Comparative Analysis of Pulse Detonation Engine with Purging

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Abstract. Pulse Detonation Engines (PDEs) are being investigated for advanced high-speed propulsion applications due to their potential for high thrust generation, rapid combustion, improved thermal efficiency, and operation at speeds up to approximately Mach 5. This study experimentally investigates multi-cycle PDE operation under non-purged and oxygen pre-flush purged conditions. Thrust-time histories are used to evaluate cycle-to-cycle repeatability for acetylene-oxygen and methane-oxygen cases. The study compares non-purged operation, oxygen pre-flush purged operation, and fuel-dependent thrust response under repeated firing conditions. The results indicate that oxygen pre-flush purging supports more repeatable thrust behaviour during multi-cycle operation, while the acetylene-oxygen case shows higher thrust response than the methane-oxygen case under the common purged operating condition.

Keywords: Pulse Detonation Engine, Oxygen Pre-Flush Purging, Multi-Cycle Operation, Thrust Repeatability, Deflagration-to-Detonation Transition

1 INTRODUCTION

PDEs have been studied as detonation-based propulsion systems because they offer a simple cyclic operating principle and potential applications across air-breathing propulsion, rocket propulsion, high-speed vehicles, launch systems, and space vehicles [3], [7]. Beyond propulsion, PDE-based concepts have also been explored for power-generation applications [5]. Conventional air-breathing propulsion systems based on the Brayton cycle are limited by constant-pressure combustion, whereas Pulse Detonation Engines (PDEs) exploit near constant-volume combustion through the Humphrey cycle and can offer higher thermal efficiency [8].

A persistent challenge in multi-cycle PDE operation is residual-gas management between successive firing cycles. An important phenomenon governing PDE operation is deflagration-to-detonation transition (DDT), in which the initially deflagrative combustion process accelerates into a detonation wave. DDT behaviour is influenced by mixture composition, tube geometry, and turbulence-enhancing devices such as the Shchelkin spiral [4]. Fuel type, equivalence ratio, initial pressure, and dilution influence the time required for detonation development [6]. In multi-cycle operation, residual burned gas can contaminate the next fresh charge, alter equivalence ratio, increase local temperature, and contribute to pre-ignition or detonation failure. Purge gas is commonly introduced to separate fresh mixture from burned gas and reduce cycle-to-cycle variation [1]. Inert purge gases such as nitrogen, argon, or helium are effective but require additional supply hardware and increase system weight and complexity [1]. Sakurai et al. also

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show that purge effectiveness becomes more important when insufficient exhaust time is available between successive cycles [1]. For high-frequency pulse detonation combustor operation, Matsuoka et al. developed a liquid-purge method in which injected liquid droplets help remove residual hot burned gases from the combustor during cyclic operation [2].
Toshimitsu et al. reported that acetylene-oxygen produced substantially higher propulsion performance than methane-oxygen in detonation propulsion experiments, with fuel-based specific impulse approximately twice that of methane-oxygen [9].
In the present oxygen-fed laboratory setup, a short oxygen pre-flush using the existing oxidizer line is investigated as a proof-of-concept approach for residual-gas removal without adding a separate purge system.

Fig. 1. Pulse Detonation Engine Setup at PEC.

2 METHODOLOGY

2.1 PDE Test Without Purging

The non-purged tests included a baseline multi-shot acetylene-oxygen case and a low-frequency acetylene-oxygen case. These cases were selected to examine repeated-cycle operation without active purging at different effective firing intervals.
The detonation tube used in the experiments was 1000 mm long with a 50 mm internal diameter. A 300 mm Shchelkin spiral made of spring steel, with 9 mm wire diameter and 28 mm pitch, was used to promote DDT.

2.2 Oxygen Pre-Flush Purging

The oxygen pre-flush purged tests included acetylene-oxygen and methane-oxygen operation. These cases were selected to compare thrust response between the two fuels under a common purged operating condition.
For purged operation, oxygen was injected 0.2 s before the gaseous fuel valve was opened. This pre-flush duration was used for the purged test cases.

The fuel and oxidizer flows were controlled using Danfoss solenoid valves. Both acetylene-oxygen and methane-oxygen purged tests retained for the final analysis were conducted at the same nominal supply-pressure condition of 30 psi fuel and 70 psi oxygen. The non-purged acetylene baseline and low-frequency non-purged acetylene case were also conducted at 30 psi acetylene and 70 psi oxygen.

2.3 Data Acquisition and Visualization

Thrust signals were recorded through the DAQ system. TDMS files were plotted using DIAdem software from National Instruments. The thrust response is plotted in Newtons (N). For the TDMS-based plots, the x-axis represents the sample index of the recorded. Based on the acquisition sampling rate of 10 kHz, 10,000 samples correspond to 1 second.

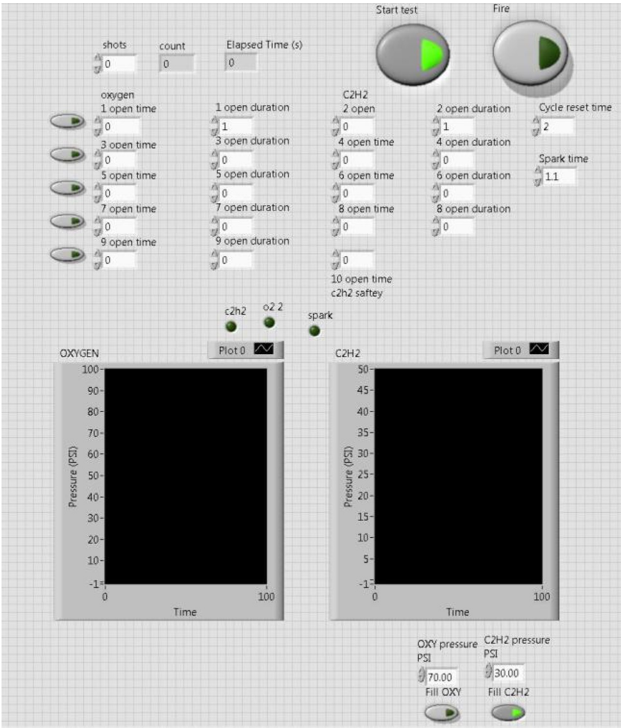

Fig. 2. LabVIEW front panel used to set oxygen/fuel valve open durations, spark time, and cycle reset time.

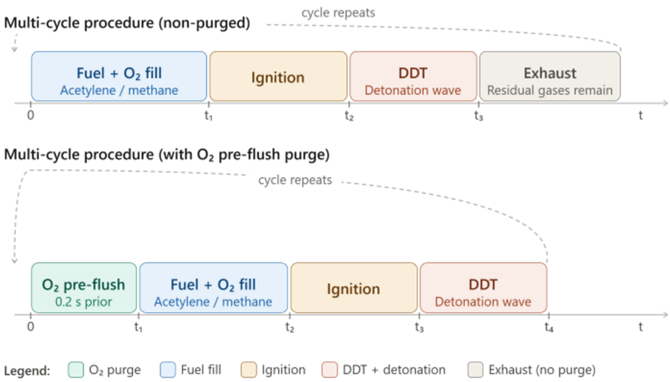

Fig. 3. Schematic cycle diagram of multi-cycle non-purged and oxygen pre-flush purged experiments.

Figures 2 and 3 show the LabVIEW front panel used to set oxygen and fuel valve timings, spark time, and cycle reset time with the experimental operating-cycle schematic. In this study, open duration refers to the time for which the fuel or oxygen valve remains open during injection, while spark timing refers to the ignition delay applied after the injection sequence. The number of shots defines the repeated firing cycles commanded during a multi-cycle test [10].

3 RESULTS AND DISCUSSION

The experimental results are evaluated using thrust-time histories. The comparison focuses on cycle-to-cycle thrust repeatability under non-purged and oxygen pre-flush purged conditions.

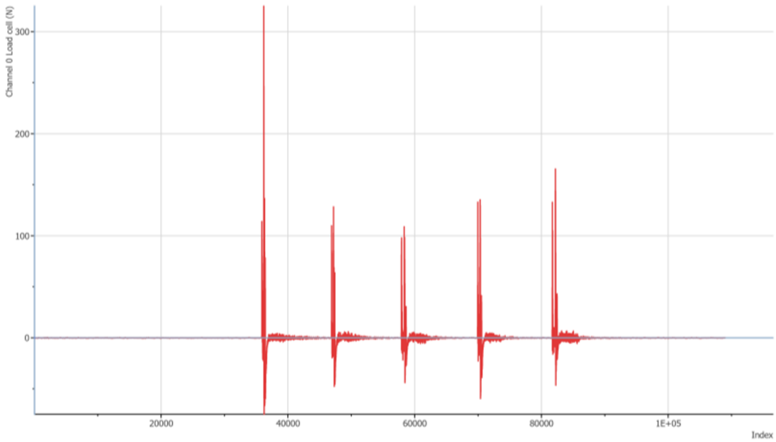

Fig. 4. Multi-shot non-purged acetylene-oxygen operation showing thrust peaks.

Fig. 4 shows the multi-shot non-purged acetylene-oxygen operation. The first cycle produces the highest thrust peak, approximately 320-330 N. The second cycle peak decreases to approximately 120-130 N, and the following peaks also remain lower than the first peak. This reduction in thrust response indicates cycle-to-cycle variation during repeated non-purged operation, which can be associated with residual burned gases affecting the next filling and combustion process.

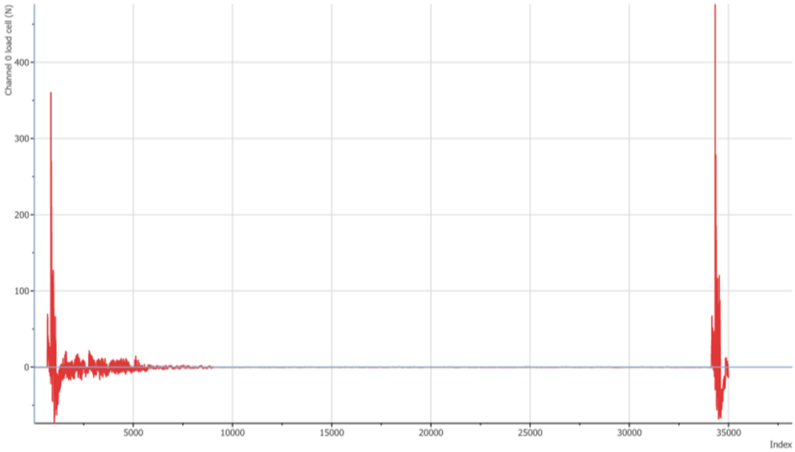

Fig. 5. Low-frequency multi-shot non-purged acetylene-oxygen operation showing comparatively consistent thrust peaks.

Fig. 5 shows the low-frequency non-purged acetylene-oxygen case. In this case, the first thrust peak is approximately 360 N, while the second peak reaches approximately 480-500 N. Unlike Fig. 4, a drop in thrust is not observed in the second cycle. This suggests that the longer interval between cycles allowed more complete natural exhaust of residual gases before the next filling process.

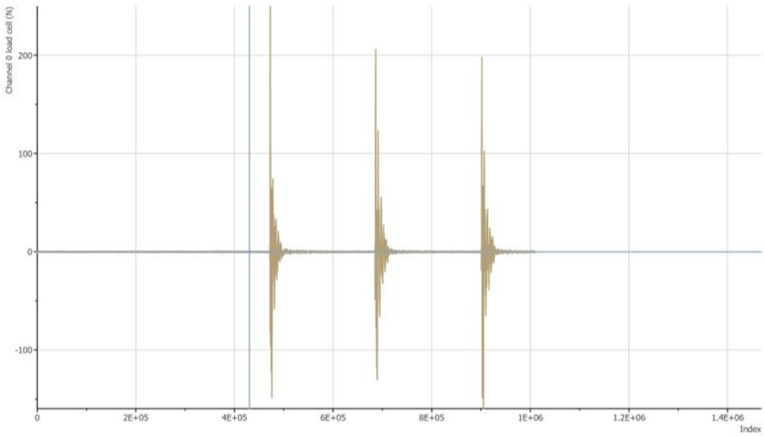

Fig. 6. Three-shot oxygen-purged acetylene-oxygen operation showing thrust history.

Fig. 6 presents the oxygen pre-flush purged acetylene-oxygen case. The first thrust peak is approximately 240-250 N, while the second and third peaks remain close to approximately 210-215 N. Compared with the non-purged multi-shot case in Fig. 4, the thrust response does not show a severe drop after the first cycle, indicating improved cycle-to-cycle repeatability.

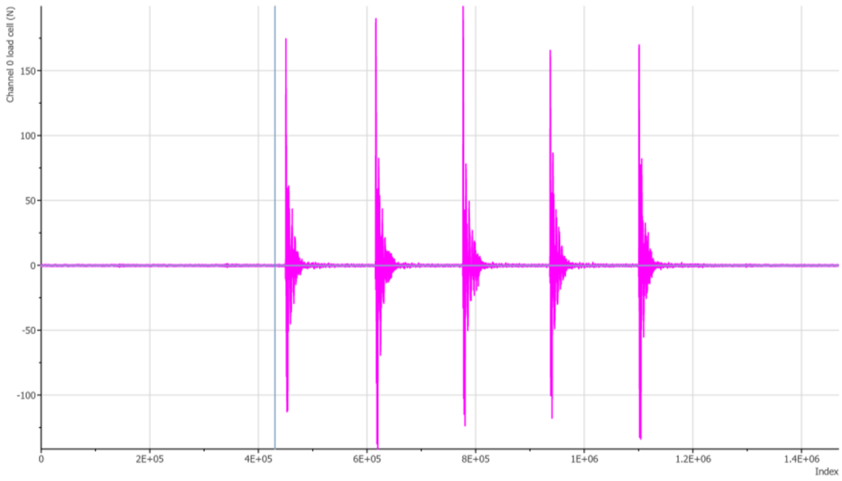

Fig. 7. Five-shot oxygen-purged methane-oxygen operation showing thrust history.

Fig. 7 shows the five-shot oxygen pre-flush purged methane-oxygen case. The thrust history shows repeated peaks without a progressive collapse in response. The first peak is approximately 170–180 N, while the second and third peaks increase to about 190–200 N. The fourth and fifth peaks remain in the approximate range of 160–175 N. This indicates stable repeated operation under purged conditions, although the peak thrust levels are lower than those observed for the purged acetylene-oxygen case.

Under the common purged operating condition described in the methodology, the acetylene-oxygen case produced higher thrust peaks than the methane-oxygen case, following the fuel-dependent trend reported in earlier detonation-propulsion studies [9].

4 CONCLUSION

This study investigated multi-cycle PDE operation with and without oxygen pre-flush purging. Under conditions where residual-gas removal is more limited, oxygen pre-flush purging supported repeatable thrust behaviour for both acetylene-oxygen and methane-oxygen cases. Future work should include pressure-channel acquisition for all purged cases, evaluation of purging effectiveness at higher operating frequencies above 50 Hz, purge-duration optimisation, and comparison with air-based purging.

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Disclosure of Interests. The authors declare no competing interests.

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