AKENTEN APPIAH - MENKA UNIVERSITY OF SKILLS TRAINING AND ENTREPRENEURIAL DEVELOPMENT

COLLEGE OF TECHNOLOGY EDUCATION-KUMASI

NUMERICAL ANALYSIS OF ALTERNATIVE POWER OUTPUT OF SPARK PLUGS ON ENGINE PERFORMANCE AND EMISSION USING RICARDO WAVE.

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A Thesis Submitted to the Department of MECHANICAL AND AUTOMOTIVE TECHNOLOGY EDUCATION, Faculty of TECHNICAL EDUCATION, School of Graduate Studies, Akenten Appiah - Menka University of Skills Training and Entrepreneurial Development - Kumasi, in Partial Fulfilment of the Requirements for the Award of Master of Philosophy in Automotive Engineering Technology Degree.

NOVEMBER, 2023

DECLARATION

STUDENT'S DECLARATION

I, Elijah Otis Awuni declare that this thesis, with exception of quotations and references contained in the published works which have all been identified and duly acknowledged, is entirely my original work, and it has not been submitted, either in part or whole, for another degree elsewhere.

SIGNATURE:..DATE: ....

SUPERVISOR'S DECLARATION

I hereby declare that the preparation and presentation of this work was supervised in accordance with guidelines for supervision of thesis as laid down by the University of Education, Winneba.

NAME OF SUPERVISOR: AMEDORME SHERRY K. (PhD)

SIGNATURE:..DATE: ....

DEDICATION

I dedicate this workpiece to God almighty for making me come out with this work. To Him be Glory now and forevermore. Amen!

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The following individuals are highly acknowledged for the invaluable contributions they have made to this masterpiece that is today, a reality.

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ABSTRACT

Emission released from the internal combustion engines run on fossil fuels which contain hydrocarbon (HC). Complete combustion produces Carbon dioxide (CO_2), water (H_2O) and Oxides of nitrogen (NO_2) while incomplete combustion produces carbon monoxide (CO), nitrogen oxide (NOx) and particulate matter (PM). These, create the most harmful effects on the environment and humans. The quest to reduce these pollutants led to various technics such as use of alternative fuels, altering of spark plug positions amongst others. The present work focused on alternating the power output of the spark plug and analyzing the performance of the engine and its related emission. The results showed that the alternating powers of the spark plug for 30 W and 30 KW respectively, did not really so much change the performance of the engine within the given range and set of parameters. Ricardo Wave was used for the simulation after the 2014 edition of SolidWorks was used for the geometry development. The work unveiled the fact that the spark plug output influences the performance of the engine. Also, improved engine performance leads to low emissions and vice versa. Further research should gear towards an increased number different power outputs of the spark plug to see if it influences engine performance and emission.

TABLE OF CONTENTS

Contents Page No.

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE

1.0 INTRODUCTION

1.1 THE BACKGROUND AND GENERAL CONCEPTS

Most of the Internal Combustion (IC) engines run on the fossil fuel which contain hydrocarbon (HC). Normal combustion products of any IC engine are Carbon dioxide (CO_2), water (H_2O) and Oxides of nitrogen (NO_2) in the complete combustion process of engine. These exhaust products are not considered as a pollutant because they do not cause direct hazard on human. In the real combustion process (incomplete) some additional products such as unburned hydrocarbon (HCs), carbon monoxide (CO), nitrogen oxide (NOx) and particulate matter (PM) also appears. These products create the most harmful effect on the environment as well as on humans. Quantity of this harmful product of Spark Ignition (SI) engine is five (5) times more than that of Compression Ignition (CI) engine.

Aside these, the legal requirements (emission standards) governing air pollutants (oxides of nitrogen (NOx), Oxides of Sulphur (SOx), carbon monoxide (CO), Hydro carbons (HC) and several others) released into the atmosphere, not excluding emissions emanating from automobiles and other powered vehicles, have given room to a wide range of research in the area of emission control.

Information on Vehicle emission standard revealed that the first automobile emissions standards were enacted in 1963 in the United States, mainly as a response to Los Angeles' smog problems. Three years later according to the site, Japan enacted their first emissions rules (in 1966), followed by Canada, Australia, and several European nations between 1970 and 1972. The early standards mainly concerned carbon monoxide (CO) and hydrocarbons

(HC). Regulations on nitrogen oxide emissions (NOx) were introduced in the United States, Japan, and Canada in 1973 and 1974, with Sweden following in 1976 and the European Economic Community in 1977. These standards gradually grew more and more stringent but have never been unified.

The research is further widened and geared towards fuel economy, combustion efficiency amongst other related but relevant topics aside emission control. This has led to the introduction of multi spark plugs on single cylinders as well as multi spark plugs on each cylinder of multi-cylinder engines as a measure of controlling emissions by the improvement of fuel economy (Bozza et al, 2004).

A U. S. Patent produced in August 9th 2011 depicts a system and method for operating a multiple cylinder internal combustion engine having at least two spark plugs per cylinder include a first control wire coupled to a first spark plug of a first cylinder and a second spark plug of a second cylinder, and a second control wire coupled to a second spark plug of the first cylinder and a first spark plug of the second cylinder with the first and second spark plugs of the first cylinder being selectively fired during the power stroke of the first cylinder and the first and second spark plugs of the second cylinder being selectively fired during the power stroke of the second cylinder to provide individual control of each spark plug using a number of control lines less than the number of spark plugs.

Even though the first automobile emissions standards were enacted in 1963 in the United States and other countries followed suit, today, emission from automobile and other power vehicles is still a challenge that requires an optimum solution. This has called for researchers across the globe especially in the automobile engineering field to delve deep into finding a lasting solution to this challenge of the century so as to reduce the emissions from automobile and their related causes.

One of the best methods to improve the engine performance and reduce the exhaust emission in a SI engine is by the introduction of twin spark into the combustion chamber Khan & Shaikh, (2019). Experiments were conducted at different load conditions and different types of engines have proved that dual spark plug ignition engines are surely better than a single spark plug engine.

Narsimha Bailkeri et al., (2015) has shown that introduction of dual spark ignition has considerably increased the performance of the engine by increasing efficiency & power and reducing its exhaust emissions. Same results can also be seen in the study done by Ajay K. Singh et. al proved that dual spark ignition system is better for improving ignition process even in 2-stroke engines. Thus, reviews and studies have clearly indicated that use of multiple spark ignitions can increase the rate of combustion by rapidly completing the process (Khan & Shaikh, 2019).

1.2 STATEMENT OF THE PROBLEM

Several strategies and techniques have been employed over the years to discover the effect of combustion and the combustion products on emission levels. Attempts have therefore been made to investigate on varied compression ratios, different types of fuels (gasoline and its related LPG and others). It is however discovered that the combustion process of the air/fuel mixture controlled by the engine’s ignition system plays a greater role in curtailing the challenges encountered in automobile and other powered vehicles emissions.

The 2022 EPA Automotive Trends Report Greenhouse Gas Emissions, Fuel Economy, and Technology records that over the last five years, seven of the fourteen largest manufacturers selling vehicles in the U.S. decreased new vehicle estimated real-world CO2 emission rates. Tesla was unchanged because their all-electric fleet produces no tailpipe CO2 emissions, and Mercedes was also unchanged. Between model years 2016 and 2021, Kia achieved the largest reduction in CO2 emissions, at 29 g/mi. Kia decreased emissions in all vehicle types that they offer, and decreased overall emissions even as their truck SUV share increased from 15% to 41%. Toyota achieved the second largest reduction in overall CO2 tailpipe emissions, at 28 g/mi, and BMW had the third largest reduction in overall CO2 tailpipe emissions at 10 g/mi. Toyota and BMW also achieved overall emission reductions by improving all vehicle types, even as their truck SUV production share increased. Five manufacturers increased new vehicle CO2 emission rates between model years 2016 and 2021. Mazda had the largest increase at 24 g/mi, due to increased CO2 emission rates within their sedan/wagon and car SUV vehicle types, along with a shift in production from 33% to 61% truck SUVs. Volkswagen had the second largest increase at 18 g/mi, as a shift in production from 21% to 66% truck SUVs more than offset emission reductions within each vehicle type. GM had the third largest increase at 17 g/mi, with a production shift towards truck SUVs and pickups and an increase in pickup emission rates more than offsetting emission improvements in all other vehicle types. It becomes evident that the need for the reduction of pollutants emitted by vehicles with SI engines is intensified in the late years. Legislation in European Union imposes mandatory emission reduction for new vehicles.

1.3 PURPOSE OF THE STUDY

The purpose of this study is to carry out a Numerical Analysis of alternating power output of the Spark Plug on Engine Performance and Emission which has never been given a close attention.

This will be achieved through the following specific objectives;

1. To evaluate the effect of different powers of the park plug output on an engine's performance parameters.
2. To determine the effect of different powers of the park plug output on an engine's exhaust emission.
3. To examine the relationship between the performance and emission of engines with different spark plug powers.

1.4 SIGNIFICANCE OF THE STUDY

The current study is vital in the sense that emission has become a global challenge. It is even compounded by the increase in the number of automobile users as well as the upsurge of industries where machines are powered by fossil fuels of various kinds. Hence, this work piece feeds into the varying and much expected desire in getting to know what the effect of the use of alternative power output of spark plugs on a single cylinder as well as its effect on emissions are.

Contribution towards the reduction of pollutants especially from fuel powered engines and machines in general as well as the individual benefit of improvement of fuel efficiency and engine performance cannot be over emphasized.

The study when completed will accord all stake holders of the Automobile industry as well as institutions relating to emissions and its related control, a great opportunity to discover the influence of alternative power output of spark plugs on the performance and emission of the spark ignition engine when successfully executed.

1.5 SCOPE OF THE STUDY

This study will look closely at alternating the power output of the spark plug to 30 W and 30 KW and analyzing their effect on engine performance and emission. The study will ideally be carried out within a spate of eight calendar months provided all favorable conditions are met for advancements and unambiguity brought to the barest minimum.

The Ricardo Wave software that gives solution to complex structural engineering problems and make better, faster design decisions will be used in the analysis. The software is used across industries to help engineers optimize product designs and reduce the costs of physical testing. An aspect of SolidWorks Software will be greatly utilized in the study. The petrol engine would be used throughout the study and as much as possible, a particular type of spark plug would be used throughout for uniformity and the avoidance of doubts and disparities. As well, a particular type of engine (vehicle) will be adopted in this study.

1.6 THE ORGANIZATION OF THE STUDY

The structure of the study consists of chapters one to five and each chapter has a focused agenda which is carefully outlined for easy comprehension.

Chapter one mainly talks about the introduction to the study and the reasons for the study as well as the strategy to use in arriving at the required conclusion.

Chapter two outlines the fundamental background of related works on engine performance and emission issues where the spark plug is the center of attraction. Attention is also given to their capabilities and how the various challenges are resolved.

In chapter three, information is provided on the tools and equipment used in the execution of the main agenda of the thesis which is the numerical analysis of the power of spark plugs on engine performance and the related emission.

Chapter four takes a close look at the results gathered from the modules and tools outlined in chapter three. Also captured is the model used and outlined generated and analyzed data.

Chapter five which is the last chapter looks at the various findings of the entire workpiece and gives a brief conclusion on the findings. Suggested future works are captures as well.

CHAPTER TWO

REVIEW OF RELEVANT LITERATURE

2.0 Overview

Many attempts have been made in the field of Automobile Engineering to ensure that engine performance is improved by way of fuel economy and low emission levels.

This section outlines the fundamental background of related works on engine performance and emission issues where the spark plug is the center of attraction. Attention is given to their capabilities and how the various challenges are resolved. Unresolved challenges are also highlighted.

2.1 DISCUSSION ON LITERATURE

2.1.1 The impact of varying spark timing at different octane numbers on the performance and emission characteristics in a gasoline engine

Cenk Sayin (2012)

The use of different research octane number gasolines (91, 93, 95 97, and 98) at varying spark timing, 20, 23 and 26 Crank Angle Before Top Dead Centre was employed in the performance and emissions of gasoline engine (Cenk Sayin, 2012). The engine used had a Crank Angle before Top Dead Centre of 23^{o} and a fuel of 95 research octane number. Other parameters considered aside a 4-stroke single cylinder using gasoline as fuel were cylinder bore of 88 mm, a stroke of 64 mm, a compression ratio of 8.5:1 and a maximum power output of 7.7 kW. According to Cenk Sayin, the experiment proceeded at three different spark timings of 20, 23 and 26 CA BTDC and at steady states for five different speeds of

500 rpm intervals from 1000rpm to 3000 rpm with an engine load of 20 Nm. Going by the results at the end of the research, octane numbers higher than the requirement of an engine was noted to have decreased brake thermal efficiency (BTE) and increased brake specific fuel consumption (BSFC). Emissions of carbon monoxide (CO) and hydrocarbon (HC) as well as BSFC had reduced after the spark timing was altered from the original 23 to 26 degree of crank angle BTDC. The values are given as 220 g/kWh for BSFC, 0.37% for BTE. For emissions, there was a tradeoff of relatively higher temperatures that led to having 0.78 g/kWh for CO and 0.45 g/kWh for HC (Cenk Sayin, 2012).

2.1.2 PERFORMANCE OF AN SI ENGINE WITH DIFFERENT SPARK PLUGS, VCR AND H2 ADDITION

Oğuz, Mustafa, Hasan & Mustafa (2020) carried an investigation to determine performance values of brake power and brake specific fuel consumption. This is because efficiency of the fossil fuel coupled with its depletion has been concerns for many in the industry. Their intent was also to enhance combustion quality and find alternative fuels for SI engines. Oğuz and friends' effort of tripartite in nature covered the use of conventional, iridium & platinum spark plugs, variable compression ratios of 8.5:1 & 10:1 and addition of Hydrogen gas at percentages of 0, 2 & 4 ($formulae\ used\ is\ \alpha \boldsymbol{H_2} = \boldsymbol{VH_2}$ ($\boldsymbol{VH_2}$ + V_{air}) × $\mathbf{100}$) with engine speeds of 1200, 1500 and 1800 rpm. As captured, "the main purpose of this study was to determine the effects of iridium and platinum spark plugs on engine performance along with hydrogen enrichment and VCR at different engine speeds and comparing their performances with the engine running with gasoline and conventional spark plug” (Oğuz, Mustafa, Hasan & Mustafa, 2020).

The outcome of the investigation revealed the following: 1. Changing conventional, iridium & platinum spark plugs resulted in lower CO and HC but records higher CO_2 and NOx emissions at all compression ratios, engine loads and hydrogen flow rates, 2. Variations in emission parameters mentioned above were more obvious for platinum spark plug than iridium type, 3. Similar to spark plug changing, hydrogen addition increased CO_2 and NOx and reduced CO and UHC values compared to un-hydrogenated fuels, 4. It is observed that higher CR and engine load provided lower HC and CO emissions and higher CO_2 and NOx emissions were emitted.

2.1.3 MULTIPLE SPARK PLUGS PER CYLINDER IGNITON SYSTEM

The problems of rapid spark plug wear and requirements for frequent spark plug maintenance are common to all commercially available ignition systems. Accordingly, Kay and Torrace (unknown) provided an improved ignition System wherein the sparkplugs have a relatively long life when compared with spark plugs in conventional ignition systems. Their work did not just end there but also provided an ignition system of the foregoing character in which spark plugs require infrequent servicing when compared with conventional ignition systems. Again, their effort provided an ignition system which includes a plurality of spark plugs per cylinder and means for firing the spark plugs in succession to allow the spark plugs a cooling period between consecutive operations sufficient to materially increase the operating life of the spark plugs.

Aside these, the ignition system of the foregoing also aids the Spark plugs for each cylinder to fire consecutively at relatively high engine speeds and simultaneously at relatively low engine speeds to ensure that the engine will start and operate efficiently at low speeds despite the occurrence of defects in one or more of the spark plugs for each cylinder which would prevent the engine from starting if used alone and which would not otherwise allow the engine to run at low speeds. Electrical circuitry connects the ignition system coil with the individual spark plugs on successive revolutions of the engine to provide a cooling period for each of the plugs as the other plug is being fired.

The ignition system for the engine includes two spark plugs extending into the cylinder, a distributor, a coil, and a wire from the coil to the distributor as well as wires from the distributor to the spark plugs. Generally, electrical energy from the coil is transferred to the distributor which in turn selectively distributes the electrical energy to the plug wires and hence to the spark plugs to fire the spark plugs simultaneously. This happens at low engine speeds. To provide for the selective distribution of electrical energy, an electrical contact mechanism is carried by a rotor cap and as the rotor cap turns, it selectively transfers electrical energy to the ends of the wires of the twin plugs per cylinder to fire the associated spark plugs. This time round, alternatively so that the plug not firing, rests awaiting its turn to fire as the currently firing plug also takes its turn to rest. The problem with this novel system is that, more power is consumed in the operation and firing of the plugs. This is in the case of simultaneous firing of the multiple plugs per cylinder. On the other hand, even though the non-firing plugs at the time are resting, they are equally exposed to the heat generated in the combustion chamber as it is not insulated from the chamber this therefore nullifies the claim that the plugs lasts longer than those used in the conventional ignition setting.

2.1.4 MULTIPLE-SPARK IGNTION SYSTEM FOR INTERNAL COMBUSTION ENGINES, PARTICULARLY FOR MOTOR VEHICLES

Di Nunzio et al,. (1990) had their concentration on the ignition systems for internal combustion engines with a multiple-spark. In order to store the energy necessary for generating the spark, the primary of each coil delivers current every 180^o of the engine. The power dissipated by the Joule effect is: P_{J1} = ieff1^2 x R_{P1} where ieff1 = effective primary winding current, R_{P1}= primary winding resistance. There is always some energy losses between the secondary winding and the plugs in the conventional ignition with the twin plugs. Di Nunzio et al,. (1990) puts the losses between 50% and 60% of which 40% is through the distributor. Also on the electronic twin plugs ignition, there is a lost spark principle where a coil that serves 2 plugs serves different cylinders. In this case, these cylinders are on different strokes and so the cylinder that is not on compression stroke losses the power that emanates from the plug. It is seen that each coil passes a current at every 360° rotation of the shaft and the Joule power dissipated is $P_{J2} = P_{J1}/2$. The diverging point from the two previous systems leads to the invention by Di Nunzio and his friends eliminates losses since the coils are mounted directly on the plugs and all the energy present in the secondary will thus be transferred and divided in approximately equal parts between the plugs. Advantages of the invention include: The coils of smaller bulk and loss; elimination of all the high-tension leads and its associated losses; spark energy and high tension at the plugs which are the same or even greater for the same energy stored in the primary and for the same coil-turn ratio.

NB here, focus was on the optimal arrangement and empowering of the coil to the spark plugs in a cylinder and not the analysis of the performance of the engine and its related emissions as a result.

2.1.5 MULTIPLE SPARK PLUGS PER CYLINDER ENGINE WITH INDIVIDUAL PLUG CONTROL

Uchida et al. (unknown) disclosed systems and methods for controlling individual plugs in an internal combustion engine having two or more spark plugs per cylinder. The problem discovered was that some multiple spark plugs are powered from a common ignition coil and fire at the same time, just as in distributor-less ignition systems where power paired spark plugs (associated with different cylinders) are fired at the same time with one cylinder in the power stroke and one in the exhaust stroke (waste spark). In overcoming this challenge, the two spark plugs per cylinder include a first control wire coupled to a first spark plug of a first cylinder and a second spark plug of a second cylinder, and a second control wire coupled to a second spark plug of the first cylinder and a first spark plug of the second cylinder with the first and second spark plugs of the first cylinder being selectively fired during the power stroke of the first cylinder and the first and second spark plugs of the second cylinder being selectively fired during the power stroke of the second cylinder to provide individual control of each spark plug using a number of control lines less than the number of spark plugs. The systems and methods presented by Uchida and his colleagues provides individual control of each spark plug associated with a common cylinder to more accurately control the combustion process while using only a total number of control lines corresponding to the number of cylinders to reduce cost and complexity of the control system. Individual spark plug control in a multiple spark plug per cylinder application facilitates selective simultaneous or off set firing of spark plugs associated with a common cylinder during the same phase of the combustion cycle. Here, every spark plug is under programmable control of the engine controller while using only a total of one control line and controller output per cylinder to reduce controller and driver cost as well as overall system complexity. It is worth mentioning that, upon all the effort to combat the challenge as outlined earlier, ultimately, one or more characteristics may be compromised to achieve desired system attributes, which depend on the specific application and implementation. These attributes include, but are not limited to: cost, strength, durability, life cycle cost, marketability, appearance, packaging, size, serviceability, weight, manufacturability, ease of assembly, etc.

NB this work had eyes on the control of the plugs in a single cylinder engine.

2.1.6 Influence of Spark Timing on Performance and Emission Characteristics of Engine with Dual Spark Plug in Single Cylinder Using Gasoline and Butanol as Fuel

Ravikumar et al., (2020) studied five sets of spark timings on engine performance parameters and exhaust emissions. It was carried out on four-stroke, single-cylinder by developing dual spark ignition, and dual spark plug ignition engines for both n-butanol and gasoline with the aim of attaining a homogeneous combustion process in SI engines and developing the performance with decreasing in exhaust emission. One main condition was full-throttle at the constant engine speed of 3000 RPM at a fixed compression ratio of 9.5:1. Performance parameters and emissions characteristics executed on a computerized, four-stroke single-cylinder engine with an impermanent compression ratio is captured in table 2.1

Table 2.1 Specifications of the quoted engine parameters

Parameter	Description
Engine	4-Stroke, Oil Cooled, Single Cylinder
Engine Displacement (CC)	220 CC
Power-(PS @ rpm)	20.76 bhp @ 8500 rpm
Torque-(Nm @ rpm)	19.12 Nm @ 7000 rpm
Bore diameter	67 mm
Stroke length	62.4 mm
Rated Compression Ratio	9.5:1
Number of Valves	2
Valves arrangement	Overhead Camshaft
Fuel Supply System	Carburetor
Engine Cooling System	Oil Cooled and Air-Cooled
Fuel Type	Petrol
Ignition type	Twin Spark Ignition

Complete burning coupled with greater octane number of available non-conventional fuels led to the research alternatives for petrol and consequently, n-Butanol blends as fuel for Otto cycle engine. The results showed the fuel consumption to be highest for n-butanol compared to gasoline fuel. Although the efficiency of the engine enhanced for n-butanol fuel, less emissions of CO, CO2, HC, and NOx were recorded.

2.1.7 Experimental and numerical investigation of effects of CNG and gasoline fuels on engine performance and emissions in a dual sequential spark ignition engine

Haven discovered that the number of CNG vehicles in the world has reached about 23 million as retrieved from http://www.iangv.org/current-ngv-stats/ ,2017.06.20, Ahmet & Yahya (2018) studied the effects of Compressed Natural Gas and gasoline fuels on engine performance and emissions in dual sequential spark ignition engine using Honda L13A4 i-DSI. At wide open throttle, gasoline and CNG were tested separately. The engine was tested and modeled, results of which is displayed in fig 6.1 (Ahmet & Yahya, 2018). Ricardo-Wave software was used in constructing a 1-D model for the entire test rig and the engine to numerically analyze the performance. The test rig according to Ahmet & Yahya mainly consists of four components; engine, eddy-current dynamometer, emission measurement unit, and instrumentation-control unit. Tests are performed by varying the engine speed with an interval of 500 rpm from 1500 rpm to 4000 rpm for both gasoline and CNG fuels, engine performance (brake torque, brake power, brake specific fuel

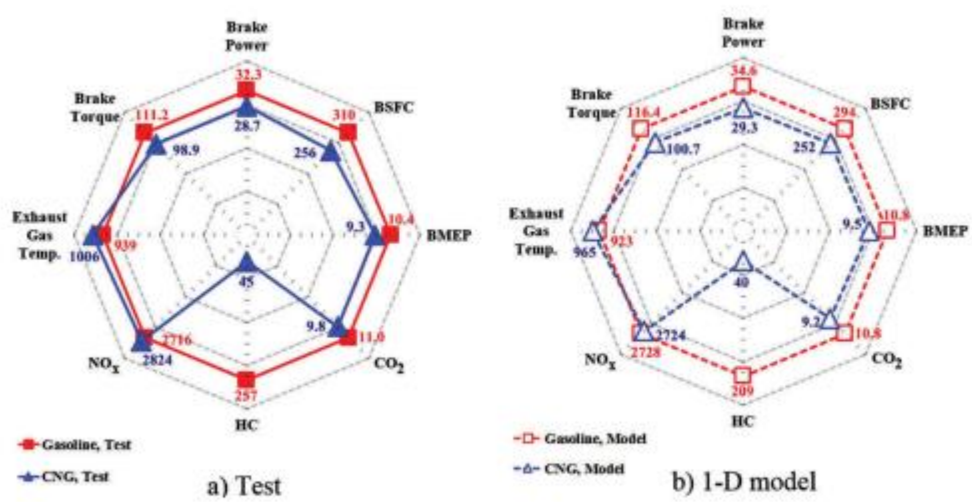

Figure. 2.1 Gasoline vrs CNG in engine performance and emissions.

consumption, brake mean effective pressure), emissions (O_2, CO_2, CO, HC, NOx, and lambda), and the exhaust gas temperature are evaluated

2.1.8 Performance and Emission Analysis of Two Stroke Dual Sparkplug SI Engine

Khan & Shaikh, (2016)

The research of Khan & Shaikh investigates the effect of twin spark plug to the single spark plug on the basis of the performance of engine and emission. The rationale for the carrying out of their work is premised on the improvement of the engine performance and reduction in the exhaust emission in a Spark Ignition engines

The parameters and components required for the experimental set up are summarized in table 2.2

Table 2.2 required components

SERIAL NUMBER	PARTICULARS	SPECIFICATION	COMPONENTS
01	2-Stroke Petrol Engine	150 Cc	Air cooled single cylinder, single spark ignition engine Air cooled single cylinder twin spark ignition engine. Dynamometer Exhaust gas analyzer Fuel consumption device Digital tachometer.
02	Spark Plug	12 Volt, Dc	
03	Electronic Magneto	12 Volt, DC	
04	Starting Coil	20,000 Volt.	
05	Ignition Coil	12 Volt, Dc	
06	Battery	12 Volt, Wet	
07	Alternator	3.5 Kw	

Gathered records indicates that considerable improvement exists in the performance of engine output and considerable reduction in Brake-Specific Fuel Consumption, Hydro Carbons and Carbon Monoxide emission in twin spark plug technology.

The experiment executed resulted in the bulletin that follows:

1. Combustion process in dual spark engine takes place 35% faster than single spark engine due to faster flame propagation.

2. Brake thermal efficiency of twin spark engine is 4.9% higher than single spark engine.

3. Volumetric efficiency of dual spark engine is 1.2% less for twin spark engine as compared to single spark engine.

4. The UBHC emission in twin spark engine is reduced up to 12% as compared to the single spark engine.

5. The CO emission in twin sparks engine is reduced to a great extent.

6. NOx emission increased by 12% in twin spark engine as compared at full load. It is clear from the ongoing that, engines with twin spark plugs out performs that of engines with single spark plugs. It was conclusive from the work carried out by Khan & Shaikh, (2016) that, dual spark technology should be the technology of the moment. As good as that may sound, the volumetric efficiency of the single spark plug technology is greater as compared to that of the twin spark plug but only increases when there’s increases in load. Another drawback was that when speed increases, NOx emission increases with increase in spark plug.

2.1.9 Evaluation of the effects of a Twin Spark Ignition System on combustion stability of a high performance PFI engine

At both part load and full load conditions, a Ducati engine equipped with a Twin Spark ignition system saw a consistent improvement in combustion stability according to Forte et al., (2015). CFD modeling and computational hardware development, alongside numerical methodology, based on a perturbation of the initial kernel were the methodologies utilized. A lagrangian ignition model was modified and used to take care of the statistical distribution of mixture around the spark plugs. The challenge to unravel was the causes of increased levels of knock. The test bench on which the engine is run is equipped with a pressure sensor located in the chamber. The pressure traces of 300 engine cycles are recorded for each engine point analyzed for both the Twin Spark plug and the single Spark plug configurations. Basic conditions met are filtering the pressure signal with butter worth zero-delay low pass filter at 3 kHz for IMEP and CHRnet, butter worth band-pass filter at 5 kHz and 20 kHz for the high frequency parameters (Forte et al., 2015). The CFD simulation is aimed at evaluation of combustion of Twin/single Spark engine and the understanding of the origin of the higher knocking behavior of TS configuration. Although the work of Forte et al., (2015) saw a consistent improvement in combustion stability at both part load and full load conditions, at full load condition the twin spark configuration showed an increase of power, but with higher knocking tendency.

2.2 CONCLUSION

From the above discussions, it is realized that research has proceeded in the areas of alternative fuels such as butanol, compressed natural gas amongst others, all in an attempt to improve the engine performance as well as reducing emissions. Alternatively, the use of multi-spark plugs (maximum of 2) have gained a wide range of application and various analysis and evaluations have been made. This is entirely different from the current researchers focus. What is not known is whether the increase of the number of spark plugs for the same engine plays any significant role in the improvement of the engine performance and reduces emissions. That gap in literature is what the current researcher seeks to bridge in the area of alternating the power output of spark plugs. Other areas that could be looked at include but not limited to the combination of multiple plugs and the variation of the various types of fuels used. Knowledge in these areas are relevant in order to inform engineers on the field, the combination of engine types that can have multiple plugs and the improvement levels to expect.

CHAPTER THREE

MATERIALS AND METHODS

3. 0 Introduction

This section provides information on the materials and methods used in the execution of the main agenda of the thesis which is the numerical analysis of alternating power output of spark plugs, the effect on engine performance and the related emission. The work zooms into the selected tool for the investigation carried out in ascertaining the effect of alternate spark plugs power on the performance of the engine in relation to its emission when the spark plugs power per cylinder is increased.

The Ricardo Wave Software (RWS) is the tool selected for this work from the many several tools (Computation Fluid Design (CFD), Analysis systems (Ansys), Engine forte, AVL) available that are capable in the simulation process. The chosen tool is a state of the art one dimension (1D) gas dynamics simulation. It is used worldwide in industry sectors including ground transportation, rail, motor sport, marine and power generation. WAVE enables performance and acoustic analyses to be performed for virtually any intake, combustion and exhaust system configuration. Also, it is used throughout the engine design process because it is the ideal tool for things such as improving volumetric efficiency, designing complex boosting systems, improving transient response or extracting the maximum performance from a race engine. This makes wave more suitable for the workpiece as compared to other simulation tools readily available.

WAVE simulation software solves the 1D form of the Navier-Stokes Equations (NSE) governing the transfer of mass, momentum and energy for compressible gas flows, and includes sub-models for combustion and emissions.

For Compressible fluids, the (isentropic) compressible Navier-Stokes equation is given as: $\partial t(\rho u) + \mathrm{div}(\rho u \otimes u) + \nabla p(\rho) = \mathrm{div}\, S(\nabla u)\ \partial t\rho + \mathrm{div}(\rho u) = 0$,

Where, S denotes the Newtonian stress tensor, and the pressure is now a constitutively given function of the density (e.g. the polytropic pressure law $p(\rho) = \rho\, \gamma$, $\gamma > 1$ the adiabatic exponent).

3.1 ROADMAP

The use of Ricardo WAVE to develop engine simulations requires several computer programs that vary in purpose from model setup and 3-Dimensional (3D) modeling, to statistical analysis of model output. The four programs used in this research are: Wave Build, Wave Mesher, Wave Solver, and Wave Post.

Figure 3.1 gives a general flow diagram for the development of the model used in this work.

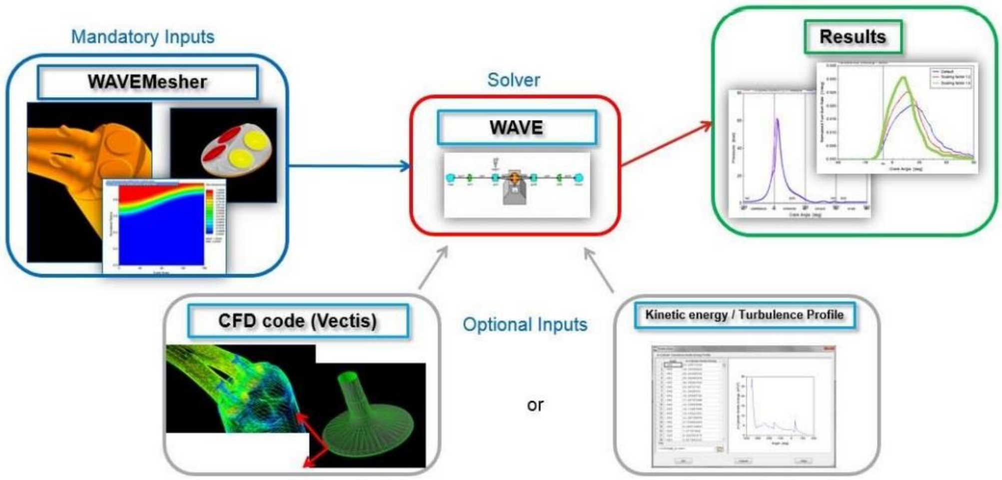

Figure 3.1 Flow diagram for model development

3.2 Materials

The first mandatory inputs into Wave Mesher as captured in figure 3.1 is an stl file from the engine geometry. The engine geometry was developed using the 2014 edition of SolidWorks.

In SolidWorks, the various parts of the engine such as the cylinder, piston, valves and the spark plug. The various dimensions of the components are used in the software to first produce the individual components and afterward assembled together to produce a gas tight combustion chamber (engine). A fully assembled geometry is captured in figure 3.2.

It is this geometry that is converted to an stl file which is in-turn used in Wave Mesher to further produce a combustion module as can be seen in the aspect covered by the Wave Mesher in the Ricardo software.

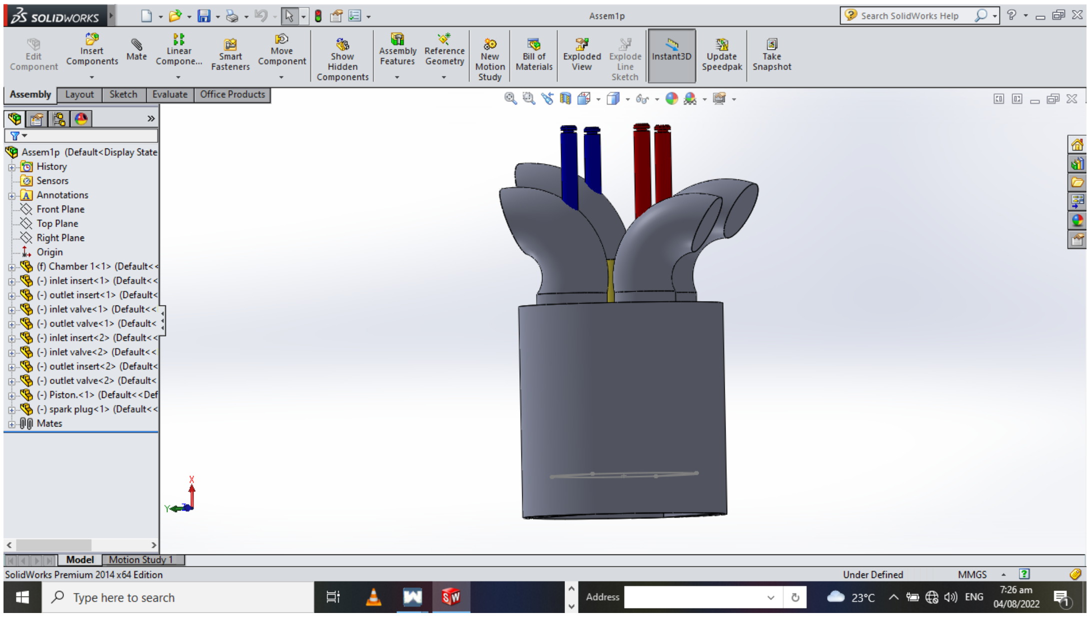

Figure 3.2 A geometry of cylinder and assembled components

3.2.2 Ricardo Wave Software (RWS)

Wave Build is the pre-processor and Graphical User Interface (GUI) that is used to define all engine and simulation parameters. All model and simulation parameters are defined from within this program with the exception of external Computer Aided Designs (CAD) geometries which has been covered earlier. A screen-capture of the GUI layout used for this work is shown in Figure 3.3. The left portion of the screen lists the elements available to be inserted into the model such as engine cylinders, ducts, and orifices. These elements and their respective values are captured in table 3.1. The right side of the screen is the visual portrayal of the engine model layout in which all parameters can be modified. There are some geometries that can be difficult and time consuming to construct with the elements available.

Table 3.1 Elements and their values used for the module

ELEMENT	VALUE
Cylinder bore	85 mm
Stroke	80 mm
Connecting rod length	150 mm
Compression ratio	10:1
Inlet manifold (Left diameter) Inlet manifold (Right diameter) Inlet manifold (Length)	40 mm 35 mm 100 mm
Inlet port (Left diameter) Inlet port (Right diameter) Inlet port (Length)	35 mm 35 mm 50 mm
Exhaust port (Left diameter) Exhaust port (Right diameter) Exhaust port (Length)	28 mm 28 mm 90 mm
Exhaust manifold (Left diameter) Exhaust manifold (Right diameter) Exhaust manifold (Length)	28 mm 40 mm 150 mm

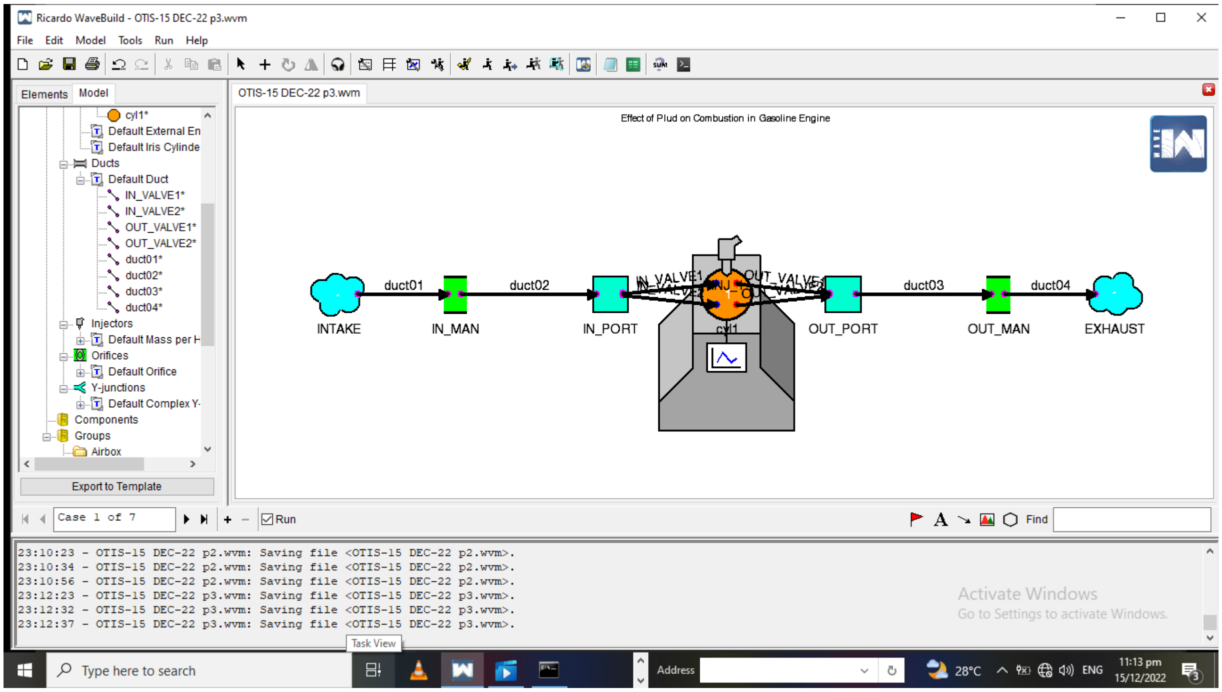

Figure 3.3 A single cylinder Wave Build GUI Engine

For this reason, Wave Build allows complex geometries to be imported into the model from 3D CAD files using a program called Wave Mesher. Wave Mesher allows the end-user to manipulate 3D CAD models of complex geometries such as intake manifolds and exhaust headers, so that the 3D models can be broken-down into a usable one-dimensional (1D) form for the WAVE processor. Figure 3.4 is a screen shot of the Wave Mesher program in which an engine geometry in figure 3.2 is developed by SolidWorks 14 and converted to a .stl file has been meshed for use in Wave Build.

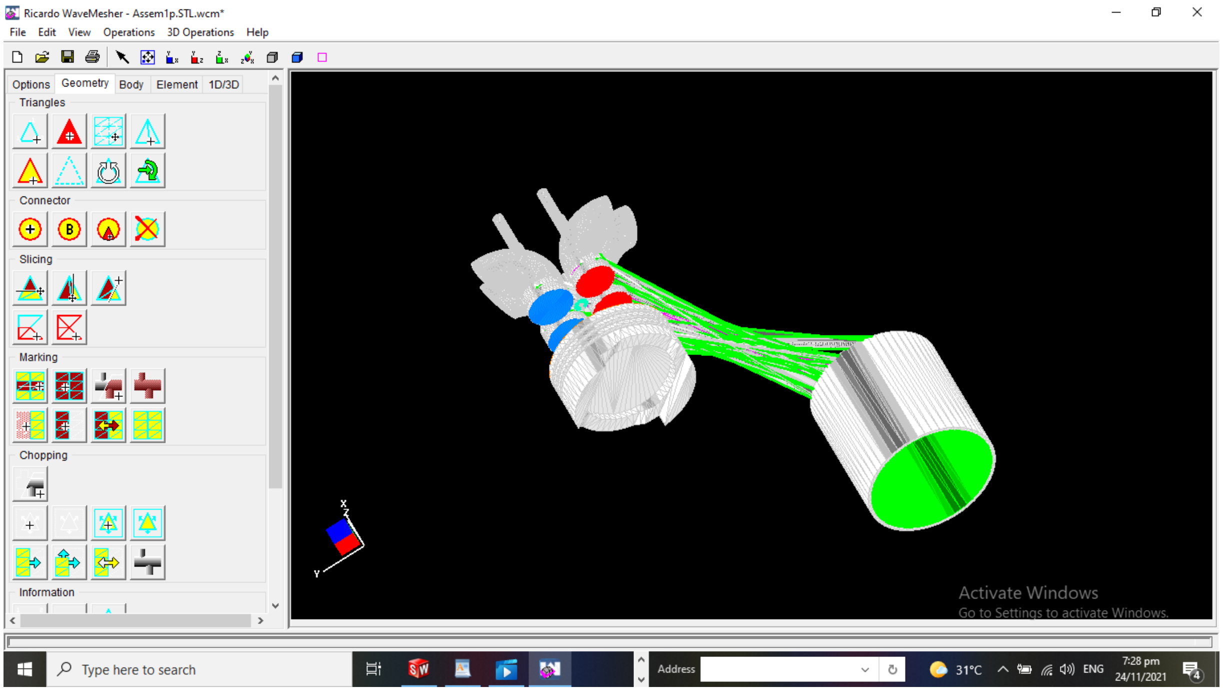

Figure 3.4 Wave Mesher

Amongst some of the files generated by wave Mesher and used in Wave Solver after building Wave Build are the Combustion SDF file containing the turbulent flame burn maps (.tfbr). This file is generated by the Wave Mesher program for the purpose of the combustion set up. If the combustion module is properly developed without any form of error, the interface shown in figure 3.5 is produced. The figure shown is just a sign of successful development of a file with an extension known as the combustion module file but it is not the product of that process.

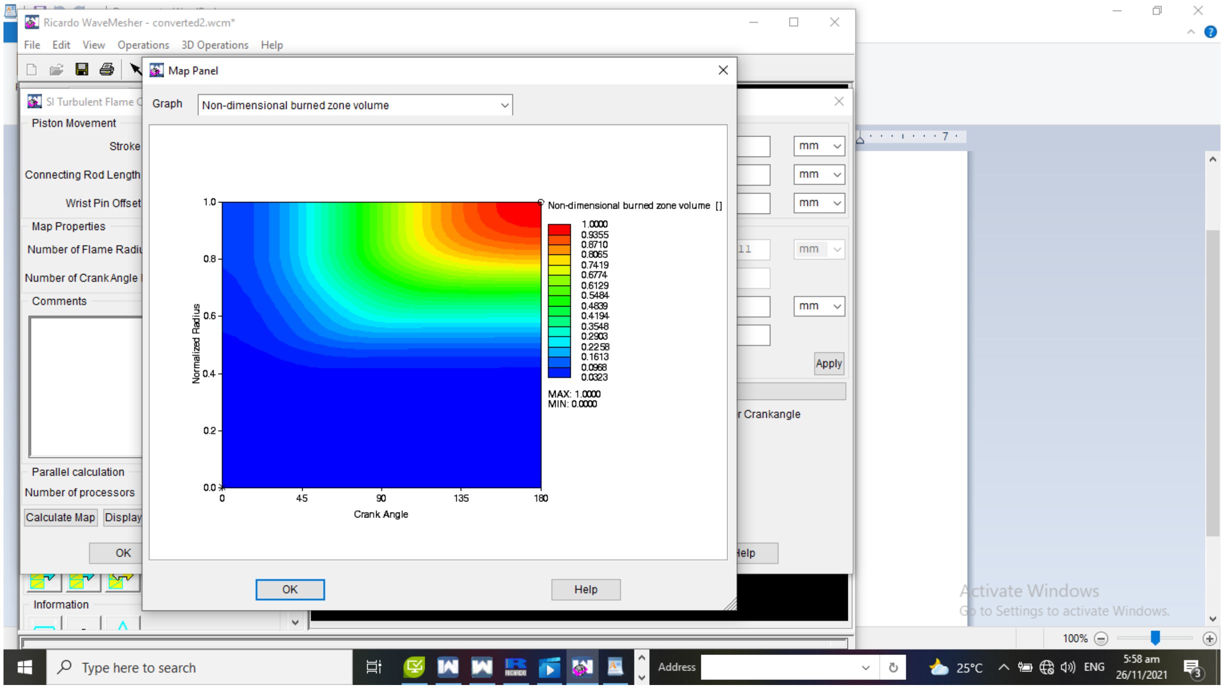

Figure 3.5 Generated Combustion module success graphical symbol

Once the model is setup in Wave Build and 3D models have been meshed, a simulation can be started by running the WAVE code. WAVE is the solver that performs all the calculations needed to simulate engine operation. It is a non-interactive program that runs in a DOS window while streaming certain output data and simulation progress. The output data shown during simulation runtime can be customized to show parameters of interest. These parameters can be used as indicators to show whether or not the simulation is producing reasonable results, allowing the simulation to be prematurely stopped if the model is not functioning properly.

With WAVE Solver, all the conditions for the advancement of the simulation are given (entered) after the necessary parameters are entered and it is set to run. Once a simulation is finished, a large output file is created that contains all data needed to analyze the simulated engine operation.

Wave Post is the post-processor for WAVE simulations that allows interpretation of simulation results. It allows for the creation of: time plots, sweep plots, spatial plots (animated), and TCMAP plots (for turbines and compressors).

The engine model is setup by defining some relatively basic inputs and then some more advanced inputs that require some engine testing. The basic inputs are composed of engine geometry and boundary conditions. Therefore, all dimensions from the intake and exhaust ducting must be recorded and input (refer to table 3.1). Likewise, manufacturer specifications for internal engine geometry such as bore, stroke, connector rod length, wrist-pin offset and compression ratio must be input. Initial conditions such as exhaust temperatures, intake temperatures, and wall temperatures need to be input as reasonable values. These can be modified to higher accuracy once actual engine measurements become available.

3.3 Combustion modules

3.3.1 SI Wiebe Combustion

The SI Wiebe function is widely used to describe the rate of fuel mass burned in thermodynamic calculations. This relationship allows the independent input of function shape parameters and of burn duration. It is known to represent quite well the experimentally observed trends of premixed SI combustion. It is a primary combustion model and the most commonly used combustion sub-model in SI engines. It can be applied to all engine cylinder elements. A list of all the available time plots from the SI Wiebe combustion sub-model is shown in table 3.2.

Table 3.2 SI Wiebe time plots

Plot #	Plot Title
146	Combustion Fuel Burn Rate
147	Cumulative Combustion Fuel Burned
148	Combustion Heat Release Rate
149	Cumulative Combustion Heat Release
154	Instantaneous Combustion Equivalence Ratio

The equation for Wiebe module is defined by $W = 0.1 \exp\{ - AWI\ (\Theta^{\theta}/BDUR)^{(WEXP+1)} \}$

where: W = Cumulative mass fraction burned

AWI = Internally calculated parameter to allow BDUR to cover the range of 10-90%

Θ^{θ} = Degrees past start of combustion

BDUR = User-entered combustion duration (10%-90%)

WEXP = User-entered exponent in Wiebe function

The burn profile in the input panel can be used to observe the effects of varying the input parameters. Varying the 50% burn point simply shifts the entire curve forward or backward. Varying the 10%-90% duration will extend the total combustion duration, making the profile extend longer or compress shorter. Varying the Wiebe exponent will shift the curve to burn mass earlier or later.

3.3.2 SI Turbulent Flame Combustion

The SI Turbulent Flame combustion sub-model is a predictive combustion model for port-injected or early direct-injected, pre-mixed (spark-ignition) engines. The combustion sub-model includes various options for flame propagation at various levels of complexity. The sub-model also includes options for spark enhancement. It is a primary combustion model and can be applied to all engine cylinder elements in an SI engine. It must be used in conjunction with one of the Turbulence and Flow sub-models.

The turbulence velocity is calculated as:

$$U' = C_{prop} \text{ x } U_{piston}$$

where: C_{prop} = User-entered ratio of turbulence velocity to mean piston speed

U_{piston} = Mean piston speed

Both measurements and CFD calculations for turbulent flows in the engine suggest that the turbulence length scale, L, varies gradually from a smaller value at TDC to a larger value at BDC. The turbulence length scale is varied sinusoidally as:

$$L = ½ ((L_{BDC} + L_{TDC}) - (L_{TDC} - L_{BDC})\cos\alpha_e)$$

where: L_{TDC} = User-entered integral length scale at TDC

L_{BDC} = User-entered integral length scale at BDC

α_e = Engine crank angle [rad]

The user-entered profile of turbulence velocity is used directly but for the "Turbulence Kinetic Energy Input" option, the user entered profile of turbulence kinetic energy is converted to a profile of turbulence velocity by the following equation:

$$U' = \sqrt{\tfrac{2}{3}K}$$

where: k = User-entered values of turbulent kinetic energy

Both measurements and CFD calculations for turbulent flows in the engine suggest that the turbulence length scale, L, varies gradually from a smaller value at TDC to a larger value at BDC. The turbulence length scale is varied sinusoidally as:

$$L = \tfrac{1}{2}\left((L_{BDC} + L_{TDC}) - (L_{TDC} - L_{BDC})\cos\alpha_e\right)$$

where: L_{TDC} = User-entered integral length scale at TDC

L_{BDC} = User-entered integral length scale at BDC

α_e = Engine crank angle [rad]

By default, Spark-Ignited combustion models in WAVE follow a constant combustion air/fuel ratio under the assumption that the fuel-air mixture is fully premixed. In certain spark-ignited engine designs (primarily Spark Injection Direct Ignition), the fuel and air are not fully mixed at the start of combustion. To alter the combustion stoichiometry and allow WAVE to adapt to mass added or removed from the cylinder during SI combustion, a stratified charge secondary combustion model can be activated. The model allows the user to specify a combustion equivalence ratio to be used during the early part of combustion.

3.3.3 Three Point Simple Wiebe Combustion

The Three Point Simple Wiebe Combustion reference object applies the Wiebe combustion sub-model to an engine cylinder. The model allows to “construct” simple Wiebe curve using 3 burn points at specified location (e.g. 10%, 50% and 90% burn points). It is a primary combustion model and can be applied to all engine cylinder elements in both SI and diesel engines.

3.3.4 Multi-Component Wiebe Combustion

The multi-component Wiebe combustion sub-model allows one to eight Wiebe curves to be superimposed to create a complete burn profile. This allows generic modeling of single, double, or triple Wiebe curve profiles, as are common in SI and diesel engine modeling, as well as more advanced profiles to account for pre-injection and late injection burns.

It is a primary combustion model and can be applied to all engine cylinder elements in both SI and diesel engines.

This is the only combustion model which can be used for multi-fuel combustion allowing combustion of both premixed (homogenous) and non-premixed (spray guided) in-cylinder charge. If a fuel file with more than one fuel is loaded the Multi-Component Wiebe Combustion Model changes to include multi fuel combustion settings. Figure 2 shows a dual fuel combustion setup where diesel fuel burns non-premixed (spray guided) and natural gas is combusted premixed (homogenous).

3.3.5 WATSON COMBUSTION MODEL.

Watson diesel air entrainment model will be used based on existing model in WAVE. Reference diesel wiebe combustion model. Air fuel ratio of combustion is calculated step by step based on the air entrainment model.

As described before, the premixed fuels and air mixture can be set to only present in the Premixed zone or set to occupy the whole cylinder. This is achieved by setting the Yes/No switch of “Burn Premixed Fuel in Shared Air” in the “Non-Premixed Combustion” input section. The “Yes” switch sets the premixed fuels and air mixture occupy the whole cylinder. Non-Premixed fuel will be super-imposed on the already premixed fuel air mixture. The “No” switch will set the premixed fuels to be confined in the Premixed zone.

In case that the “Yes” switch is set for “Burn Premixed Fuel in Shared Air” in the “Non-Premixed Combustion” input section, the premixed fuels exist in the air mixture already. As the non-premixed fuel combusts, the premixed fuels with air will be passively combusted in the process. The premixed fuel mass presented in this zone is given by

CHAPTER FOUR

RESULTS AND ANALYSIS

4.1 Introduction

This chapter takes a close look at the results gathered from the modules and tools outlined in chapter three. Ricardo Wave Post is the model used in accessing the results generated in large files. The generated data is outlined and then analyzed subsequently under two broad headings of Performance and Emission.

4.2 Performance

Under this section, a good number of performance related results generated are displayed and each of those relevant ones relating to the performance of the engine discussed. The results generated concentrates on the use of the Wiebe Combustion Model as the base model alongside the use of the Turbulence Flame Model of which the spark plug power of 30 W and 30 KW are used. The tables and graphs that follow, gives a clear picture of the performance of the engine as captured by the results of those models considered. In all, what is considered is the comparative performance of the Wiebe viz a viz the Turbulence module of 30W and 30 KW of spark plug power to ascertain the one under which maximum engine performance is achieved.

4.2.1 Brake Torgue.

The values for brake torque are displayed in table 4.1. Even though there are variations in the values of both the 30W and 30KW power of the spark plug, the variations are insignificant. The peak of the power for both Spark plug powers and Wiebe is at a speed of 4500 RPM with the values being 168.30 and 165.80 respectively. Both build their power from a lower value to the peak point as mentioned earlier but declines from the peak point till the 6000 RPM mark of engine speed.

Table 4.1 Brake Torque vs Engine Speed

BRAKE TORQUE (NM) VS ENGINE SPEED (RPM)											
WIEBE	143.44	150.00	151.56	159.68	155.30	165.60	164.00	165.80	158.10	139.37	125.30
SPARK POWER (30 W)	104.00	127.32	141.00	155.60	156.50	169.26	167.30	168.70	155.6	130.24	108.78
SPARK POWER (30 KW)	104.00	127.32	141.00	155.60	156.10	169.26	167.32	168.30	155.6	130.22	109.26

As can be seen clearly in figure 1, the Wiebe module which is a standard module for combustion, records a higher engine performance than the turbulent module for both powers of the spark plug. Even though the blue curve is what is seen, it is worth mentioning that the yellow curve represented by the spark power of 30W is over shadowed. Reference may be made to table 1 for clarity in terms of the values.

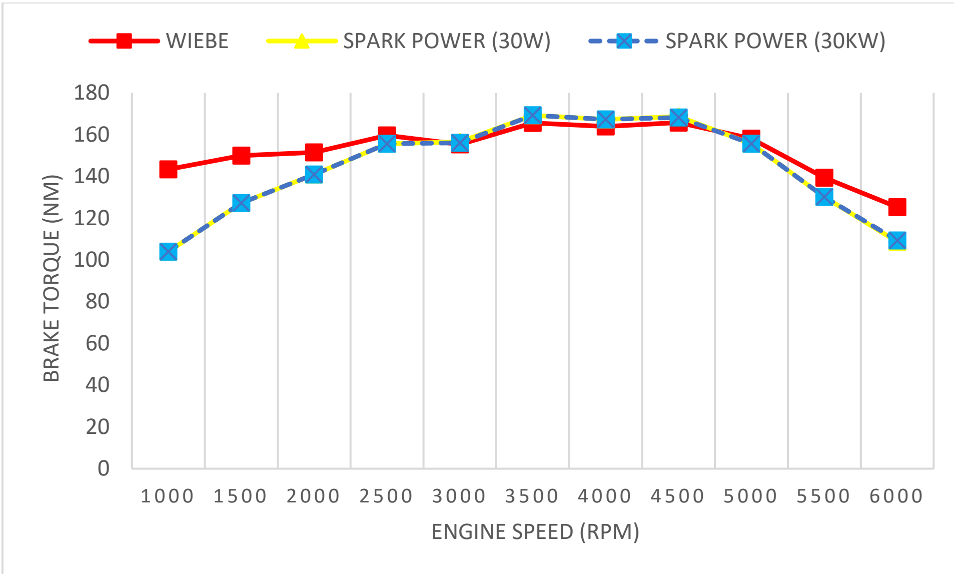

Figure 4.1 Brake Torque vs Engine Speed

4.2.2 Brake Power

Table 4.2 illustrates the brake power of the engine which is a function of the power generated by the engine as compared to the spark plug power of 30W and 30KW. The Wiebe module registers high values than that of the increase in the spark plug power. This significantly suggests that the varied spark power of the plug has a zero or no effect on the performance of the engine relating to the brake power.

Table 4.2 Brake Power vs Engine Speed

BRAKE POWER (KW) VS ENGINE SPEED (RPM)											
WIEBE	14.64	23.75	31.75	42.09	48.8	61	68.93	77.47	83.35	79.91	78.69
SPARK POWER (30 W)	10.37	20.13	29.28	40.87	49.41	62.22	70.76	79.30	81.13	75.00	68.32
SPARK POWER (30 KW)	10.35	19.52	29.28	40.87	49.41	62.22	70.15	78.69	84.13	75.64	68.93

Between the speed of 2000 RPM to 3500 RPM the influence of spark plug power is the same but rather varied slightly in favour of 30W in the beginning and in favour of 30KW in the end at speeds above 5000 RPM. It is also realized from table 4.2 that at a speed of 5000 RPM, the performance of the engine declines. Indeed, the power of the spark plug to an extent increases the performance of the engine but not at all speeds.

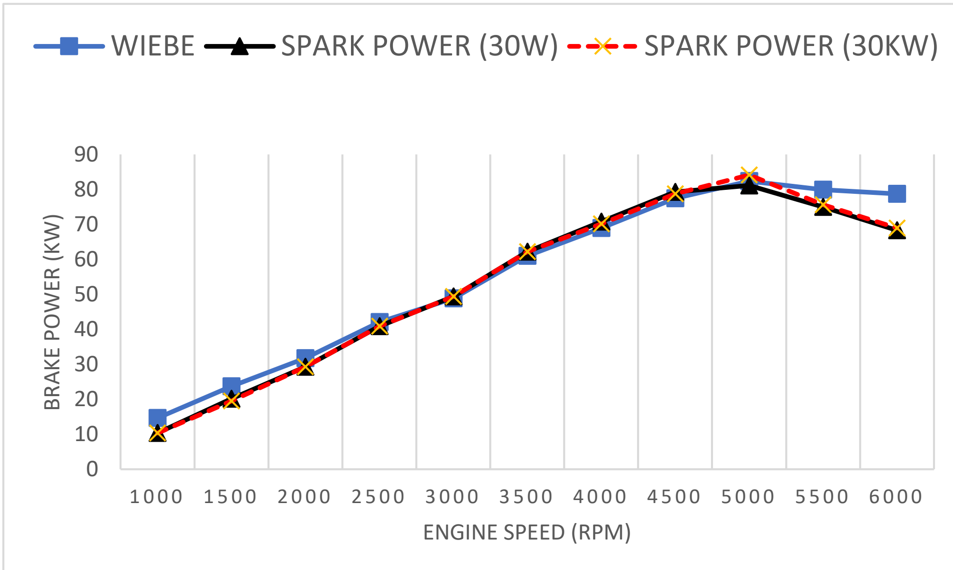

Figure 4.2 Brake Power vs Engine Speed

4.2.3 INDICATED TORQUE

From the graph of Indicated Torque versus Engine Speed in Revolutions per Minute in figure 4.3, it is observed that the power remains constant at speeds of 3500, 4000 and 4500 RPM but declines afterwards at speeds of 5000 to 6000 RPM on the part of the 30W power of the spark plug power for Turbulence. It is noted that the Wiebe also records a decline of indicated torque at the same speeds of 5000 to 6000 as that of the spark plug powers.

Whereas that of the values for the plug powers are 185.30, 163.41 and 143.90, the values for Wiebe are 188.75, 172.50 and 161.56 respectively.

Table 4.3 Indicated Torque vs Engine Speed

Indicated Torque (NM) vs Engine Speed (RPM)											
30kw	117.07	142.6	157.30	174.40	176.83	192.68	192.68	192.68	185.36	164.02	144.5
30w	117.07	142.00	157.32	176.00	176.83	192.68	192.68	192.68	185.30	163.41	143.90
WIEBE	154.375	162.81	166.56	176.87	175.00	187.81	189.0625	193.75	188.75	172.50	161.56

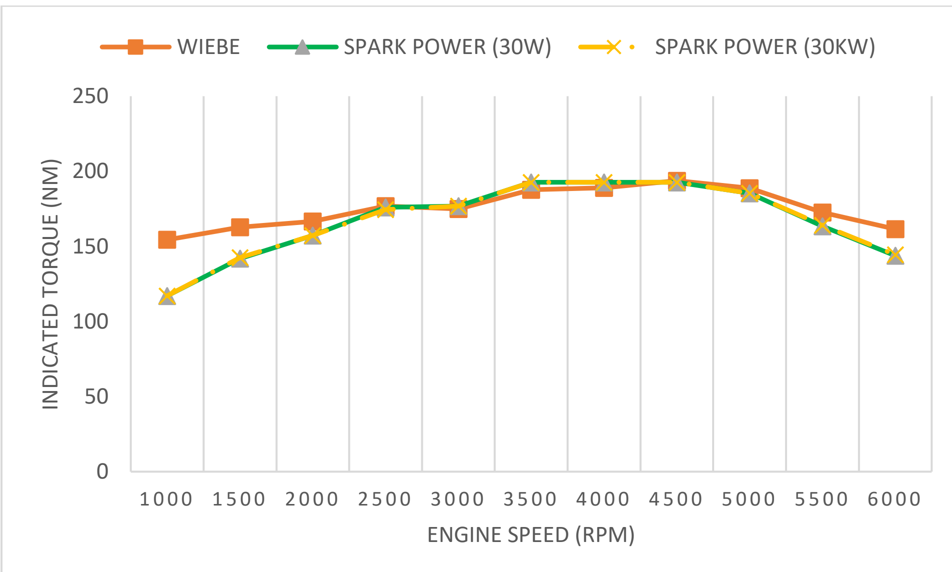

Figure 4.3 Indicated Torque vs Engine Speed

4.2.4 INDICATED POWER

Here, it is observed that the curves of both plug powers at 30W and 30KW rises steadily from 16.07 at a speed of 1000 RPM to 130.36 which is 5000 RPM and then slopes to 121,43 at a speed of 6000 RPM. The Wiebe module on the other hand rises from 21.78 through to 138.75 at a speed of 6000 as it can be seen in figure 4. The implication of this shows that at a speed beyond 5000 RPM, there can be no improvement of the engine's performance with the given parameters and conditions remaining the same.

Table 4.4 A table of indicated power

Indicated Power (hp) vs Engine Speed (RPM)											
30kw	16.07	30.35	43.75	61.60	75.00	94.64	108.03	124.11	130.36	125.89	121.43
30w	16.07	30.35	43.75	61.60	75.00	94.64	108.03	125.00	130.35	125.50	121.42
WIEBE	21.78	36.96	48.03	62.67	76.96	95.17	107.14	123.57	126.07		138.75

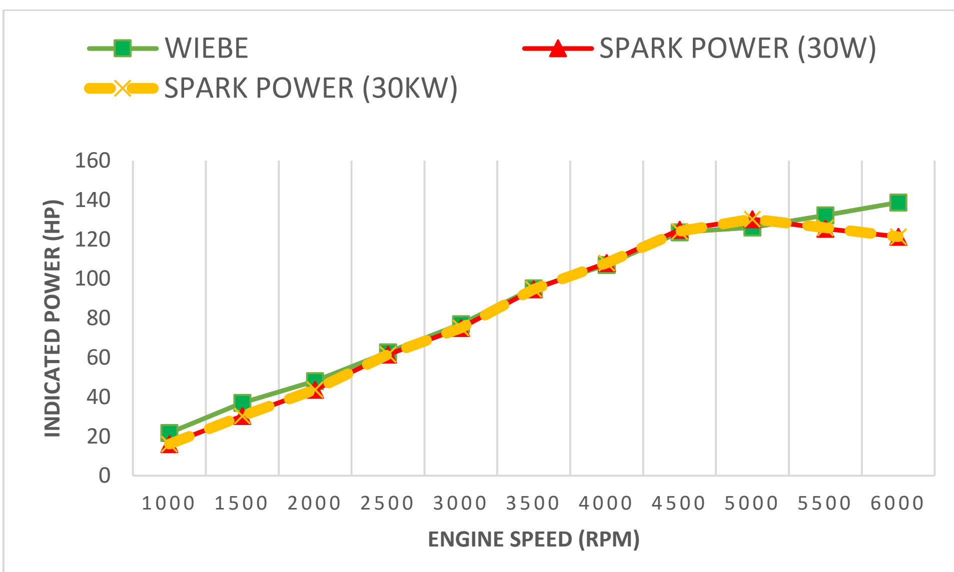

Figure 4.4 ***Indicated Power vs Engine Speed***

4.2.5 BRAKE THERMAL ENGINE EFFICIENCY

For the brake thermal engine efficiency, all the values obtained for both the 30W and 30KW of spark plug power as captured in table 4, are the same with no single variation. Together, the values start from 19.5 at an engine speed of 1000 RPM, and rises to 27.25 at a speed of 3500 RPM. It them falls from there to 19.80 at a speed of 6000 RPM. This gives a curved shape of both 30W and 3 KW spark plug power. As compared to the Wiebe module, the rise is only from 26.90 to 27.50 from which it declines to 25.565 at 3500. It then rises sharply to 26.25 at 4000 RPM and then falls to 22.80 at a speed of 6000 RPM.

Table 4.5 Brake Thermal engine efficiency

Brake Thermal engine efficiency (%) vs Engine Speed (RPM)											
30KW	19.50	23.25	25.25	26.25	27.00	27.25	26.30	25.80	24.25	22.25	19.80
30W	19.50	23.25	25.25	26.25	27.00	27.25	26.30	26	24.25	22.25	19.80
WIEBE	26.90	27.50	27.50	27.35	26.90	25.65	26.25	25.50	24.75	23.75	22.80

In all, the efficiency of the engine performance in terms of brake thermal engine, is slightly higher in the Wiebe module which is a standard Spark Ignition model as compared to the increase in the power of the Spark Plug in the case of both the 30W and the 30KW.

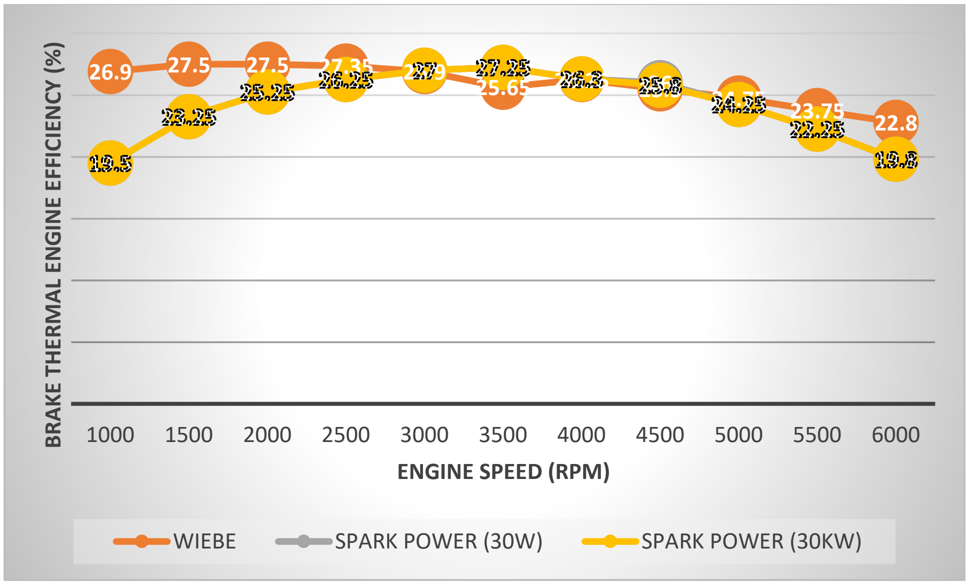

Figure 4.5 Brake Thermal engine efficiency vs Engine Speed

4.3 EMISSION

This aspect looks at the nature of the emissions from the performance of the engine with the 30W, 30KW respective powers as well as the Wiebe module to ascertain which operation ensures poisonous free gases emanating from the engine after combustion. The following emissions related to the spark ignition engine are considered.

4.3.1 ENGINE OUT OXIDES OF NITROGEN

For both modules, the emission levels of oxides of nitrogen can actually be said to be low as seen in the values from table 6, the same values are measured for both powers of the spark plug.

Table 4.6 A table of oxides of Nitrogen

ENGINE OUT OXIDES OF NITROGEN (NO 2) MASS FLOW VS ENGINE SPEED											
WIEBE	0.034	0.034	0.048	0.063	0.08	0.095	0.112	0.129	0.144	0.152	0.162
POWER (30W)	0.02	0.034	0.048	0.063	0.078	0.093	0.105	0.122	0.143	0.143	0.122
POWER (30KW)	0.02	0.034	0.048	0.063	0.078	0.093	0.105	0.122	0.143	0.143	0.122

It is also noticed that the emission for the spark powers are even lower as compared to that of the Wiebe module. It is worth noting therefore that we don't have much to worry about when it comes to oxides of nitrogen as a pollutant. It could be an indication that the powers of the plugs so emitted are enough to eliminate the poisonous pollutant in the gases so emitted.

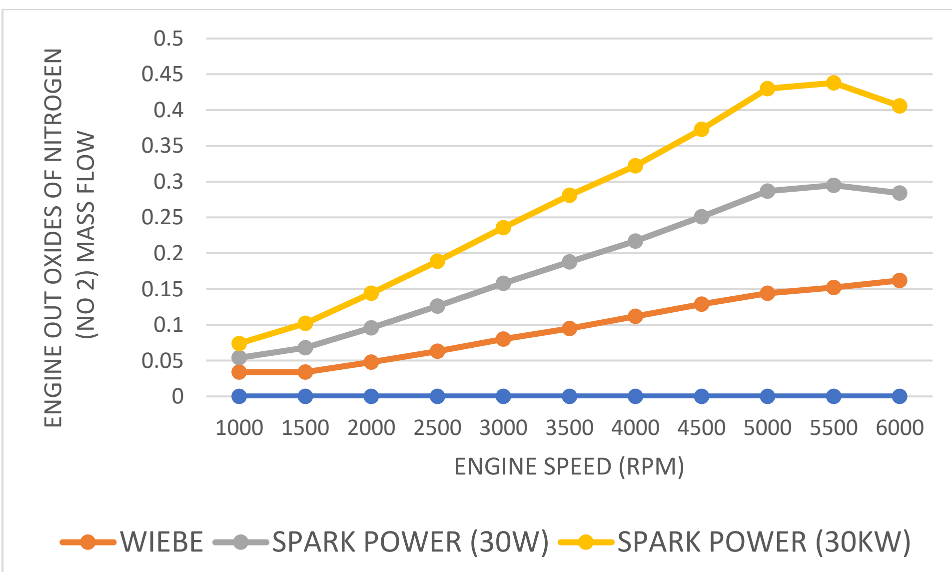

Figure 4.6 Engine Out Oxides of Nitrogen

4.3.2 BRAKE SPECIFIC EMISSION

The figure (7) shows the brake specific emission vs engine speed. It is clearly seen that the Wiebe module gives a slightly raised straight line graph from 206.25 to 244.37. both spark powers of 30W and 30KW gave rise to the same curves as a result of the same values. This indicates clearly that the increase of the spark power does not in any way affect the emission of the engine.

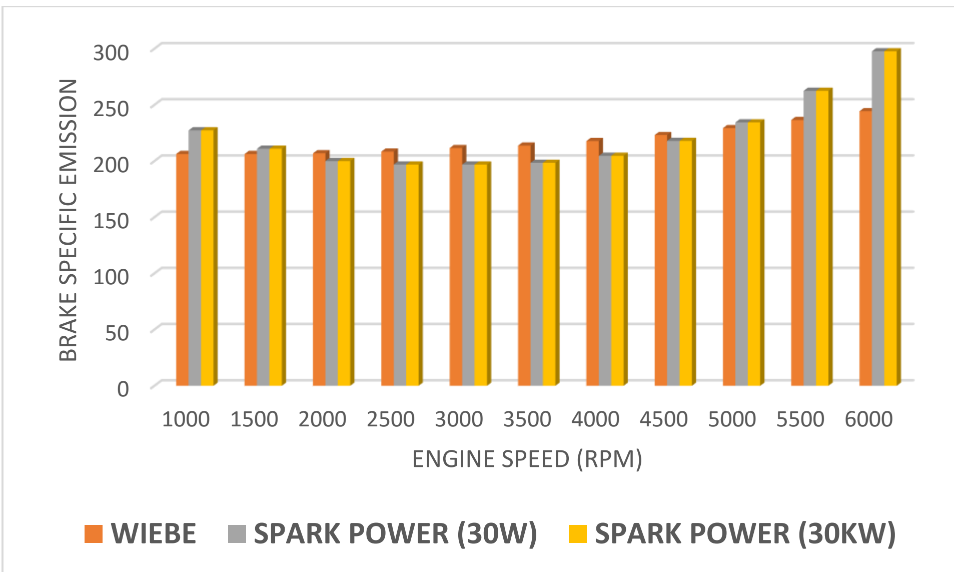

Figure 4.7 Brake Specific Emission

4.3.3 BRAKE SPECIFIC UNBURNED FUEL EMISSION

For the brake specific unburned fuel emission, whereas the Wiebe module starts with a low value of 4.5 and rises, that of the turbulent module of the same values of spark powers begins with a high value 9.2 and declines to meet the rising Wiebe at about a value of 6.00

with a speed of 4700 RPM. Again, whereas the Wiebe continuous to rise to the end at a value of 7.5 corresponding to a speed of 6000 RPM, the spark powers of 30 W and 3000 W falls to 5.9 before rising sharply in the end to a value of 6.9 at 6000 RPM.

Table 4.7

BRAKE SPECIFIC UNBURNED FUEL EMISSION VS ENGINE SPEED											
WIEBE	4.5	4.5	4.8	4.8	5.4	5.5	5.8	5.9	6.3	6.9	7.5
SPARK POWER (30W)	9.2	7.4	6.8	6.4	6.5	6.2	6.2	6.0	5.9	5.9	6.9
SPARK POWER (30KW)	9.2	7.4	6.8	6.4	6.5	6.2	6.2	6.0	5.9	5.9	6.9

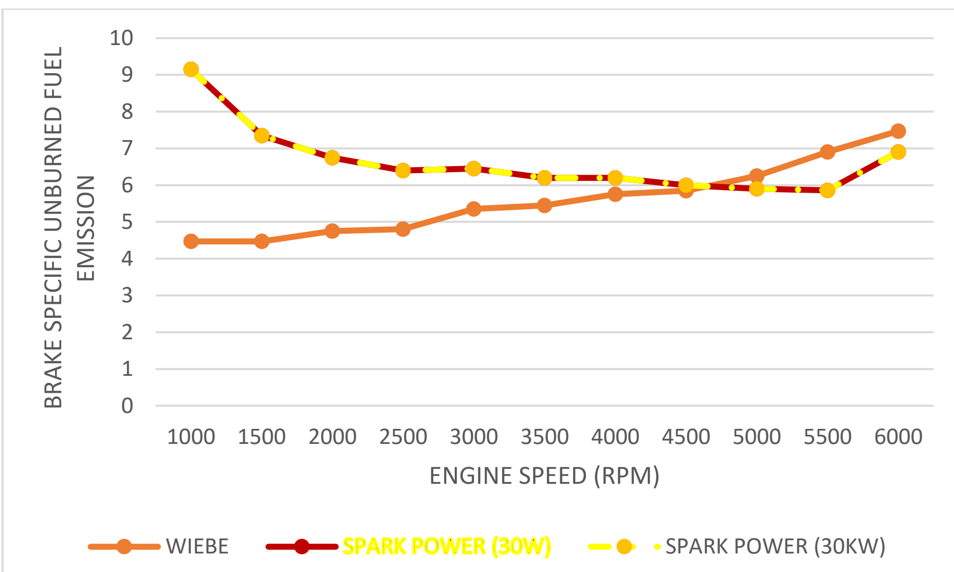

Figure 4.8 Brake Specific Unburned Fuel Emission

4.3.4 BRAKE SPECIFIC NO2 EMISSION

Under this emission product, the values for both spark power of 30 W and 3000 W are significantly the same and are within the range of 5.3 to 6.8. That of the module for Wiebe ranges from 5.1 to 5.1. At a speed of 4000 and 4500 RPM, it is observed that the Wiebe

Table 4.8 A table of Brake Specific Emissions

BRAKE SPECIFIC NO2 EMISSION VS ENGINE											
WIEBE	8.1	5.1	5.4	5.5	5.9	5.6	5.9	5.9	6.3	7.0	7.4
SPARK POWER (30W)	6.6	6.0	5.8	5.6	5.7	5.3	5.4	5.5	6.4	6.8	6.4
SPARK POWER (30KW)	6.6	6.0	5.9	5.6	5.7	5.4	5.4	5.6	6.4	6.8	6.4

remains fairly constant and there after rises to 7.4 through 6.3 and 7.0 respectively.

The turbulent powers of the plug however records a slightly constant values of 5.4 at speeds of 3500 and 4000 which are the lowest values on the curve from a value of 6.6 at 1000 and then sharply rises to 6.8 which is the highest value on the curve before declining to a value of 6.4 at a speed of 6000 RPM.

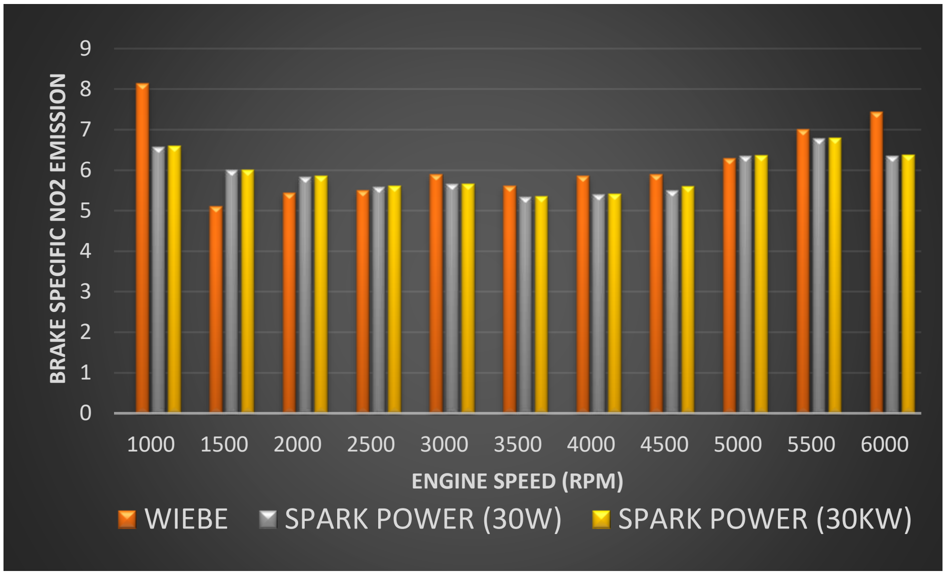

Figure 4.9 Brake Specific NO2

4.3.5 NITROGEN OXIDE

For both modules, the emission levels of nitrogen can actually be said to be uniformly distributed across the graph as clearly displayed in figure 6. There is a convergence from a high value of Wiebe and a low value of spark powers from a speed of 1000. From the point of convergence at a speed of 1500, the uniform distribution continues to a speed of 5000 after which there is divergence. The Wiebe registering an upward value as compared to the opposing value recorded by the spark powers. The same values are measured for both powers of the spark plug.

Table 4.9 A table of Nitrogen Oxide

	NITROGEN OXIDE (NO) VS ENGINE SPEED										
WIEBE	1209.75	785.36	839.02	843.9	883	843.9	853.66	843.9	863.41	931.7	946.34
POWER (30W)	719.51	780.49	826.83	831.71	854.88	814.63	809.76	802.44	864.63	850	706.1
POWER (30KW)	719.51	780.49	826.83	831.71	854.88	814.63	809.76	802.44	864.63	850	706.1
	1000	1500	2000	2500	3000	3500	4000	4500	5000	5500	6000

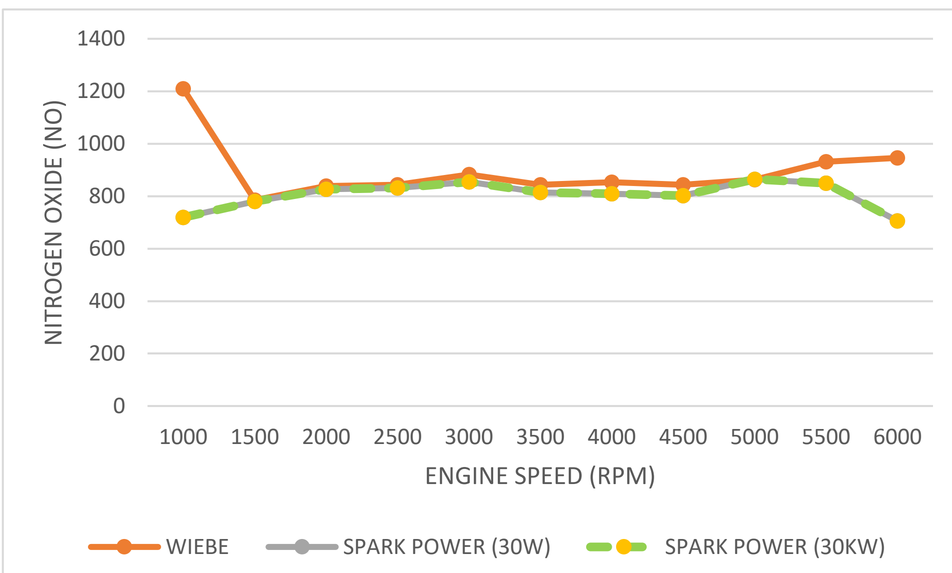

Figure 4.10 Nitrogen Oxide

4.3.6 ENGINE OUT CO MASS FLOW

The mass flow of carbon monoxide out of the engine cylinders is low as a table of low values can be seen in table 10. Observing the table critically, it is deduced that at low engine speeds, low mass flow of carbon monoxide is recorded as 0.9 and 0.7 for the Wiebe and turbulent modules respectively. At higher engine speeds, the records stand at 5.4 and 5.7 respectively for both Wiebe and turbulence. In both cases, there is increase in the flow as the engine speed is increased from 1000 RPM to 6000 RPM.

Table 4.10 A table of Engine Mass Flow

ENGINE OUT CO MASS FLOW VS ENGINE SPEED											
WIEBE	0.9	1.4	1.9	2.5	3.0	3.7	4.2	4.9	5.3	5.3	5.4
SPARK POWER (30W)	0.7	1.3	1.8	2.2	2.7	3.5	4.0	4.8	5.4	5.5	5.7
SPARK POWER (30KW)	0.7	1.3	1.8	2.2	2.7	3.5	4.0	4.8	5.4	5.5	5.7

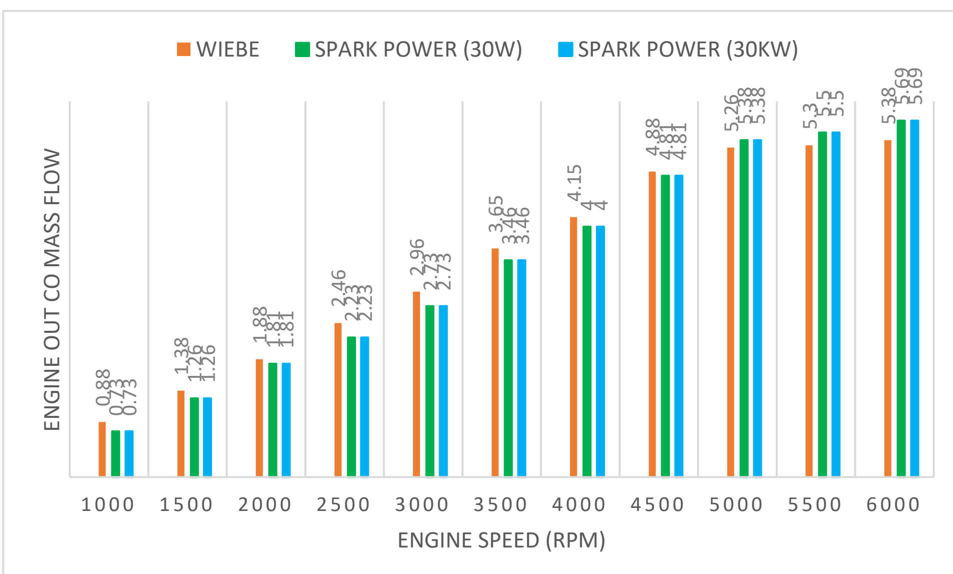

Figure 4.11 Engine Out CO Mass Flow

4.3.7 ENGINE OUT UNBURNED FUEL FLOW

For engine out unburned fuel flow, both modules give a rise as is captured by the graph in figure 4.12. The flow is from a smallest value of 0.02 and 0.03 for Wiebe and Turbulence respectively and records a high value of flow of 0.16 for the Wiebe module and 0.13 for turbulence. Whereas the Wiebe records a straight like graph, that of the Turbulent spark powers assumes a similar straight like graph until a speed of somewhere 5000 RPM where they meet and then it descends to 0.12 at a speed of 5500 RPM and then rises to 0.13 again.

Table 4.11

ENGINE OUT UNBURNED FUEL FLOW VS ENGINE SPEED											
WIEBE	0.02	0.03	0.04	0.06	0.07	0.09	0.11	0.13	0.14	0.15	0.16
SPARK POWER (30W)	0.03	0.05	0.06	0.07	0.09	0.11	0.12	0.14	0.13	0.12	0.13
SPARK POWER (30KW)	0.03	0.05	0.06	0.07	0.09	0.11	0.12	0.14	0.13	0.12	0.13

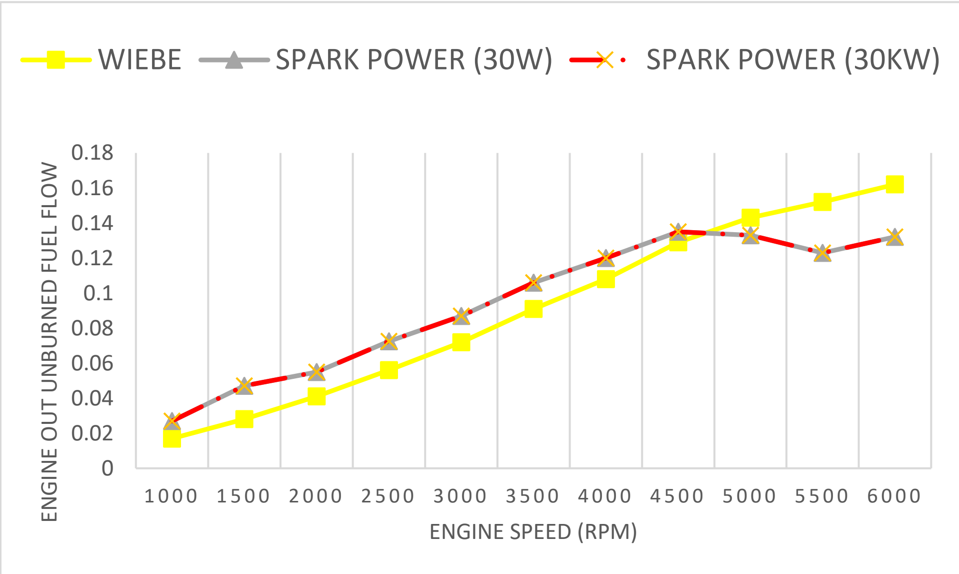

Figure 4.12 Engine Out Unburned Fuel Flow

4.3.8 CARBON MONOXIDE

While the emission of carbon monoxide remains fairly stable and constant throughout the speed range of 1000 RPM to 6000 RPM for the Wiebe module, it rises steadily with the turbulent module for both the divers power output of the spark plugs and is maintained at and above an engine speed of 6000 RPM. It is believed from the ongoing that the emission rate of the carbon monoxide will not exceed this range. Even though the emissions almost equalize at an engine speed of 5000 RPM, there is a shoot up in the turbulent module as can be seen in figure 4.13.

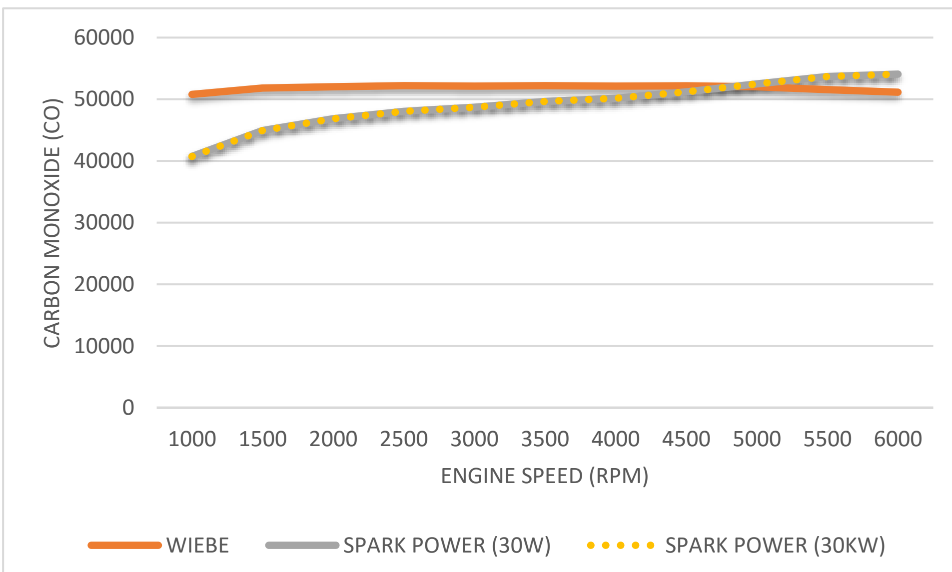

Figure 4.13 Carbon Monoxide

Table 4.12 Carbon Monoxide (Co) Vs Engine Speed

CARBON MONOXIDE (CO) VS ENGINE SPEED											
WIEBE	50,793	51,841	52,035	52,207	52,134	52,207	52,110	52,195	52,012	51,549	51,134
POWER (30W)	40,741	44,907	46,852	48,058	48,704	49,630	50,185	51,200	52,500	53,700	54,074
POWER (30KW)	40,741	44,907	46,852	48,058	48,704	49,630	50,185	51,200	52,500	53,700	54,074

4.3.9 HYDRO CARBON

In the Wiebe module, it is clearly seen from figure 4.14 that at low engine speeds, emission of hydro carbon is low but increases at high engine speeds. Here again, there is no difference between the alternate powers of the spark plug. The turbulence module on the other hand, gives a decline of the hydrocarbon emission as it begins at a higher value and after some peaks registered in its operation, it comes to a lowest value at an engine speed of 5500 RPM. It is worth mentioning that at a point where both diverse powers of the spark plug give the same operative value, one overlaps the other, and in this case, only the 30KW power lines are shown in figure 4.14.

Table 4.13 A table of Hydro Carbon

HYDRO CARBON (CO) VS ENGINE SPEED											
WIEBE	2188	2234	2406	2531	2641	2672	2742	2781	2859	3008	3141
SPARK POWER (30W)	3300	3150	3163	4931	3200	4931	3113	2869	2663	2419	2519
SPARK POWER (30KW)	3300	3150	3163	4931	3200	4931	3113	2869	2663	2419	2519

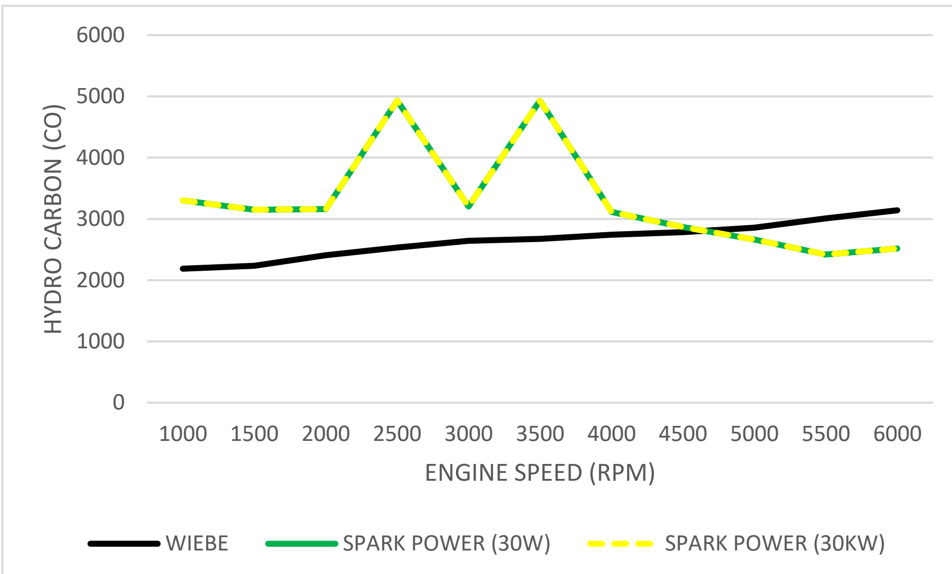

Figure 4.14 Hydro Carbon (Co) Vs Engine Speed

4.4 SUMMARY OF THE CHAPTER

The general deductions on performance gives a clear instruction that the alternating power of the spark plug does affect the performance of the engine but not to a very large extent as in some cases it is seen that the variation in the performance of the engine is negligible. However, it can be confidently proved from the undergoing that the Wiebe module does have a performance index that surpasses that of the Turbulent module for the particular plug powers chosen in this discussion. It is possible to record a performance which is vice versa with departing spark plug powers from those used in this study or closely, a wider variation of performance for varied spark powers as the case may be with different conditions and engine parameters.

On the emission aspect, it can also be concluded that the emission of the products of combustion does depend on the performance of the engine. In situations where there is complete combustion that leads to a higher generation of power for better performance, emission products where available are brought to the barest minimum. So conclusively, there is a close and a probable nonseparation between the performance of the engine and its related emission.

CHAPTER FIVE

FINDINGS CONCLUSION AND FUTURE WORKS

5.0 INTRODUCTION

The chapter looks at the various findings of the entire research conducted and gives a brief conclusion drawn on the findings. Works that could not be completed due to limitations in time and resources are captures as suggestions for future works.

5.1 FINDINGS

From the discussion so far, it has come to light that the alternating powers of the spark plug has an effect on the performance of the engine and its related emission. However, under certain conditions including high temperatures, the increase in the power or output of the spark plug becomes insignificant, which can also be said to be a negative effect due to power losses, since the increase does not positively impact the performance of the engine.

Again, the Wiebe model which is the standard model in this research work has a high performing rate comparatively to the Turbulent model within specified conditions. The performance index may change significantly with change in conditions.

5.2 CONCLUSION

It can be concluded from the ongoing discussion that the emission of the by-products of combustion is affected by the performance of the engine which also in-turn affects the emission of the engine. The work unveiled the fact that the spark plug output influences the performance of the engine. Improved engine performance leads to low emissions and weak or poor performance of the engine results in high pollutants or high harmful emissions. A clear and direct relationship does exist between the performance and emission.

5.3 FUTURE WORKS

Further research should gear towards an increase in the number of power outputs of the spark plug and analyzing its influence on engine performance and emission.

The spark plug should literally be inserted in the cylinder head and made to operate at the same time and the performance of the engine ascertained.

Different performance conditions should be captured and tested in order to find the conditions under which the performance index can be increased.

Tests should be carried out on different makes and capacities of engines to discover if the makes and capacities of the engine has any influencing factors on the performance of the engine and its related emission.

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