NUMERICAL ANALYSIS OF THE COMBUSTION CHARACTERISTIC OF COMPRESSION-IGNITION ENGINE FOR THE APPLICATION OF BIODIESEL

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UNIVERSITI SAINS MALAYSIA

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DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

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ANALISA NUMERASI KARAKTERISTIK KOMBUSI MESIN KOMPRESI-IGNITION UNTUK PENGAPLIKASIAN BIODIESEL

ABSTRAK

Simulasi dan penyelidikan enjin pembakaran dalaman sedang dilakukan untuk mencari cara yang berpotensi untuk meningkatkan kecekapan enjin diesel. Kesan yang telah difokuskan pada kajian ini adalah kelajuan mesin dan masa suntikan terhadap tingkah laku fizikal dalam proses silinder pada mesin diesel. Kajian ini menekankan pada kadar pembebasan haba pada NOx di dalam silinder. Kajian penyelidikan ini menunjukkan komitmen yang signifikan dari segi masa dan peranti teknologi tinggi. Hasilnya, simulasi yang diprogram ANSYS Fluent dapat digunakan untuk melakukan penelitian mengenai prestasi dan pelepasan mesin diesel. Simulasi akan dilakukan dengan menetapkan kelajuan mesin 2500rpm dan waktu suntikan CA15 BTDC menggunakan model disipasi eddy. Dalam kajian ini, parameter termasuk CA, masa injap sudut semburan, halaju suntikan, dan jisim yang disuntik semuanya tetap. Hasil simulasi menunjukkan bahawa kelajuan mesin yang lebih tinggi dalam revolusi per minit menurunkan kadar bahan bakar yang tidak terbakar. Oksigen di udara berlebihan membantu mengoksidakan hidrokarbon gas dan karbon monoksida, mengurangkan pengecutan terlalu kecil dalam gas ekzos. Oleh itu, menghasilkan kadar bahan bakar yang tidak dibakar lebih rendah.

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ABSTRACT

Simulations and research of the internal combustion engine are being done to discover the potential ways to improve the efficiency of diesel engine. The effects that had been focused on this study is engine speeds and the injection timings on the physical behaviour in cylinder process in a diesel engine. This study stresses on the apparent heat release rate on of NOx in the cylinder. This research study implies a significant commitment in terms of time and high technology device. As a result, the simulation programmed ANSYS Fluent can be used to conduct a research on a bio-diesel engine's performance and emissions. The simulation will be conducted by setting the engine speeds of 2500rpm and injection timings CA15 BTDC using eddy dissipation model. In this study, parameters including CA, spray angle valve timing, injection velocity, and injected mass are fixed. Simulations results showed that higher engine speed in revolution per minute lowers the rate of unburnt fuel. Excess oxygen contributes in the oxidation of gaseous hydrocarbons and carbon monoxide in the exhaust gas, reducing them to extremely small amounts and resulting in lower rate of unburn fuel.

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LIST OF ABBREVIATIONS

BTDC	Before Top Dead Centre
BTE	Brake thermal efficiency
CO	Carbon Monoxide
EGR	Exhaust Gas Recirculation
HC	Hydrocarbon
HRR	Heat Release Rate
IMEP	Indicated Mean Effective Pressure
PIT	Pilot Injection Timing
PM	Particular Matter
SFC	Specific Fuel Consumption
SI	Spark Ignition
CA	Crank Angle
NO_x	Nitrogen Oxide
CNG	Compressed Natural Gas
EVC	Exhaust Valve Closing
IVO	Intake Valve Opening

CHAPTER 1

INTRODUCTION

1.1 Overview of Overall Structure of the Project

Exhaust gases are undoubtedly affecting air quality. This may be seen from the exhaust gas pollution law which has a significant impact on the environment and on human, allowing power plants to undergo significant modifications. Due to the development of a low-carbon engine, the use of diesel engines in ships and automobiles is gradually reducing. The MTU 4000 is a common rail fuel established and since the advent of the common rail fuel injection technology, emissions have reduced, and the combustion cycle may be prolonged with less fuel use.

Figure 1.1 Emission of hazardous gases from ships (Renault, Apr 24, 2018).

Compression ignition engines is a common source of energy for automobiles. It is studied for a greater thermal performance as compared to spark ignition (SI) engines due to its excellent fuel economy, low carbon dioxide and carbon monoxide emissions. On the other hand, gasoline engines often emit a higher volume of pollutants from environmental issues, like nitrogen oxide (NOx).

Study has shown that Biodiesel (liquid fuel) has significantly taking over diesel engines due to its nontoxic, sustainable, and biodegradable. Biodiesel is produced transesterification process using agricultural renewables, such as waste oils, animal fats, and vegetable oils. The application of biodiesel reduces the gases of carbon monoxide (CO), sulphur dioxide (SO_2), hydrocarbon (HC), and other particulate matter (PM) during combustion. Furthermore, its high amount of cetane is also making it to be a bright potential in ignition engines as compared to standard diesel fuel (Yoon and Lee, 2011).

Japanese Laid-Open Publication introduced a patent of dual fuel injector that utilised water, as the secondary fuel and delivered into the engine cylinder post fuel injection. The fuel injection burns fuel and air mixtures, increasing the cylinder's heat generating efficiency. The primary gasoline was pushed into the moving plunger's distributor, which delivered the main and secondary fuel to the injection nozzle at different times, affecting the multi-stage fuel injection. As we know, adding two injection nozzles to each cylinder's head is critical. While the method appears simple, getting the injection nozzles to line up correctly is difficult. In particular, excessive and uncontrolled fuel injection lead to low thermal efficiency to the engine cylinder hence resulting in inaccurate orientation (Shojiro Otsuka; Hideaki Komada, Sep. 8, 1987).

A study has been made to improve two common-rail diesel engine technologies. At par with the technological advances, a new dual-technology of common-rail diesel engine is introduced to evaluate the influence of a diesel engine prototype on soot, and the brake specific fuel consumption, and combustion noise that is NOx related (Badami et al., 2003). A note of fact that NO_X one disease-causing agent that would catastrophically reduce human immunity. The authorities have created stringent pollution laws in recent years as a result of rapid decreases in fossil fuels and increasing of pullotion, with experts doing comprehensive studies into renewable and renewable diesel oil (Ning et al., 2020).

1.2 Problem Statement

A chemical reaction between fatty acids and alcohol produces biodiesel of engine fuel. The percentage of hazardous chemicals and greenhouse gases from Biodiesel are much lesser. Be it in pure, or mixed-blend like the known B2 Petro-diesel, B5 Petro-diesel, and B20 Petro-diesel. Since biodiesel in diesel engine only leaves little alteration to the engine system, it has benefitted some countries in lowering their dependence on foreign oil. If we are using the wrong type of fuel, it affects the life span of the engine itself. So, to magnifies and improvise the engine system, a modern tool of numerical simulation is used in this study. Different models of combustion process can be created easily via computational fluid dynamics (CFD) simulation. To provide a sustainable environment, the ideal operating conditions for the diesel engine will be evaluated throughout this thesis.

1.3 Objectives

The objectives of this project are:

1. To construct a simulation model on CI engine using ANSYS Fluent for the test fuel's combustion engine.
2. To analyse the NOx formation, poor fuel atomisation and poor combustion for direct application of biodiesel in engine at higher engine operating speed of 2500rpm.

1.4 Scope Of the Project

To complete the project effectively, a simulation of the Internal Combustion Engine is done through ANSYS FLUENT software. Analysis on how the internal combustion engine works is made by constructing a simulation model in the following software. In addition, the engine's out-response such as performance, emissions, and combustion characteristics had been accessed through the simulation process. Internal Combustion Engine has a sub-module that can be used to see how the simulation works in ANSYS Workbench.

CHAPTER 2

THEORY

2.1 Internal Combustion Engine

Internal combustion engines normally occur in gas turbines, rockets, and rotary engines, any component involves reciprocating motion. Cylinder, piston, and crankshaft are the crucial of an internal combustion engine.

Generally, internal combustion engine is a machine that performs mechanical work involving the ignition of air-fuel mixture under high pressure. A complete mechanism takes place by having the intake manifold inserting the air-fuel mixture into the combustion chamber. This enhances a steady ignition charge supply. Also, the presence of sidewall on the manifold's design prevents the charge from pre-ignition due to its lower temperature. On the other hand, piston in internal combustion engine, produces horsepower. The piston is lightweight and high in thermal properties. The exhaust manifold controls at the exit of the combustion chamber, where the hot gases leave from. It is designed to preserve the continuity of the flow of exhaust gases. Which then, a loss of back pressure due to an exhaust system failure can have a significant influence on engine performance.

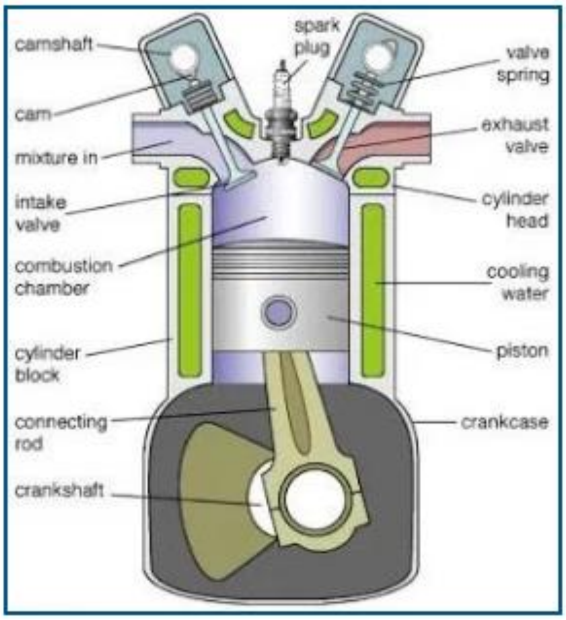

Figure 2.1 : Illustration of 4-stroke internal combustion engine(Aan and Heinloo, 2012).

2.1.1(a) Cylinder

Cylinder is a section of the engine that converts heat energy into mechanical work. The piston inside the cylinder moves back and forth. Because energy conversion takes place inside the cylinder, it must withstand high pressure and temperature. It should be able to tolerate wear and tear while dissipating heat. As a result, material selection must be taken into a crucial consideration. Ordinary cast iron is used in light-duty engines, while alloy steels are used in heavy-duty engines.

Figure 2.2: Cylinder head of combustion engine (Shukla).

2.1.1(b) Piston

This is a cylindrical component with a closed one end that fits in the engine cylinder. It is attached to the connecting rod via piston pin. The expanding gases on the closed end of the piston transfer down into the cylinder, rotating the connecting rod and hence the crankshaft. Pistons are frequently made of cast iron. Piston that is cast-iron made more prone to have higher compressive strength, high temperature resistance, and also low cost. The piston's head is the top of the piston. One of the piston's components is the skirt, which is designed to absorb the piston's side motions.

Figure 2.3 : Piston of engine cylinder(C, 2010).

2.1.1(c) Piston ring

Piston ring is located in the internal groove of the piston. Piston ring provides a gas-tight combustion chamber to its respective pistons, reducing the contact area between the cylinder and the piston wall which resulting in a low friction and wear by, it also generates cylinder lubrication that transmits heat evenly from the piston to the respective cylinder walls. Piston ring is generally made up of pressed steel alloy or cast iron.

Figure 2.4 : Piston rings used in internal combustion engine (CarBikeTech, January 4,2021).

2.1.1(d) Connecting rods

Connecting rod is a one-of-a-kind rod that is attached to the piston on one end and the crankshaft on the other. It sends combustion energy to the crankshaft, causing it to spin constantly. Drop forged steel is a type of steel that is utilised in a variety of applications.

Figure 2.5 : Connecting rods that connecting the piston head in internal combustion engine (Bari et al., 2017).

2.1.1(e) Crankshaft

Crankshaft is the major shaft in an engine that generates the reciprocating motion of the piston by making the flywheel to turn into a rotational motion which typically is made up of cast steel. The main journal supports the crankshaft in the cylinder block, whereas the crank journal is the component to which the connecting rod is linked.

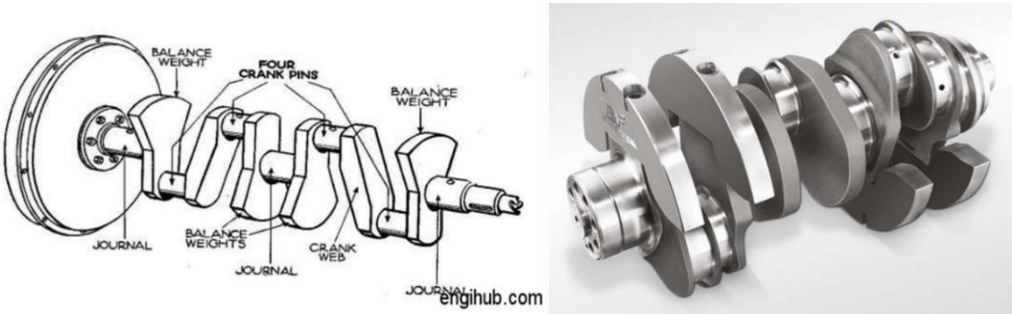

Figure 2.6 : Shows the crankshaft of engine (Prasanna, 17/09/2009).

2.1.1(f) Engine valve

In an engine operation, an engine valve controls the fluid flow in and out of the combustion chambers. It interacts with other adjacent engine components such as rocker arms to open and close in a correct and arranged manner. Furthermore, the intake and the exhaust valve are the two main types of valves for four stroke internal combustion engines. Intake valves plays role at the compression and ignition allowing fluid enters the engine's cylinders, while exhaust valves close.

the obvious difference is that intake valves are prone to experience a lower thermal stress due to the cooling effects of the air/fuel mix that flows in the valve during an intake cycle. On the contrary, exhaust valves are subjected to higher levels of thermal stress, this is because the exhaust valve is open throughout the exhaust cycle and not in contact with the cylinder head, the smaller thermal mass of the combustion face and valve head has a greater potential for a rapid temperature change.

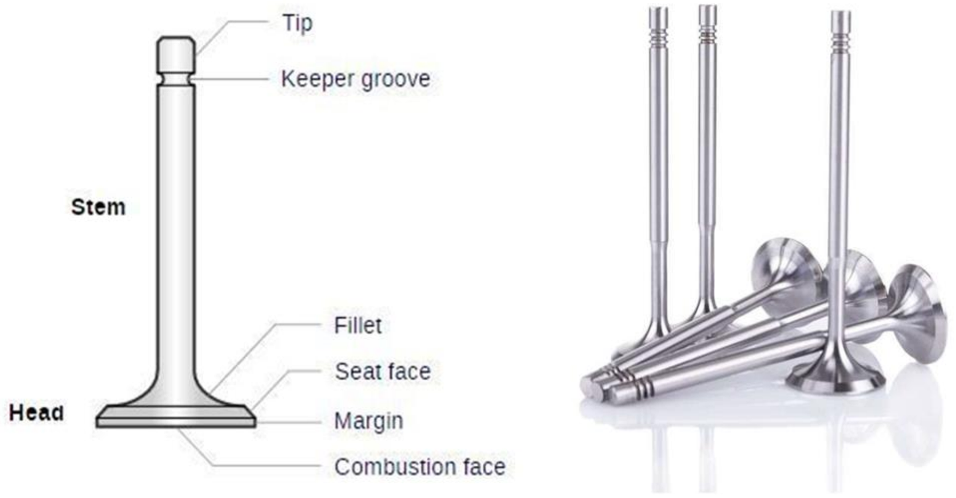

Figure 2.7 : The engine valve (Thomas)

2.1.1(g) Inlet manifold and exhaust manifold

The exhaust gas for each cylinder is collected via the exhaust manifold located in the exhaust collector. Exhaust manifold is the first component that will encounter high-temperature exhaust in a harsh environment with fluctuating temperatures, making fracture, thermal fatigue cracking, and leakage are common defaults that happens as an occurrence of high stress alternation created by the immediate heating and cooling process.

Figure 2.8 : Exhaust manifold that made of cast iron (Shukla).

2.1.1(h) Compression engine

An internal-combustion engine that involves high temperature of air being compressed to ignite the fuel located in the cylinder, is termed as a diesel engine. The conversion of fuel’s chemical energy into mechanical energy takes place to transmit power that is widely used in a automobiles and electric power plants. The diesel engine consists of a piston-cylinder mechanism that burns seldom. The diesel engine might have two or four-stroke cycle.

In contrast, a gasoline engine will only inject air into the combustion chamber on the intake stroke with the aid of spark ignition. 14:1 to 22:1 is the typical compression ratios allowed. A less than 0.6 metre width of cylinder bore is built in both two-stroke and four-stroke engines. While bores that exceeds 0.6 metre of diameter, is commonly used in a two-stroke cycle.

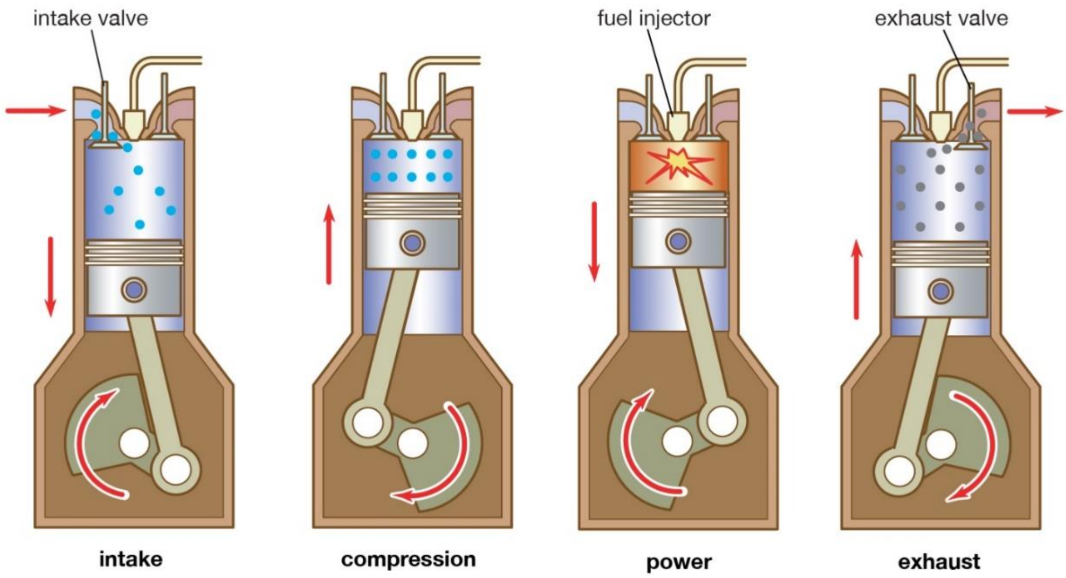

Figure 2.9 : The normal cycle phenomenon in a four-stroke diesel engine (Proctor, 2021, February 21).

2.1.1(i) Combustion in compression engine

The compression stroke begins when air is delivered into the combustion chamber. Fuel is fed into one or more jets at extremely high speeds toward the end of this stroke. The fuel atomizes and vaporises because of the high velocity injection and the high temperature. Again, combustion takes place when the fuel reaches the temperature where it self-ignites. This then followed by ignition delay. This occurs during the early phase of fuel injection and combustion. This then followed by premixed or fast combustion is the next phase. This phenomenon happens when the fuel gained in the combustion chamber exceeds its ignition temperature. This usually proceeds with a significant heat release in the end. The mixing regulated combustion phase is the third step. This burning phase is more controlled and reduces the amount of heat released. The late combustion phase is the final step. This phase produces the least amount of heat because burning only requires a tiny amount of fuel to be injected.

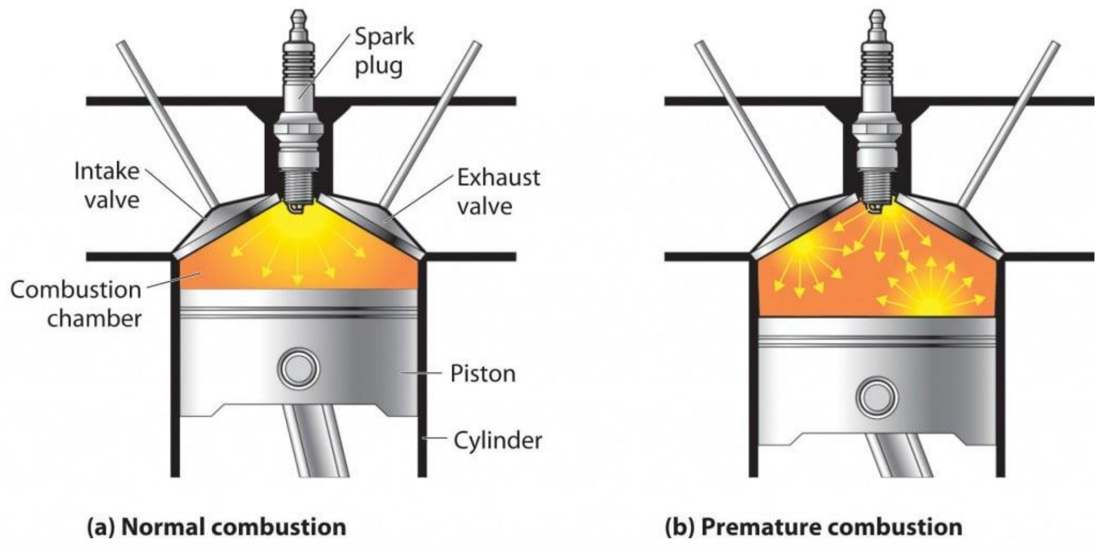

Figure 2.10 : Combustion phenomenon in compression engine (Kashyap).

CHAPTER 3

LITERATURE REVIEW

3.1 Overview of Auxiliary Fuel Injection System for A Converted Common-Rail Diesel Engine

Buratti and Canale since the year of 1995 reported how the injection process produces a form of auxiliary pre-injection during the engine intake stroke. The pre-injection occurs at the beginning of the intake stroke and includes the injection of a small volume of fuel, which is equivalent to a small part of the fuel injected at the main injection point, resulting in the production of partially oxidized and/or over-oxidized materials, with high chemical composition in the compression stroke (Buratti and Canale, 1995).

The auxiliary fuel injection unit is composed of two blast tanks with separate walls, a butterfly valve that alternately connects and disconnects the two vent tanks, and an auxiliary fuel injection valve, which pumps into the vent tank at the opposite direction of intake air flow. The rotating shaft rotates the plate surface and the valve plate surface seals the opening in the surge tank wall to form a valve. The auxiliary fuel injection valve has two connected injection ports, which are used to inject auxiliary fuel to the surface of the control valve and the bottom surface of the surge tank. (Mori et al., 2004).

An article from Buratti and リッカルド shows how to use a typical rail injection system to regulate the combustion of a direct injection diesel engine. At least the first auxiliary fuel injection occurs before the first main injection, and at least once the second auxiliary fuel injection occurs after the first main injection. The first main fuel injection occurs at the end of compression of each engine cycle. Points and each cylinder engine, according to the control system. This article looks at how to use a typical rail injection system to regulate the combustion of a direct injection diesel engine. Before the initial main fuel injection, the control system requires at least a first auxiliary fuel injection (Buratti and リッカルド, 2000).

The ejector then forms parallel main and auxiliary phases, both of which are electronically controlled. The deformation of the track or line is determined by a sensor that sends a signal to the controller. Determine the duration of the main injection and monitor the main injection cycle. The controller should predict the timing of the secondary injection based on the fuel mixture of the main and auxiliary fuels, the delay of the auxiliary injection, the duration of the main injection, and the deformation of the track or line. Each parameter belongs to the appropriate control unit and computer readable medium (Hafner and McGee, 2001).

Additionally, PIT is a key starting characteristic that affects engine efficiency and emissions, especially under high loads. This study changed the pilot injection timing of the Diamond DI 800 single cylinder diesel engine that has been converted to a dual fuel engine to understand how it affects engine power, combustion, and high load emissions (110, 130, 150, 170, and 190 BTDC). Carbon monoxide, hydrocarbon, and particulate emissions are evaluated, as well as cylinder pressure, ignition delay, burn time, horsepower, heat release rate, SFC, and brake thermal efficiency (Sudarmanta et al., 2019).

Finally, since China has the world's largest natural gas engine market, and the natural gas market is very different, dual-fuel natural gas diesel engines may be a solution to the instability of gas prices. In the low compression ratio of 14.2 6-cylinder dual-fuel engine, the effect of combustion and emission equivalence ratio was tested through experiments. During stoichiometric combustion, there is a difference between dual-fuel engines with the same IMEP and positive-ignition engines. Regardless of nozzle parameters, exhaust gas recirculation rate (EGR) or injection parameters, the intake rate decreases as the equivalence ratio increases. Due to the high equivalence ratio in the dual-fuel ignition mode, the maximum heat release rate and exhaust gas temperature increase, while the combustion duration decreases. The fuel consumption mode of the spark ignition mode is similar to the fuel consumption mode of the dual fuel engine, but it has a higher equivalence ratio. The combustion phase of a spark ignition (SI) gas engine is comparable to that of a dual fuel engine with a compression ratio of 14.2. The difference lies in the ignition process. The maximum heat release rate of the dual fuel engine is higher than that of the SI engine, but the combustion cycle of the dual fuel engine is shorter and the intake rate of the dual fuel engine is lower (Zheng et al., 2019).

3.2 Method of Controlling the Emission on NOx Gas

The power of a gas (dual fuel) diesel engine is evaluated under light load, and an appropriate threshold is selected for the combustion of gas fuel through the overall flame transfer. Let us examine the relationship between this limit and several main operating parameters. When testing in a cylinder environment during diesel fuel ignition, comparing the expected maximum value with the value corresponding to the lower gaseous fuel flammability limit, a similar trend was observed. This similarity is used as a criterion for determining the lean performance limit of dual-fuel engines. A basic calculation method for the rial of methane dual-fuel steam turbine (Badr et al., 1999).

A multi-zone thermodynamic model with accurate kinetic diagrams has been developed to analyse the combustion process of dual-fuel engines and some of its performance characteristics. Consider the result of the interaction between gaseous fuel and diesel fuel, as well as the transition to the combustion process. The reaction zone model is used to illustrate the partial oxidation of the combination of air and fuel gas. Next, determine the exhaust gas emissions and the resulting emissions. The model will predict the impact and operating characteristics of the most challenging light-load performance conditions and the onset of emissions (Liu and Karim, 1997).

To gain feedback and understanding of the complex coupling mechanism in the stratified charge engine, numerical models are being created to simulate the single-cylinder dynamics of the engine cycle. Low Mach number fluid dynamics, two-phase flow (fuel droplet spray injection), turbulence, combustion mechanism, chemistry (turbulent flame propagation, emission formation), wall heat transfer and phenomena related to wall extinction, and boundary motion surfaces are just Some key physical characteristics. Grasping effect (valve and piston). In the study of disc engines, many findings are applicable to other ignition engines or diesel engines (Butler et al., 1978).

Based on a turbocharged and inter-cooled direct injection (D.I.) diesel engine, a fully electronically controlled, fully electronically controlled diesel/compressed natural gas (CNG)/diesel engine with sequential injection ports and lean burn is created. During the optimization of the total engine power, the effects of the equivalent ratio of pilot diesel and CNG/air premix on emissions (CO, HC, NOx, soot), knock, misfire and fuel efficiency were examined. Considering the required NOx and THC emission levels, the rich and lean limits of the premixed CNG/air mixture in relation to the engine load are also shown. It is worth mentioning that every step of loading a ship requires a large amount of pilot diesel fuel (Lin and Su, 2003).

Given the growing concern about diesel pollutants such as nitrogen oxides (NOX) and particulate matter (PM) and the increase in energy use, alternative diesel fuels have become a viable option. Due to its domestic availability, large-scale distribution infrastructure, low cost, and clean-burning characteristics, natural gas is an attractive product particularly suitable for use as a transportation fuel. Natural gas / diesel dual fuel is a mode of operation in which natural gas is injected into the intake air upstream of the manifold and directly into the cylinder (Wei and Geng, 2016).

CHAPTER 4 METHODOLOGY

4.1 Introduction

This simulation is mainly focused on the direct injection compression ignition engine process. The cylinders with sector of 60 degree will be stimulated. All the boundary conditions will be stated in the next section. The whole methodology process had been shown below.

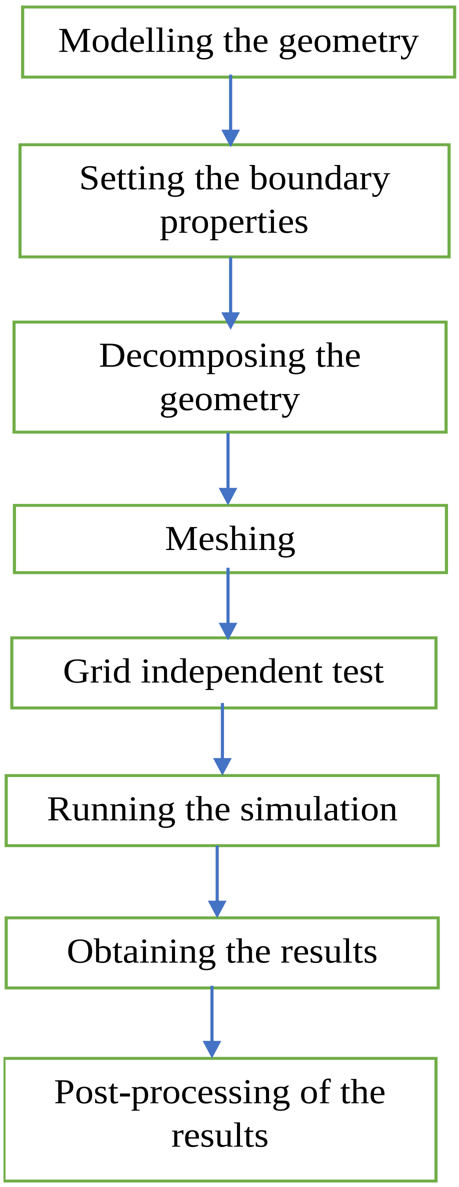

Figure 4.1 : Flow chart of methodology

4.2 Engine Modelling

The real dimensions of the engine are used to create a complete Direct Injection (DI) Compression Engine (CI). Only a portion of the engine is used, which includes the inlet and output valves, valve seat faces, cylinder liner faces, and piston. This is the critical components required to cover the simulation. Before conducting the simulation, the geometry of the engine of the engine components involved, such as connecting rod length, inlet and outlet valves, crank shaft, piston stroke, and crank radius will be set before the stimulation. The ANSYS library will be accessed for the geometry modelling. After that, the file will be imported into the IC Engine Fluent. The parameters of the engine are set as in Table 1.

Table 1: Engine Parameter

Engine parameter	Value
Crank Shaft Speed (rpm)	2500
Starting Crank Angle (deg)	570
Ending Crank Angle (deg)	833
Crank Angle Step Size (deg)	0.5
Piston stroke (mm)	110
Crank radius (mm)	55
Connecting rod length (mm)	165

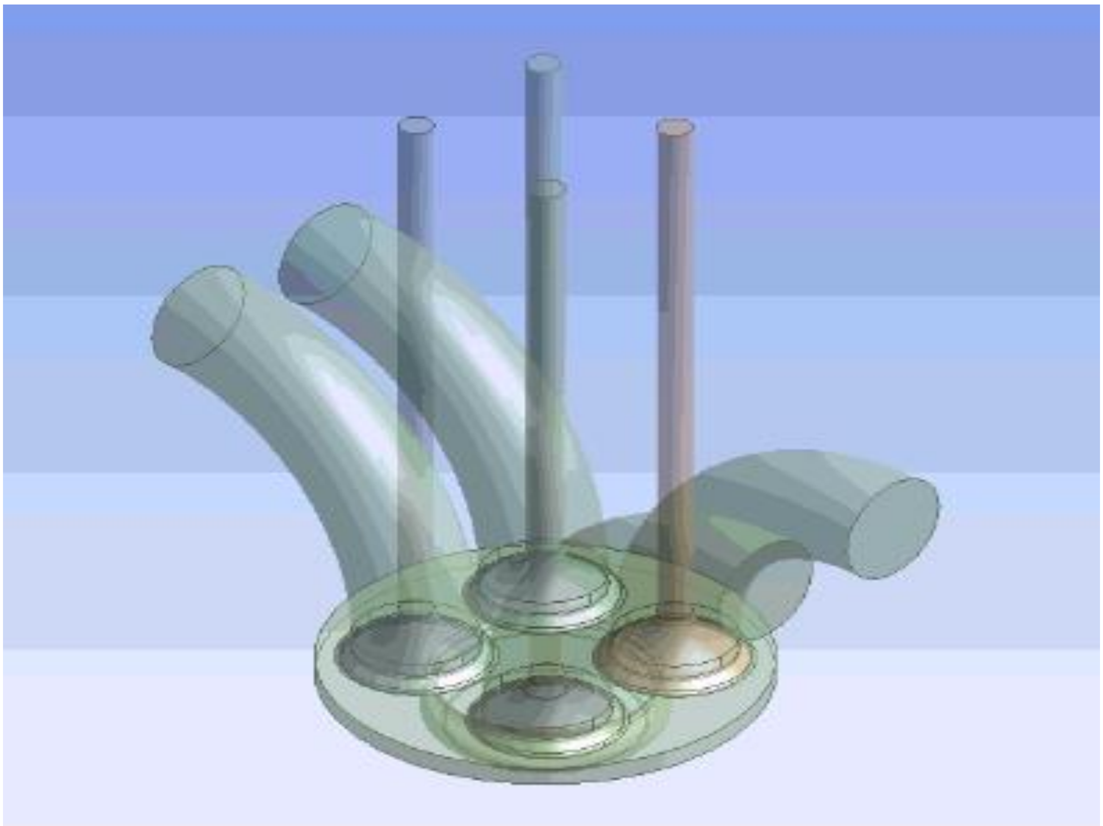

Figure 4.2 : Illustration of engine cylinder with four valve

4.3 Setting The Properties

In this simulation, the IC Engine (FLUENT) is transferred into the workbench to establish an IC Engine analysis system. Combustion simulation is selected from the simulation type in the properties section, and it is a combustion sector simulation. According to Table 1, the connecting rod length and crank radius values are 165 and 55, respectively. The input option for IVC and EVO will be selected from the drop-down list to enter direct values. IVC and EVO have values of 570 and 833 degrees, respectively. The engine must rev at a rate of 2500 RPM. Because this is a direct injection simulation, the IVC and EVO input options must be "insert direct value: option." The ICE should be updated by right-clicking on it and selecting update. All the options are listed below. Because the simulation is based on a sector combustion simulation, the Table 2 below explains how to establish the parameters of the IC Engine's design.

Table 2: Input manager of the section

Details of inputManager1	
Slice	InputManager1
Decomposition Position	IVC
Decomposition Angle	Click on generate
Sector Decomposition Type	Complete Geometry
Cylinder Liner Faces	1 Face
Sector Angle	60
Validate Compression Ratio	Yes
Compression Ratio	15.83
Crevice H/T Ratio	3
Spark Points (optional)	Not Selected
IC Valves Data 1 (RMB)	
Valve Bodies	4 Bodies
Valce Seat Faces	4 Faces
IC Injection 1 (RMB)	
Spray Location Option	Height and radius
Spray Location Height	0 mm
Spray Location Radius	0 mm
Spray Direction Option	Spray Angle
Spray Angle	70

4.4 Decomposition

In this step, the geometry file is loaded into the ICE – DesignModeler editor. The geometry is produced after the files are imported. The value of sector angle is set to 60 degrees in the input management section to lessen the time for the geometry to be stimulated. The crevice H/T Ratio and compression ratio, on the other hand, are 3 and 15.83, respectively. Figures 3.5 and 3.6 show how the cylinder faces are chosen. Valve bodies and valve seat faces are selected below the IC valves data 1 (RMB) in Figure 4.4. Under IC Injection 1, the spray location height and radius options are kept. The height and radius are 0.3 and 0.5 millimeters, respectively. The spray angle input is 70 degrees. After all of the input has been completed, the create button is clicked, followed by decomposition. After a few moments, only a sector based on the sector angle will be displayed as the final decomposition result. All the valves are removed, and the piston is shifted to the proper position using the above-mentioned decomposition crank angle. The DesignModeler is then closed, and the file is saved.