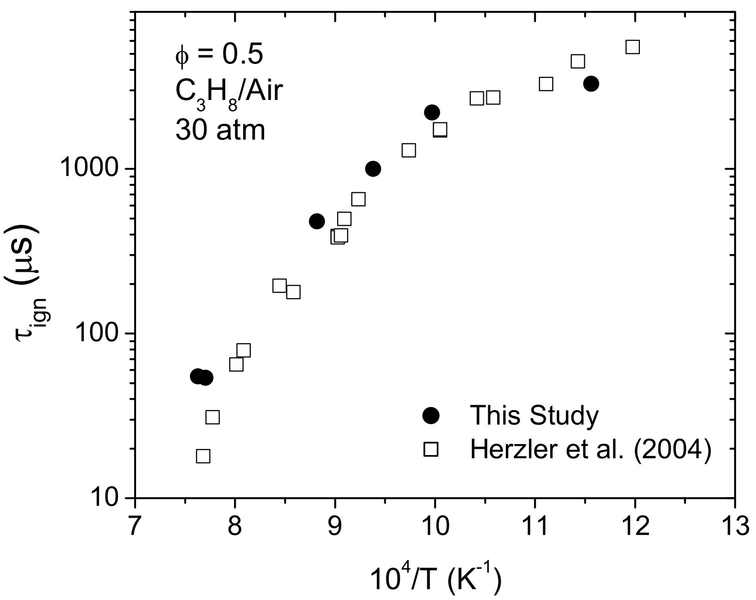

Figure 1: Fuel-lean propane-air ignition delay times from present study and study of Herzler et al.[6]

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