

# IDEAL CYCLE ANALYSIS OF A PULSE DETNATION ENGINE

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# IDEAL CYCLE ANALYSIS OF A PULSE DETONATION ENGINE

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## ABSTRACT

Pulse Detonation Engine (PDE) is expected to be one candidate for the next generation of high performance propulsion engines and power plants. The need for heavy air compression in common gas turbines could be eliminated in PDEs, allowing the operation with fewer compressor stages. This advantage would yield higher thermal efficiency and decrease the size of the engine. So, PDEs could be proposed as an alternative to gas turbines especially for small commercial power generation plants. Cycle analysis would be an excellent tool to compute and analyse the performance of PDE without the necessity of expensive experimental tests. In the current study, the effects of fuel types and frequency of a PDE on the thermal efficiency through thermodynamic cycle analysis is evaluated. The generic models for the cycle analysis are developed by Matlab. The Humphrey, ZND and Brayton cycles are adopted for this analysis. Thermal efficiency of Biogases for its less emission characteristic is studied in an ideal cycle against Hydrogen, Methane and Propane. It is concluded that the Biogas could be an appropriate fuel for theoretically PDE studies. To find a relation between thermal efficiency and frequency, at constant geometry, in two different attempts, the relation between thermal efficiency and detonation speed, and that of frequency and the velocity of filling and purging are studied. It's seen a direct relation between thermal efficiency of PDE cycle and its frequency cannot be found.

## ABSTRAK

Pulse Letupan bahan Enjin (PDE) dijangka menjadi salah satu calon untuk generasi akan datang pendorongan enjin prestasi tinggi dan loji kuasa. Keperluan untuk pemampatan udara berat dalam turbin gas yang sama ini dapat dihapuskan dalam PDE, membolehkan operasi dengan lebih sedikit peringkat pemampat. Kelebihan ini akan menghasilkan kecekapan haba yang lebih tinggi dan mengurangkan saiz enjin. Jadi, PDE boleh dicadangkan sebagai alternatif kepada gas turbin terutama bagi kecil loji penjanaan kuasa komersial. Analisis kitaran akan menjadi satu alat yang sangat baik untuk mengira dan menganalisis prestasi Pde tanpa keperluan ujian eksperimen mahal. Dalam kajian ini, kesan-kesan jenis bahan api dan kekerapan yang Pde pada kecekapan haba melalui analisis kitaran termodinamik dinilai. Model generik untuk analisis kitaran dibangunkan oleh Matlab. Humphrey, ZND dan Brayton kitaran diterima pakai bagi analisis ini. Kecekapan terma Biogases untuk ciri pancarannya kurang dikaji dalam kitaran ideal terhadap Hidrogen, Metana dan Propana. Ia menyimpulkan bahawa Biogas boleh menjadi bahan api yang sesuai untuk kajian secara teori Pde. Untuk mengetahui hubungan antara kecekapan haba dan kekerapan, pada geometri berterusan, dalam dua percubaan yang berbeza, hubungan antara kecekapan haba dan kelajuan letupan, dan kekerapan dan halaju mengisi dan penyingkiran dikaji. Ia melihat hubungan secara langsung antara kecekapan haba kitar PDE dan kekerapan tidak boleh didapati.

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## LIST OF ABBREVIATIONS

PDE	-	Pulse Detonation Engine
CJ	-	Chapman-Jouguet
ZND	-	Zeldovich-von Nuemann –Doring
DDT	-	Deflagration Detonation Transition
LHV	-	Low Heating Value

## **CHAPTER 1**

### **INTRODUCTION**

#### **1.1 Background**

Efficient and high powered engine is now in high demand. One of the most common types of power engines are internal combustion engines. In an internal combustion engine, the combustion of a fuel occurs with an oxidizer in a combustion chamber that is an integral part of the working fluid flow circuit. The expansion of the high-temperature and high-pressure gases produced by combustion is applied typically to pistons, turbine blades, or a nozzle. This force moves the component over a distance, transforming chemical energy into useful mechanical energy. By increasing the rate of released energy, the efficiency of engine will be increased.

One way to increase the rate of released energy, is changing the type of combustion. In common engine, the type of combustion is deflagration. Deflagration is a subsonic combustion process where the flame propagates at a few meters per second. Deflagration is the means of chemical energy addition for conventional internal combustion engines, gas turbine engines and rockets. There is another type of combustion called detonation. A detonation, unlike deflagration, produces a supersonic combustion wave that propagates at a few thousands of meters per second relative to an unburned reactant–air mixture. A detonation wave compresses the fluid, increasing its pressure and density, in addition to increasing its temperature, thereby triggering chemical reactions. The energy from the chemical reactions support the traveling shock wave in turn and a balance is attained to form a self-sustaining detonation wave[1-3]. The rates of energy release in detonation mode are three orders

of magnitude higher than energy release in deflagration combustion mode[4]. By using detonation instead of deflagration, it's possible to increase efficiency of engine. Theoretical analyses have shown that pulsed detonation devices have improved efficiency compared to existing deflagration-type systems, such as those based on the Brayton cycle[5-14]. Some advantages of pulse detonation engine are as following:

- PDE is able to operate without initial compression because of the self-compression behavior of detonation.
- Self-compression by detonation yields high thermal efficiency in PDE.
- PDEs can be made smaller and lighter and can be easily maintained. Therefore can be used for small commercial scale power generators.

## 1.2 Problem Statement

The cycle analysis of PDEs is a great analytical tool to estimate the performance of such engines without the necessity of heavy computational fluid dynamics or expensive experimental equipment. Performing this analysis in such a way that the energy released in the chemical reaction is in a generalized form, independent of the fuel-oxidizer mixture, creates the possibility of applying the analysis for different purposes, such as propulsion or power production.

PDE has been tested and analysed using a wide variety fuels, both gases and liquids. When choosing fuels the various factor must be considered including: combustion characteristics, economic, environmental and finally application (air craft or ground base application). In the current study, thermal efficiency of biogases in comparison with common fuels as Hydrogen, Methane and Propane for ideal cycle are studied.

PDE is a pulse detonation engine and its frequency need to be taken into account. The thermal efficiency depends only on the heat added to system and work

extracted from system. For every cycle, the heat added and work extracted are always the same so finding a relation between thermal efficiency and frequency can be a challenge discussed in the current study.

### **1.3 Thesis objective**

The objectives of current research are as following:

- (i) To develop generalized thermodynamic relations that can be applied to a cycle analysis that will be dependent on the initial condition and fuel oxidizer mixture.
- (ii) To compare cycle analysis of detonation and deflagration.
- (iii) To compare thermal efficiency of different fuels can be used in the PDE.
- (iv) To identify PDE frequency effect on thermal efficiency of the PDE.

### **1.4 Scope of work**

The research is focused on the cycle analysis of pulse detonation engine with following assumption:

- Ideal cycle
- Fuels are Propane, Methane, Hydrogen and Biogases.
- Fully mix fuel –air mixture.
- $\gamma$  is constant and is considered for reactant.
- There is stoichiometric mixture.

- There is complete thermodynamic equilibrium.
- $Q$  added to cycle is considered as L.H.V per unit mass of mixture.
- The ZND, Humphrey and Brayton cycle are used for cycle analysis.
- To determine the effect of frequency on thermal efficiency, Endo model is used.

## 1.5 Methodology of work

The methodology of the research is as follows:

- To be familiar with theories of pulse detonation engine by studying the references in this field.
- To derive relations of PDE cycle analysis as: Hugoniot relation, CJ and Neumann Spike point, thermal efficiency, thermodynamic relations and frequency effect.
- To calculate the input data needed in code:  $\gamma$ ,  $R$ , L.H.V and specific volume.
- To write codes which identify thermodynamic relation by MATLAB software.
- To validate the results by similar studies if it's possible.
- Results and Discussion

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