AN EXPERIMENTAL STUDY ON KEROSENE BASED PULSE DETONATION ENGINE

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ABSTRACT

The paper summarizes the experimental study on kerosene based pulse detonation engine in a tube for three different equivalence ratios. The kerosene was vaporized in a pre-evaporator before injected into combustion chamber. Pre-heated air was injected through a nozzle into the detonation tube. The charged tube was electrically ignited near the injector end. To enhance the DDT and to reduce the transition distance Shchelkin spiral was used inside the tube. Comparison of measured pressure at different locations of the tube with the CEA values were made that confirms to have crossed the CJ point and provide a stable detonation.

KEYWORDS: Deflagration to Detonation transition (DDT), Equivalence ratio, Pulse Detonation Engine (PDE), Vapour kerosene.

I. INTRODUCTION

Every engine that is practically available in the industrial sector works on the deflagration combustion and this is known to have lower thermodynamic cycle efficiencies than those which work on detonation combustion [1]. Brophy et al. [2] showed that the theoretical thermal efficiencies for Chapman–Jouguet (CJ) detonation combustion and deflagration combustion are 56.4 and 36.3 % respectively. Fully constant volume combustion, corresponding to zero combustion time which is difficult to achieve since the combustion must be very rapid. Therefore, it is inferred that a pulse detonation engine (PDE) can offer better performance compared to current propulsion devices. Detonation can be initiated in many ways such as direct method, deflagration to detonation transition (DDT), etc. Practically detonation initiation using direct method will not be efficient since it requires high energy. The other method is via DDT which uses a low energy source to accelerate a flame to a detonation. The transition distance required to attain detonation in a tube is considered to be too high for the fuel/air mixtures. Reduction of transition distance is desirable for PDE applications with the added advantages of reduction of length and weight. Methods to promote DDT in shortening the distance are proposed using DDT enhancement devices. These methods include inserting regular or irregular obstacles such as a Shchelkin spiral, orifice plates, etc.

Geraint Thomas et al. [3] carried studies on flame acceleration transition to detonation in a relatively long unobstructed piping system using different fuels like hydrogen, ethylene, methane, propane and acetone. The aim of the work was to obtain sufficient experimental data to predicting potential detonation flame acceleration and DDT in industrial process pipes. The result shows that for straight pipes, detonation was observed only in hydrogen–air and ethylene–air mixtures. Detonation was not observed with methane, propane or acetone as fuel.
C. S. Wen et al. [4] worked on detonation initiation of JP-8–oxygen mixtures at different initial temperatures in PDE. The initiation of detonation of liquid fuel by vaporizing will increases its specific energy density and reduces its volume. For JP-8, the fully vaporized temperature ranges from 380 to 410 K. In this study, detonation initiation was observed at a shorter distance for the mixture of fully vaporized JP-8 and oxygen when the initial temperature exceeded 413 K.

The Chemical Equilibrium with Applications (CEA) [5] is a NASA’s Computer program that calculates chemical equilibrium compositions and properties of complex mixtures. The program is written in ANSI standard FORTRAN by Bonnie J. McBride and Sanford Gordon. CEA program uses CJ detonations model to get the pressure values which is used for validating the experimental values.

In the present work, experiments were conducted to show the possibility of achieving the detonation with kerosene and air mixtures. Tests for three different equivalence ratios were carried out and the data’s were captured. The results shown are compared with theoretical values obtained from CEA.

II. EXPERIMENTAL SETUP

The experimental setup shown in fig. 1 consists of a kerosene evaporator, a pre-heater for air, 2 m long detonation tube of 43mm internal diameter and associated measurement devices that include signal conditioner, oscilloscope, ignition electrodes, pulse generator, ignition transformer and pressure transducer PT1, PT2, and PT3 mounted on tube at a distance 960 mm, 1090mm and 1210mm from igniter. Nitrogen was used to pressurize the liquid kerosene tank to prevent the vapour pressures do not lead to auto-ignition of the kerosene. The vaporizing temperature of the kerosene was set to vary from 150°C to 220°C to meet its vaporization characteristics [6]. In order to ensure that vaporization of the kerosene was complete, the heating was made just above vaporizing temperature and with a relatively larger residence time than that of its demand for the evaporation. To avoid the condensation of the fuel, air was pre-heated to about 180°C before injected to the detonation tube. A Shchelkin spiral was inserted into the detonation tube to get enhanced DDT performance.

At constant flow rates, derived from a pressurized fuel tank that was made to flow into the evaporator and kerosene vapour from the outlet of evaporator was injected into the detonation tube through a nozzle. Specially calibrated rotameter was used to measure the flow rate of air through the tube. Hot air from the air pre-heater was made to enter the detonation tube through the same nozzle and allowed to mix with kerosene vapour before the ignition.

The gaseous mixture of air and kerosene were injected into the detonation tube. Combustion was initiated at a distance of 140mm from the injection point through the pair of electrodes. Consequently it was observed that the combustion starts with deflagration and the flame propagates towards the open end. Compression waves would get formed in the propagating direction due to the acceleration of the combustion wave and expansion of the burned gas. This compression wave accumulated to form a local explosion in the unburned gases ahead of the combustion wave and has led to successful transition that ends up as a detonation wave. The specially procured high speed pressure transducers mounted at different locations along the tube length record the pressures in the tube with the help of signal conditioner and digital storage oscilloscope.
III. RESULTS AND DISCUSSION

CEA program provides theoretical pressure value of detonation using the CJ detonation model. The table 1 shows the pressure value of detonation for different equivalence ratios predicted by CEA program.

<table>
<thead>
<tr>
<th>Equivalence ratio (ϕ)</th>
<th>CEA values in bar</th>
</tr>
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<tbody>
<tr>
<td>1.14</td>
<td>19.27</td>
</tr>
<tr>
<td>1</td>
<td>18.60</td>
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<tr>
<td>0.89</td>
<td>17.78</td>
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The CEA program provides theoretical pressure value of detonation using the CJ detonation model. The table 1 shows the pressure value of detonation for different equivalence ratios predicted by CEA program.

The fig. 2 shown here gives the pressure-time record, captured from three transducers PT1, PT2, and PT3 mounted on the detonation tube at designated lengths of the tube, for ϕ = 1. The peak pressure recorded by PT1 was 18.12 bar and the peak pressure recorded by PT2 was 26.17 bar. The observation indicate clearly that the compression waves were formed in the propagating direction due to acceleration of the combustion wave have resulted in the expansion of the burned gas as seen the raise in pressure across PT1 and PT2 and has resulted in the expected deflagration to detonation transition (DDT). The peak pressure at PT3 was found to be 9.4 bar indicating the drop in pressure across PT2 and PT3 representing the expansion process of exhaust gases. From the theoretical value of CJ point predicted from CEA for the detonation (see the table 1) and the experimental value, it clears that the DDT has well established in the PDE confirming the detonation before the point PT2 which was 1090mm or within about 25 times the diameter of the tube, measured from the ignition point.

The fig. 2 shows the record of pressure versus time plot for ϕ = 1.14, the peak pressures observed at the transducers PT1 and PT2 were 14.76 and 24.83 bars respectively that confirms again a clear detonation before PT2 (see table 1 for the CJ point for this). The pressure at PT3 was decaying to 8.05 bar as also was observed in the earlier case indicating exhaust process of the engine.
Fig. 3: Plot of Pressure v/s Time for $\phi = 1.14$

Fig. 4: Plot of Pressure v/s Time for $\phi = 0.89$
The fig. 4 shows the record of pressure versus time plot for $\phi = 0.89$, the pressure at PT1 and PT2 were 8.05 bar and 19.46 bar respectively. With reference to table 1, the experimental value at PT2 confirms to have the detonation occurred. The pressure at PT3 was 6.03 bar, consistent with the earlier explanations.

The experiments were carried repeatedly for all the three equivalence ratios and results were captured. The table 2 shows the comparison of CEA values with experimental values for three equivalence ratio. Each equivalence ratio shown confirms the detonation before the point PT2 which was 1090 mm about 25 times the diameter of the tube from the ignition point.

<table>
<thead>
<tr>
<th>Equivalence ratio ($\phi$)</th>
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<tr>
<td></td>
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Table 2: - Comparison of CEA values with experimental values for three equivalence ratio

IV. CONCLUSION

The experiments have been conducted in a specially built PDE for kerosene and have been tested for successful functioning of it for three different equivalence ratios. Kerosene was heated just above its vaporizing temperature and air was pre-heated to about 180°C to ensure the fuel and air were in the condition of gaseous mix for a clean detonation to occur. Pressure transducers mounted on the detonation tube along with ignition source have enabled to capture the process of DDT clearly and observations were found to be very repeatable. The present work shows out a clear possibility of managing controlled detonation at the tested equivalence ratios and make path for extended study for building a PDE as possible futuristic high efficiency engines using storable fuels like kerosene and using ambient air for the combustion.

V. REFERENCE