BACHELOR THESIS – ME 141502

THE EFFECT OF COMPRESSION RATIO IMPROVEMENT ON ENGINE PERFORMANCE YANMAR TF 85 MH-DI USING COMPRESSED NATURAL GAS

FAISHAL AFIF HERFANDA
NRP 04211441000035

SUPERVISORS
Prof. Semin, S.T., M.T., Ph.D
Beny Cahyono, S.T., M.T., Ph.D

DOUBLE DEGREE PROGRAM OF
MARINE ENGINEERING DEPARTMENT
FACULTY OF MARINE TECHNOLOGY
INSTITUT TEKNOLOGI SEPULUH NOPEMBER
SURABAYA
2018

BACHELOR THESIS – ME 141502

THE EFFECT OF COMPRESSION RATIO IMPROVEMENT ON ENGINE PERFORMANCE YANMAR TF 85 MH-DI USING COMPRESSED NATURAL GAS

FAISHAL AFIF HERFANDA

NRP 04211441000035

SUPERVISOR 1

Prof. Semin, S.T., M.T., Ph.D

NIP 1971 0110 1997 02 1001

SUPERVISOR 2

Beny Cahyono, S.T., M.T., Ph.D

NIP 1979 0319 2008 01 1008

DOUBLE DEGREE PROGRAM OF

MARINE ENGINEERING DEPARTMENT

FACULTY OF MARINE TECHNOLOGY

INSTITUT TEKNOLOGI SEPULUH NOPEMBER

SURABAYA

2018

"This page intentionally left blank"

SKRIPSI – ME 141502

PENGARUH VARIASI RASIO KOMPRESI TERHADAP UNJUK KERJA MESIN YANMAR TF 85 MH-DI MENGGUNAKAN *COMPRESSED NATURAL GAS*

FAISHAL AFIF HERFANDA

NRP 04211441000035

DOSEN PEMBIMBING 1

Prof. Semin, S.T., M.T., Ph.D

NIP 1971 0110 1997 02 1001

DOSEN PEMBIMBING 2

Beny Cahyono, S.T., M.T., Ph.D

NIP 1979 0319 2008 01 1008

PROGRAM DOUBLE DEGREE

DEPARTEMEN TEKNIK SISTEM PERKAPALAN

FAKULTAS TEKNOLOGI KELAUTAN

INSTITUT TEKNOLOGI SEPULUH NOPEMBER

SURABAYA

2018

"This page intentionally left blank"

APROVAL FORM

THE EFFECT OF COMPRESSION RATIO IMPROVEMENT ON ENGINE PERFORMANCE YANMAR TF 85 MH-DI USING COMPRESSED NATURAL GAS

BACHELOR THESIS

Submitted to Comply One of The Requirements to Obtain a Bachelor of Engineering Degree in Double Degree of Marine Engineering (DDME) Program Department of Marine Engineering – Faculty of Marine Technology

Institut Teknologi Sepuluh Nopember

Departement of Maritime Studies

Hochschule Wismar, University of Applied Sciences

Submitted by:

FAISHAL AFIF HERFANDA

NRP 04211441000035

Approved by Bachelor Thesis Supervisors:

1. **Prof. Semin, S.T., M.T., Ph.D** ( )
   NIP 1971 0110 1997 02 1001

2. **Beny Cahyono, S.T., M.T., Ph.D** ( )
   NIP 1979 0319 2008 01 1008

"This page intentionally left blank"

APROVAL FORM

THE EFFECT OF COMPRESSION RATIO IMPROVEMENT ON ENGINE PERFORMANCE YANMAR TF 85 MH-DI USING COMPRESSED NATURAL GAS

BACHELOR THESIS

Submitted to Comply One of The Requirements to Obtain a Bachelor of Engineering Degree in Double Degree of Marine Engineering (DDME) Program Department of Marine Engineering – Faculty of Marine Technology

Institut Teknologi Sepuluh Nopember

Departement of Maritime Studies

Hochschule Wismar, University of Applied Sciences

Submitted by:

FAISHAL AFIF HERFANDA

NRP 04211441000035

Approved by

The Head Department of Marine Engineering:

Dr. Eng. M. Badrus Zaman, S.T., M.T.

NIP. 1977 0802 2008 02 1007

"This page intentionally left blank"

DECLARATION OF HONOUR

I hereby who signed below declare that:

This thesis has been written and developed independently without any plagiarism act. All contens and ideas drawn directly from internal and external sources are indicated such as cited sources, literatures, and other professional sources.

Name	: Faishal Afif Herfanda
Student ID Number	: 04211441000035
Thesis Title	: The Effect of Compression Ration Improvement on Engine Performance Yanmar TF 85 MH-DI using Compressed Natural Gas
Departement	: Double Degree of Marine Engineering

Surabaya, July 2018

Faishal Afif Herfanda.

"This page intentionally left blank"

THE EFFECT OF COMPRESSION RATIO IMPROVEMENT ON ENGINE PERFORMANCE YANMAR TF 85 MH-DI USING COMPRESSED NATURAL GAS

Name	: Faishal Afif Herfanda
Student ID Number	: 04211441000035
Department	: Double Degree of Marine Engineering
Supervisor	: Prof. Semin, S.T., M.T., Ph.D
	Beny Cahyono, S.T., M.T., Ph.D

ABSTRACT

In this era the need for conventional energy is always increasing every year, some researchers predict future energy crisis related to conventional fuel oil due to always increasing human needs. The main obstacle to the ever-binding costs and emissions from toxic exhaust gases is that researchers are now beginning to look for alternative fuels. Due to the fact that in this research, the modification of Yanmar TF 85 MH-DI with addition of Compressed Natural Gas (CNG) as an alternative fuel to reduce fuel oil consumption on conventional oil. In this research use two method simulation and experiment. In the simulation, improvisation of the piston by varying the compression ratio (CR) aimed to see the best performance of Yanmar TF 85 MH-DI with addition of CNG. In the CR selection process is done simulation with GT-Power. The CR difference is obtained by modifying the piston shape. The best results of the simulations occur at CR 1:16 by looking at torque, power and specific fuel oil consumption (sfoc). Furthermore, during the experiment stage, performance testing is done by comparing power, torque, sfoc and specific energy consumption (sec). Performance testing is done by comparing CR 1:18 with CR 1:16. Not only that, at this stage the fuel variation is done with Pertamina Dex + 1L / min CNG, Pertamina Dex + 2L / min CNG and Pertamina Dex + 3 L / min CNG. In experiment this time does not reduce the injection of Pertamina Dex so the injection remains at 100%. Because injection fuel on this engine still works mechanically so it is difficult to do the amount of Pertamina Dex injection on the combustion chamber. From experiment result increase of torque and power at CR 1:16 with Pertamina Dex + 1L / min. The lowest sfoc of CR 1:16 occurs at 2200 rpm and the lowest sec of CR 1:16 occurs at rpm 2000 with Pertamina Dex + 2L / min CNG.

Keywords: Compressed Natural Gas, Compression Ratio, Engine Performance, Modification, Improve Piston.

"This page intentionally left blank"

PENGARUH VARIASI RASIO KOMPRESI TERHADAP UNJUK KERJA MESIN YANMAR TF 85 MH-DI MENGGUNAKAN *COMPRESSED NATURAL GAS*

Nama Mahasiswa	: Faishal Afif Herfanda
NRP	: 04211441000035
Departemen	: Double Degree of Marine Engineering
Pembimbing	: Prof. Semin, S.T., M.T., Ph.D
	Beny Cahyono, S.T., M.T., Ph.D

ABSTRAK

Pada era ini kebutuhan akan energi konvensional selalu meningkat pada setiap tahunnya, beberapa peneliti dunia memprediksi akan terjadi krisis energi dimasa mendatang terkait bahan bakar minyak konvensional dikarenakan selalu meningkatnya kebutuhan manusia. Kendala utama terjadi pada biaya yang selalu menikat serta emisi dari gas buang yang beracun membuat para ahli saat ini mulai mencari bahan bakar alternatif. Dikarenakan hal tersebut pada penelitian kali ini dilakukan modifikasi mesin Yanmar TF 85 MH-DI dengan penambahan Compressed Natural Gas (CNG) sebagai alternatif untuk mengurangi konsumsi bahan bakar dengan minyak konvensional. Dalam penelitian kali ini menggunakan dua metode yaitu simulasi dan eksperimen. Pada tahap simulasi dilakukan improvisasi pada piston dengan memvariasikan kompresi rasio (CR) yang bertujuan untuk melihat performa terbaik dari mesin Yanmar TF 85 MH-DI dengan penambahan CNG. Pada proses pemilihan CR dilakukan simulasi dengan *GT-Power*. Perbedaan CR didapatkan dengan memodifikasi bentuk piston. Hasil terbaik dari simulasi terjadi pada CR 1:16 dengan melihat torsi, daya dan *specific fuel oil consumption* (sfoc). Selanjutnya pada tahap eskperimen dilakukan pengujian performa dengan membandingkan daya, torsi, sfoc dan *spesific energy consumption* (sec). Pengujian performa dilakukan dengan membandingan CR 1:18 dengan CR 1:16. Tidak hanya itu, pada tahap ini dilakukan variasi bahan bakar dengan komposisi Pertamina Dex + 1L/min CNG, Pertamina Dex + 2L/min CNG dan Pertamina Dex + 3 L/min CNG. Pada eksperimen kali ini tidak mengurangi jumlah bahan bakar Pertamina Dex sehingga penyemprotannya tetap pada 100%. Dikarenakan penyemprotan bahan bakar pada mesin ini masih bekerja secara mekanik sehingga sulit dilakukan pengaturan jumlah Pertamina Dex yang disemprotkan pada ruang bakar. Dari hasil eskperimen meningkatnya torsi dan daya pada CR 1:16 dengan bahan bakar Pertamina Dex + 1L/min. Sfoc terendah dari CR 1:16 terjadi saat rpm 2200 dan sec terendah dari CR 1:16 terjadi saat rpm 2000 dengan Pertamina Dex + 2L/min CNG.

Kata kunci: *Compressed Natural Gas, Compression Ratio, Engine Performance, Modification, Improve Piston.*

"This page intentionally left blank"

PREFACE

Alhamdulillah hirabbil ‘alamin a huge thanks to Allah SWT the God almighty who give the intelligent, strength, and favor so the author can finish this bachelor thesis. This bachelor thesis is defined about “**The Effect of Compression Ratio Improvement on Engine Performance Yanmar TF 85 MH-DI using Compressed Natural Gas”** On this occasion the author would to express his immeasurable appreciation and deepest gratitude for those who have helped in completing this bachelor thesis:

1. My parents and sister who always supporting both mentally, financially, and the prayers were given to the author.
2. Prof. Semin, S.T., M.T., Ph.D as first supervisor lecturer author and MPP Laboratory who has guided the author in completing the thesis research and provide motivation to continue to learn and develop themselves.
3. Beny Cahyono, S.T., M.T., Ph.D as a second supervisor as well as Head of MPP Laboratory who has guided the author in completing the research of Final Project, providing motivation, and lesson both academic and non academic in the form of character, ethics, and attitude.
4. Indra Ranu Kusuma, S.T., M.Sc as Academic Supervisor author during course at Marine Engineering Department FTK-ITS which has provided much guidance and education both academic and non academic so that we as students guardians can learn to work hard, never give up, and cooperate.
5. Dr. Eng. M. Badrus Zaman, S.T., M.T. as Head Marine Engineering Department FTK-ITS, Surabaya.
6. Nurrafandi as technician of marine power plant laboratory who has been very helpful in the process of bachelor thesis.
7. All lecturers and staff in Department of Marine Engineering who always give their best effort to support the program.
8. All comrades in arms MERCUSUAR '14 who has become friends and family from the author's experience while in the Marine Engineering Department.
9. Azizah, Sulfia, Salsa, Dinar, Word, Abyan, Grandfather, Isom, Barok, Rayka, Salvin, Rizal, Udin, Kemas, Ceje, Opal, Azis, Rivaldi, Joel and Bagus who have become family in HIMASISKAL ASIK! 2016/2018 in a period of stewardship and taught many things to the author in every faces of joy and sorrow during the board in HIMASISKAL FTK-ITS.
10. All of PINISI’10, AMPHIBI’11, BISMARCK'12, BARAKUDA'13, SALVAGE’15, VOYAGE’16 and BERDIKARA’17 have been exemplary and part of the author's experience in learning to be a good student and member of HIMASISKAL FTK-ITS.

11. Linggar, Uyab, Reggi, Pravensa, Hanifan, Koko, AA, Azzam, Ilham, Wafiq, Azka and All of Marine Power Plant (MPP) friends who always supporting place to live, ideas, and prayer.
12. Presidium 2014 which always provides a container for mutual complain and motivate in all things for the author
13. Anggy, Chirsty, Fika, Izzan, Laras, Putri, Sasa, Vigita, Irul, lahud, Jaya, Andrew, Upek, Bramantio, all friends of Vidatra 33, and HMB Surabaya who always give the word spirit in everything for the author
14. Al member of Anri O'xhatmi who always give prayers and spirit to the author
15. Salsabilla Annisa Rengganis who always give greatest support to author.

The author also aware in the writing of this thesis is far from perfection and there are still mistaken in this bachelor thesis because there are still many limitations of the author. On writing of this thesis expected to expand knowledge for readers and can be developed for further research.

Surabaya, July 2018

Faishal Afif Herfanda

TABLE OF CONTENT

APROVAL FORM ... iii
APROVAL FORM ... vi
DECLARATION OF HONOUR ... viii
TABLE OF CONTENT ... xvii
LIST OF FIGURE ... xix
LIST OF TABLE ... xxi
CHAPTER I INTRODUCTION ... xxii
I.1 Background ... 1
I.2 Statement of Problem ... 1
I.3 Research Objective ... 2
I.4 Research Limitation ... 2
I.5 Research Benefit ... 2
CHAPTER II LITERATURE REVIEW ... 3
II. 1 Diesel Engine ... 3
II.2 Natural Gas ... 6
II.2.1 CNG as an alternate fuel for internal combustion engines ... 8
II.3 Dual Fuel (CNG-Diesel) ... 9
II.4 Compression Ratio (CR) ... 15
II.5 Engine Performance ... 16
II.5.1 Mean Effective Pressure ... 17
II.5.2 Torque and Power ... 18
II.5.3 Thermal efficiency and bsfc ... 18
II.5.4 Combustion Pressure and Heat Release Profile ... 19
CHAPTER III METHODOLOGY ... 23
III.1 Statement of Problem ... 24
III.2 Literature Review ... 24
III.3 Simulation and Experiment ... 24
III.3.1 Load for Diesel Engine Performance ... 26
III.3.2 Performance Test of Diesel Engine fueled by Pertamina Dex and CNG with variation compression ratio of the simulation results. ... 27
III.4 Collecting Data ... 27
III.5 Data analysis ... 27

III.6 Conclusion and Suggestion.. 27
CHAPTER IV RESULTS AND DISCUSSION.. 28
IV.1 Modification Yanmar TF 85 MH-DI with CNG Performance Based on Simulation Result 29
IV.2 Modification Piston Yanmar TF 85 MH-DI.. 37
IV.3 Experiment Result 39
IV.3.1 Power Analysis with Pertamina Dex... 39
IV.3.2 Power Analysis with Pertamina Dex + 1l/min CNG............................ 40
IV.3.3 Power Analysis with Pertamina Dex + 2l/min CNG............................ 41
IV.3.4 Power Analysis with Pertamina Dex + 3l/min CNG............................ 42
IV.3.5 Torque Analysis with Pertamina Dex 43
IV.3.6 Torque Analysis with Pertamina Dex + 1l/min CNG 44
IV.3.7 Torque Analysis with Pertamina Dex + 2l/min CNG 45
IV.3.8 Torque Analysis with Pertamina Dex + 3l/min CNG 46
IV.3.9 SFOC (Specific Fuel Oil Consumption) Analysis with Pertamina Dex 47
IV.3.10 SEC (Specifiq Energy Consumption) Analysis with Pertamina Dex + 1 L/min CNG... 52
IV.3.11 SEC (Specifiq Energy Consumption) Analysis with Pertamina Dex + 2 L/min CNG... 57
IV.3.12 SEC (Specifiq Energy Consumption) Analysis with Pertamina Dex + 3 L/min CNG... 62
IV.3.13 Total Power Analysis 67
IV.3.14 Total Torque Analysis.. 68
IV. 3.15 Total SEC Analysis 69
CHAPTER V CONCLUSION AND SUGGESTION 71
V.1 Conclusion 71
V.2 Suggestion.. 72
REFERENCES 73

LIST OF FIGURE

Figure 2.1. Diesel combustion stages (Heywood,1988) 3
Figure 2.2. Cylinder pressure, *p* of a conventional diesel engine by (Heywood,1988) 4
Figure 2.3. The formation of NOx as a function of temperature (Pulkrabek, 2013).. 5
Figure 2.4. NO_x, CO and HC missions as a function of equivalence ratio (Pulkrabek, 2013) 5
Figure 2.5. TAGP project connection (Ismail, 2004)... 7
Figure 2.6. Combustion process of a dual fuel engine (Mansor, 2014) 10
Figure 2.7. Variations of NOx as a function of load (Mansor, 2014) 12
Figure 2.8. HC and CO emission as a function of load and type of fuel (Mansor, 2014) 13
Figure 2.9. Brake specific fuel consumption variation (Mansor, 2014) 14
Figure 2.10. Engine's bsfc for diesel and dual fuel operation as a function of brake power 19
Figure 2.11. Engine's efficiency for diesel and dual fuel operation as a function of brake power.. 19
Figure 2.12. Pressure trace and heat realese rate profile at 0% load........................ 20
Figure 2.13. Pressure trace and heat realese rate profile at 25% load..................... 21
Figure 2.14. Pressure trace and heat realese rate profile at 50% load...................... 21
Figure 2.15. Pressure trace and heat realese rate profile at 75% load...................... 22
Figure 2.16. Pressure trace and heat release rate profile at 100% load................... 22
Figure 3.1. Flowchart Proses... 23
Figure 3.2. Schematic system of dual fuel engine 25
Figure 4.1. Yanmar TF 85 MH-DI in simulation.. 29
Figure 4.2. Torque vs RPM with Pertamina Dex.. 30
Figure 4.4. Torque vs RPM with Pertamina Dex + 2 l/min CNG........................... 31
Figure 4.6. Power Vs RPM with Pertamina Dex 33
Figure 4.7. Power Vs RPM with Pertamina Dex + 1 l/min CNG 33
Figure 4.8. Power Vs RPM with Pertamina Dex + 2 l/min CNG 34
Figure 4.9. Power Vs RPM with Pertamina Dex + 3 l/min CNG 34
Figure 4.10. ISFC Vs Power (kW) with Pertamina Dex.. 35
Figure 4.11. ISFC Vs Power (kW) with Pertamina Dex + 1 l/min CNG................. 36
Figure 4.12. ISFC Vs Power (kW) with Pertamina Dex + 2 l/min CNG................. 36

Figure 4.13. ISFC Vs Power (kW) with Pertamina Dex + 3 l/min CNG................. 37
Figure 4.14. Sketch drawing of Piston Yanmar TF 85 MH-DI 38
Figure 4.15. Modification piston from CR 1:18 to CR 1:16.................................... 38
Figure 4.16. RPM Vs Power using Pertamina Dex.. 39
Figure 4.17. RPM Vs Power using Pertamina Dex + 1 L/min CNG 40
Figure 4.20. RPM Vs Torque using Pertamina Dex 43
Figure 4.22. RPM Vs Torque using Pertamina Dex + 2 L/min CNG...................... 45
Figure 4.23. RPM Vs Torque using Pertamina Dex + 3 L/min CNG...................... 46
Figure 4.24. Power Vs SFOC at 1800 rpm using Pertamina Dex............................ 47
Figure 4.25. Power Vs SFOC at 1900 rpm using Pertamina Dex............................ 48
Figure 4.26. Power Vs SFOC at 2000 rpm using Pertamina Dex............................ 49
Figure 4.27. Power Vs SFOC at 2100 rpm using Pertamina Dex............................ 50
Figure 4.28. Power Vs SFOC at 2200 rpm using Pertamina Dex............................ 51
Figure 4.29. Power Vs SEC at 1800 rpm using Pertamina Dex + 1 L/min CNG 52
Figure 4.30. Power Vs SEC at 1900 rpm using Pertamina Dex + 1 L/min CNG 53
Figure 4.31. Power Vs SEC at 2000 rpm using Pertamina Dex + 1 L/min CNG 54
Figure 4.32. Power Vs SEC at 2100 rpm using Pertamina Dex + 1 L/min CNG 55
Figure 4.33. Power Vs SEC at 2200 rpm using Pertamina Dex + 1 L/min CNG 56
Figure 4.34. Power Vs SEC at 1800 rpm using Pertamina Dex + 2 L/min CNG 57
Figure 4.35. Power Vs SEC at 1900 rpm using Pertamina Dex + 2 L/min CNG 58
Figure 4.36. Power Vs SEC at 2000 rpm using Pertamina Dex + 2 L/min CNG 59
Figure 4.37. Power Vs SEC at 2100 rpm using Pertamina Dex + 2 L/min CNG 60
Figure 4.38.Power Vs SEC at 2200 rpm using Pertamina Dex + 2 L/min CNG 61
Figure 4.39. Power Vs SEC at 1800 rpm using Pertamina Dex + 3 L/min CNG 62
Figure 4.40. Power Vs SEC at 1900 rpm using Pertamina Dex + 3 L/min CNG 63
Figure 4.41.Power Vs SEC at 2000 rpm using Pertamina Dex + 3 L/min CNG 64
Figure 4.42. Power Vs SEC at 2100 rpm using Pertamina Dex + 3 L/min CNG 65
Figure 4.43. Power Vs SEC at 2200 rpm using Pertamina Dex + 3 L/min CNG 66
Figure 4.44. Power total.. 67
Figure 4.45. Torque total 68
Figure 4.47. SEC at 2200 rpm... 70

LIST OF TABLE

Table 2.1: Properties of CNG as a Fuel at 25℃ and 1 atm (Reddy et al., 2015) 9
Table 2.2 : Advantages and Disadvantages of natural gas engine (Ismail)................ 9
Table 3.1. Specification of Diesel Engine.. 24

"This page intentionally left blank"

CHAPTER I
INTRODUCTION

I.1 Background

Based on the current condition, researchers predicted future energy crises associated with conventional fuel oil with increasing human needs, costs, and toxic emissions make experts start looking for alternative fuel. One of them is an alternative clean and non-pollution gas for the engine currently under development. The emissions-related regulations on current diesel engines are very tight, especially at. Because the demand of Compress Natural Gas (CNG) to be developed. The potential generated for particulate emissions and NOx is low. The best way to control diesel fuel diesel engines and dual fuel diesel fuel and CNG is one of them (Zheng et all., 2008)

Dual fuel engines are conventional diesel engines that burn gas or diesel fuel or both at the same time. The operating method is defined with straight diesel fuel if diesel oil and dual fuel are used at the same time. In dual fuel operation, the fuel gas is mixed with clean air entering through the air intake and the mixture is then compressed during the compression stroke. Toward the end of compression stroke, diesel fuel is injected. After a short ignition delay the combustion of diesel occurs first, igniting the natural gas and the flame propagation begins resulted the power stroke. The Injection of gas together with intake air resulted in its own thermodynamic and chemical properties of mixing within the cylinder. Thus, dual fuel combustion has its own characteristics on the performance and emissions of dual fuel diesel engines. The diesel fuel which acts as a source of ignition is often referred to as pilot diesel. The quantity of pilot diesel and concentration of CNG in the intake air have important effects on the performance and emissions of a dual fuel engine.

In this thesis, an optimization of compression ratio (CR) on diesel engine with dual fuel (diesel oil-CNG) to find the best performance and emission on dual fuel engine. Theoretically increasing the CR of a machine can improve the overall efficiency of the engine by generating more power output. Indeed, to improve CR, there are many aspects about the operation of the machine that must be considered to check the compatibility of the part.

I.2 Statement of Problem

Based on the description above the problems of this thesis are:

1. How to find the optimum compression ratio based on the resulted of simulation

2. How to know the optimum engine performance based on the simulation compression ratio as evidenced by the experiment

I.3 Research Objective

The objectives of this thesis are:

1. To find the best result from variation of compression ratio on engine performance with simulation
2. To prove the optimum compression ratio based on the result of the simulation on dual fuel engine performance

I.4 Research Limitation

The limitation of this thesis is:

1. This thesis is focusing on engine performance with different compression ratio
2. The engine that used for the experiment is a Yanmar TF 85 MH-DI one-cylinder engine

I.5 Research Benefit

The benefits of this thesis is:

The optimum Yanmar TF 85 MH-DI with CNG engine performance based on compression ratio.

CHAPTER II
LITERATURE REVIEW

II. 1 Diesel Engine

The combustion process of a diesel engine starts when fuel is injected into the cylinder at the end of compression stroke. During the compression stroke, pure air is compressed with a high compression ratio, heating the gas above the diesel self-ignition temperature. A small amount of diesel fuel is injected and ignited in the high temperature air. Just after the ignition and before the combustion occurs, a short ignition delay exists followed by a sudden and rapid rise in cylinder pressure known as the premixed combustion phase. CI diesel combustion on the typical heat-release diagram in Figure 2.1 and the in-cylinder pressure diagram, *p-θ* in Figure 2.2. The AB phase is the ignition delay period. This ignition delay is determined from the change in slope on the *p-θ* diagram. This data is from a pump-line-injector mechanical system, as opposed to a high pressure common rail system. The BC phase is described as a premixed or rapid combustion phase. In this phase, the heat release rate has a high peak because the burning mixture is premixed. The burning mixture is composed of the injected fuel at the start of injection (SOI), which has mixed with surrounding air to within the flammability limits during period AB. The premixed portion of the charge undergoes rapid combustion. This phase is often referred to as chemically controlled combustion (Heywood, 1988)

Period CD is the combustion phase where the heat release rate is controlled by the rate of mixing, termed mixing control combustion. At the end of combustion phase DE, during the expansion stroke, the heat release rate becomes slower. This happens as the temperature of the cylinder gases drop during this part of the stroke.

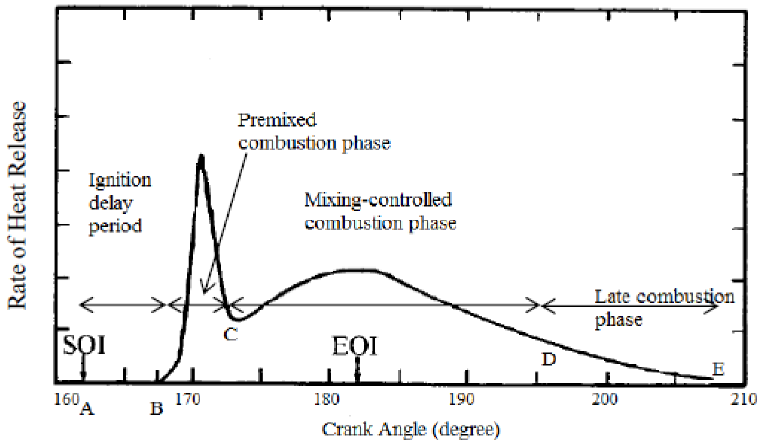


Figure 2.1. Diesel combustion stages (Heywood,1988)

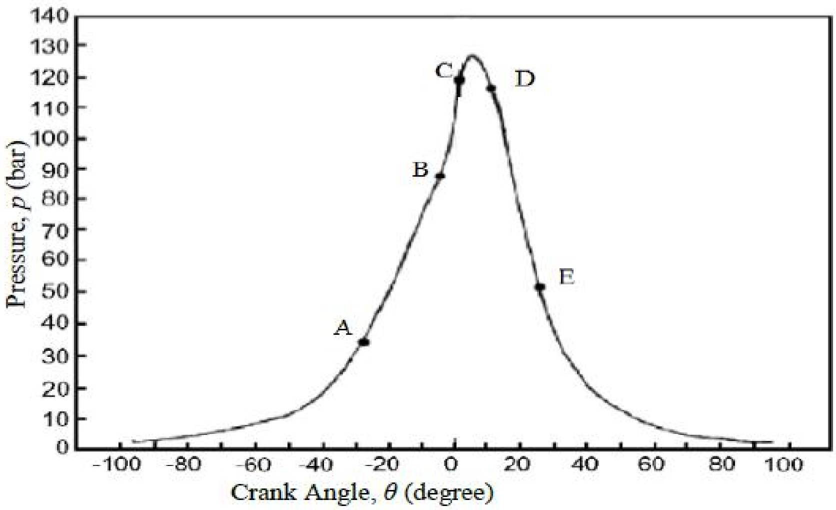


Figure 2.2. Cylinder pressure, *p* of a conventional diesel engine by (Heywood,1988)

There are several forms of diesel emissions that are created during the combustion process, primarily PM, NO_x, CO, and HC. The PM is generated in fuel-rich zones where there is insufficient oxygen to oxidize all carbon to CO_2.

$$C(s) + O_2 = CO_2 \quad (1)$$

In diesel engines, 90% of carbon particles that are originally generated early in the combustion process are consumed later in the end of the combustion and power stroke (Pulkrabek, 2013).

Exhaust gases of diesel engines also contain NO_x emissions, primarily NO, with lower levels of NO_2 and other nitrogen-oxygen combinations. NO_x emissions do not form until the cylinder charge temperature reaches about 2800°F (1540 °C) as shown in Figure 2.3. For premixed SI engines, HC emissions have a direct relation with Φ as shown in Figure 2.4_(for premixed SI engines). HC emissions are significant at richer conditions when there is not enough oxygen to react with the excess fuel, resulting in a high concentration of HC emissions in the exhaust products. HC emissions are also significant at low load when the mixture is too lean to burn and the flame is quenched, leaving some fuel particles unreacted.

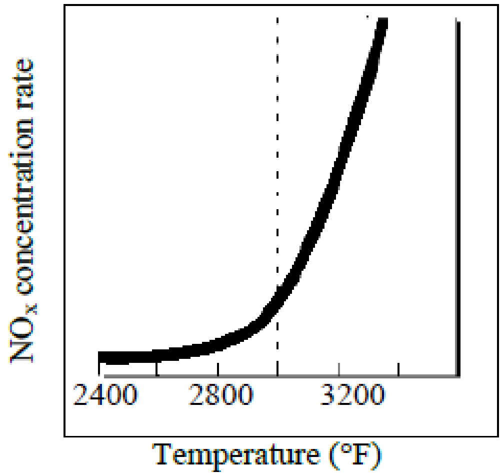


Figure 2.3. The formation of NOx as a function of temperature (Pulkrabek, 2013)

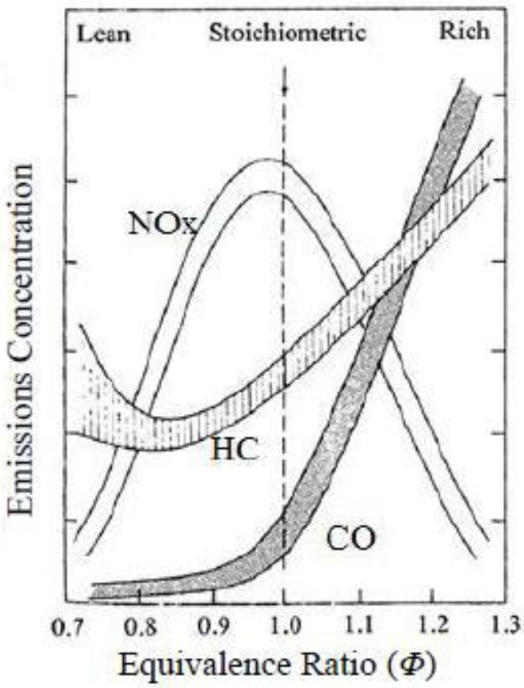


Figure 2.4. NO_x, CO and HC missions as a function of equivalence ratio (Pulkrabek, 2013)

II.2 Natural Gas

Natural gas has been known for many centuries. It was first found by the people of Mount Parnassus in ancient Greece. Around 500 B.C., it is known that the Chinese started using natural gas that seeped to the surface to boil sea water for drinking water. The first usage of commercial natural gas was in Britain in the 1780s, where gas derived from coal or coal gas was used for powering houses and streets. In the USA, Natural gas was discovered in the 1620s when natives were sighted by French explorers igniting gases that seeped into and around Lake Erie. Centuries later in 1821, the first well was dug by William Hart in Fredonia, New York; Fredonia Gas Light later became the first American Natural gas distribution company in the USA (Mansor, 2014).

During most of the 19th century, Natural gas was used almost exclusively as a source of light, but the invention of the Bunsen burner by Robert Bunsen in 1885 opened new opportunities to use Natural gas. Since then, Natural gas applications have expanded to home appliances such as stoves, clothes dryers, and furnaces and industrial applications such as engines for electrical power generation, pumping, and compression and boilers for process heating (Mansor, 2014).

On 8 August 1967 the Association of Southeast Asian Nations (ASEAN) was established. The objective is to promote economic growth by promoting one product to all ASEAN members. The ASEAN region has abundant natural gas, ASEAN is taking steps to build a natural gas transportation route by using pipes by crossing the border. A "Cebu Declaration on East Asian Energy Security" was held in Cebu, Philippines on January 15, 2007 with support for the multibillion-dollar project of Trans-Asia Gas Pipeline (TAGP). Figure 2.5 ilustrate the mega project connection involving the ASEAN country. According to Sovacool (2009) ASEAN had already invested $14.2 billion for 3452 km gas pipeline to supply 3095 million cubic feet (mcf) of gas per day. Two operational cross border projects that currently involving Malaysia are Trans-Thailand-Malaysia (TTM) and PETRONAS-Keppel which connects Gulf of Thailand to Changlun, Malaysia and Peninsular Gas Utilisation Johor, Malaysia to Jurong Island, Singapore that cost USD 2.42 billion and USD 4 million respectively (Ismail, no date)

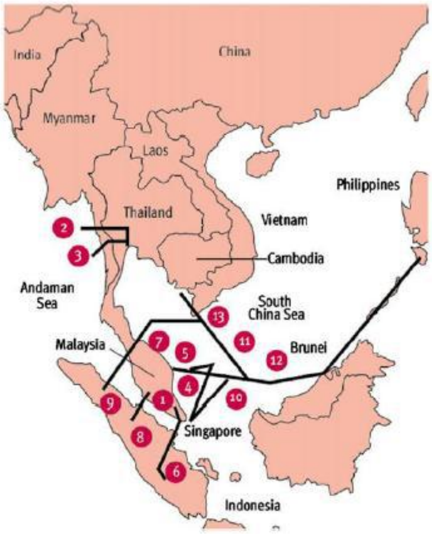


Figure 2.5. TAGP project connection (Ismail, 2004)

Natural gas is a mixture of gases which are rich in hydrocarbons. All these gases (methane, nitrogen, carbon dioxide etc.) are naturally found in atmosphere. Natural gas reserves are deep inside the earth near other solid & liquid hydrocarbons beds like coal and crude oil. Natural gas is not used in its pure form; it is processed and converted into cleaner fuel for consumption. Many by-products are extracted while processing of natural gas like propane, ethane, butane, carbon dioxide, nitrogen etc., Which can be further used (Mansor, 2014)

Fossil fuels occur in three fundamentals of states: in solid form as coal, in liquid form as oil, and in gaseous form as natural gas. Natural gas is a non-renewable fuel and similar to another fossil fuel. The formation of natural gas occurs when the buried plants and animal were exposed to the heat for thousands of years. The composition of Natural gas is made up primarily of methane ethane, propane, nitrogen, helium, carbon dioxide, hydrogen sulphate, and water vapor with normally 95% of natural gas composition is methane. The physical chemical properties described natural gas as colorless, and odorless lighter than air with a specific gravity about 0.6 – 0.8; inflamed during range 5 – 15% by volume of gas in air self-ignition temperature is 537 – 540°C; lower environmental impact compare to other fuel; octane number of 130 (Ismail, no date)

Natural gas is mainly used as fuel for generating electricity and heat. Natural gas in compressed form is used as fuel for vehicles which is known as CNG. It is used as fuel for boilers and air conditioners worldwide. This is used for making fertilizers also, mainly ammonia. A green field project is going on in Russia to produce LNG to run aircrafts. Russia, USA and Canada are major producers & consumers. For transporting, two variants are used - LNG for cross countries exchange and CNG for domestic purpose (Mansor, 2014)

II.2.1 CNG as an alternate fuel for internal combustion engines

CNG has emerged as a promising alternative fuel due to its clean burning characteristics and very low amount of exhaust emissions. In petrol engines CNG is used by installing a Bi-Fuel Conversion kit and the converted engine has the flexibility of operation either on CNG or petrol. Diesel engines can also be converted to run on CNG by installing a dual fuel conversion kit or converting the existing diesel engine into SI engine. Most existing CNG vehicles use petrol engines, modified by after-market retrofit conversions and retain bi-fuel capability. Such bi-fueled converted engines generally suffer from a power loss and can encounter drivability problems, due to the design and installation of the retrofit conversion kit. Whereas single fuel engines optimized for CNG are likely to be considerably more attractive in terms of performance and emissions. In diesel engines CNG as a fuel can be used in dual fuel mode and offers the advantage of reduced emissions of NOX, particulate matter and CO2 while retaining the thermal efficiency of the conventional diesel engine (Reddy *et al.*, 2015).

The safety aspects of converting engines to run on CNG are of great concern to users of CNG vehicles. However, CNG has four big safety features that make it an inherently safer fuel than petrol, diesel, or LPG. Its specific gravity is 0.587 which means that it is lighter than air and even if it leaks out it just rises up and dissipates into the atmosphere. Its self-ignition temperature is 5400C compared to 227-5000C for petrol and 2570C for diesel fuel and higher flammability limits give the gas a high dispersal rate and make the likelihood of fire in the event of a gas leak much less than for petrol or diesel. CNG has to mix with air within small range of 4 to 14% by volume for combustion to occur which is far narrower range than for petrol or diesel fuels. CNG cylinders are designed and built with special materials to the highest safety specifications, which makes its storage far safer than petrol or diesel fuel tanks (Singh and Maji, 2012).

The life of engine increases by using CNG. Lubricating oil life is extended considerably because CNG does not contaminate and dilute the crankcase oil. A big advantage of CNG is that it is virtually pollution free. CNG has a good mixture quality with air and when correct proportions are brought together they mix thoroughly and rapidly, which improves combustion efficiency of the engine. The higher Research Octane Number (130) for CNG as compared to that of petrol (87) allows a higher compression ratio (15.6:1) and consequently more efficient fuel consumption. Due to higher compression ratio Diesel engines can also use CNG as a fuel. But it cannot replace diesel completely like petrol due to poor cetane rating of CNG. Hence CNG seems a very attractive option for its use in diesel engines. The properties of CNG as a fuel for IC Engines are given in Table 2.1 (Reddy *et al.*, 2015).

Table 2.1: Properties of CNG as a Fuel at 25℃ and 1 atm (Reddy et al., 2015)

CNG properties	Value
Density (kg/m³)	0.72
Falmmability limits (volume%in air)	4.3-15
Falmmability imits (Ø)	0.4-1.6
Auto ignition temperature in air (℃)	723
Minimum ignition energy (MJ)	0.28
Flame velocity (m/sec)	0.38
Adiabatic flame velocity (K)	2214
Quenching distance (mm)	2.1
Stoichiometric fuel/air mass ratio	0.069
Stoichiometric volume fraction (%)	9.48
Lower heating value (MJ/Kg)	45.8
Heat of combustion (MJ/Kg_{air})	2.9

The advantages of natural gas over other fuels include the following; it has fewer impurities, it is less chemically complex, and its combustion generally results in less pollution. In most application, using natural gas produces less of the following substances than oil or coal. Table 2.2 shows the advantages and disadvantages of using natural gas engine based on report (Ismail, 2004).

Table 2.2 : Advantages and Disadvantages of natural gas engine (Ismail, no date)

Advantages	**Disadvantages**
60 – 90% less smog pollutants	Require large space for fuel storing tank
30 – 40% less greenhouse gas emissions	Lack of infrastructure leading for fuelling stasion
Less expensive than gasoline and diesel	Fewer driving kilometer
Good for engine, as cylinder and oil contamination is reduce.	Issues around the spare part and maintenance

II.3 Dual Fuel (CNG-Diesel)

The dual fuel engine, in its ideal burn process burns from diesel fuel which then evolves through the air and locally homogeneous mix gas. The premixed air and gaseous fuel burn in the presence of the diesel flame and a premixed flame is initiated by the diesel flame and propagates through the remaining air and gaseous fuel mixture. During the compression stroke, the premixed mixture’s temperature and pressure is greatly increased, forming the pre-ignition reaction environment. During this phase, partial oxidation products can form at the end of compression to induce diesel fuel ignition and combustion. The spread of the diesel flame front is greatly influenced by turbulence, swirl, and squish within the cylinder (Mansor, 2014)

Mansor described with five stages the combustion process in dual fuel engine. The data is taken on a single cylinder pre-chamber diesel engine with a pump-line-injector mechanical diesel injection system. The combustion phases of a dual fuel engine are illustrated with a cylinder pressure trace in Figure 2.5. After diesel fuel is injected at point A, a longer ignition delay period AB is observed in dual fuel combustion than in conventional diesel engines due to the reduction in oxygen concentration resulting from the introduction of natural gas to the intake charge. The premixed combustion phase BC in dual fuel is slower compared to conventional diesel premixed combustion. This is because the dual fuel engine is injecting a smaller amount of liquid fuel, therefore a smaller amount of burning mixture is added to the fuel. Period CD shows a decrease in pressure until it rises at period DE. Period CD is described as the primary fuel (premixed air and natural gas fuel) delay period. The DE phase is the actual combustion of the natural gas fuel starting with the flame propagation initiated by the spontaneous liquid fuel ignition. Period EF as a diffusion combustion stage starting at the end of gaseous fuel combustion. It is unclear why this phase of combustion is characterized as diffusion combustion. It may be more appropriate to characterize it as the late combustion phase (Mansor, 2014)

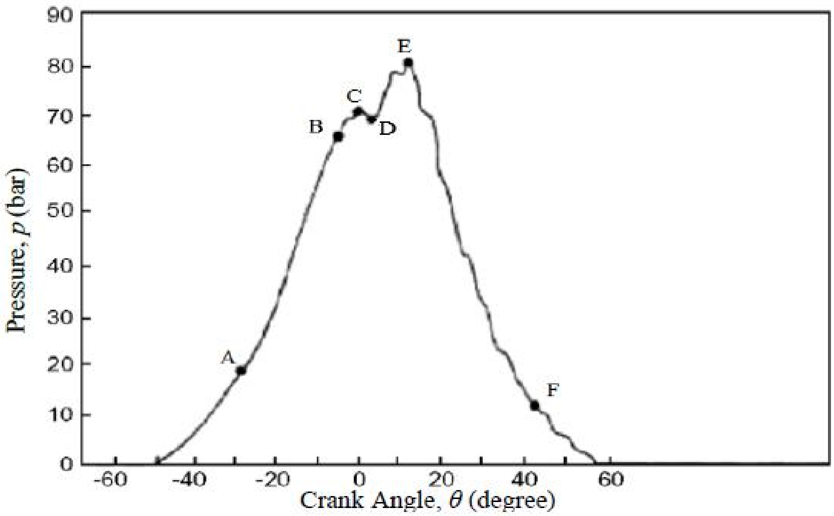


Figure 2.6. Combustion process of a dual fuel engine (Mansor, 2014)

In diesel engines, higher peak cylinder pressures are observed compared to dual fuel engines. This is due to the CR being not knock-limited ratio in CI dual fuel engine, while the CR value of SI and dual fuel engines are knock limited. The conventional diesel engine uses a heterogeneous mixture, where the cylinder charge is pure air. The mixture undergoes a non-premixed, or diffusion flame, combustion process except when rapid premixed combustion occurs (period BC in Figure 2.1 and Figure 2.2). In the diesel engine, the ignition starts at several points in the chamber where a local stoichiometric air/fuel ratio (AF) is formed, regardless of the overall AF in the cylinder. On the other hand, in the dual fuel engine the primary fuel combustion is homogeneous (premixed). The cylinder charge is a mixture of air and natural gas and ignited by the injection of diesel fuel. It is characterized as non-premixed combustion of diesel fuel, followed by premixed combustion of the natural gas. The premixed combustion is very sensitive to AF; therefore, in lean combustion as observed in dual fuel engines the in-cylinder pressure has a lower peak value (Mansor, 2014)

Since the dual fuel operates at lean mixtures, the flame temperature is lowered, therefore reducing the formation of NOx. Other factors that affect the formation of NOx in dual fuel engines are the quantity of gaseous fuel and Φ of the air-fuel mixture (Pulkrabek, 2004). The effect of Φ on emissions is shown in Figure 2.4. This figure is specific to SI engines but the general trends are similar for CI and dual fuel engines. This figure shows that maximum NOx is formed at slightly lean conditions, around Φ = 0.95. As the mixture goes leaner, increasing excess air concentration reduces the gas temperature. At low temperature, atmospheric nitrogen is a stable diatomic molecule (N2) and less oxides of nitrogen are produced. In contrast, at high temperatures some of N2 breaks down to reactive monotonic nitrogen radicals (Heywood, 1988). At high temperatures with excess oxygen available oxygen can combine with the nitrogen to form nitric oxide:

$$O + N2 \longrightarrow NO + N \quad (2)$$

$$N + O2 \longrightarrow NO + O \quad (3)$$

Oxygen radicals (O) are produced from the dissociation of oxygen molecules (O2) or from a collision between the H radical and O2. These oxygen radicals combine with N2 to start the simple chain shown, called the Zeldovich mechanism. Nitric oxide can further oxidize to form NO2. In order to minimize NOx formation in ICEs, reducing flame temperature is crucial, which slows the reaction rates in the Zeldovich mechanism (Mansor, 2014).

There are substantial numbers of studies investigating emissions from dual fuel engines. They mentioned that the presence of gaseous fuels in dual fuel operation reduces the amount of diffusion combustion and replaces it with lean premixed combustion, which affects the rate of NOx formation. However, the NOx formation at high load is lower for the diesel engine as shown in Figure 2.6. The author of this study attributes this to the combustion of liquid fuel near TDC creating a high charge temperature which remains at a high temperature longer in gas-diesel dual fuel engine than in the diesel case (Mansor, 2014). Figure 2.7 compares CO and HC emissions for diesel and dual fuel by Lounici et al. at 2000 rpm. The data shows extremely lower CO emissions for the dual fuel case at high load, while HC emissions are significantly higher in the dual fuel case.

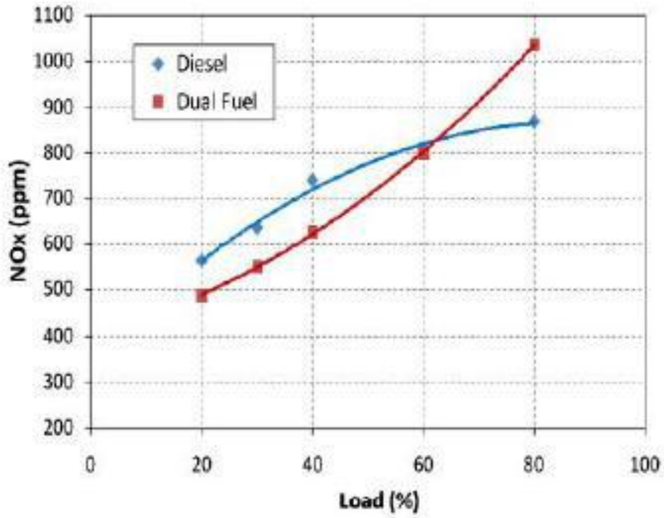
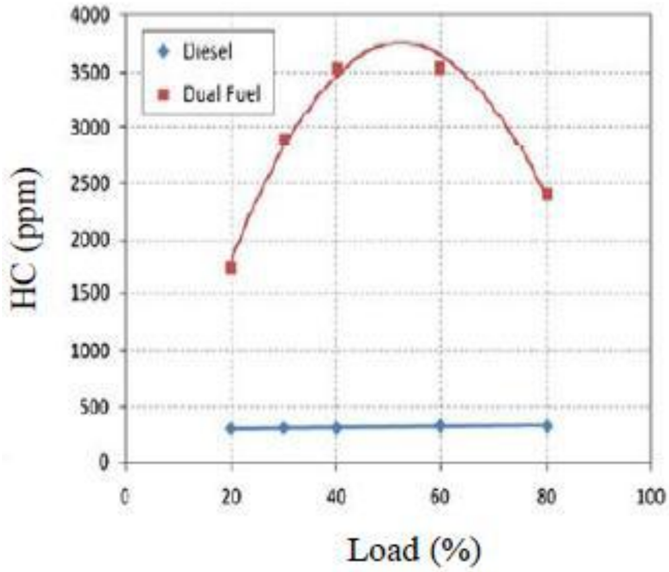


Figure 2.7. Variations of NOx as a function of load (Mansor, 2014)



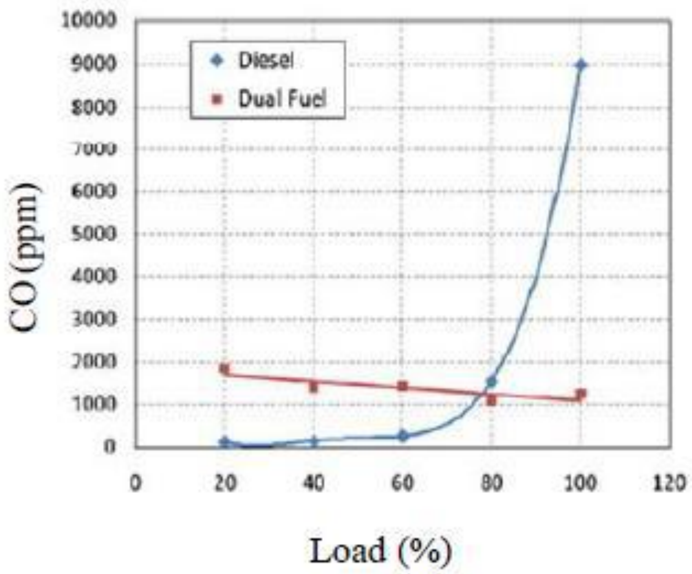


Figure 2.8. HC and CO emission as a function of load and type of fuel (Mansor, 2014)

(Namasivayam et al., 2009) HC emissions trend higher at all conditions in the dual fuel natural gas-diesel engine. This is consistent with the data in Figure 2.7. It is theorized that HC emissions are substantially higher because natural gas survives through the combustion process and ends up in the exhaust gas stream. Flame quenching at the wall and very lean mixtures also result in high levels of HC emissions.

(Bueno et al., 2012) Another important parameter in determining an engine's performance is the heat release rate (HRR) calculation. The net HRR is calculated by computing the amount of energy release from the fuel to obtain the experimentally observed pressure, while the combustion reaction extent is evaluated through the released fraction of the total fuel chemical energy. (Abdelaal et al., 2012) Abdelaal et al. in their study using naturally aspirated diesel engine, describe that longer ignition delays in the dual fuel engine have a negative impact on the HRR. Generally, the diesel engine exhibits better HRR trends than the dual fuel engine. In the diesel engine, a large amount of diesel is utilized especially at high load resulting in high in cylinder temperatures. The reduced HRR in dual fuel operation is mainly due to the very lean mixture of air and gaseous fuels. This affects the combustion in dual fuel; a portion of natural gas usually escapes the combustion process resulting in low combustion efficiency and high HC emissions.

Some experimental studies show similar trends in thermal efficiency between dual fuel and diesel operation and some observed lower efficiencies in dual fuel than diesel engines (Namasivayam, 2009) (Weaver et al., 1994). This suggests that the thermal efficiency comparison is dependent on engine design and operating conditions. (Papagiannakis et al., 2003) The authors identify that dual fuel experiences lower thermal efficiencies because of the reduced combustion duration, which also reduces cylinder charge temperature. This is exacerbated by very lean mixtures of air and gaseous fuels at low load. (Abdelaal et al., 2012) As previously mentioned, in their work using a naturally aspirated diesel engine, at part load some of the air and gaseous fuel mixture is burned but some escape from the combustion process due to valve overlap. Increased valve overlap at part load causes the intake charge to flow directly into the exhaust leading to poor combustion especially during idling. The authors also define better fuel utilization in dual fuel engine at high loads. This is due to larger amount of natural gas introduced leading to better combustion and higher brake thermal efficiency at high loads. In contrast, at high loads diesel engine combustion sees increment in heat loss to the cylinder wall, therefore negatively impacting the thermal efficiency. As a consequence, more power may be produced in dual fuel combustion.

Brake specific fuel consumption (bsfc) depends on CR and Φ (Pulkrabek, 2004). As mentioned earlier, Lounici and associates used a naturally aspirated diesel engine to investigate dual fuel engine performance at several engine speeds. Figure 2.8 compares dual fuel and diesel totsl bsfc at 2000 rpm. The authors conclude an improvement in total bsfc in conventional diesel engine at low load, but lower at high loads.

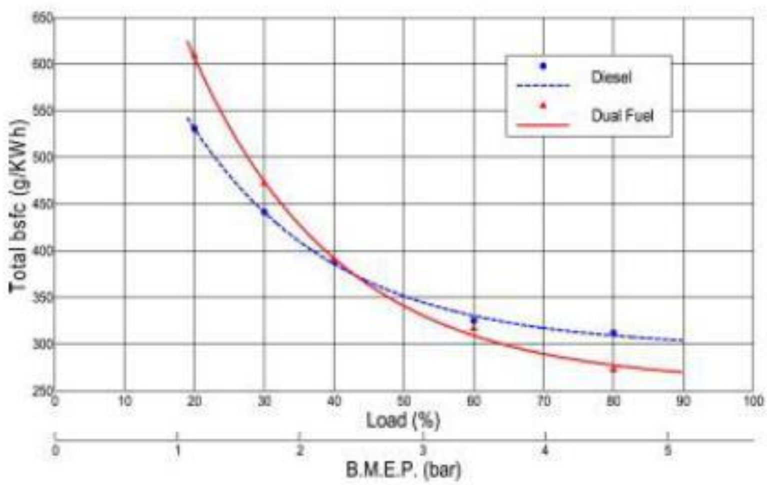


Figure 2.9. Brake specific fuel consumption variation (Mansor, 2014)

If necessary, the compression ratio has to be reduced to prevent knock in the combustion chamber due to the high pressure and self-ignite characteristic of CNG. Theoretically, increasing the compression ratio can improve the thermal efficiency by promoting better mixing for the CNG and air. However, the theory of the compression ratio for use on CNG and diesel in combustion processes is not linear and there is no formula Various parameters must be taken care not to knock. Increased compression ratio will increase fuel consumption that causes vibrations in the vehicle. Therefore, the ratio of air fuel and ignition timing is reduced to promote surgery without stroke (Shamsudin & Yusaf 1995, p.110).

It is concluded that correct proportion of CNG composition and diesel fuel are supplied to the combustion chamber. Besides that, all the relevant analysis related to the crank angle, pressure distribution, temperature distribution and the heat transfer in the combustion chamber are carried out to analyze their effects on the engine performance. Engine performances such as the efficiency of the combustion process and the mixing quality of the gas mixture are investigated to minimize the existence of knocking prior to the start of the combustion process.

II.4 Compression Ratio (CR)

Modern spark Ignition (SI) engine have compression ratios of 8 to 11, while compression ignition (CI) engines have compression ratios in the range 12 to 24. Engine with supercharger or turbocharger usually have lower compression ratios than naturally aspirated engine. Because of limitation in engine materials, technology and fuel quality, very early engine had low compression ratios, on the order of 2 to 3. (Pulkrabek,2004)

It is the ratio is the volume above the piston when it is at the bottom-most position (BDC) to the volume above the piston when it is at the top-most position (TDC). The compression ratio indicates the extent to which the air-fuel mixture is compressed in the engine. In other words, it is a value that indicates the ratio of the volume of the combustion chamber from its largest capacity to its smallest capacity. It is the ratio between the combined volume of the cylinder along with the combustion chamber when the piston is at BDC (bottom dead center) to the volume of the combustion chamber alone when the piston is at TDC (top dead center). 'Compression Ratio' is one of the fundamental specifications for all internal combustion engines. The formula expressing the definition of compression ratio is based on equation 1 and 2

Equation 2.1: Compression ratio (Pulkrabek, 2004)

$$rc = \frac{Vc+Vd}{Vc} \quad (4)$$

Equation 2.2: Displacement volume (Pulkrabek, 2004)

$$Vd = Nc\ (\frac{\pi}{4})B^2S \quad (5)$$

$B =$ Bore
$S =$ Stroke
$N_c =$ Number of cylinder
$V_c =$ Clearance volume (combustion chamber)
$V_d =$ Displacement volume
$r_c =$ Compression ratio

Generally, increasing the CR of an engine can improve the overall efficiency of the engine hence producing more power output. However, if the compression ratio approaches the limit of maximum allowable CR the engine will suffer a knocking phenomenon (Saidur *et al.*, 2007; Wong, 2005). Thus, it is important for the engine to obtain the optimum CR.

Investigate the effect of CR on the performance and emissions in a CNG dedicated engine. The result indicates increasing the CR gave more power output. The NOx emission showed a trend of increasing and decreasing which is unstable. The overall HC emissions are higher as the increase of CR and reflected to lower CO emissions (Damrongkijosol,2006)

The increase of CR resulted to higher break thermal efficiency. For exhaust emissions, CO decrease while NOx increase of CR. The HC concentration shows a decreasing trend and then an increasing CR (Zheng et al., 2009)

II.5 Engine Performance

Alternative fuels are popularly discussed in many countries owing to increased environmental awareness and the rising price of diesel. Developing alternative diesel fuels is driven by the necessity to reduce the environmental impact of emissions without modifying engines. Using alternative fuels instead of diesel reduces the fuel consumption and improves the engine efficiency. Engine performance is an indication of the degree of success with which it is doing assigned job, i.e. the conversion of chemical energy contained in the fuel into the useful mechanical work (Rowen, 1971)

In the evaluation of the engine performance certain parameters are chosen and the effects of various operating conditions, design concepts and modifications on these parameters are studied. Three points of interest when determining engine performance are brake mean effective pressure (BMEP), brake-specific fuel consumption (BSFC), and thermal efficiency (Rowen, 1971).

II.5.1 Mean Effective Pressure

The pressure in the cylinder of an engine is continuously changing during the cycle. An average of mean effective pressure (mep) is defined by:

$$\omega = (mep)\Delta v \qquad (6)$$

Or:

$$mep = \frac{\omega}{\Delta v} = \frac{W}{Vd} \qquad (7)$$

$$\Delta v = vBDC - vTDC \qquad (8)$$

Where W = work

ω = specific work of one cycle

Vd = displacement volume

Mean effective pressure is a good parameter to compare engine for design or output because it is independent of engine size and/or speed. If torque is used for engine comparison, speed becomes very important.

Various mean effective pressures can be defined by using different work terms in equation(). If brake work is used, brake mean effective pressure is obtained:

$$\text{bmep} = \omega b/\Delta v \qquad (9)$$

Indicated work gives indicated mean effective pressure:

$$\text{imep} = \omega i/\Delta v \qquad (10)$$

the imep can further be devide into gross indicated mean effective pressure and net indicated mean effective pressure:

$$\text{(imep)gross} = (\omega i)\text{gross} /\Delta v \qquad (11)$$

$$\text{(imep)net} = (\omega i)\text{net} /\Delta v \qquad (12)$$

Pump mean effective pressure (which can have negative value):

$$\text{pmep} = \omega pump/\Delta v \qquad (13)$$

Friction mean effective pressure:

$$\text{fmep} = \omega f/\Delta v \qquad (14)$$

The following equations relate some of the previous definitions:

$$\text{nmep} = \text{gmep} + \text{pmep} \qquad (15)$$

$$\text{bmep} = \text{nmep} – \text{fmep} \qquad (16)$$

$$\text{bmep} = \eta m\ imep \qquad (17)$$

$$\text{bmep} = \text{imep} – \text{fmep} \qquad (18)$$

where: nmep = net mean effective pressure

ηm = mechanical efficiency of engine (19)

Typical maximum value of bmep for naturally aspirated SI engine are in the range of 850 to 1050 kPa (120 to 150 psi). For CI engine, typical maximum values are 700 to 900 kPa (100 to 130 psi) for naturally aspirated engine and 1000 to 1200 kPa (145 to 175 psi) for turbocharged engine.

II.5.2 Torque and Power

Torque is a good indicator of an engine's ability to do work. It is defined as force acting at a moment distance and has units of N-m or lbf-ft. Torque τ is related to work by:

$$2\pi\tau = Wb = \text{(bmep)}\ Vd/n \qquad (20)$$

Where: Wb = brake work of one revolution

Vd = displacemen volume

n = number of revolutions per cycle

For a two-stroke cycle engine with one cycle for each revolution:

$$2\pi\tau = Wb = \text{(bmep)}\ Vd/n \qquad (21)$$

τ = (bmep) $Vd/2\pi$ two-stroke cycle

For a four-stroke cycle engine with one cycle for each revolution:

$$2\pi\tau = Wb = \text{(bmep)}\ Vd/n \qquad (22)$$

τ = (bmep) $Vd/4\pi$ four-stroke cycle

In these equations, bmep and brake work Wb are used because torque is measured off the output crankshaft.

According to research result from (Mansor, 2014) comparison engine performance between diesel engine and dual fuel engine shows the following results:

II.5.3 Thermal efficiency and bsfc

The bsfc is calculated by dividing the total fuel mass flow rate (diesel and natural gas) by engine shaft power as shown in (23). The brake thermal efficiency is calculated by using inverse proportion of bsfc and the weighted average lower heating value (LHV) as shown in (24).

$$bsfc = \frac{mf}{Wb} \qquad (23)$$

$$efficiency = \frac{1}{bsfc \times LHV} \qquad (24)$$

Comparisons of efficiency and bsfc of diesel and dual fuel engine are shown in Figure 2.9 and Figure 2.10. At low loads, the efficiency is lower for the dual fuel operation compared to normal diesel operation while the bsfc is higher for dual fuel operation. This may be due to slower combustion rate and poor utilization of the gaseous fuel in the combustion chamber. Additionally, on a mass basis the specific heat of natural gas is higher than pure air and higher than diesel vapor. This may also play a role by reducing combustion temperature and consequently slowing the combustion process. The trends are improved at intermediate and high loads. It is observed that ignition delay is decreased at high loads in dual fuel operation, which promotes faster combustion.

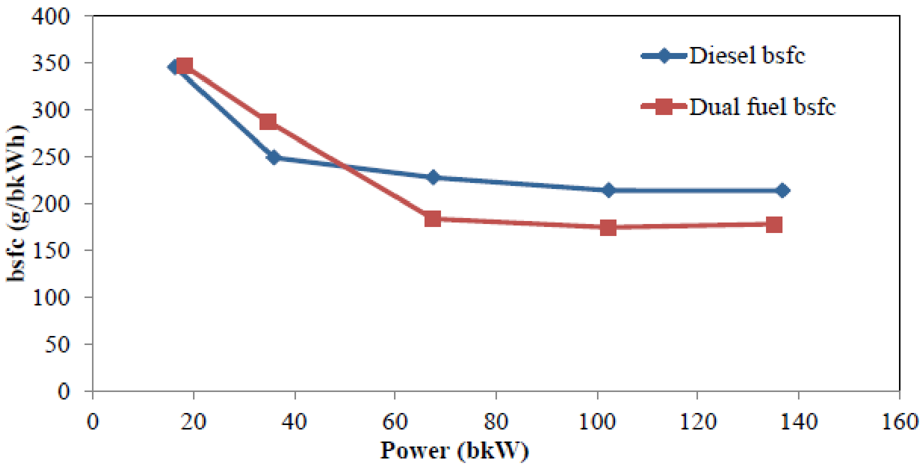


Figure 2.10. Engine's bsfc for diesel and dual fuel operation as a function of brake power (Mansor, 2014)

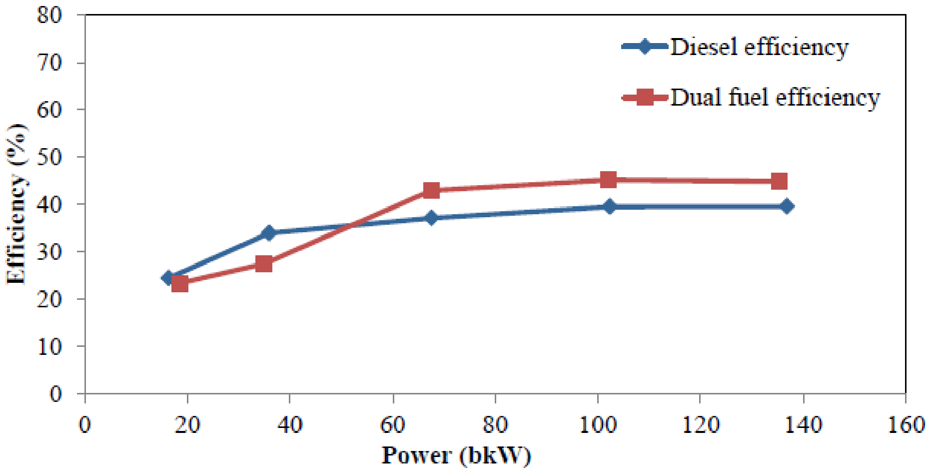


Figure 2.11. Engine's efficiency for diesel and dual fuel operation as a function of brake power (Mansor, 2014)

II.5.4 Combustion Pressure and Heat Release Profile

Figure 2.11 and Figure 2.12 show combustion pressures and net heat release rates versus crank angle at low loads. At low loads, the cylinder pressure is lower in dual fuel operation due primarily to later heat release. While the motoring pressure peaks of both traces are nearly identical, the dual fuel case fails to reach similar peak pressures as the diesel case due to a late pressure peak. Also at both loads, the diesel case reaches complete combustion more quickly. Complete combustion is shown as a mass burn fraction value of one. In both low load cases, the mass burn fraction rises much faster for diesel than dual fuel.

Figure 2.13 shows pressure and heat release rate trend at 50% load. Dual fuel motoring and peak combustion pressures are slightly lower than the diesel condition. The heat release rate is also lower in dual fuel engine. The diesel case shows two heat release peaks, the first premixed combustion and the second mixing controlled combustion. For dual fuel only one heat release peak is observed. The pressure and heat release rate profile at higher loads are presented in Figure 2.14 and Figure 2.15. The motoring pressures for dual fuel are lower at 75 and 100% loads. Peak combustion pressures double over the selected testing range. Although the compression ratio is fixed, the intake air pressure is much higher at 100% load compared to 12% load. Two heat release peaks are present for diesel and dual fuel at the higher loads. At high loads, dual fuel and diesel combustion appears similar, with dual fuel mass burn fraction rising slightly faster. Both regimes have completed combustion by approximately 45° aTDC.

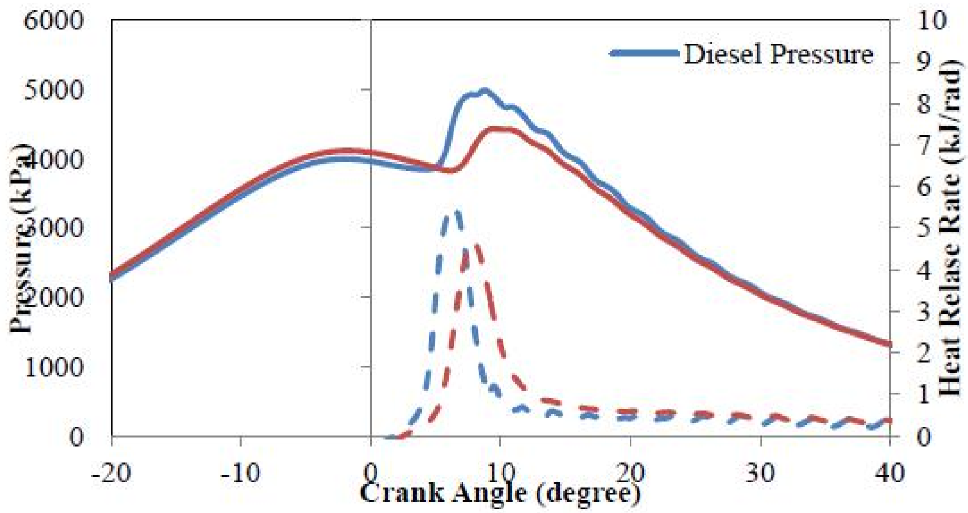


Figure 2.12. Pressure trace and heat release rate profile at 0% load (Mansor, 2014)

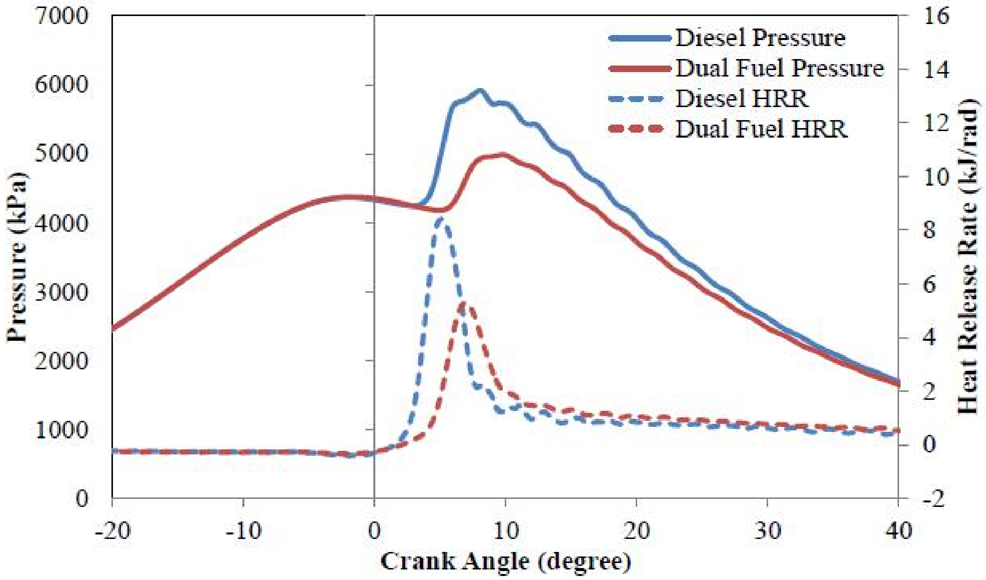


Figure 2.13. Pressure trace and heat release rate profile at 25% load (Mansor, 2014)

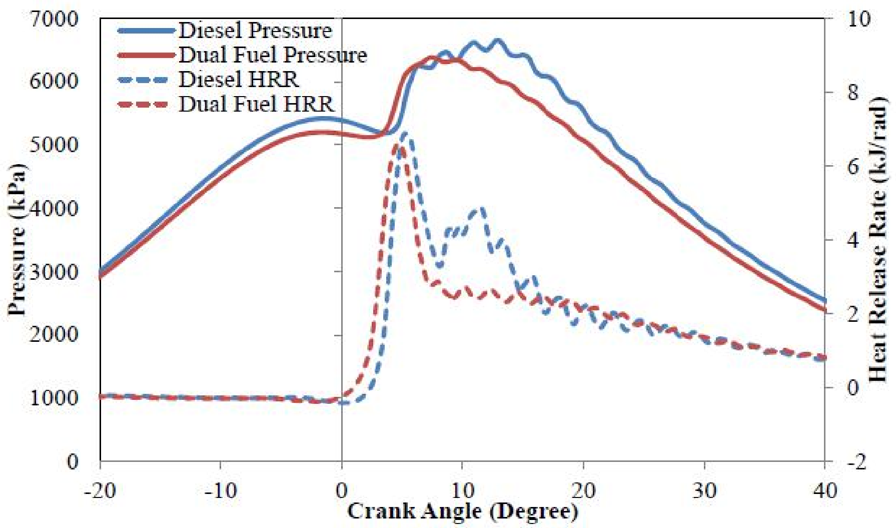


Figure 2.14. Pressure trace and heat release rate profile at 50% load (Mansor, 2014)

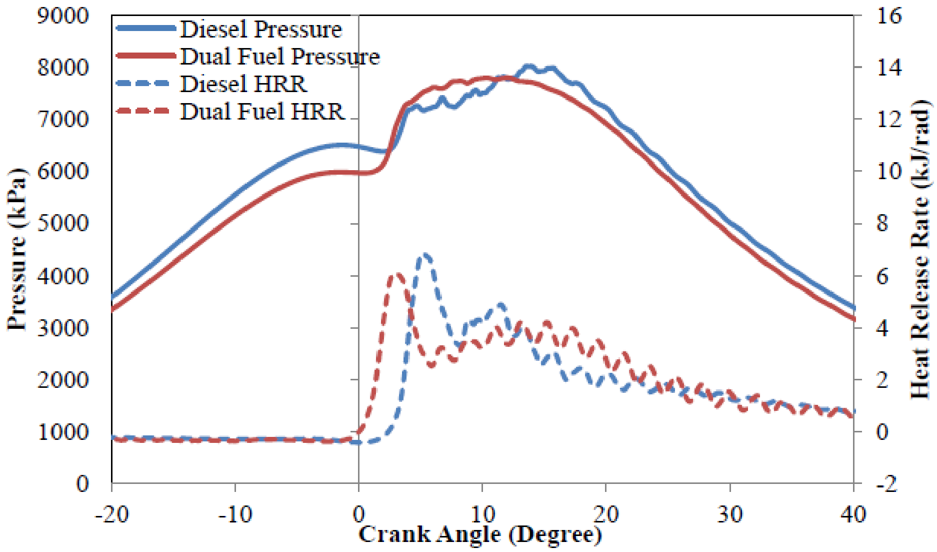


Figure 2.15. Pressure trace and heat release rate profile at 75% load (Mansor, 2014)

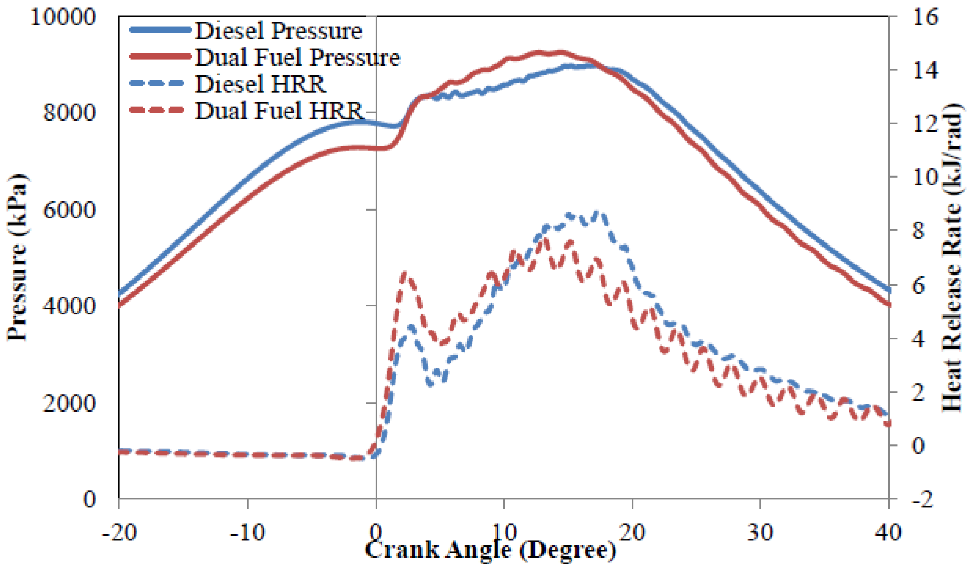


Figure 2.16. Pressure trace and heat release rate profile at 100% load (Mansor, 2014)

CHAPTER III

METHODOLOGY

The method used to set the layers in this study is to use simulation and experiments. In the simulation process using GT Power aims to select the right compression ratio based on performance on dual fuel engine. Experiments were conducted with diesel engine to determine the performance of diesel engine by using two comparing diesel fuel with Pertamina Dex and Pertamina Dex - CNG fuel. Details of workmanship are as follows:

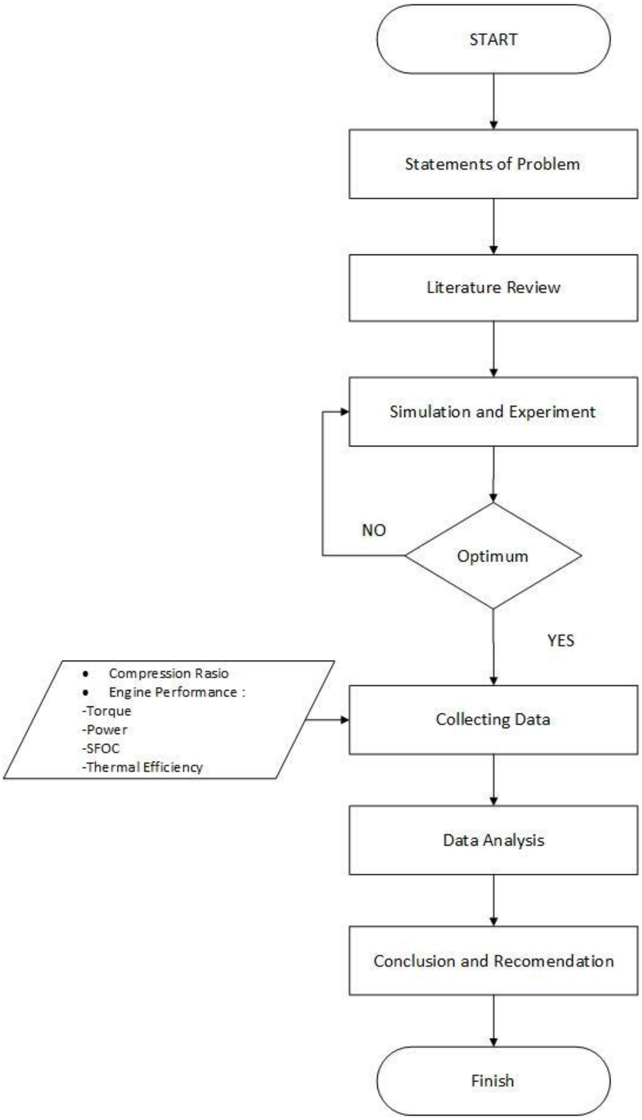


Figure 3.1. Flowchart Process

III.1 Statement of Problem

The problem identification in this research is to know the exact compression ratio to be used in dual fuel engine using CNG to avoid knocking and performance test from comparison of each compression ratio

III.2 Literature Review

The literature review was conducted to study the theory that support the research problem. For this research, literature studies refer to the characteristics of CNG and Pertamina Dex, research of dual fuel engine performance, and compression ratio of diesel engines. Literature in the form of sources such as journals, books, and the final task obtained through the internet and library.

III.3 Simulation and Experiment

At this stage done collection of materials and data to support the course of research. Checking the diesel engine for engine condition, basic engine performance, full load from diesel motor before experiment. Engine data used are as follows:

Table 3.1. Specification of Diesel Engine

Brand	Yanmar
Model	TF-85 MH
Tipe	In line, single cylinder, 4 stroke, water cooled, direct injection
Bore x Stroke (mm)	85 x 87
Piston Displacement (L)	0.493
Output / Crankshaft Speed (HP / rpm)	7.5 / 2200
Compressed Ratio	18 : 1

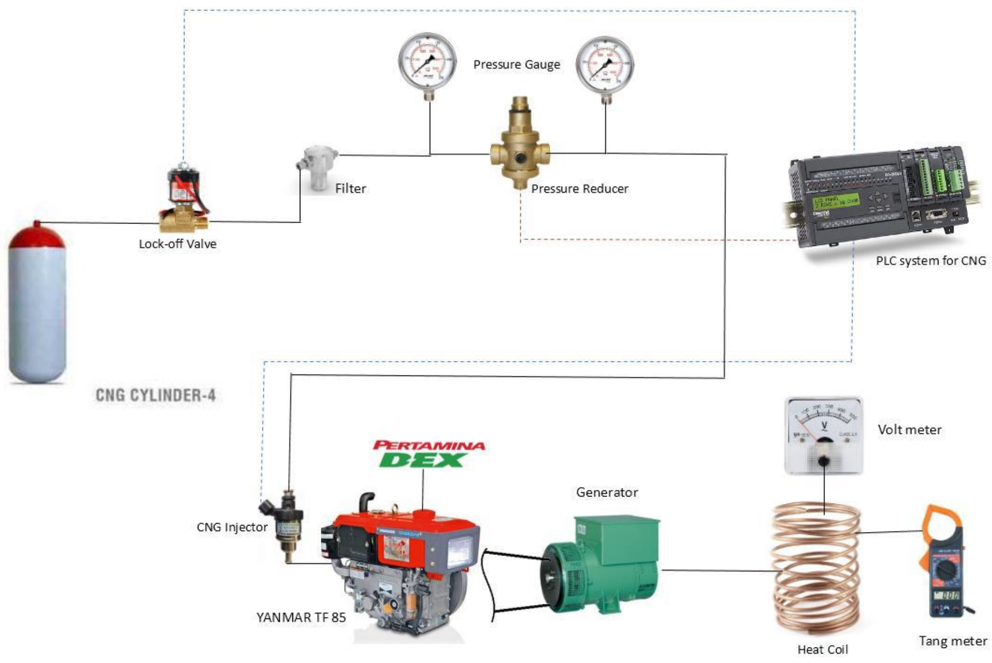


Figure 3.2. Schematic system of dual fuel engine

In figure 3.2 is a schematic of the experimental process using Yanmar TF 85 MH-DI with the addition of CNG and there are several supporting elements to perform the measurement in the data retrieval. The tools and materials that will be used to perform this experiment are as follows:

1. Compressed Natural Gas
2. Pertamina Dex
3. Diesel engine single cylinder YANMAR TF 85 MH-DI
4. PLC system of dual fuel engine
5. Tachometer
6. Alternator
7. Tang meter
8. Volt meter
9. Heat coil

In performance testing engine setup must be done first to know the location of the full load on each round varied. In testing engine setup is used Pertamina Dex fuel. In testing engine setup is used variation of the rounds of 1500, 1800, and 2200 rpm. It aims to find out the maximum power estimation and maximum torque at certain rounds, with load variations of 1000, 2000, 3000 and 4000. The existence of rotation difference in engine and alternator so used pulley as bales round generated. With the variation of loading, we can know the power and the resulting rotation.

III.3.1 Load for Diesel Engine Performance

Load for performance of this diesel engine using a heater to obtain the power generated diesel engine. First for the choice of alternator which is adjusted to diesel engine rotation, which is meant when diesel engine reaches maximum rotation then the alternator reaches the maximum rotation so that the data taken has been sync. For this study the market-generated alternator does not match the rotation of the diesel engine, so calculations are needed to determine the diameter of the pulley as the material for synchronizing the diesel engine rotation with alternator rotation. Here's the calculation:

- Pulley Count

comparison Ø pulley = rpm engine / rpm
alternator = 2200/1500
= 1.4666667

Pulley Election
Ø alternator = Ø pulley engine / comparison Ø pulley
= 11 / 1.467
= 7.5 cm

That way the pulley used is with 7.5 cm in diameter. For loading use heater with a total power of 5 kW, therefore required installation of cables in accordance with the load of the heater, for the selection of security cable can be seen from the following table:

Cable cross section (mm^2)	KHA (Ampere)	Safety (Ampere)
1	11	2, 4, 6
1.5	14	10
2.5	20	15
4	25	20
6	31	25
10	43	35
16	75	60
25	100	80

Table 3.2. Cable safety selection

From the above data then selected cable with cross section 2.5 mm^2, so that security for electrical system can be guaranteed.

III.3.2 Performance Test of Diesel Engine fueled by Pertamina Dex and CNG with variation compression ratio of the simulation results.

At this stage, performance testing of diesel engine with Pertamina Dex and CNG fuels is done in marine power plant workshop FTK-ITS, this test is done to get performance test result from dual fuel diesel engine modification.

- Data retrieval

At this stage the data is taken in the form of performance comparisons of two different diesel engines namely diesel engines with Pertamina Dex fuel and dual fuel engine, Pertamina Dex-CNG. The data obtained is a comparison by using different loading variations on diesel engines. The resulting data will be delivered in the form of graphs and tables.

- Dual Fuel Engine Performance Test

Experiment at this stage by using dual-fuel diesel engine between Pertamina Dex and CNG, for testing of dual fuel engine performance test this mass between CNG and Pertamina Dex will be varied so as to get the most optimum value with low SFC value. In taking performance test data, gradually Pertamina Dex data collection, 1 l/min CNG, 2 l/min CNG, and 3 l/min CNG respectively. The data taken are data such as current, voltage, and rpm. The data will be used to obtain SFOC, SEC, mixed fuel ratio data on full load, etc.

III.4 Collecting Data

Data collection was obtained after doing the best compression ratio modeling on GT-POWER application then continued with experiment of performance analysis with Pertamina Dex-CNG fuel. The results obtained some data from the experiment. The data is compression ratio and engine performance

III.5 Data analysis

In this section analysis is done with armed with the data that have been obtained from the results of performance test to answer the questions underlying this research is, how to find the optimum compression ratio based on the resulted of simulation? and How to know the optimum engine performance based on the simulation compression ratio as evidenced by the experiment?

III.6 Conclusion and Suggestion

At this stage can be done drawing the conclusions and answers of the problems underlying this research. This suggestion is intended to allow this thesis to continue its research to be refined.

"This page intentionally left blank"

CHAPTER IV RESULTS AND DISCUSSION

This chapter improves results and discussion on performance tests on diesel engines. The fuel used is Pertamina Dex, Pertamina Dex -CNG 1 l/min, Pertamina Dex -CNG 2 l/min, and Pertamina Dex -CNG 3 l/min. The topics in this chapter are performance including power, torque, and SFC (Specific Fuel Consumption) and SEC (Specific Energy Consumption).

IV.1 Modification Yanmar TF 85 MH-DI with CNG Performance Based on Simulation Result

Performance test on this diesel engine aims to find out the comparison of performance based on variation of ratio compression from diesel engine with power, torque and SFC (specific fuel consumption) through simulation. Pertamina Dex fuel is used as a reference for comparison in measuring diesel engine performance. Figure 4.1 is a simulated of the Yanmar TF 85 MH-DI.

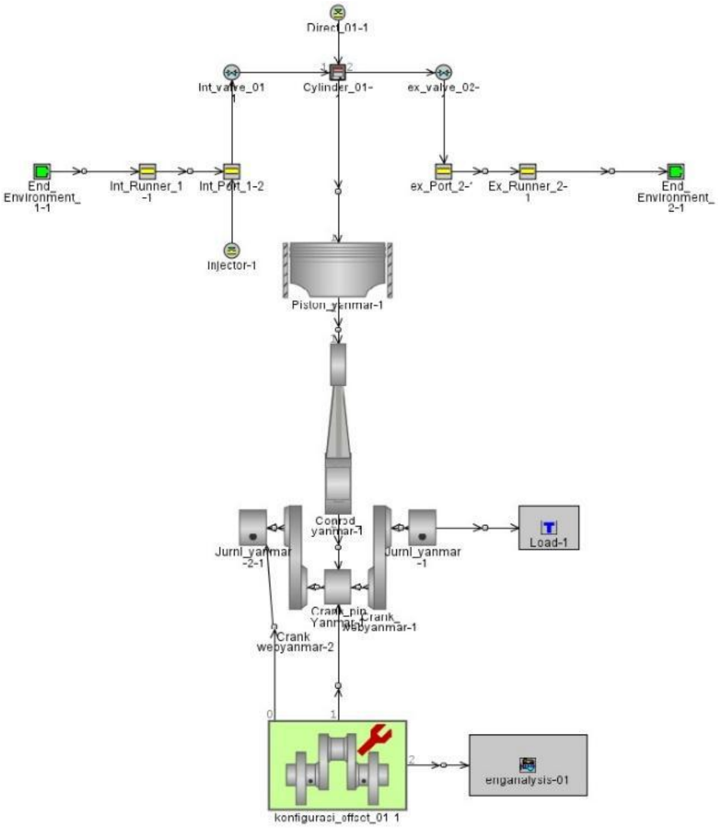


Figure 4.1. Yanmar TF 85 MH-DI in simulation

From the figure 4.1 the results are a comparison of torque vs. rpm with variations of compression ratio at 1500, 1800 and 2200 rpm engine speeds using 100% Pertamina Dex. By looking at the graph 4.1 it can be seen that there is no significant difference from any compression ratio that is so with graph 4.3 using 1L/min CNG fuel – Pertamina Dex as well as 2 L/min CNG-Pertamina Dex and 3L/min CNG-Pertamina Dex can be seen in figure 4.2 to 4.5.

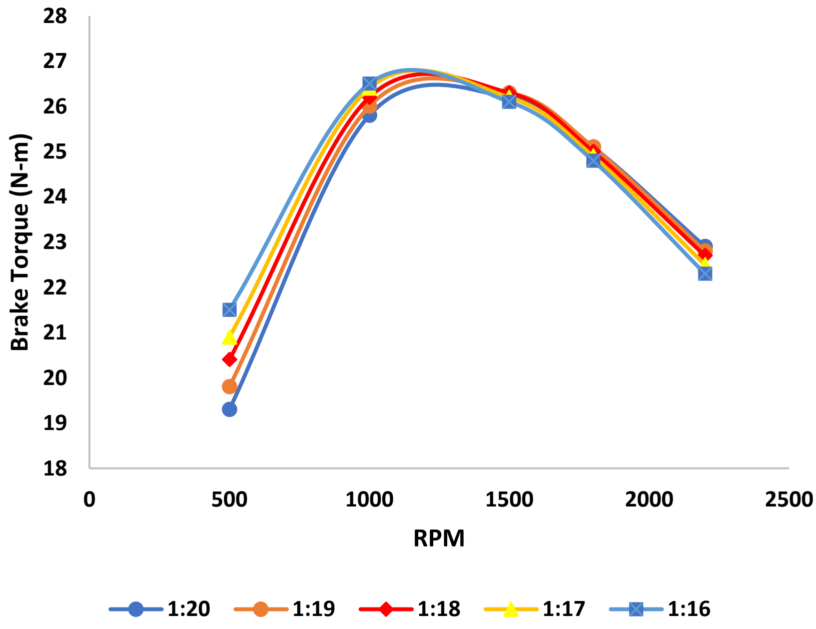


Figure 4.2. Torque vs RPM with Pertamina Dex

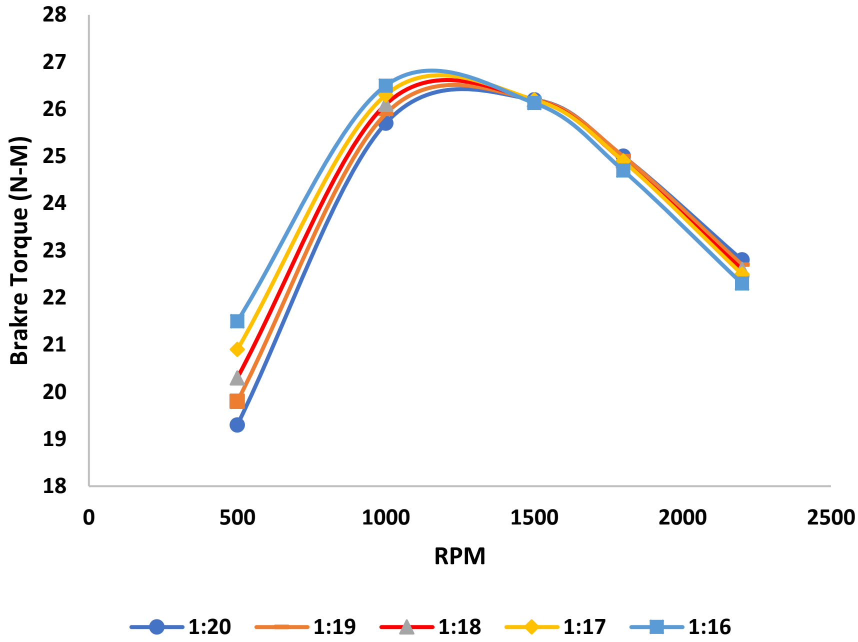


Figure 4.3. Torque vs RPM with Pertamina Dex + 1 l/min CNG

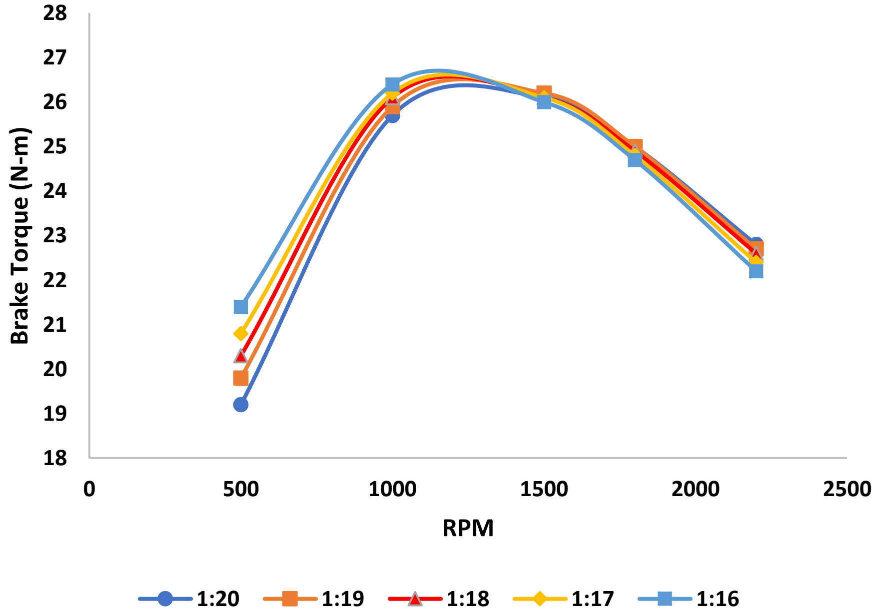


Figure 4.4. Torque vs RPM with Pertamina Dex + 2 l/min CNG

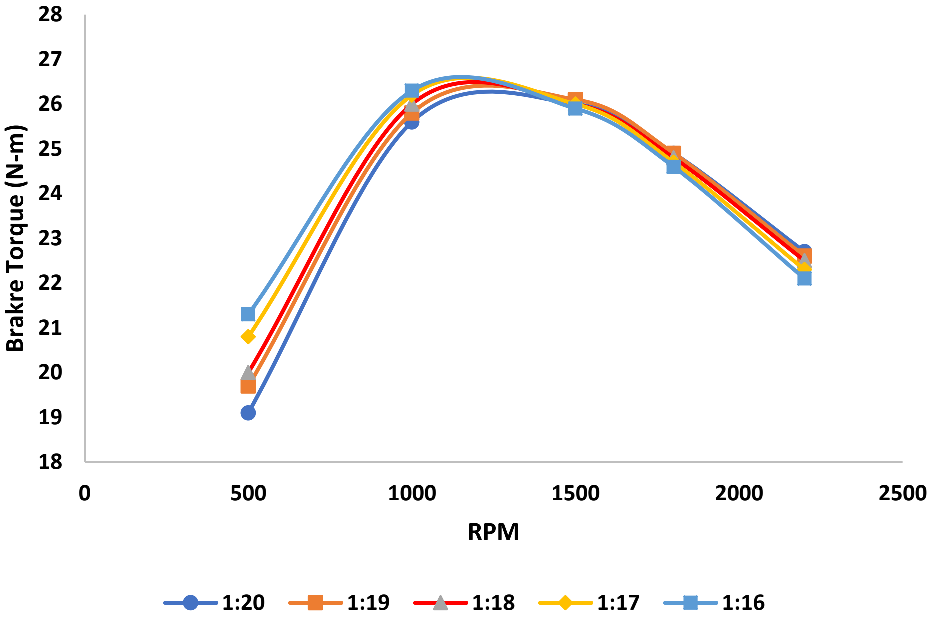


Figure 4.5. Torque vs RPM with Pertamina Dex + 3 l/min CNG

In the four comparison charts torque vs rpm with different variations of compression ratio seen several different results each case. the authors rate the best results contained at 1:16 compression because at the time of low rpm this ratio has a high enough torque to at high rpm the result was not proportional. So, the authors rate at 1:16 compression ratio has a good result.

The next discussion is power vs rpm ratio. In the charts 4.5 to 4.8 there is a difference of power with different compression ratio variations. Although in this result there is no significant difference in the loyalty of the compression ratio with cases ranging from 0 L/min CNG to 3 L/min CNG. Here's the power vs rpm comparison chart.

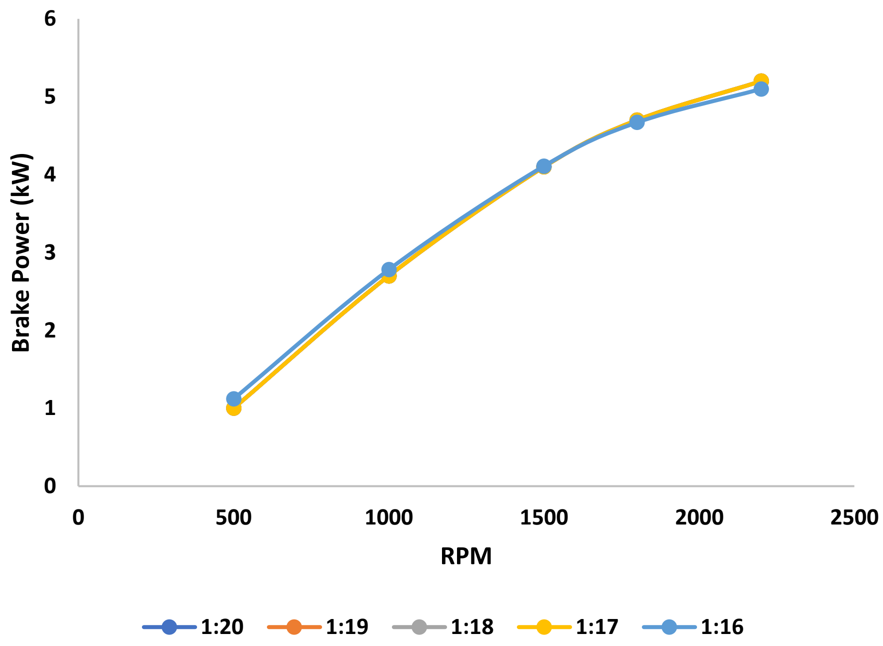


Figure 4.6. Power Vs RPM with Pertamina Dex

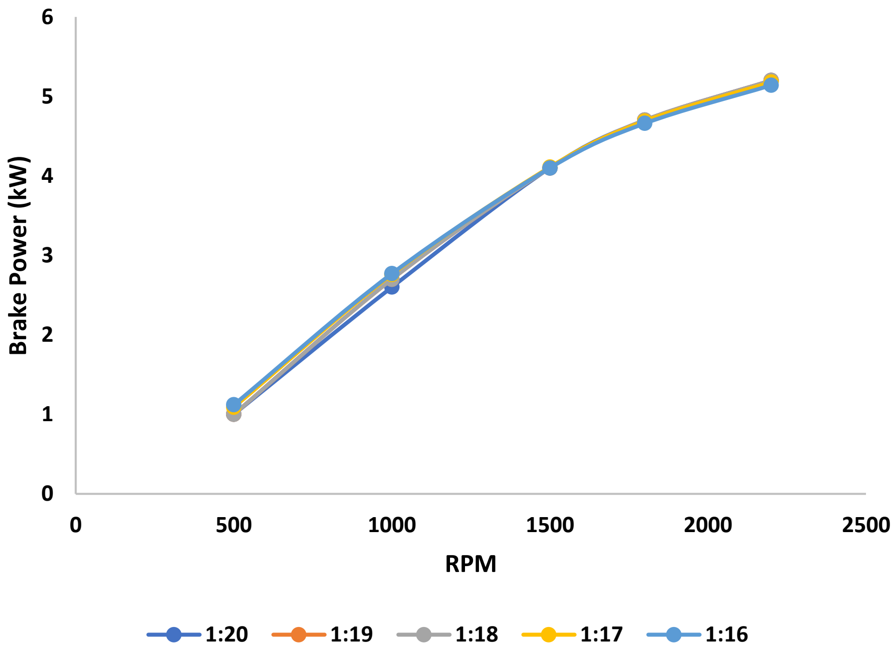


Figure 4.7. Power Vs RPM with Pertamina Dex + 1 l/min CNG

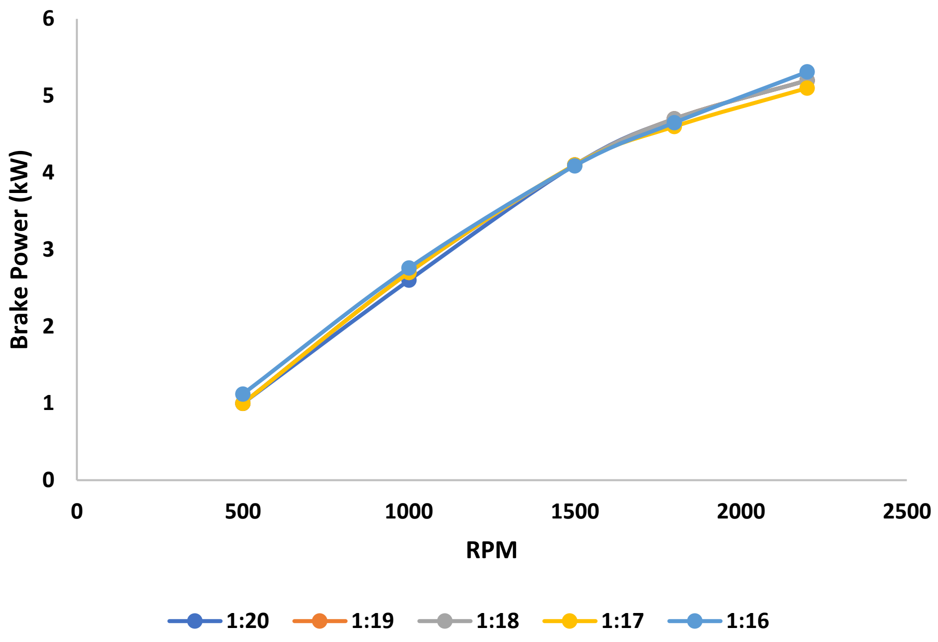


Figure 4.8. Power Vs RPM with Pertamina Dex + 2 l/min CNG

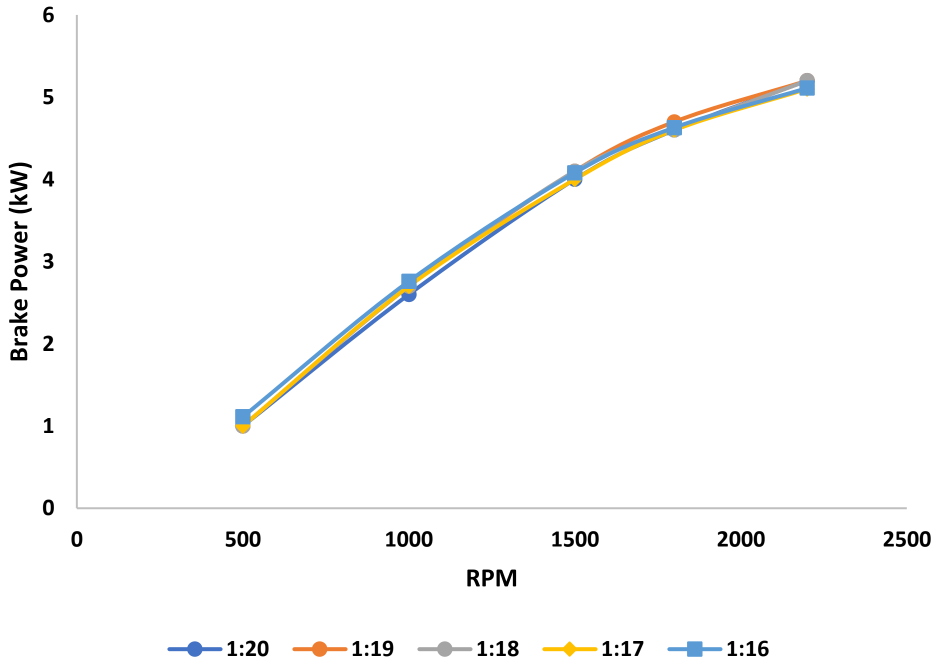


Figure 4.9. Power Vs RPM with Pertamina Dex + 3 l/min CNG

Of the power vs rpm comparison graphs with variable compression ratio and CNG has good results although still not in accordance with the actual engine specifications because there are some constraints from making this simulation so as not to achieve maximum results. From this result seen at 1:16 compression have good result from comparison of power vs rpm.

In the next figure the comparison between indicated specific fuel consumption (ISFC) vs rpm. In this graph using variable difference of compression ratio and CNG addition. From this result it does not seem very distinguished that if from some references there should be a very significant comparison of each of these CNG additions. Here is the comparison graph of ISFC vs rpm.

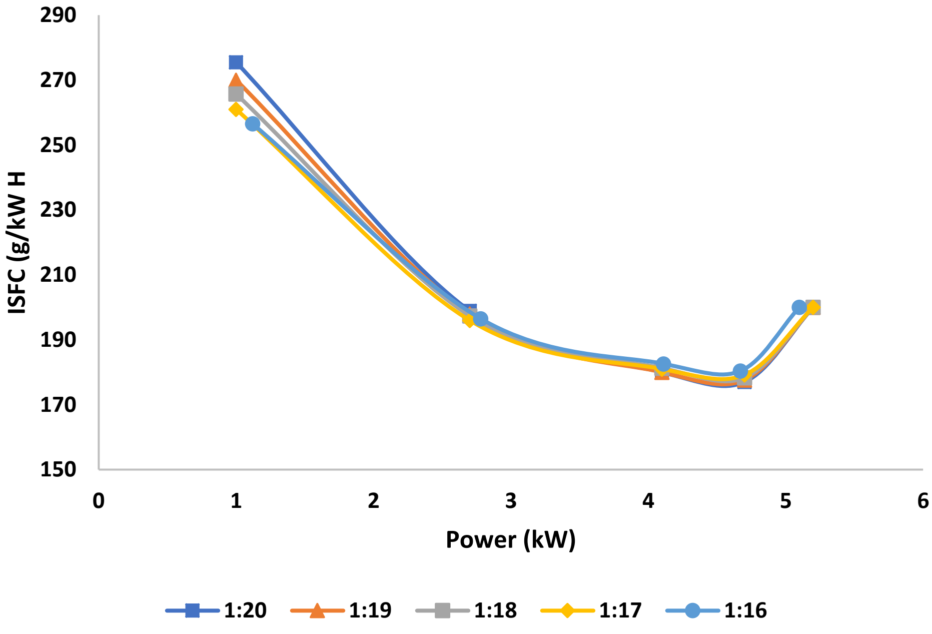


Figure 4.10. ISFC Vs Power (kW) with Pertamina Dex

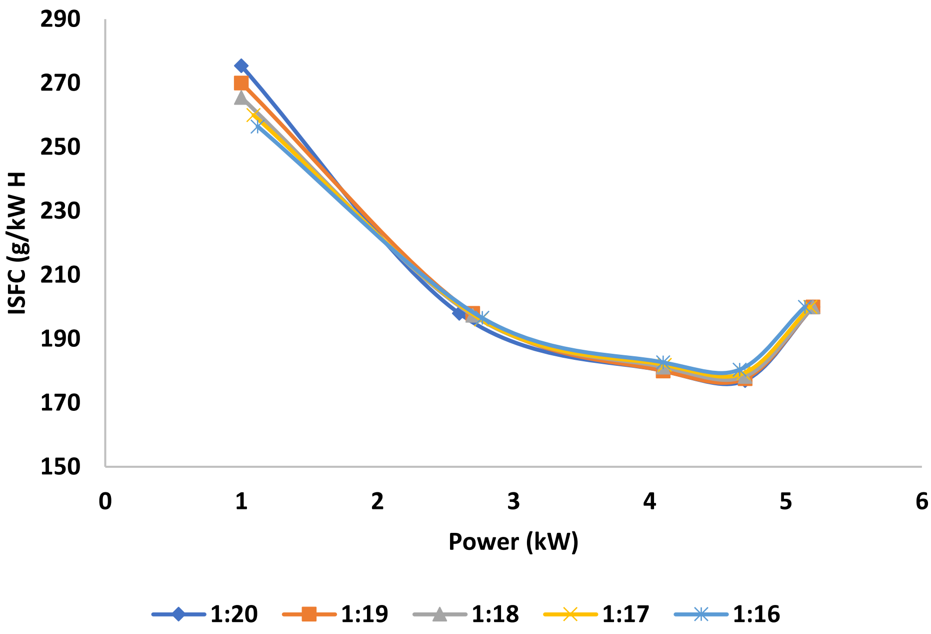


Figure 4.11. ISFC Vs Power (kW) with Pertamina Dex + 1 l/min CNG

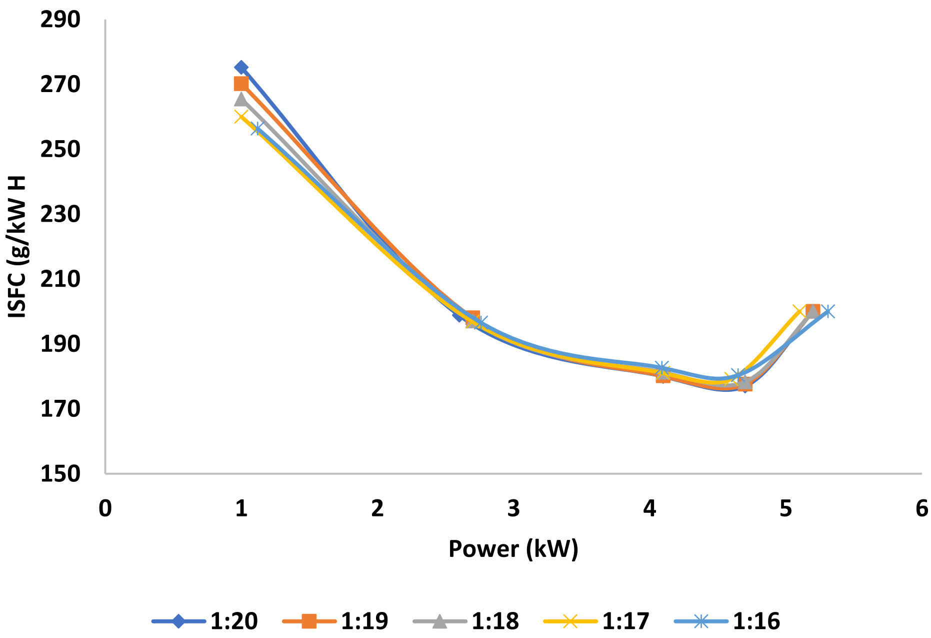


Figure 4.12. ISFC Vs Power (kW) with Pertamina Dex + 2 l/min CNG

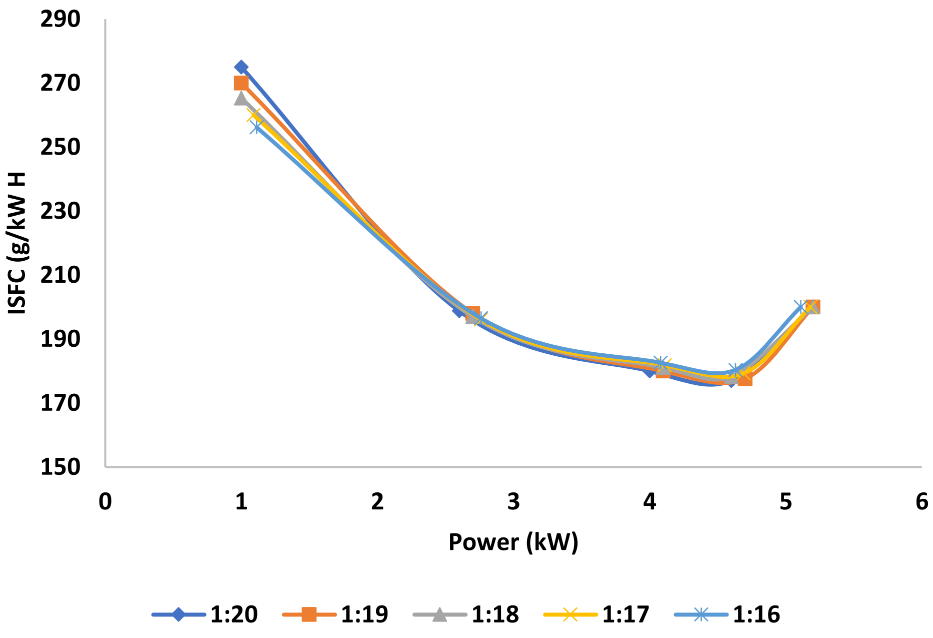


Figure 4.13. ISFC Vs Power (kW) with Pertamina Dex + 3 l/min CNG

Of the four figure 4.10 to 4.13 is in accordance with the existing theory that the higher the rpm the fuel consumption will be lower. However, this chart is still not satisfactory because it is not clearly visible difference between diesel engines fueled Pertamina Dex 100% with the addition of CNG 1 L/min, 2 L/min, and 3 L/min of CNG. Of the three data presented there are still many shortcomings in the results of this cause less valid data to be used as a reference. Therefore, the author will try with experiment directly on diesel engine which will be compared the results of both experiments.

IV.2 Modification Piston Yanmar TF 85 MH-DI

The process of this modification is done by calculating the volume of the combustion chamber first by using a burette glass to know in detail the volume of the combustion chamber when the CR condition is 1:18. From these results it is found that the piston must be reduced 2 ml to become CR 1:16.

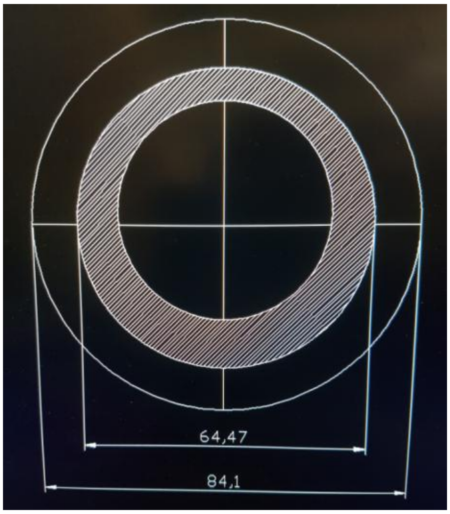


Figure 4.14. Sketch drawing of Piston Yanmar TF 85 MH-DI

Figure 4.15. Modification piston from CR 1:18 to CR 1:16

IV.3 Experiment Result

This chapter described the results and discussion of experimental test of diesel engine performance between CR 1:18 and CR 1:16. Comparison of fuel use to the subject by comparing the compression ratio used. Engine performance discussed includes power, torque, SFC (Specific Fuel Consumption) and SEC (Specific Energy Consumption). It also analyzes the effect of compression ratio on diesel engine performance.

IV.3.1 Power Analysis with Pertamina Dex

In this test aims to determine the power generated by different compression ratio is done with full load. In the graph CR 1:18 tendency to produce better power at 1800, 1900 and 2100 rounds while at CR 1:16 is better in lap 2000 and 2200. The results can be seen in figure 4.16.

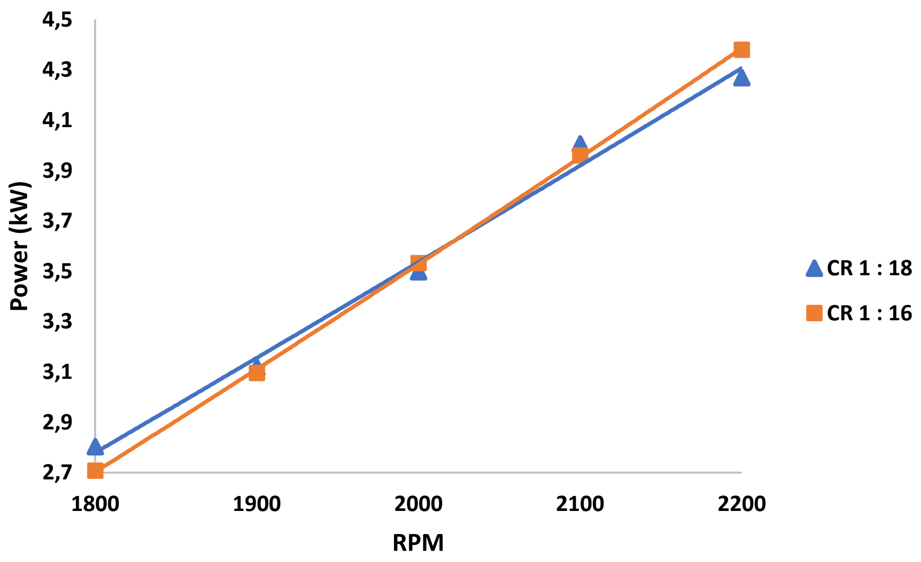


Figure 4.16. RPM Vs Power using Pertamina Dex

In figure 4.16 shows that the higher rpm and power generated during full load. At rpm 1800, the maximum power when using CR 1:18 and CR 1:16 respectively is 2.8 kW and 2.7 kW. When the 1900 rpm, the maximum power is 3.1 kW and 3.09 kW successively between CR 1:18 and CR 1:16. At 2000 rpm, obtained 3.49 kW and 3.53 kW CR 1:18 and CR 1:16. Then the power generated 4 kW at CR 1:18 and 3.95 kW with CR 1:16 at rpm 2100. At the time of rpm 2200, the maximum power when using CR 1:18 and CR 1:16 in a row is 4.27 kW and 4.38 kW. This phenomenon shows that the effect of compression ratio can improve engine power.

IV.3.2 Power Analysis with Pertamina Dex + 1l/min CNG

In this test aims to determine the power generated by different compression ratio is done with full load. In the graph CR 1:18 tendency to produce better power at rpm 1900 while at CR 1:16 at rpm 1800, 2000,2100 and 2200. The results can be seen in figure 4.17.

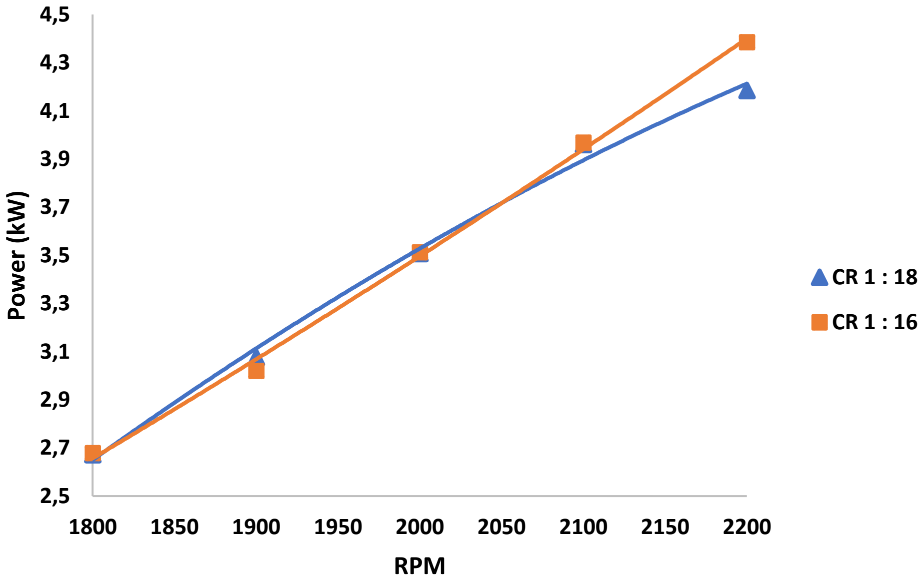


Figure 4.17. RPM Vs Power using Pertamina Dex + 1 L/min CNG

In figure 4.17 shows that the higher rpm and power generated during full load. At rpm 1800, the maximum power when using CR 1:18 and CR 1:16 respectively is 2.69 kW and 2.65 kW. When the 1900 rpm, the maximum power is 3 kW and 3.01 kW successively between CR 1:18 and CR 1:16. At 2000 rpm, obtained 3.5 kW and 3.53 kW CR 1:18 and CR 1:16. Then the power generated 3.9 kW at CR 1:18 and 3.96 kW with CR 1:16 at rpm 2100. At the time of rpm 2200, the maximum power when using CR 1:18 and CR 1:16 in a row is 4.1 kW and 4.38 kW. This phenomenon shows that the effect of compression ratio can improve engine power performance.

IV.3.3 Power Analysis with Pertamina Dex + 2l/min CNG

In this test aims to determine the power generated by different compression ratio is done with full load. In the graph CR 1:18 tendency to produce better power at rpm 2100 and 2200 while at CR 1:16 at rpm 1800, 2200. At rpm 1900 produce the same result in CR 1:18 and CR 1:16. The results can be seen in figure 4.18.

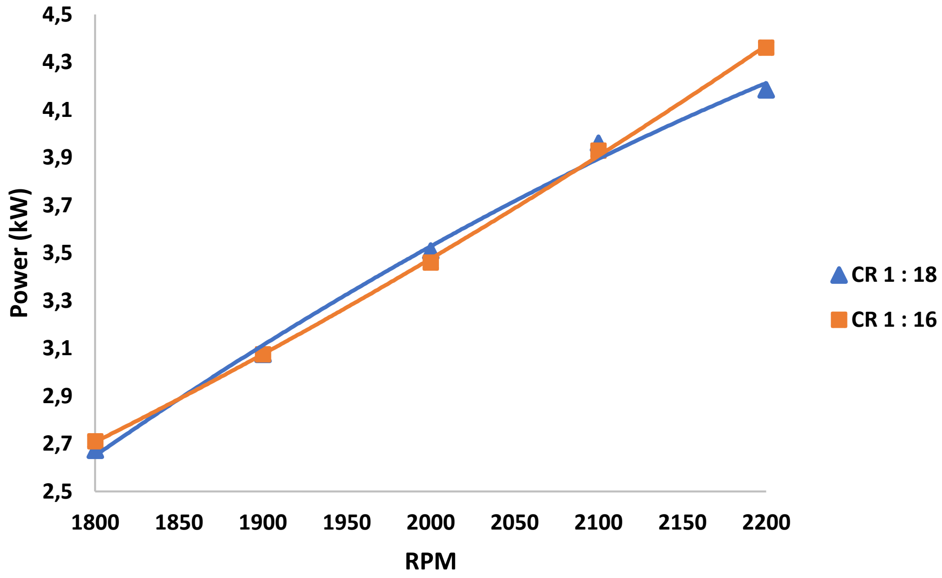


Figure 4.18. RPM Vs Power using Pertamina Dex + 2 L/min CNG

In figure 4.18 shows that the higher rpm and power generated during full load. At rpm 1800, the maximum power when using CR 1:18 and CR 1:16 respectively is 2.67 kW and 2.62 kW. When the 1900 rpm, the maximum power is 3 kW same result between CR 1:18 and CR 1:16. At 2000 rpm, obtained 3.5 kW and 3.48 kW CR 1:18 and CR 1:16. Then the power generated 3.91 kW at CR 1:18 and 3.89 kW with CR 1:16 at rpm 2100. At the time of rpm 2200, the maximum power when using CR 1:18 and CR 1:16 in a row is 4.1 kW and 4.4 kW. This phenomenon shows that the effect of compression ratio can improve engine power performance.

IV.3.4 Power Analysis with Pertamina Dex + 3l/min CNG

In this test aims to determine the power generated by different compression ratio is done with full load. In the graph CR 1:18 tendency to produce better power at rpm 1800, 1900 and 2000 while at CR 1:16 at rpm 2100 and 2200. The results can be seen in figure 4.19.

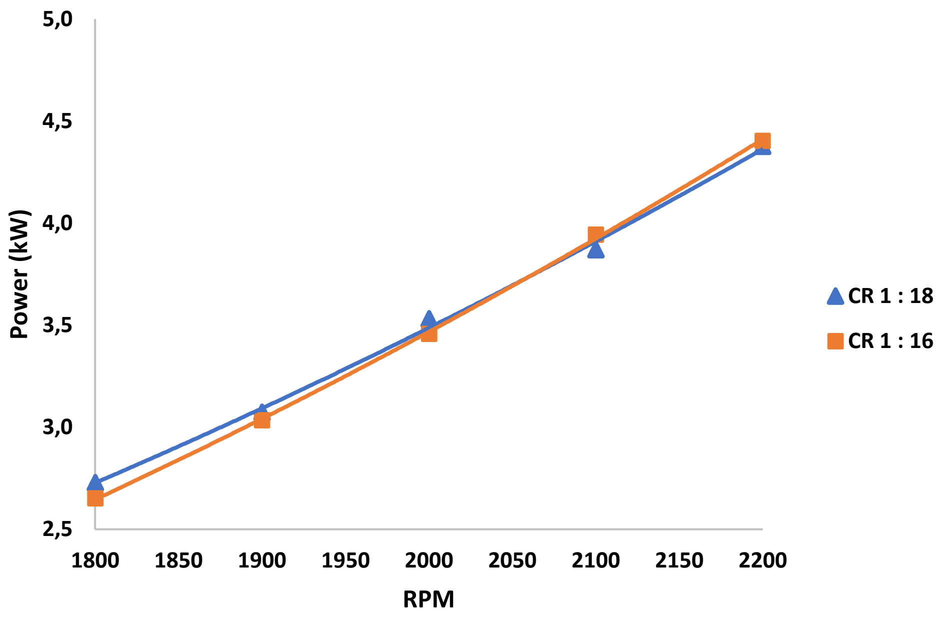


Figure 4.19. RPM Vs Power using Pertamina Dex + 3 L/min CNG

In figure 4.19 shows the higher power generated during full load. At rpm 1800, the maximum power when using CR 1:18 and CR 1:16 respectively is 2.72 kW and 2.65 kW. When the 1900 rpm, the maximum power is 3.1 kW at CR 1:18 and 3 kW at CR 1:16. At 2000 rpm, obtained 3.53 kW and 3.45 kW CR 1:18 and CR 1:16. Then the power generated 3.85 kW at CR 1:18 and 3.95 kW with CR 1:16 at rpm 2100. At the time of rpm 2200, the maximum power when using CR 1:18 and CR 1:16 in a row is 4.37 kW and 4.4 kW. This phenomenon shows that the effect of compression ratio can improve engine power performance.

IV.3.5 Torque Analysis with Pertamina Dex

In this test aims to determine the torque generated by different compression ratio is done with full load. In the graph CR 1:18 tendency to produce better torque at rpm 1800, 1900 and 2100 while at CR 1:16 at rpm 1900 and 2200. The results can be seen in figure 4.20.

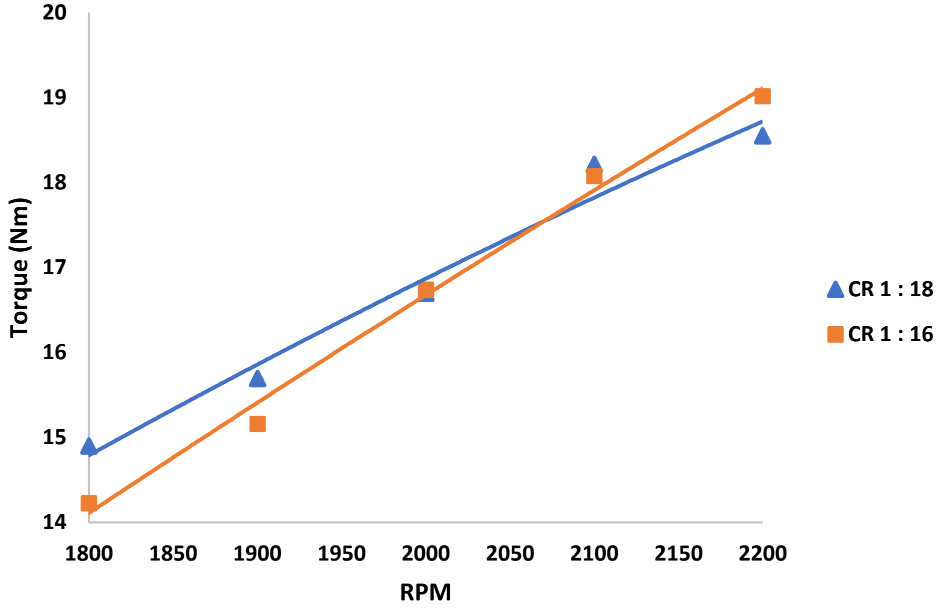


Figure 4.20. RPM Vs Torque using Pertamina Dex

The result in figure 4.20 shows the torque that produces when full load. At 1800 rpm, maximum torque when using CR 1:18 is 14.9 Nm and at CR 1:16 14.2 Nm where at this rpm CR 1:18 has better torque than CR 1:16. While 1900 rpm, maximum torque is 15.96 Nm at CR 1:18 and 15.15 Nm at CR 1:16. From 1900 rpm results look better using CR 1:18. At 2000 rpm, 16.69 Nm was obtained for CR 1:18 and 16.73 Nm at CR 1:16. At 2000 rpm the torque of CR 1:16 is better. Then the torque generated at 2100 rpm for CR 1:18 is 18.21 Nm and 18.07 Nm with CR 1:16. At rpm 2100 CR 1:18 has lower result than CR 1:16. At 2200 rpm, maximum torque when using CR 1:18 and CR 1:16 in a row is 18.54 Nm and 19 Nm. In maximum rpm where the maximum torque at CR 1:16 is better than CR 1:18. This phenomenon shows that the compression ratio can improve engine performance.

IV.3.6 Torque Analysis with Pertamina Dex + 1l/min CNG

In this test aims to determine the torque generated by different compression ratio is done with full load. In the graph CR 1:18 tendency to produce better torque at rpm 1900 rpm while at CR 1:16 at 1800, 2100, and 2200 rpm. At 2000 rpm has the same result. The results can be seen in figure 4.21.

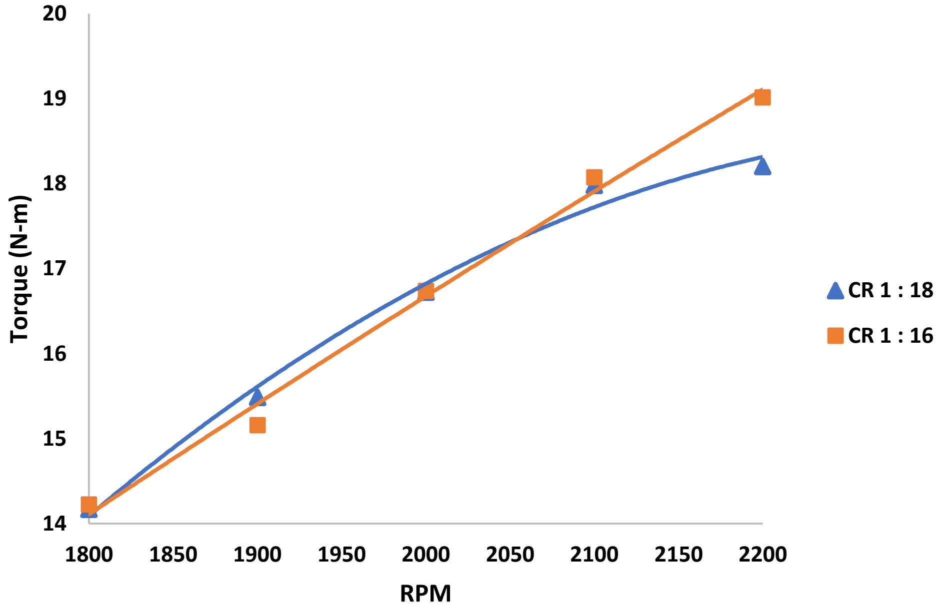


Figure 4.21. RPM Vs Torque using Pertamina Dex + 1 L/min CNG

The result in figure 4.21 shows the torque that produces when full load. At 1800 rpm, maximum torque when using CR 1:18 is 14,1 Nm and at CR 1:16 14,2 Nm where at this rpm CR 1:18 has better torque than CR 1:16. While 1900 rpm, maximum torque is 15.48 Nm at CR 1:18 and 15.15 Nm at CR 1:16. At 1900 rpm results look better using CR 1:16. At 2000 rpm, 16,72 Nm was obtained for CR 1:18 and 16.72 Nm at CR 1:16. At 2000 rpm the torque of CR 1:16 and CR 1:18 has same result. Then the torque generated at 2100 rpm for CR 1:18 is 17,97 Nm and 18.07 Nm with CR 1:16. At rpm 2100 CR 1:18 has lower result than CR 1:16. At 2200 rpm, maximum torque when using CR 1:18 and CR 1:16 in a row is 18,2 Nm and 19 Nm. In maximum rpm where the maximum torque at CR 1:16 is better than CR 1:18. This phenomenon shows that the compression ratio can improve engine performance.

IV.3.7 Torque Analysis with Pertamina Dex + 2l/min CNG

In this test aims to determine the torque generated by different compression ratio is done with full load. In the graph CR 1:18 tendency to produce better torque at rpm 1900, 2000 and 2100 while at CR 1:16 at rpm 1800 and 2200. The results can be seen in figure 4.22.

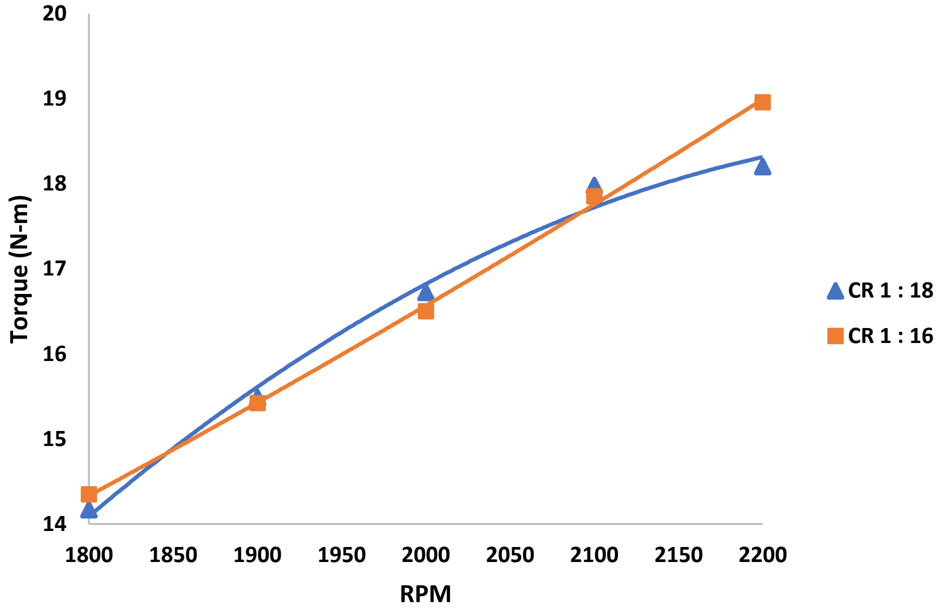


Figure 4.22. RPM Vs Torque using Pertamina Dex + 2 L/min CNG

The result in figure 4.22 shows the torque that produces when full load. At 1800 rpm, maximum torque when using CR 1:18 is 14,1 Nm and at CR 1:16 14,3 Nm where at this rpm CR 1:16 has better torque than CR 1:18. While 1900 rpm, maximum torque is 15.48 Nm at CR 1:18 and 15,4 Nm at CR 1:16. From 1900 rpm results look better using CR 1:18. At 2000 rpm, 16.72 Nm was obtained for CR 1:18 and 16,5 Nm at CR 1:16. At 2000 rpm the torque of CR 1:18 is better. Then the torque generated at 2100 rpm for CR 1:18 is 17,97 Nm and 17,9 Nm with CR 1:16. At rpm 2100 CR 1:16 has lower result than CR 1:18. At 2200 rpm, maximum torque when using CR 1:18 and CR 1:16 in a row is 18,2 Nm and 19 Nm. In maximum rpm where the maximum torque at CR 1:16 is better than CR 1:18. This phenomenon shows that the compression ratio can improve engine performance.

IV.3.8 Torque Analysis with Pertamina Dex + 3l/min CNG

In this test aims to determine the torque generated by different compression ratio is done with full load. In the graph CR 1:18 tendency to produce better torque at rpm 1800, 1900, 2000, 2100 while at CR 1:16 at rpm 2200. The results can be seen in figure 4.23.

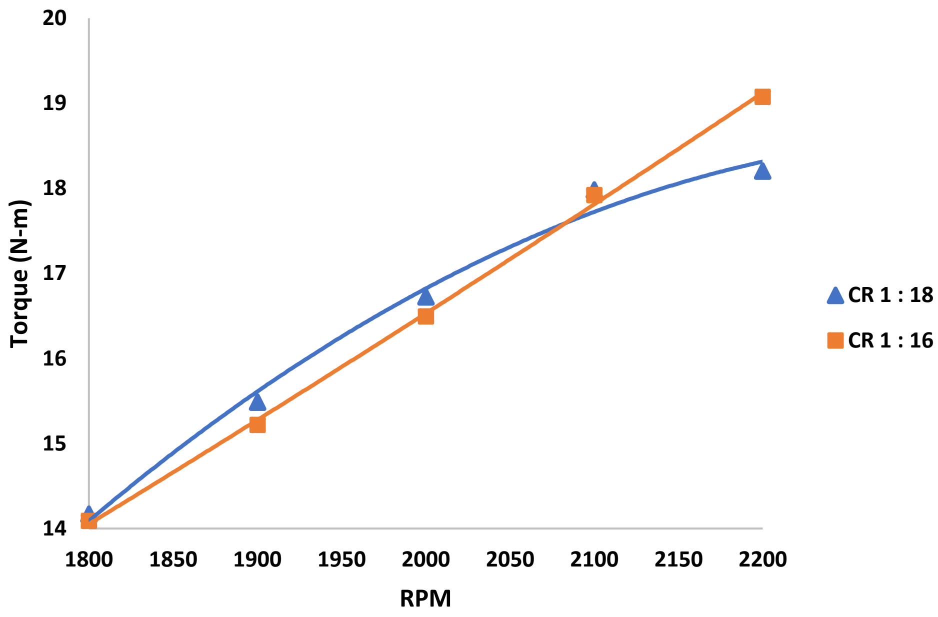


Figure 4.23. RPM Vs Torque using Pertamina Dex + 3 L/min CNG

The result in figure 4.23 shows the torque that produces when full load. At 1800 rpm, maximum torque when using CR 1:18 is 14,1 Nm and at CR 1:16 14 Nm where at this rpm CR 1:18 has better torque than CR 1:16. While 1900 rpm, maximum torque is 15.48 Nm at CR 1:18 and 15,21 Nm at CR 1:16. From 1900 rpm results look better using CR 1:18. At 2000 rpm, 16.72 Nm was obtained for CR 1:18 and 16,49 Nm at CR 1:16. At 2000 rpm the torque of CR 1:18 is better. Then the torque generated at 2100 rpm for CR 1:18 is 17,97 Nm and 17,91 Nm with CR 1:16. At rpm 2100 CR 1:16 has lower result than CR 1:18. At 2200 rpm, maximum torque when using CR 1:18 and CR 1:16 in a row is 18,2 Nm and 19 Nm. In maximum rpm where the maximum torque at CR 1:16 is better than CR 1:18. This phenomenon shows that the compression ratio can improve engine performance.

IV.3.9 SFOC (Specific Fuel Oil Consumption) Analysis with Pertamina Dex

In this test aims to find out SFOC of Yanmar TF 85 MH-DI with different compression ratio between CR 1:18 and CR 1:16. Data is taken at four variation load of 1 kW to 4kW. The data are presented in the chart below when the engine rpm is 1800. The results can be seen in figure 4.24.

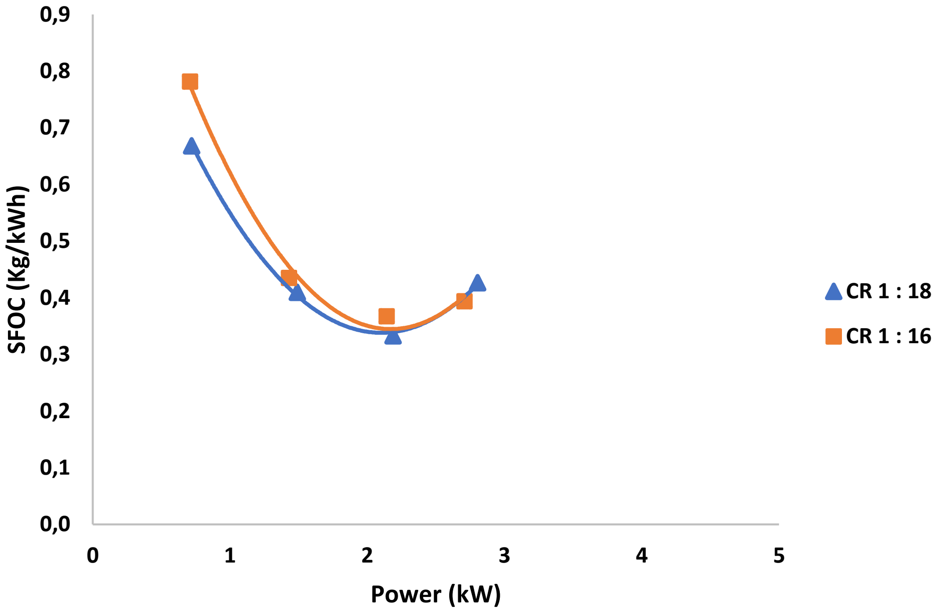


Figure 4.24. Power Vs SFOC at 1800 rpm using Pertamina Dex

In figure 4.24 the results obtained that the SFOC has decreased until a certain power increase again. This causes when the maximum power does not mean fuel consumption becomes the highest point or otherwise. At 1800 rpm when the maximum power, fuel consumption between CR 1:18 and CR 1:16 respectively is 0,42 Kg / kWh and 0,39 Kg / kWh. This suggests that when using CR 1:16 leads to lower energy consumption when the maximum power at a constant rotation of 1800 rpm with Pertamina Dex. The difference of fuel consumption caused by viscosity between Pertamina Dex and CNG, besides the difference of calorific value.

At 1900 rpm can be seen in figure 4.25 where the trend is different than before when using CR 1:18 energy consumption is lower when compared with CR 1:16. But there is a same from the previous where the maximum fuel consumption load is lower at CR 1:16.

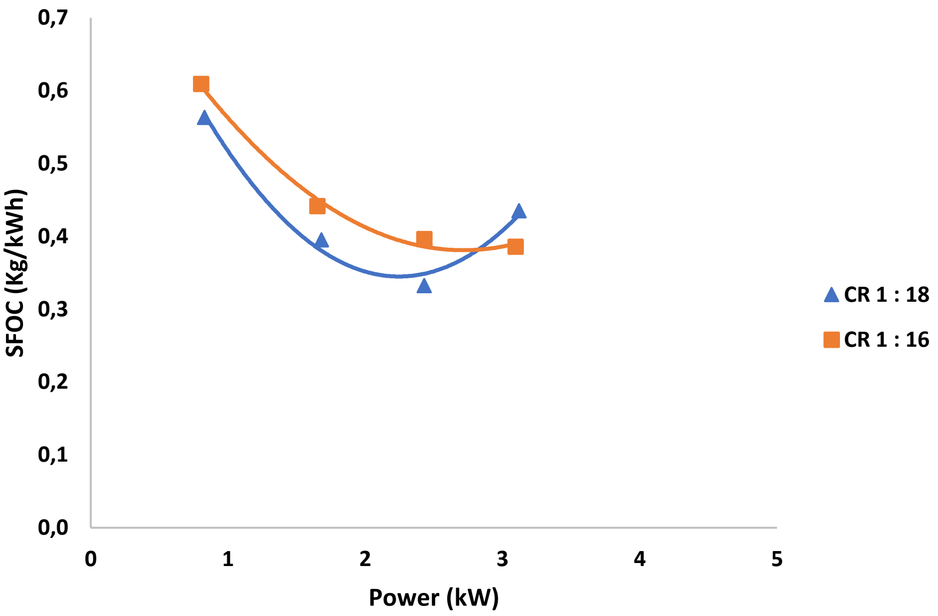


Figure 4.25. Power Vs SFOC at 1900 rpm using Pertamina Dex

In figure 4.25 the results obtained that the SFOC has decreased until a certain power increase again. This causes when the maximum power does not mean fuel consumption becomes the highest point or otherwise. At 1900 rpm when the maximum power, fuel consumption between CR 1:18 and CR 1:16 respectively is 0,43 Kg / kWh and 0,38 Kg / kWh. This suggests that when using CR 1:16 leads to lower fuel consumption when the maximum power at a constant rotation of 1900 rpm with Pertamina Dex. The difference of fuel consumption caused by viscosity between Pertamina Dex and CNG, besides the difference of calorific value.

At 2000 rpm can be seen in figure 4.26 where the trend is still the same than before when using CR 1:18 energy consumption is lower when compared with CR 1:16. But there is a different from the previous where the maximum fuel consumption load is lower at CR 1:18.

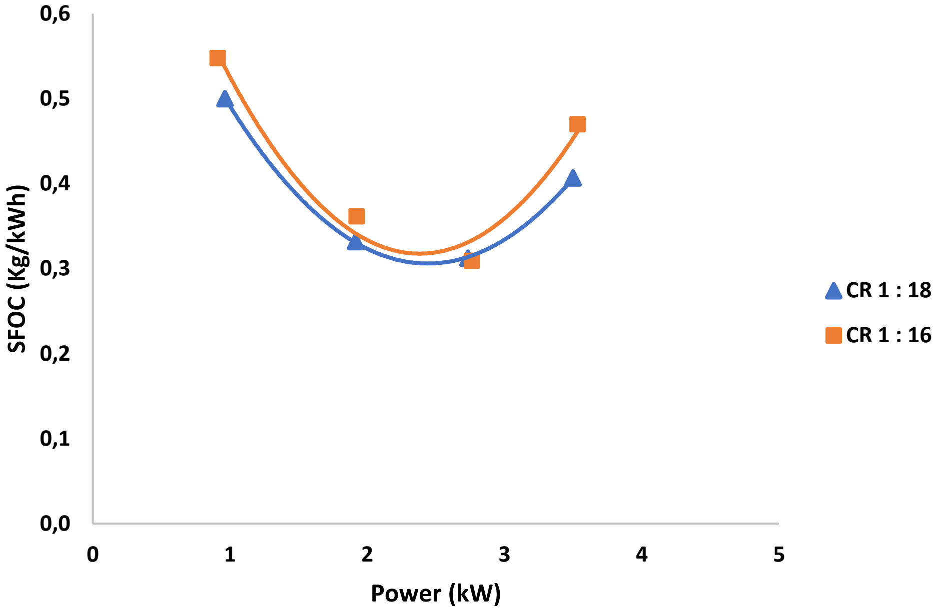


Figure 4.26. Power Vs SFOC at 2000 rpm using Pertamina Dex

In figure 4.26 the results obtained that the SFOC has decreased until a certain power increase again. This causes when the maximum power does not mean fuel consumption becomes the highest point or otherwise. At 1900 rpm when the maximum power, fuel consumption between CR 1:18 and CR 1:16 respectively is 0,4 Kg / kWh and 0,47 Kg / kWh. This suggests that when using CR 1:18 leads to lower fuel consumption when the maximum power at a constant rotation of 2000 rpm with Pertamina Dex. The difference of fuel consumption caused by viscosity between Pertamina Dex and CNG, besides the difference of calorific value.

At 2000 rpm can be seen in figure 4.27 where the trend is different than before. When using CR 1:18 at 2100 rpm fuel consumption is lower when compared with CR 1:16. But there is a different from the previous where the maximum fuel consumption load is lower at CR 1:16.

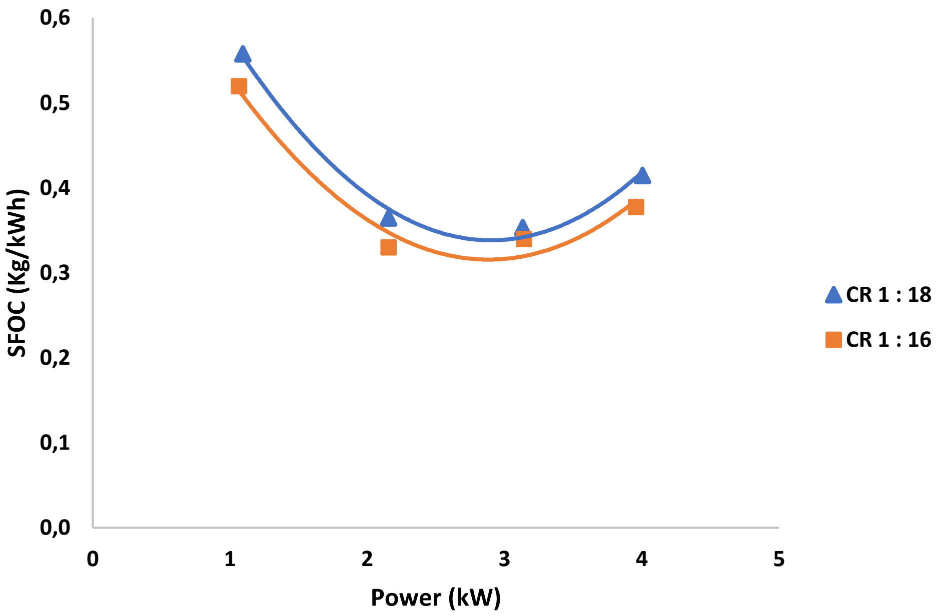


Figure 4.27. Power Vs SFOC at 2100 rpm using Pertamina Dex

In figure 4.27 the results obtained that the SFOC has decreased until a certain power increase again. This causes when the maximum power does not mean fuel consumption becomes the highest point or otherwise. At 1900 rpm when the maximum power, fuel consumption between CR 1:18 and CR 1:16 respectively is 0,41 Kg / kWh and 0,37 Kg / kWh. This suggests that when using CR 1:16 leads to lower fuel consumption when the maximum power at a constant rotation of 2100 rpm with Pertamina Dex. The difference of fuel consumption caused by viscosity between Pertamina Dex and CNG, besides the difference of calorific value.

At 2200 rpm can be seen in figure 4.28 where the trend is same than before. When using CR 1:16 at 2200 rpm energy consumption is lower when compared with CR 1:18. There is a same from the previous where the maximum load fuel consumption is lower at CR 1:16.

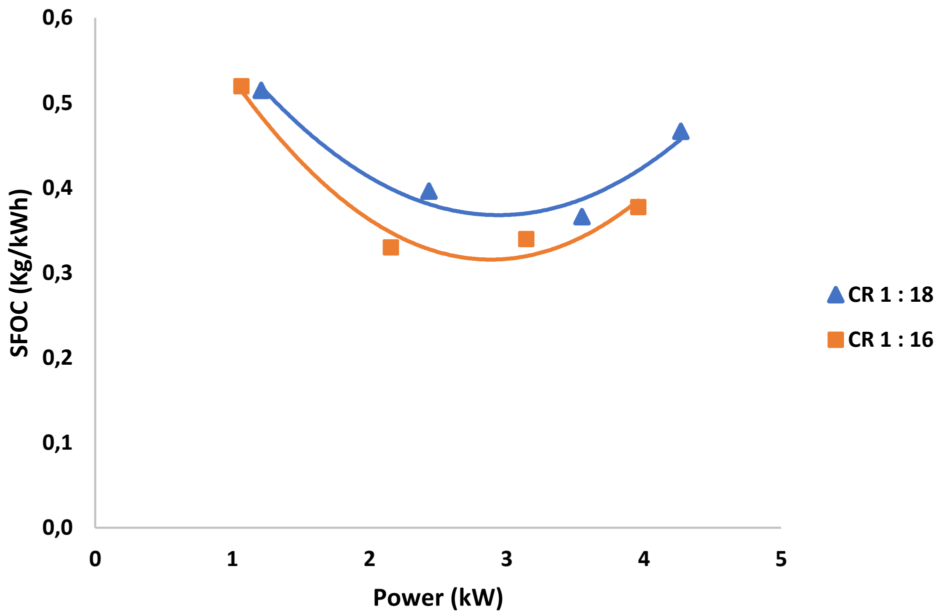


Figure 4.28. Power Vs SFOC at 2200 rpm using Pertamina Dex

In figure 4.28 the results obtained that the SFOC has decreased until a certain power increase again. This causes when the maximum power does not mean fuel consumption becomes the highest point or otherwise. At 1900 rpm when the maximum power, fuel consumption between CR 1:18 and CR 1:16 respectively is 0,46 Kg / kWh and 0,37 Kg / kWh. This suggests that when using CR 1:16 leads to lower fuel consumption when the maximum power at a constant rotation of 2200 rpm with Pertamina Dex. The difference of fuel consumption caused by viscosity between Pertamina Dex and CNG, besides the difference of calorific value.

IV.3.10 SEC (Specifiq Energy Consumption) Analysis with Pertamina Dex + 1 L/min CNG

In this test aims to find out SEC of Yanmar TF 85 MH-DI with fuel Pertamina Dex + 1 L/min when different compression ratio between CR 1:18 and CR 1:16. Data is taken at four variation load of 1 kW to 4kW. The data are presented in the chart below when the engine rpm is 1800. The results can be seen in figure 4.29.

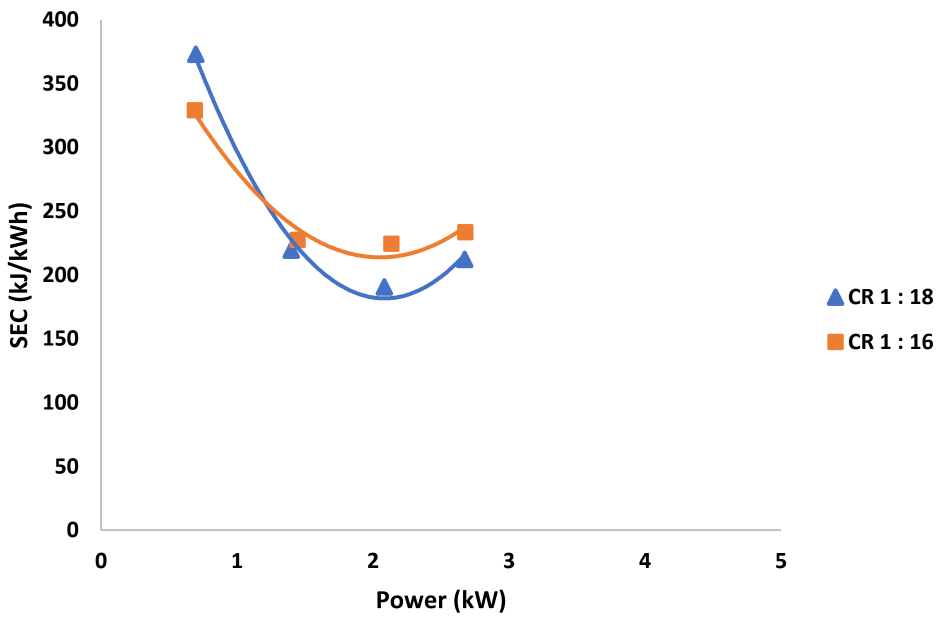


Figure 4.29. Power Vs SEC at 1800 rpm using Pertamina Dex + 1 L/min CNG

In figure 4.29 the results obtained that the SEC has decreased until a certain power increase again. This causes when the maximum power does not mean fuel consumption becomes the highest point or otherwise. At 1800 rpm when the maximum power, energy consumption between CR 1:18 and CR 1:16 respectively is 212 kJ / kWh and 218 kJ / kWh. This suggests that when using CR 1:18 leads to lower fuel consumption when the maximum power at a constant rotation of 1800 rpm with Pertamina Dex + 1 L/min. The difference of energy consumption caused by viscosity between Pertamina Dex and CNG, besides the difference of calorific value.

At 1900 rpm can be seen in figure 4.30 where the trend is same than before. When using CR 1:16 at 1900 rpm energy consumption is lower when 25% and 50 % load and CR 1:18 at 75% and 100% lod. There is same like the previous where the maximum load energy consumption is lower at CR 1:18.

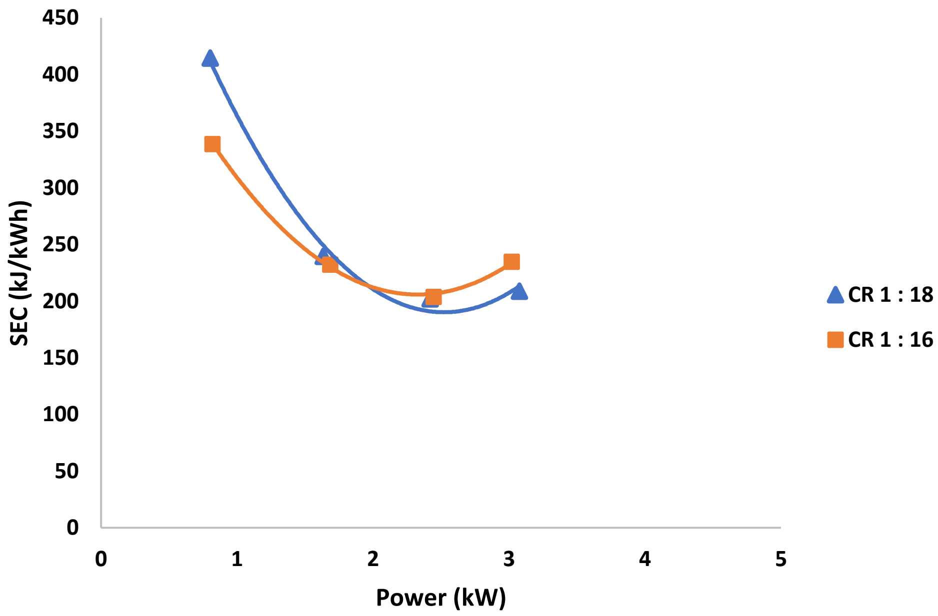


Figure 4.30. Power Vs SEC at 1900 rpm using Pertamina Dex + 1 L/min CNG

In figure 4.30 the results obtained that the SEC has decreased until a certain power increase again. This causes when the maximum power does not mean fuel consumption becomes the highest point or otherwise. At 1900 rpm when the maximum power, energy consumption between CR 1:18 and CR 1:16 respectively is 208 kJ / kWh and 221 kJ / kWh. This suggests that when using CR 1:18 leads to lower energy consumption when the maximum power at a constant rotation of 1900 rpm with Pertamina Dex + 1 L/min. The difference of energy consumption caused by viscosity between Pertamina Dex and CNG, besides the difference of calorific value.

At 2000 rpm can be seen in figure 4.31 where the trend is same than before. When using CR 1:16 at 2000 rpm energy consumption is lower when compared with CR 1:18. Different like the previous where the maximum load energy consumption is lower at CR 1:16.

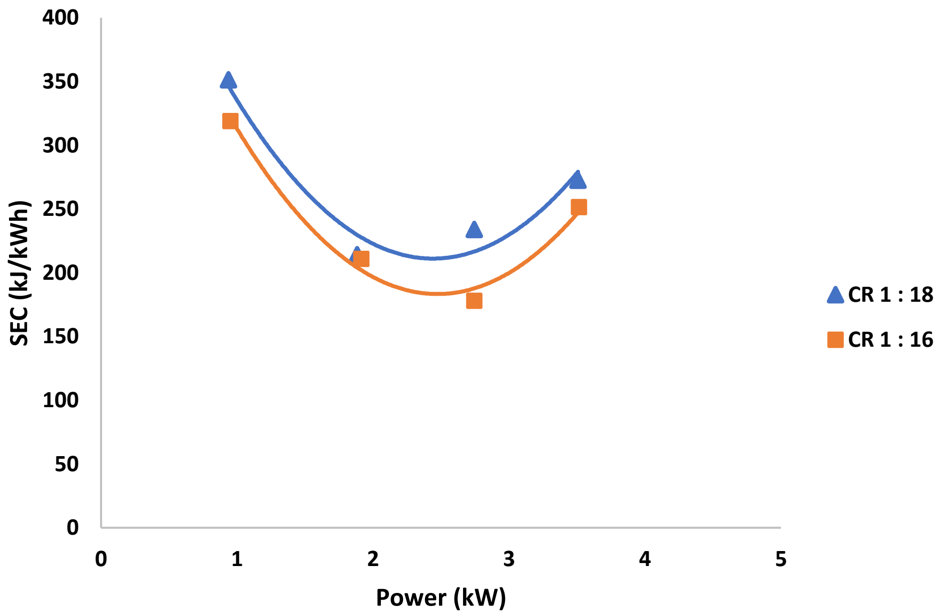


Figure 4.31. Power Vs SEC at 2000 rpm using Pertamina Dex + 1 L/min CNG

In figure 4.31 the results obtained that the SEC has decreased until a certain power increase again. This causes when the maximum power does not mean fuel consumption becomes the highest point or otherwise. At 2000 rpm when the maximum power, energy consumption between CR 1:18 and CR 1:16 respectively is 272 kJ / kWh and 240 kJ / kWh. This suggests that when using CR 1:16 leads to lower energy consumption when the maximum power at a constant rotation of 2000 rpm with Pertamina Dex + 1 L/min. The difference of energy consumption caused by viscosity between Pertamina Dex and CNG, besides the difference of calorific value.

At 2100 rpm can be seen in figure 4.32 where the trend is same than before. When using CR 1:16 at 2100 rpm energy consumption is lower when 25% and 50% load and CR 1:18 at 75% and 100% load. Different like the previous where the maximum load energy consumption is lower at CR 1:16 and CR 1:18.

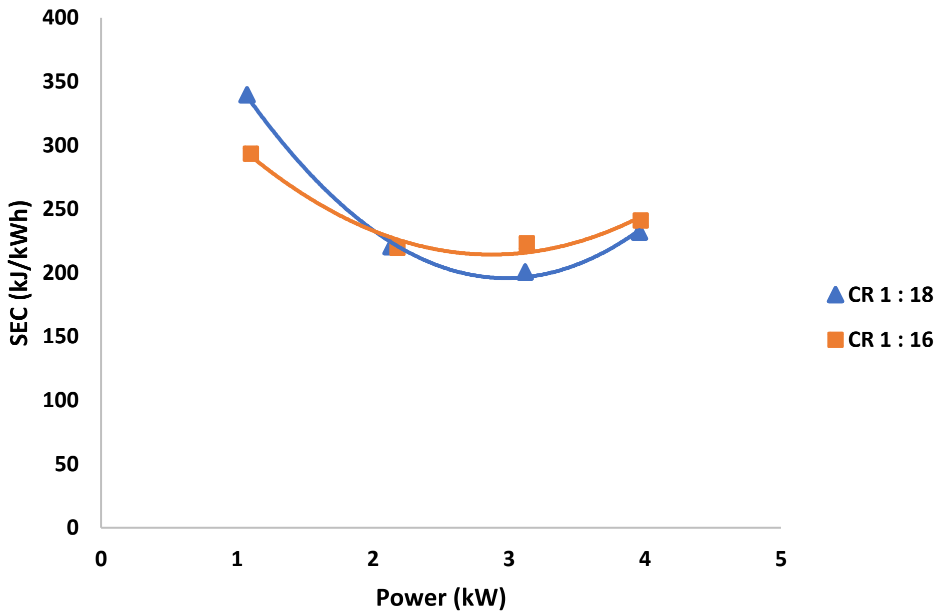


Figure 4.32. Power Vs SEC at 2100 rpm using Pertamina Dex + 1 L/min CNG

In figure 4.32 the results obtained that the SEC has decreased until a certain power increase again. This causes when the maximum power does not mean fuel consumption becomes the highest point or otherwise. At 2100 rpm when the maximum power, energy consumption between CR 1:18 and CR 1:16 respectively is same 231 kJ / kWh. This suggests that when using CR 1:16 or CR 1:18 leads to lower energy consumption when the maximum power at a constant rotation of 2100 rpm with Pertamina Dex + 1 L/min. The difference of energy consumption caused by viscosity between Pertamina Dex and CNG, besides the difference of calorific value.

At 2200 rpm can be seen in figure 4.33 where the trend is same than before. When using CR 1:16 at 2200 rpm energy consumption is lower when 75% and 100% load and CR 1:18 at 50% and 25% load. Different like the previous where the maximum load energy consumption is lower at CR 1:16.

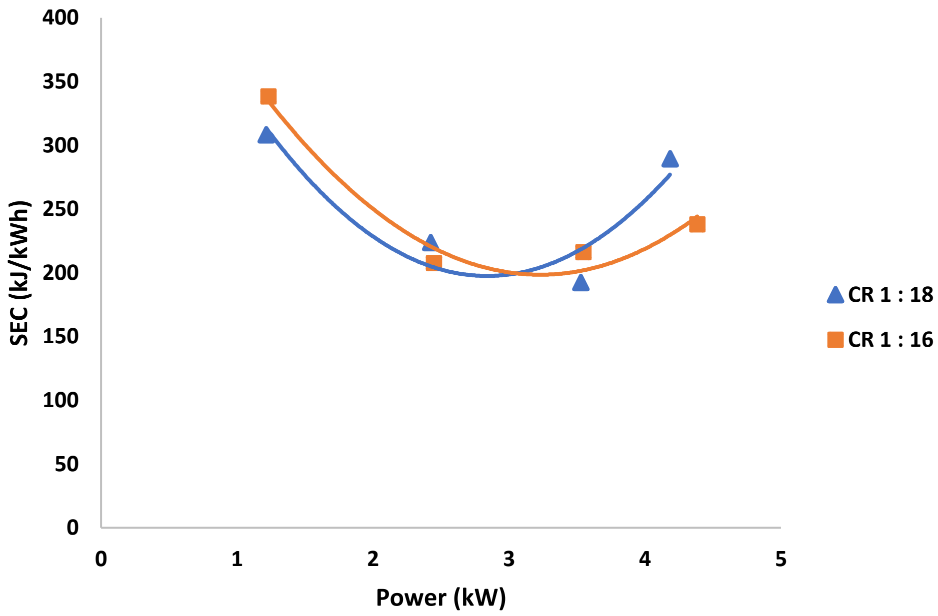


Figure 4.33. Power Vs SEC at 2200 rpm using Pertamina Dex + 1 L/min CNG

In figure 4.33 the results obtained that the SEC has decreased until a certain power increase again. This causes when the maximum power does not mean fuel consumption becomes the highest point or otherwise. At 2200 rpm when the maximum power, energy consumption between CR 1:18 and CR 1:16 respectively is 289 kJ/kWh and 229 kJ / kWh. This suggests that when using CR 1:16 leads to lower energy consumption when the maximum power at a constant rotation of 2200 rpm with Pertamina Dex + 1 L/min. The difference of energy consumption caused by viscosity between Pertamina Dex and CNG, besides the difference of calorific value.

IV.3.11 SEC (Specific Energy Consumption) Analysis with Pertamina Dex + 2 L/min CNG

In this test aims to find out SEC of Yanmar TF 85 MH-DI with fuel Pertamina Dex + 2 L/min when different compression ratio between CR 1:18 and CR 1:16. Data is taken at four variation load of 1 kW to 4kW. The data are presented in the chart below when the engine rpm is 1800. The results can be seen in figure 4.34.

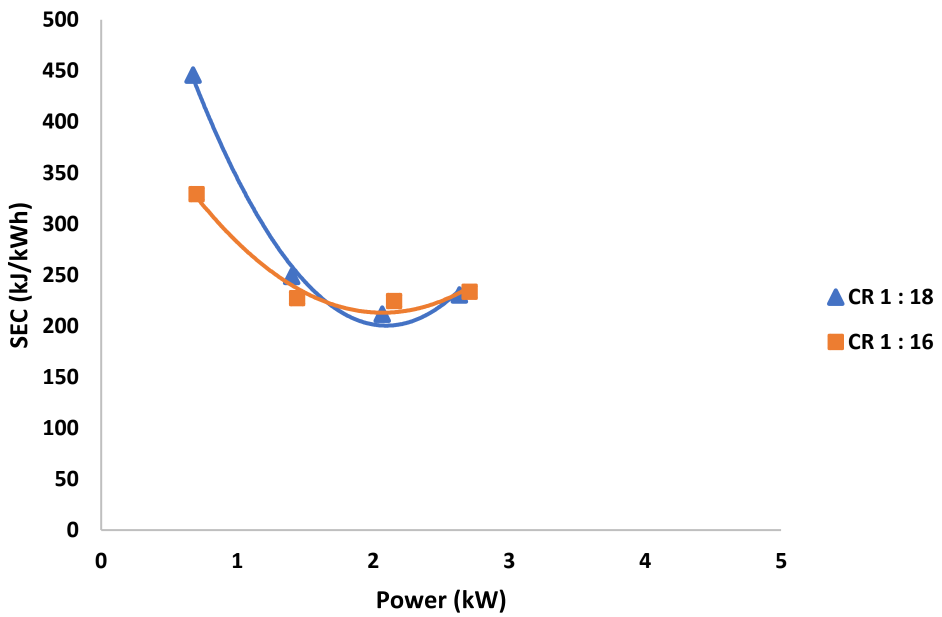


Figure 4.34. Power Vs SEC at 1800 rpm using Pertamina Dex + 2 L/min CNG

In figure 4.34 the results obtained that the SEC has decreased until a certain power increase again. This causes when the maximum power does not mean fuel consumption becomes the highest point or otherwise. At 1800 rpm when the maximum power, energy consumption between CR 1:18 and CR 1:16 respectively is 231 kJ/kWh and 218 kJ / kWh. This suggests that when using CR 1:16 leads to lower energy consumption when the maximum power at a constant rotation of 1800 rpm with Pertamina Dex + 2 L/min. The difference of energy consumption caused by viscosity between Pertamina Dex and CNG, besides the difference of calorific value.

At 1900 rpm can be seen in figure 4.35 where the trend is different than before. When using CR 1:16 at 1900 rpm fuel consumption is lower when compared with CR 1:18. Same like the previous where the maximum load energy consumption is lower at CR 1:16.

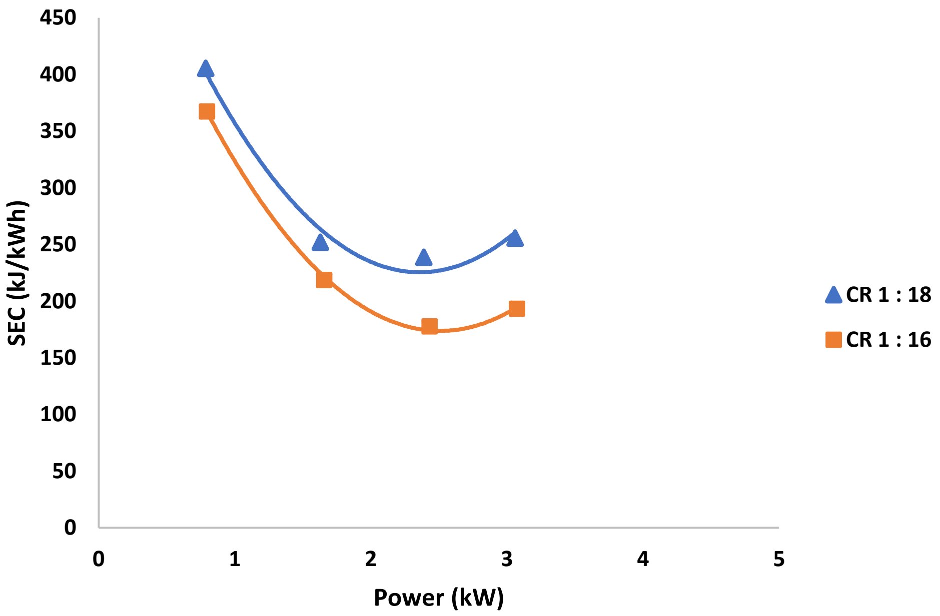


Figure 4.35. Power Vs SEC at 1900 rpm using Pertamina Dex + 2 L/min CNG

In figure 4.35 the results obtained that the SEC has decreased until a certain power increase again. This causes when the maximum power does not mean fuel consumption becomes the highest point or otherwise. At 1900 rpm when the maximum power, energy consumption between CR 1:18 and CR 1:16 respectively is 256 kJ/kWh and 193 kJ / kWh. This suggests that when using CR 1:16 leads to lower energy consumption when the maximum power at a constant rotation of 1900 rpm with Pertamina Dex + 2 L/min. The difference of energy consumption caused by viscosity between Pertamina Dex and CNG, besides the difference of calorific value.

At 2000 rpm can be seen in figure 4.36 where the trend is same than before. When using CR 1:16 at 2000 rpm energy consumption is lower when compared with CR 1:18. Same like the previous where the maximum load energy consumption is lower at CR 1:16.

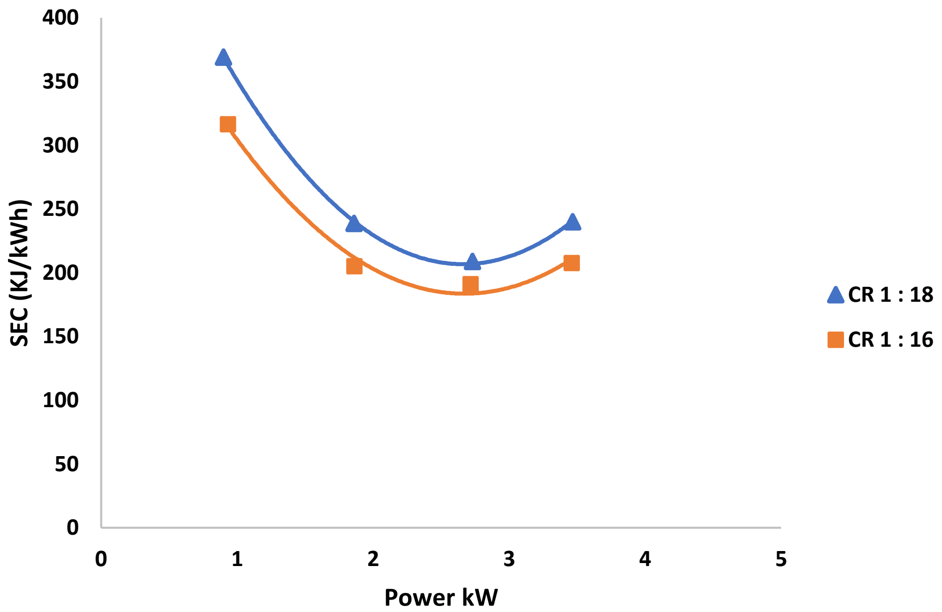


Figure 4.36. Power Vs SEC at 2000 rpm using Pertamina Dex + 2 L/min CNG

In figure 4.36 the results obtained that the SEC has decreased until a certain power increase again. This causes when the maximum power does not mean fuel consumption becomes the highest point or otherwise. At 2000 rpm when the maximum power, energy consumption between CR 1:18 and CR 1:16 respectively is 240 kJ/kWh and 207 kJ / kWh. This suggests that when using CR 1:16 leads to lower energy consumption when the maximum power at a constant rotation of 2000 rpm with Pertamina Dex + 2 L/min. The difference of energy consumption caused by viscosity between Pertamina Dex and CNG, besides the difference of calorific value.

At 2100 rpm can be seen in figure 4.37 where the trend is same than before. When using CR 1:16 at 2100 rpm energy consumption is lower when 50% load and at 75 % and 100 % load CR 1:18 lower than CR 1:16. But different like the previous where the maximum load energy consumption is lower at CR 1:18.

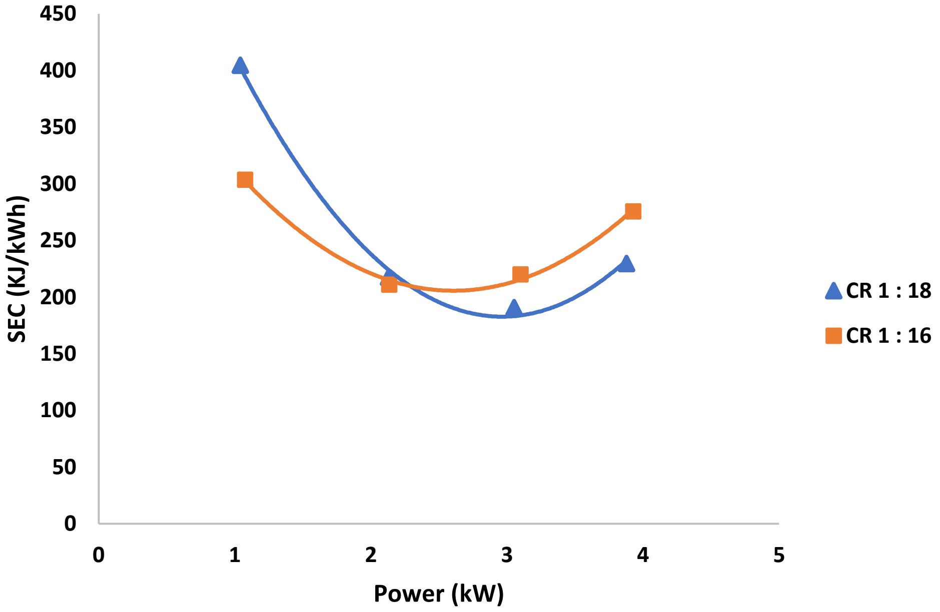


Figure 4.37. Power Vs SEC at 2100 rpm using Pertamina Dex + 2 L/min CNG

In figure 4.37 the results obtained that the SEC has decreased until a certain power increase again. This causes when the maximum power does not mean fuel consumption becomes the highest point or otherwise. At 2100 rpm when the maximum power, energy consumption between CR 1:18 and CR 1:16 respectively is 230 kJ/kWh and 275 kJ / kWh. This suggests that when using CR 1:18 leads to lower energy consumption when the maximum power at a constant rotation of 2100 rpm with Pertamina Dex + 2 L/min. The difference of energy consumption caused by viscosity between Pertamina Dex and CNG, besides the difference of calorific value.

At 2200 rpm can be seen in figure 4.38 where the trend is same than before. When using CR 1:16 at 2200 rpm energy consumption is lower when 25 % and 50% load and at 75 % and 100 % load CR 1:18 lower than CR 1:16. Same like the previous where the maximum load energy consumption is lower at CR 1:18.

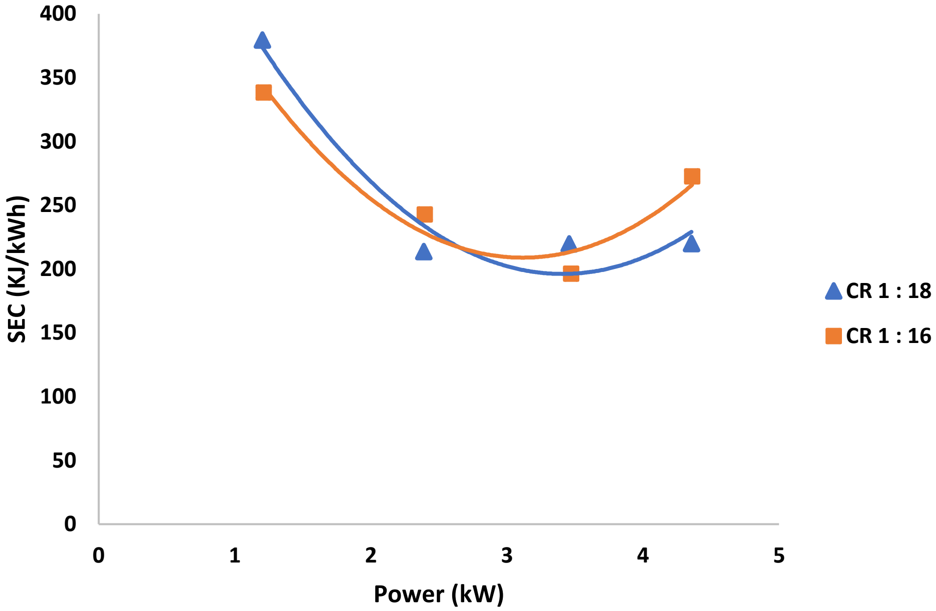


Figure 4.38.Power Vs SEC at 2200 rpm using Pertamina Dex + 2 L/min CNG

In figure 4.38 the results obtained that the SEC has decreased until a certain power increase again. This causes when the maximum power does not mean fuel consumption becomes the highest point or otherwise. At 2200 rpm when the maximum power, energy consumption between CR 1:18 and CR 1:16 respectively is 220 kJ/kWh and 272 kJ / kWh. This suggests that when using CR 1:18 leads to lower energy consumption when the maximum power at a constant rotation of 2200 rpm with Pertamina Dex + 2 L/min. The difference of energy consumption caused by viscosity between Pertamina Dex and CNG, besides the difference of calorific value.

IV.3.12 SEC (Specific Energy Consumption) Analysis with Pertamina Dex + 3 L/min CNG

In this test aims to find out SEC of Yanmar TF 85 MH-DI with fuel Pertamina Dex + 3 L/min when different compression ratio between CR 1:18 and CR 1:16. Data is taken at four variation load of 1 kW to 4kW. The data are presented in the chart below when the engine rpm is 1800. In the CR 1:16 chart the SEC trend is lower at 1800 rpm and 2200 rpm. The results can be seen in figure 4.39.

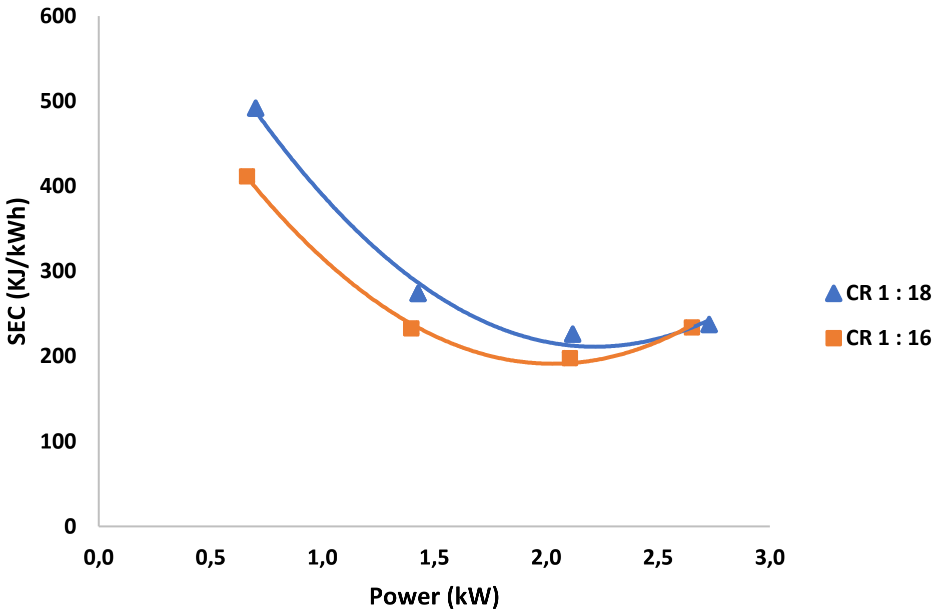


Figure 4.39. Power Vs SEC at 1800 rpm using Pertamina Dex + 3 L/min CNG

In figure 4.39 the results obtained that the SEC has decreased until a certain power increase again. This causes when the maximum power does not mean fuel consumption becomes the highest point or otherwise. At 1800 rpm when the maximum power, energy consumption between CR 1:18 and CR 1:16 respectively is 237 kJ/kWh and 234 kJ / kWh. This suggests that when using CR 1:18 leads to lower energy consumption when the maximum power at a constant rotation of 1800 rpm with Pertamina Dex + 3 L/min. The difference of energy consumption caused by viscosity between Pertamina Dex and CNG, besides the difference of calorific value.

At 1900 rpm can be seen in figure 4.40 where the trend is diffrent than before. When using CR 1:18 at 1900 rpm energy consumption is lower when compared with CR 1:16. Different like the previous where the maximum load energy consumption is lower at CR 1:18.

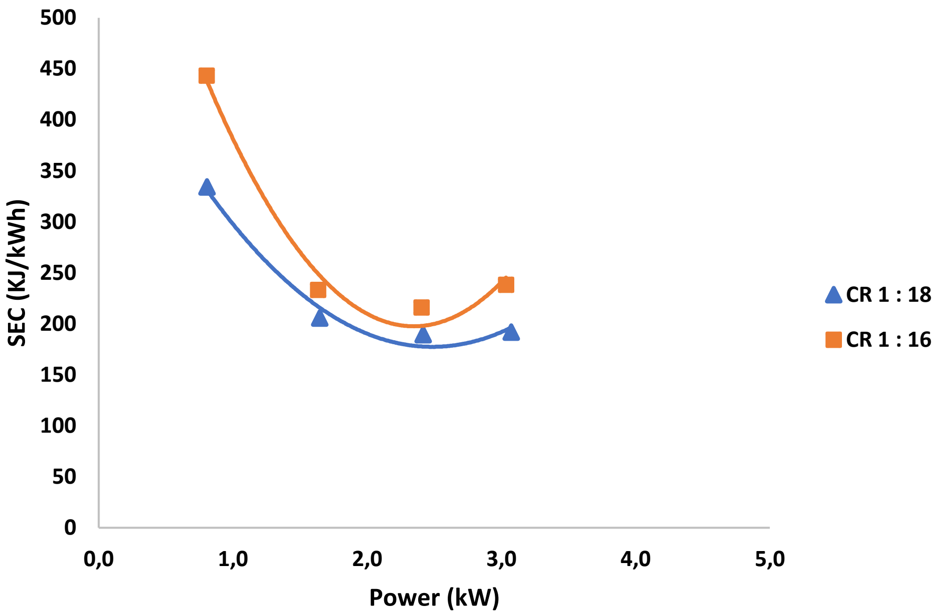


Figure 4.40. Power Vs SEC at 1900 rpm using Pertamina Dex + 3 L/min CNG

In figure 4.40 the results obtained that the SEC has decreased until a certain power increase again. This causes when the maximum power does not mean fuel consumption becomes the highest point or otherwise. At 1900 rpm when the maximum power, energy consumption between CR 1:18 and CR 1:16 respectively is 191 kJ/kWh and 238 kJ / kWh. This suggests that when using CR 1:18 leads to lower energy consumption when the maximum power at a constant rotation of 1900 rpm with Pertamina Dex + 3 L/min. The difference of energy consumption caused by viscosity between Pertamina Dex and CNG, besides the difference of calorific value.

At 2000 rpm can be seen in figure 4.41 where the trend is same than before. When using CR 1:18 at 2000 rpm energy consumption is lower when compared with CR 1:18. Same like the previous where the maximum load energy consumption is lower at CR 1:18.

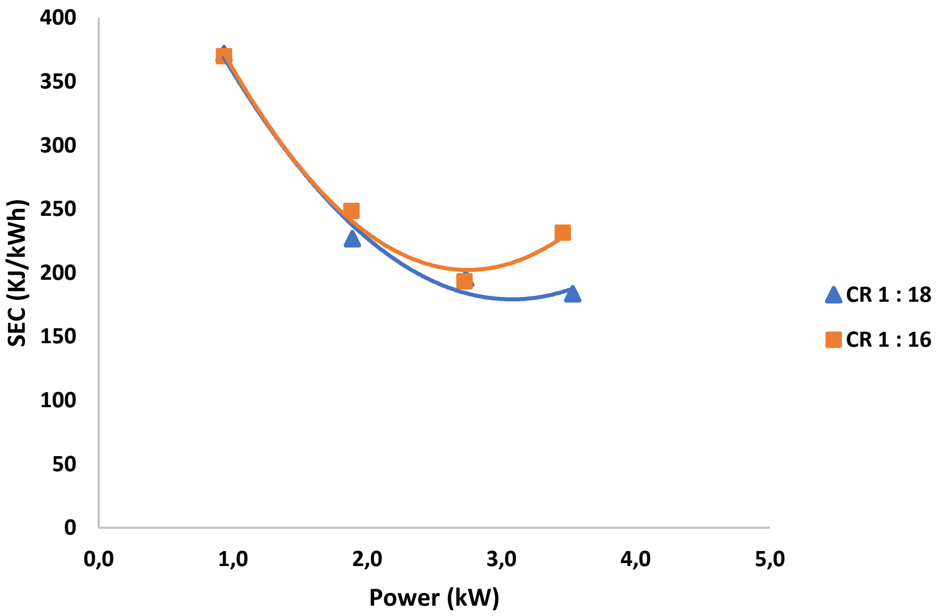


Figure 4.41.Power Vs SEC at 2000 rpm using Pertamina Dex + 3 L/min CNG

In figure 4.41 the results obtained that the SEC has decreased until a certain power increase again. This causes when the maximum power does not mean fuel consumption becomes the highest point or otherwise. At 2000 rpm when the maximum power, energy consumption between CR 1:18 and CR 1:16 respectively is 183. kJ/kWh and 231 kJ / kWh. This suggests that when using CR 1:18 leads to lower energy consumption when the maximum power at a constant rotation of 2000 rpm with Pertamina Dex + 3 L/min. The difference of energy consumption caused by viscosity between Pertamina Dex and CNG, besides the difference of calorific value.

At 2100 rpm can be seen in figure 4.42 where the trend is same than before. When using CR 1:18 at 2100 rpm energy consumption is lower when compared with CR 1:16. Different like the previous where the maximum load energy consumption is lower at CR 1:18.

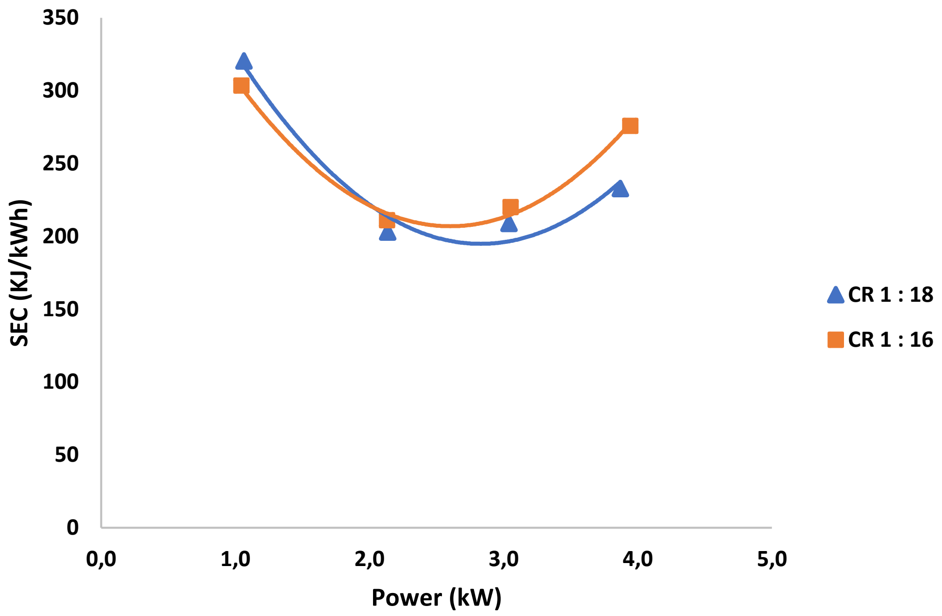


Figure 4.42. Power Vs SEC at 2100 rpm using Pertamina Dex + 3 L/min CNG

In figure 4.42 the results obtained that the SEC has decreased until a certain power increase again. This causes when the maximum power does not mean fuel consumption becomes the highest point or otherwise. At 2200 rpm when the maximum power, energy consumption between CR 1:18 and CR 1:16 respectively is 289 kJ/kWh and 229 kJ / kWh. This suggests that when using CR 1:16 leads to lower energy consumption when the maximum power at a constant rotation of 2200 rpm with Pertamina Dex + 1 L/min. The difference of energy consumption caused by viscosity between Pertamina Dex and CNG, besides the difference of calorific value.

At 2200 rpm can be seen in figure 4.43 where the trend is different than before. When using CR 1:16 at 2200 rpm fuel consumption is lower when compared with CR 1:18. Different like the previous where the maximum load energy consumption is lower at CR 1:16.

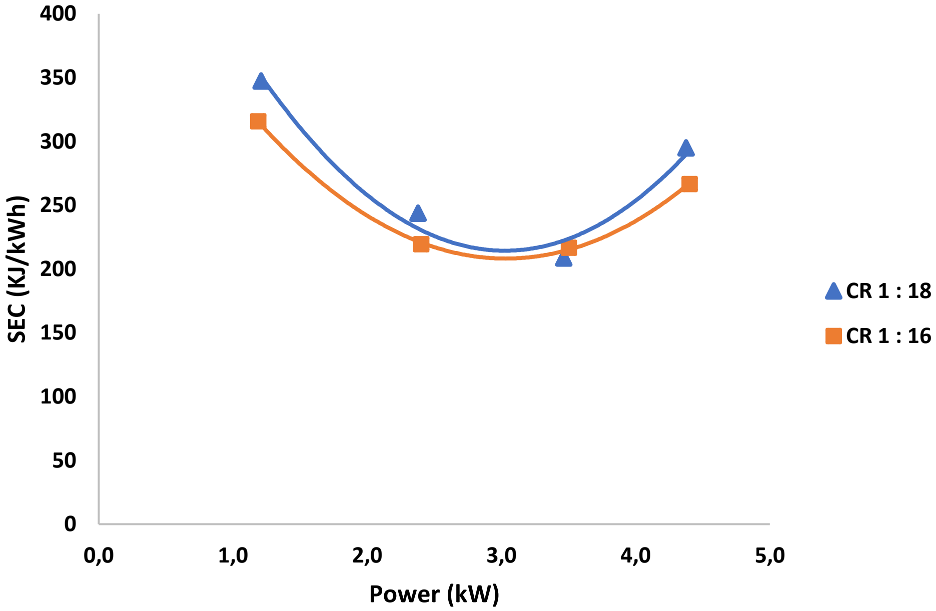


Figure 4.43. Power Vs SEC at 2200 rpm using Pertamina Dex + 3 L/min CNG

In figure 4.43 the results obtained that the SEC has decreased until a certain power increase again. This causes when the maximum power does not mean fuel consumption becomes the highest point or otherwise. At 2200 rpm when the maximum power, energy consumption between CR 1:18 and CR 1:16 respectively is 294 kJ/kWh and 266 kJ / kWh. This suggests that when using CR 1:16 leads to lower energy consumption when the maximum power at a constant rotation of 2200 rpm with Pertamina Dex + 3 L/min. The difference of energy consumption caused by viscosity between Pertamina Dex and CNG, besides the difference of calorific value.

IV.3.13 Total Power Analysis

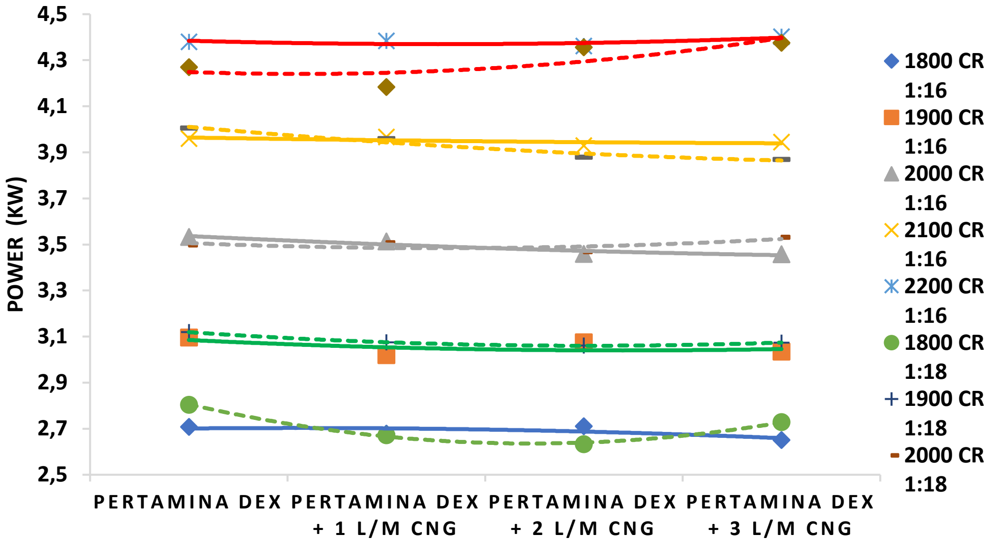


Figure 4.44. Power total

In figure 4.44 can be seen that the phenomenon of total power in each fuel and rpm not significant power difference between CR 1:18 and CR 1:16. The difference when the 2200 rpm with Pertamina Dex and Pertamina Dex + 1 l / min. although not much different at 2200 rpm with Pertamina Dex but can be seen the power generated at CR 1:18 of 4.26 kW and at CR 1:16 of 4.4 kW. 3.3% increase occurs when using CR 1:16 at 2200 rpm with Pertamina Dex. While on the Pertamina Dex + 1 l / m CR 1:18 generate power of 4.18 kW and at CR 1:16 produce power of 4.38 kW. From this result there was an increase of 4.8% when using CR 1:16. The rest between CR 1:18 and CR 1:16 at each rpm and no significant fuel difference.

IV.3.14 Total Torque Analysis

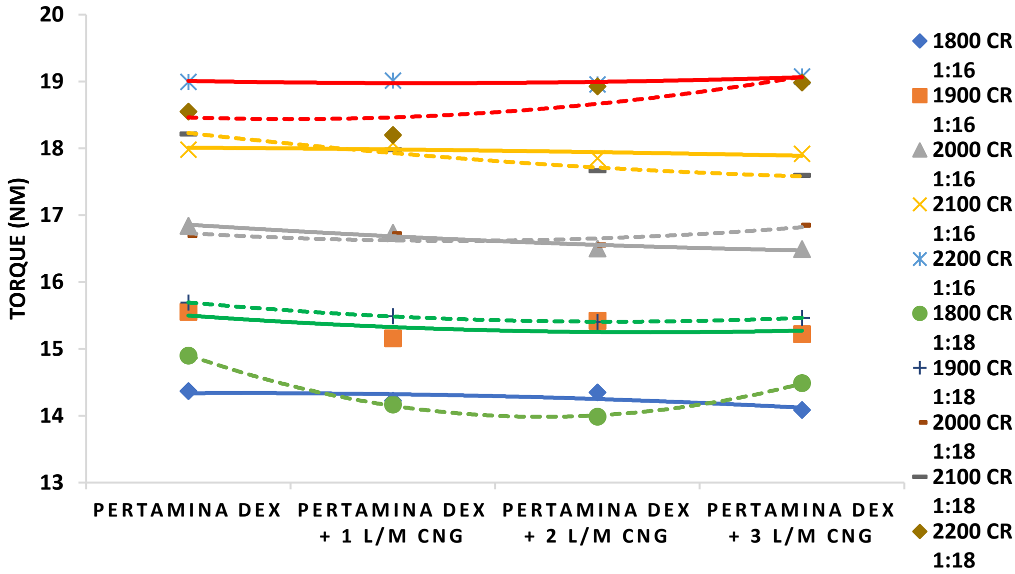


Figure 4.45. Torque total

In figure 4.45 can be seen the phenomenon of total torque on each fuel and rpm no significant torque difference between CR 1:18 with CR 1:16. Because power and torque are directly proportional. So just like the previous graph where the difference looks when the 2200 rpm Pertamina Dex and Pertamina Dex + 1 l / min. Although not so much different at 2200 rpm Pertamina Dex can be seen the torque generated at CR 1:18 of 18.5 Nm and at CR 1:16 of 19 Nm. There was a 2.7% increase when using CR 1:16 at 2200 rpm with Pertamina Dex fuel. While on the fuel Pertamina Dex + 1 l / m CR 1:18 produce torque of 18.2 Nm and at CR 1:16 produce torque of 19 Nm. From this result there was an increase of 6.6% when using CR 1:16 at 2200 rpm Pertamina Dex + 1 l / m. The rest between CR 1:18 and CR 1:16 at each rpm and no significant fuel difference.

IV. 3.15 Total SEC Analysis

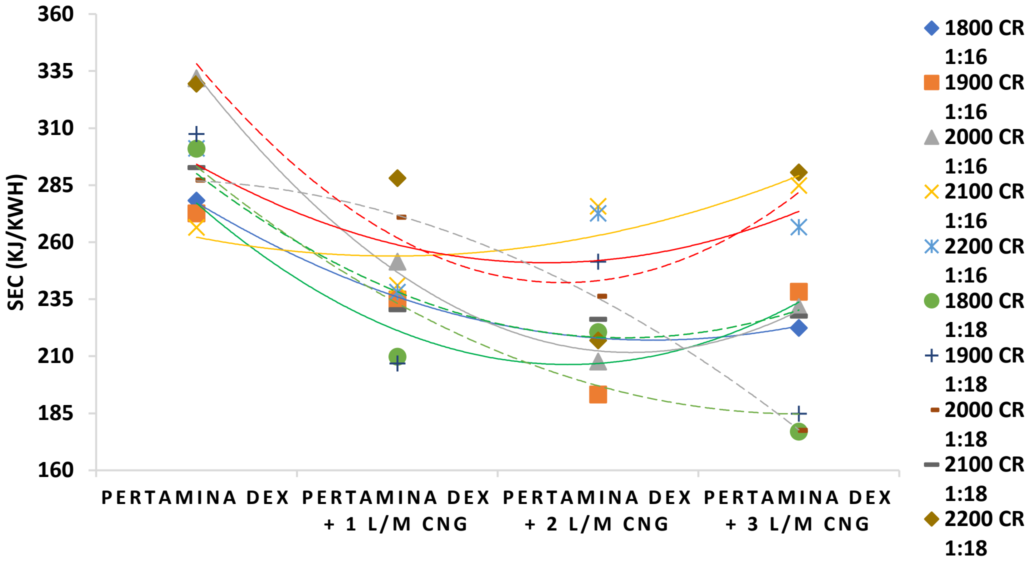


Figure 4.46. SEC Total

In figure 4.46 can be seen the total SEC phenomenon in each fuel looks so different. When looking at the above graph it will be very difficult to see the difference of each fuel and rpm how the SEC happens. Due to this the authors take one rpm where there is a difference seen when rpm 2200 between CR 1:18 and CR 1:16 can be seen in figure 4.47.

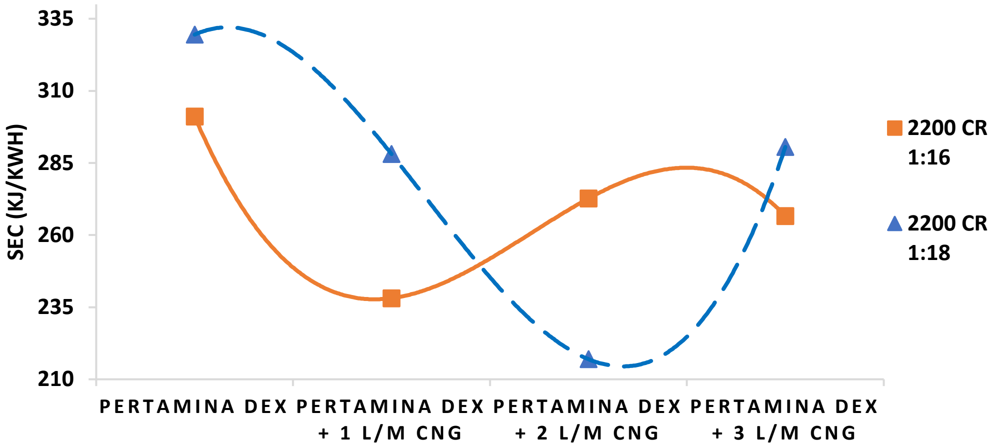


Figure 4.47. SEC at 2200 rpm

In Figure 4.47 chart we can see the comparison between CR 1:16 and CR 1:18 at 2200 rpm on each fuel. The phenomenon that occurs when using CR 1:16 lower fuel consumption on Pertamina Dex, Pertamina Dex + 1l / m CNG and Pertamina Dex + 3l / m CNG. While using CR 1:18 the lowest amount of fuel consumption on Pertamina Dex + 2l / m CNG. From this CR ratio it can be seen that CR can be upgraded to decrease machine performance especially from SEC.

CHAPTER V

CONCLUSION AND SUGGESTION

V.1 Conclusion

In this chapter will be deduced from the results of simulation and experimental study of Yanmar TF 85 MH-DI experiments with the addition of CNG which the result of diesel engine diesel fuel modification, the conclusion of engine performance obtained as follows:

A. In the simulation process aims to select the optimum of compression ratio on engine performance and from the graph above can be concluded that the most optimum compression ratio is CR 1:16.

B. The power at CR 1:18 and CR 1:16 does not occur significantly different with average of only 0.1%. But it can be seen at 1800, 1900 and 2000 rpm the power produced maximum power at CR 1:18 and at 2100 rpm and 2200 CR 1:16 is better. This data is collected at 100% load with Pertamina Dex, Pertamina Dex + 1l / min CNG, 2 l / min CNG and 3 l / min CNG.

C. The torque at CR 1:18 and CR 1:16 does not occur very significantly with an average 0.3%. But it can be seen on the graph at rpm 1800, 1900 and 2000 is the maximum torque at CR 1:18 and at 2100 rpm and 2200 CR 1:16 is better. However, at 1800 rpm with Pertamina Dex + 2 l / min CNG the maximum torque is higher at CR 1:16. This data is collected at 100% load with Pertamina Dex, Pertamina Dex + 1l / min CNG, 2 l / min CNG and 3 l / min CNG.

D. SFOC with different compression ratios shows that CR 1:16 at 1800, 1900 and 2000 rpm has increased fuel consumption when compared to CR 1:18. However at rpm 2100 and 2200 at CR 1:16 the fuel consumption is lower when compared to CR 1:18. There was no significant difference with the average difference ranging 0.3%.

E. SEC with different compression ratio shows that CR 1:16 of fuel consumption is lowest at 1900 rpm Pertamina Dex + 2 l / min with 75% load 177 kJ / kWh. At CR 1:18 the lower fuel consumption at 2000 rpm Pertamina Dex + 3 l / min for 183 kJ / kWh at 100% load. The higher fuel consumption CR 1:16 at 1800 rpm with Pertamina Dex + 3 l / min of 447 kJ / kWh at 25% load. At 1:18 CR the highest fuel consumption at 1800 rpm Pertamina Dex + 3 l / min for 492 kJ / kWh at 25% load.

V.2 Suggestion

In the simulation process there are still not been valid so that the piston selection is still not optimum. To the authors suggest to continue the research with other compression variations to improve the engine performance especially in SEC.

REFERENCES

Bassi, A. 1990, '*Natural gas vehicles for a clean environment - an overview and the trends for the future'*, in Carvallo, Maria da Graca, Fiveland, Woodrow A., Lockwood, F.C. & Papadopoulos, Christos (eds), *Clean combustion technologies*, vol 2, Part B, pp.739-762.

Cassarrubios, David Sancho. (2015). Modelling and CNG distribution study of Natural Gas-Diesel Dual Fuel Engine, Lund, Sweden : Lund University, 2015. Thesis.

Damrongkijkosol, C. (2006). *An Experiment Study on Influence of Compression Ratio for Performance and Emissions of Natural Gas Retrofit Engine Master Thesis*. Skindhorn International Thai-German Graduate School of Engineering (TGGS) Graduate College King Mongkut‟s Institute of Technology North Bangkok.

Heywood, John B. *Internal Combustion Engine Fundamentals.* New York : Tata McGraw-Hill, 1988.

Ismail, M. Y. Bin (no date) 'One-Dimensional Simulation of a Retrofitted Medium Duty Engine Running Using Compressed Natural Gas'.

Li, LIM Pei. (2004) *The Effect of Compression Ratio on The CNG-Diesel Engine*, West St, Darling Heights QLD 4350, Australia : University of Southern Queensland, 2004. Distertation.

Liu, Zhigang. (1995) *An examination of the combustion characteristics of compression ignition engines fuelled with gaseous fuels.* Calgary, Canada : University of Calgary, 1995. PhD Thesis.

Mansor, W. N. (2014) 'Dual Fuel Engine Combustion and Emissions – an Experimental', p. 162.

Reddy, A. G. *et al.* (2015) 'Effect Of Compression Ratio On The Performance Of Diesel Engine At Different Loads', *Journal of Engineering Research and Applications www.ijera.com ISSN*, 5(102), pp. 2248–962262. Available at: www.ijera.com.

Rowen, Alan L. (1971). *Marine Engineering* (p. 91). The Society Of Naval Architects and Marine Engineers. 601 Pavonia Avenue, Jersey City, N.J. 07306

Saidur, R., Jahirul, M. I., Moutushi, T. Z., Imtiaz, H., & Masjuki, H. H. (2007). Effect of partial substitution of diesel fuel by natural gas on performance parameters of a four-cylinder diesel engine. *Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy*, *221*(1), 1–10. doi:10.1243/09576509JPE182

Shamsudin, A.H & Yusaf, T.F. 1995, '*A review on the use of natural gas in internal combustion engine*', ASEAN Journal Science Technology Development, pp. 101-113.

Singh, R. and Maji, S. (2012) 'Performance and Exhaust Gas Emissions Analysis of Direct Injection CNG-Diesel Dual Fuel Engine', *International Journal of Engineering Science*, 4(3), pp. 833–846. Available at: http://www.ijest.info/docs/IJEST12-04-03-035.pdf.

W.Pulkrabek, W. (2004). *Engineering Fundamentals of the Internal Combustion Engine* (Second Edi., p. 478). Pearson Prentice-Hall.

Zheng, J.-J., Wang, J.-H., Wang, B., & Huang, Z.-H. (2009). Effect of the compression ratio on the performance and combustion of a natural-gas direct-injection engine. *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering*, *223*(1), 85–98. doi:10.1243/09544070JAUTO976

ATTACHMENT

Yanmar TF 85 MH-di pada Kompresi Rasio 1:18 Berbahan Bakar Pertamina DEX

Putaran Engine (rpm) kontrol	Putaran Engine (rpm) aktual	Beban (watt)	Putaran Generator (Rpm)	Alternator Tegangan (Volt)	Alternator Arus (Ampere)	Volume Bahan Bakar (m3)	Waktu Menit	Waktu Detik	Waktu Jam	Densitas (gr/m3)	Massa Masuk Bahan Bakar (Kg)	Effisiensi Slip	Daya kW	Daya HP	FCR (gr/h)	Nilai Kalor (KJ/Kg)	SFOC (Kg/kwh)	SEC (KJ/kwh)	Torsi (Nm)	BMEP (N/m2)	LHV (J/kg)	Eff. Thermal (%)
1800	1801	0	1320	190	0	0,00002	2,200	132	0,0367	830	0,0166	0,9821	0,0000	0,0000	0,4527	706,1308	0,0000	0,0000	0,0000	0,00	42.538	0,0
1800	1802	1000	1322	186	3,6	0,00002	2,067	124	0,0344	830	0,0166	0,9831	0,7212	0,9671	0,4819	706,1308	0,6682	471,8636	3,8259	15520,96	42.538	12664676,2
1800	1804	2000	1324	182	7,6	0,00002	1,633	98	0,0272	830	0,0166	0,9835	1,4892	1,9970	0,6098	706,1308	0,4095	289,1461	7,8957	32031,13	42.538	20667751,7
1800	1798	3000	1320	180	11,3	0,00002	1,367	82	0,0228	830	0,0166	0,9838	2,1892	2,9357	0,7288	706,1308	0,3329	235,0696	11,5942	47035,27	42.538	25422261,8
1800	1799	4000	1322	175	14,9	0,00002	0,833	50	0,0139	830	0,0166	0,9847	2,8038	3,7599	1,1952	706,1308	0,4263	301,0114	14,8986	60440,47	42.538	19853069,4
1900	1902	0	1402	200	0	0,00002	2,533	152,000	0,0422	830	0,0166	0,9877	0,0000	0,0000	0,3932	706,1308	0,0000	0,0000	0,0000	0,00	42.538	0,0
1900	1903	1000	1401	198	3,9	0,00002	2,133	128,000	0,0356	830	0,0166	0,9865	0,8288	1,1114	0,4669	706,1308	0,5633	397,7741	4,1632	16889,37	42.538	15023601,3
1900	1899	2000	1400	196	8	0,00002	1,500	90,000	0,0250	830	0,0166	0,9879	1,6806	2,2537	0,6640	706,1308	0,3951	278,9918	8,4375	34229,27	42.538	21419983,3
1900	1899	3000	1396	190	11,9	0,00002	1,233	74,000	0,0206	830	0,0166	0,9851	2,4303	3,2590	0,8076	706,1308	0,3323	234,6417	12,2272	49603,08	42.538	25468622,7
1900	1900	4000	1389	185	15,6	0,00002	0,733	44,000	0,0122	830	0,0166	0,9796	3,1194	4,1831	1,3582	706,1308	0,4354	307,4515	15,6940	63667,26	42.538	19437212,8
2000	1999	0	1482	222	0	0,00002	2,700	162	0,0450	830	0,0166	0,9934	0,0000	0,0000	0,3689	706,1308	0,0000	0,0000	0,0000	0,00	42.538	0,0
2000	2002	1000	1482	215	4,2	0,00002	2,067	124	0,0344	830	0,0166	0,9919	0,9639	1,2926	0,4819	706,1308	0,5000	353,0625	4,6068	18688,92	42.538	16926179,2
2000	1997	2000	1471	210	8,5	0,00002	1,567	94	0,0261	830	0,0166	0,9871	1,9148	2,5677	0,6357	706,1308	0,3320	234,4474	9,1380	37070,89	42.538	25489721,9
2000	2002	3000	1465	201	12,6	0,00002	1,167	70	0,0194	830	0,0166	0,9806	2,7347	3,6673	0,8537	706,1308	0,3122	220,4377	13,0835	53077,26	42.538	27109700,6
2000	2003	4000	1463	196	16,5	0,00002	0,700	42	0,0117	830	0,0166	0,9787	3,4986	4,6916	1,4229	706,1308	0,4067	287,1779	16,6964	67733,89	42.538	20809400,1
2100	2099	0	1555	230	0	0,00002	2,500	150	0,0417	830	0,0166	0,9927	0,0000	0,0000	0,3984	706,1308	0,0000	0,0000	0,0000	0,00	42.538	0,0
2100	2098	1000	1548	227	4,5	0,00002	1,633	98	0,0272	830	0,0166	0,9887	1,0939	1,4670	0,6098	706,1308	0,5574	393,6207	4,9793	20200,12	42.538	15182126,5
2100	2102	2000	1542	220	9,1	0,00002	1,267	76	0,0211	830	0,0166	0,9830	2,1564	2,8917	0,7863	706,1308	0,3646	257,4844	9,8201	39838,26	42.538	23209171,3
2100	2101	3000	1538	215	13,5	0,00002	0,900	54	0,0150	830	0,0166	0,9809	3,1330	4,2014	1,1067	706,1308	0,3532	249,4257	14,2403	57770,04	42.538	23959035,8
2100	2101	4000	1532	210	17,6	0,00002	0,600	36	0,0100	830	0,0166	0,9771	4,0051	5,3709	1,6600	706,1308	0,4145	292,6680	18,2131	73886,77	42.538	20419042,9
2200	2201	0	1624	250	0	0,00002	2,100	126	0,0350	830	0,0166	0,9887	0,0000	0,0000	0,4743	706,1308	0,0000	0,0000	0,0000	0,00	42.538	0,0
2200	2199	1000	1620	240	4,7	0,00002	1,600	96	0,0267	830	0,0166	0,9872	1,2099	1,6224	0,6225	706,1308	0,5145	363,3176	5,2518	21305,55	42.538	16448419,7
2200	2201	2000	1615	233	9,7	0,00002	1,033	62	0,0172	830	0,0166	0,9832	2,4339	3,2638	0,9639	706,1308	0,3960	279,6470	10,5745	42898,63	42.538	21369801,6
2200	2199	3000	1611	230	14,3	0,00002	0,767	46	0,0128	830	0,0166	0,9817	3,5474	4,7571	1,2991	706,1308	0,3662	258,5982	15,3987	62469,35	42.538	23109206,0
2200	2200	4000	1602	215	18,3	0,00002	0,500	30	0,0083	830	0,0166	0,9758	4,2694	5,7253	1,9920	706,1308	0,4666	329,4625	18,5496	75251,98	42.538	18138635,1

Modifikasi Yanmar TF 85 MH-di Berbahan Bakar Pertamina DEX dan CNG 1 L/min pada Kompresi Rasio 1:18

Putaran Engine		Beban	Putaran	Alternator		Volume	Waktu	Waktu	Waktu	Densitas	Effisiensi	Daya	FCR	SFOC	Torsi	BMEP	LHV	LHV	Eff. Thermal	Volume	Waktu	Waktu	Densitas	Massa Masuk Bahan Bakar (Kg)		FCR (Kg/h)		Nilai Kalor (J/kg)		SFC	SEC
(rpm) kontrol	(rpm) aktual	(watt)	Generator (Rpm)	Tegangan (Volt)	Arus (Ampere)	Bahan Bakar (m3)	(Menit)	(Detik)	(Jam)	(gr/m3)	Slip	(Kw)	(gr/h)	(gr/kwh)	(Nm)	(N/m2)	(KJ/kg)	(KJ/kg)	(%)	Gas (m3)	CNG (Detik)	(Jam)	(gr/m3)	Pertamina DEX	CNG	Pertamina DEX	CNG	Pertamina DEX	CNG	(gr/Kwh)	(kJ/Kwh)
1800	1802	0	1328	182	0	0,00002	4,467	268	0,0744	830	0,9875	0,0000	0,2230	0,0000	0,0000	0,00	42.538	7.698	0,0	0,004	268	0,074	0,78	0,0166	0,0035	0,223	0,047	706,13	26,82	0,000	0,0
1800	1804	1000	1326	185	3,5	0,00002	3,200	192	0,0533	830	0,9849	0,6961	0,3113	0,4472	3,6905	14971,71	42.538	7.698	18926383,7	0,003	192	0,053	0,78	0,0166	0,0025	0,311	0,047	706,13	19,21	0,514	373,1
1800	1802	2000	1320	180	7,2	0,00002	2,633	158	0,0439	830	0,9816	1,3980	0,3782	0,2706	7,4039	30036,05	42.538	7.698	31280708,0	0,003	158	0,044	0,78	0,0166	0,0021	0,378	0,047	706,13	15,81	0,304	219,5
1800	1802	3000	1323	176	11	0,00002	1,967	118	0,0328	830	0,9838	2,0836	0,5064	0,2431	11,0473	44816,61	42.538	7.698	34818971,1	0,002	118	0,033	0,78	0,0166	0,0015	0,506	0,047	706,13	11,81	0,266	190,6
1800	1799	4000	1316	173	14,3	0,00002	1,333	80	0,0222	830	0,9802	2,6722	0,7470	0,2795	14,1681	57477,27	42.538	7.698	30274782,5	0,001	80	0,022	0,78	0,0166	0,0010	0,747	0,047	706,13	8,01	0,297	212,1
1900	1901	0	1402	200	0	0,00002	3,367	202,000	0,0561	830	0,9883	0,0000	0,2958	0,0000	0,0000	0,00	42.538	7.698	0,0	0,003	202	0,056	0,78	0,0166	0,0026	0,296	0,047	706,13	20,21	0,000	0,0
1900	1904	1000	1403	197	3,8	0,00002	2,400	144,000	0,0400	830	0,9874	0,8027	0,4150	0,5170	4,0345	16367,05	42.538	7.698	16370246,5	0,002	144	0,040	0,78	0,0166	0,0019	0,415	0,047	706,13	14,41	0,575	414,5
1900	1900	2000	1398	195	7,8	0,00002	2,000	120,000	0,0333	830	0,9860	1,6334	0,4980	0,3049	8,1963	33250,81	42.538	7.698	27758150,1	0,002	120	0,033	0,78	0,0166	0,0016	0,498	0,047	706,13	12,01	0,334	239,5
1900	1897	3000	1397	191	11,8	0,00002	1,567	94,000	0,0261	830	0,9868	2,4183	0,6357	0,2629	12,1603	49331,71	42.538	7.698	32191987,0	0,002	94	0,026	0,78	0,0166	0,0012	0,636	0,047	706,13	9,41	0,282	202,0
1900	1902	4000	1385	184	15,4	0,00002	1,167	70,000	0,0194	830	0,9758	3,0748	0,8537	0,2776	15,4861	62823,98	42.538	7.698	30481122,3	0,001	70	0,019	0,78	0,0166	0,0009	0,854	0,047	706,13	7,01	0,293	208,9
2000	1999	0	1479	215	0	0,00002	3,067	184	0,0511	830	0,9914	0,0000	0,3248	0,0000	0,0000	0,00	42.538	7.698	0,0	0,003	184	0,051	0,78	0,0166	0,0024	0,325	0,047	706,13	18,41	0,000	0,0
2000	2000	1000	1468	212	4,1	0,00002	2,433	146	0,0406	830	0,9836	0,9357	0,4093	0,4374	4,4722	18142,80	42.538	7.698	19346844,6	0,002	146	0,041	0,78	0,0166	0,0019	0,409	0,047	706,13	14,61	0,487	351,3
2000	2001	2000	1478	207	8,5	0,00002	1,933	116	0,0322	830	0,9898	1,8823	0,5152	0,2737	8,9917	36477,53	42.538	7.698	30921001,0	0,002	116	0,032	0,78	0,0166	0,0015	0,515	0,047	706,13	11,61	0,299	214,3
2000	2004	3000	1461	201	12,6	0,00002	1,167	70	0,0194	830	0,9769	2,7449	0,8537	0,3110	13,1062	53169,24	42.538	7.698	27211079,7	0,001	70	0,019	0,78	0,0166	0,0009	0,854	0,047	706,13	7,01	0,328	234,0
2000	2004	4000	1460	196	16,5	0,00002	0,767	46	0,0128	830	0,9762	3,5075	1,2991	0,3704	16,7224	67839,19	42.538	7.698	22849481,0	0,001	46	0,013	0,78	0,0166	0,0006	1,299	0,047	706,13	4,60	0,384	272,7
2100	2101	0	1551	231	0	0,00002	2,933	176	0,0489	830	0,9892	0,0000	0,3395	0,0000	0,0000	0,00	42.538	7.698	0,0	0,003	176	0,049	0,78	0,0166	0,0023	0,340	0,047	706,13	17,61	0,000	0,0
2100	2099	1000	1545	227	4,4	0,00002	2,167	130	0,0361	830	0,9863	1,0722	0,4597	0,4287	4,8758	19780,16	42.538	7.698	19739651,1	0,002	130	0,036	0,78	0,0166	0,0017	0,460	0,047	706,13	13,01	0,472	339,7
2100	2098	2000	1539	220	9	0,00002	1,633	98	0,0272	830	0,9830	2,1328	0,6098	0,2859	9,7080	39383,39	42.538	7.698	29600003,4	0,002	98	0,027	0,78	0,0166	0,0013	0,610	0,047	706,13	9,81	0,308	220,4
2100	2104	3000	1536	215	13,4	0,00002	1,200	72	0,0200	830	0,9783	3,1183	0,8300	0,2662	14,2005	57608,39	42.538	7.698	31795371,6	0,001	72	0,020	0,78	0,0166	0,0009	0,830	0,047	706,13	7,21	0,281	200,6
2100	2103	4000	1535	209	17,5	0,00002	0,800	48	0,0133	830	0,9781	3,9594	1,2450	0,3144	17,9796	72939,53	42.538	7.698	26914734,2	0,001	48	0,013	0,78	0,0166	0,0006	1,245	0,047	706,13	4,80	0,326	231,9
2200	2204	0	1621	249	0	0,00002	2,833	170	0,0472	830	0,9855	0,0000	0,3515	0,0000	0,0000	0,00	42.538	7.698	0,0	0,003	170	0,047	0,78	0,0166	0,0022	0,352	0,047	706,13	17,01	0,000	0,0
2200	2202	1000	1622	241	4,7	0,00002	2,100	126	0,0350	830	0,9870	1,2151	0,4743	0,3903	5,2672	21367,97	42.538	7.698	21681311,1	0,002	126	0,035	0,78	0,0166	0,0016	0,474	0,047	706,13	12,61	0,429	308,2
2200	2199	2000	1614	232	9,7	0,00002	1,400	84	0,0233	830	0,9835	2,4227	0,7114	0,2937	10,5117	42643,96	42.538	7.698	28820023,8	0,001	84	0,023	0,78	0,0166	0,0011	0,711	0,047	706,13	8,41	0,313	223,6
2200	2196	3000	1611	229	14,3	0,00002	1,100	66	0,0183	830	0,9830	3,5272	0,9055	0,2567	15,3248	62169,38	42.538	7.698	32967489,8	0,001	66	0,018	0,78	0,0166	0,0009	0,905	0,047	706,13	6,60	0,270	192,4
2200	2198	4000	1603	211	18,3	0,00002	0,600	36	0,0100	830	0,9773	4,1836	1,6600	0,3968	18,2014	73839,52	42.538	7.698	21328673,3	0,001	36	0,010	0,78	0,0166	0,0005	1,660	0,047	706,13	3,60	0,408	289,6

Modifikasi Yanmar TF 85 MH-di Berbahan Bakar Pertamina DEX dan CNG 2 L/min pada Kompresi Rasio 1:18

Putaran Engine (rpm) kontrol	Putaran Engine (rpm) aktual	Beban (watt)	Putaran Generator (Rpm)	Alternator Tegangan (Volt)	Alternator Arus (Ampere)	Volume Bahan Bakar (m3)	Waktu (Menit)	Waktu (Detik)	Waktu (Jam)	Densitas (gr/m3)	Effisiensi Slip	Daya (Kw)	FCR (Kg/h)	SFOC (Kg/kwh)	Torsi (Nm)	BMEP (N/m2)	LHV (KJ/kg)	Eff. Thermal (%)	Volume Gas (m3)	Waktu CNG (Detik)	Waktu (Jam)	Densitas (gr/m3)	Massa Masuk Bahan Bakar (gr) Pertamina DEX	Massa Masuk Bahan Bakar (gr) CNG	FCR (Kg/h) Pertamina DEX	FCR (Kg/h) CNG	Nilai Kalor (KJ/kg) Pertamina DEX	Nilai Kalor (KJ/kg) CNG	SFC (gr/Kwh)	SEC (kJ/Kwh)
1800	1799	0	1330	190	0	0,00002	3,867	232	0,0644	830	0,9907	0,0000	0,2576	0,0000	0,0000	0,00	42.538	0,0000	0,0089	268	0,074444	0,78	0,0166	0,007	0,223	0,094	706,13	53,64	0,000	0,0
1800	1801	1000	1324	185	3,4	0,00002	3,300	198	0,0550	830	0,9851	0,6761	0,3018	0,4464	3,5905	14565,95	42.538	18957243,7325	0,0064	192	0,053333	0,78	0,0166	0,005	0,311	0,094	706,13	38,43	0,599	445,9
1800	1802	2000	1318	180	7,2	0,00002	2,667	160	0,0444	830	0,9801	1,4001	0,3735	0,2668	7,4275	30131,73	42.538	31724734,1164	0,0053	158	0,043889	0,78	0,0166	0,004	0,378	0,094	706,13	31,62	0,337	248,6
1800	1799	3000	1319	176	10,9	0,00002	2,200	132	0,0367	830	0,9825	2,0675	0,4527	0,2190	10,9618	44469,70	42.538	38648540,2359	0,0039	118	0,032778	0,78	0,0166	0,003	0,506	0,094	706,13	23,62	0,290	211,8
1800	1797	4000	1320	170	14,4	0,00002	1,367	82	0,0228	830	0,9843	2,6333	0,7288	0,2768	13,9851	56734,58	42.538	30579687,4442	0,0027	80	0,022222	0,78	0,0166	0,002	0,747	0,094	706,13	16,01	0,319	230,5
1900	1902	0	1403	200	0	0,00002	3,333	200,000	0,0556	830	0,9884	0,0000	0,2988	0,0000	0,0000	0,00	42.538	0,0000	0,0067	200	0,055556	0,78	0,0166	0,005	0,299	0,094	706,13	40,03	0,000	0,0
1900	1904	1000	1403	198	3,7	0,00002	2,967	178,000	0,0494	830	0,9874	0,7856	0,3357	0,4274	3,9462	16008,81	42.538	19802946,7684	0,0059	178	0,049444	0,78	0,0166	0,005	0,336	0,094	706,13	35,63	0,547	405,4
1900	1904	2000	1398	194	7,8	0,00002	2,133	128,000	0,0356	830	0,9839	1,6285	0,4669	0,2867	8,1715	33149,93	42.538	29518868,4295	0,0043	128	0,035556	0,78	0,0166	0,003	0,467	0,094	706,13	25,62	0,344	251,9
1900	1898	3000	1395	190	11,7	0,00002	1,433	86,000	0,0239	830	0,9849	2,3899	0,6949	0,2908	11,9924	48650,58	42.538	29106738,5470	0,0029	86	0,023889	0,78	0,0166	0,002	0,695	0,094	706,13	17,21	0,330	238,6
1900	1900	4000	1390	184	15,4	0,00002	1,000	60,000	0,0167	830	0,9803	3,0605	0,9960	0,3254	15,4061	62499,22	42.538	26005321,3844	0,0020	60	0,016667	0,78	0,0166	0,002	0,996	0,094	706,13	12,01	0,356	255,7
2000	2001	0	1476	215	0	0,00002	3,167	190	0,0528	830	0,9884	0,0000	0,3145	0,0000	0,0000	0,00	42.538	0,0000	0,0063	190	0,052778	0,78	0,0166	0,005	0,315	0,094	706,13	38,03	0,000	0,0
2000	2001	1000	1475	210	4	0,00002	2,800	168	0,0467	830	0,9878	0,9004	0,3557	0,3950	4,2993	17441,38	42.538	21422850,9659	0,0056	168	0,046667	0,78	0,0166	0,004	0,356	0,094	706,13	33,62	0,499	369,1
2000	2003	2000	1472	206	8,4	0,00002	1,933	116	0,0322	830	0,9848	1,8605	0,5152	0,2769	8,8835	36038,44	42.538	30564075,6083	0,0039	116	0,032222	0,78	0,0166	0,003	0,515	0,094	706,13	23,22	0,327	238,6
2000	2002	3000	1467	201	12,6	0,00002	1,433	86	0,0239	830	0,9819	2,7310	0,6949	0,2544	13,0266	52846,12	42.538	33260796,3759	0,0029	86	0,023889	0,78	0,0166	0,002	0,695	0,094	706,13	17,21	0,289	208,8
2000	2004	4000	1460	195	16,4	0,00002	0,933	56	0,0156	830	0,9762	3,4685	1,0671	0,3077	16,5527	67151,04	42.538	27507110,8898	0,0019	56	0,015556	0,78	0,0166	0,001	1,067	0,094	706,13	11,21	0,335	240,1
2100	2103	0	1550	230	0	0,00002	2,533	152	0,0422	830	0,9876	0,0000	0,3932	0,0000	0,0000	0,00	42.538	0,0000	0,0051	152	0,042222	0,78	0,0166	0,004	0,393	0,094	706,13	30,42	0,000	0,0
2100	2103	1000	1546	225	4,3	0,00002	2,067	124	0,0344	830	0,9851	1,0399	0,4819	0,4634	4,7245	19166,15	42.538	18261484,2208	0,0041	124	0,034444	0,78	0,0166	0,003	0,482	0,094	706,13	24,82	0,553	404,5
2100	2102	2000	1543	220	9	0,00002	1,833	110	0,0306	830	0,9836	2,1313	0,5433	0,2549	9,6828	39281,33	42.538	33201544,8339	0,0037	110	0,030556	0,78	0,0166	0,003	0,543	0,094	706,13	22,02	0,299	217,6
2100	2098	3000	1535	211	13,4	0,00002	1,400	84	0,0233	830	0,9804	3,0535	0,7114	0,2330	13,8791	56304,76	42.538	36324301,7016	0,0028	84	0,023333	0,78	0,0166	0,002	0,711	0,094	706,13	16,81	0,264	190,6
2100	2099	4000	1534	205	17,5	0,00002	0,867	52	0,0144	830	0,9793	3,8788	1,1492	0,2963	17,6638	71658,38	42.538	28563798,6326	0,0017	52	0,014444	0,78	0,0166	0,001	1,149	0,094	706,13	10,41	0,320	229,6
2200	2201	0	1626	245	0	0,00002	1,900	114	0,0317	830	0,9899	0,0000	0,5242	0,0000	0,0000	0,00	42.538	0,0000	0,0038	114	0,031667	0,78	0,0166	0,003	0,524	0,094	706,13	22,82	0,000	0,0
2200	2204	1000	1618	238	4,7	0,00002	1,867	112	0,0311	830	0,9837	1,2040	0,5336	0,4432	5,2263	21202,22	42.538	19096753,4424	0,0037	112	0,031111	0,78	0,0166	0,003	0,534	0,094	706,13	22,42	0,521	379,5
2200	2198	2000	1612	231	9,6	0,00002	1,633	98	0,0272	830	0,9827	2,3893	0,6098	0,2552	10,3573	42017,26	42.538	33159316,4708	0,0033	98	0,027222	0,78	0,0166	0,003	0,610	0,094	706,13	19,61	0,294	213,7
2200	2199	3000	1605	225	14,2	0,00002	1,033	62	0,0172	830	0,9780	3,4589	0,9639	0,2787	15,0350	60993,96	42.538	30370110,7055	0,0021	62	0,017222	0,78	0,0166	0,002	0,964	0,094	706,13	12,41	0,306	219,7
2200	2202	4000	1602	218	18,4	0,00002	0,800	48	0,0133	830	0,9749	4,3566	1,2450	0,2858	18,9284	76788,71	42.538	29614471,5448	0,0016	48	0,013333	0,78	0,0166	0,001	1,245	0,094	706,13	9,61	0,307	219,9

Modifikasi Yanmar TF 85 MH-di Berbahan Bakar Pertamina DEX dan CNG 3 L/min pada Kompresi Rasio 1:18

Putaran Engine		Beban	Putaran Generator	Alternator		Volume Bahan Bakar	Waktu	Waktu	Waktu	Densitas	Effisiensi	Daya	FCR	SFOC	Torsi	BMEP	LHV	Eff. Thermal	Volume	Waktu CNG	Waktu	Densitas	Massa Masuk Bahan Bakar (gr)		FCR (gr/h)		Nilai Kalor (J/kg)		SFC	SEC
(rpm) kontrol	(rpm) aktual	(watt)	(Rpm)	Tegangan (Volt)	Arus (Ampere)	(m3)	(Menit)	(Detik)	(Jam)	(Kg/m3)	Slip	(Kw)	(Kg/h)	(Kg/kwh)	(Nm)	(N/m2)	(J/kg)	(%)	Gas (m3)	(Detik)	(Jam)	(gr/m3)	Pertamina DEX	CNG	Pertamina DEX	CNG	Pertamina DEX	CNG	(gr/Kwh)	(kJ/Kwh)
1800	1802	0	1331	190		0,00002	6,700	402	0,1117	830	0,9898	0,0000	0,1487	0,0000	0,0000	0,00	42.538	0,0000	0,0134	268	0,074444	0,78	0,0166	0,0105	0,223	0,14	706,13	80,459	0,00	0,00
1800	1803	1000	1330	187	3,5	0,00002	5,467	328	0,0911	830	0,9885	0,7011	0,1822	0,2599	3,7171	15079,69	42.538	32565759,4622	0,0096	192	0,053333	0,78	0,0166	0,0075	0,311	0,14	706,13	57,643	0,64	492,03
1800	1798	2000	1323	182	7,3	0,00002	3,900	234	0,0650	830	0,9860	1,4267	0,2554	0,1790	7,5603	30670,57	42.538	47279576,6490	0,0079	158	0,043889	0,78	0,0166	0,0062	0,378	0,14	706,13	47,435	0,36	273,93
1800	1800	3000	1326	178	11,1	0,00002	2,700	162	0,0450	830	0,9871	2,1193	0,3689	0,1741	11,2614	45685,22	42.538	48620632,8188	0,0059	118	0,032778	0,78	0,0166	0,0046	0,506	0,14	706,13	35,426	0,31	226,33
1800	1801	4000	1314	175	14,4	0,00002	1,833	110	0,0306	830	0,9777	2,7292	0,5433	0,1991	14,4863	58767,86	42.538	42515295,6937	0,004	80	0,022222	0,78	0,0166	0,0031	0,747	0,14	706,13	24,018	0,33	237,41
1900	1902	0	1406	200		0,00002	8,100	486,000	0,1350	830	0,9906	0,0000	0,1230	0,0000	0,0000	0,00	42.538	0,0000	0,0243	486	0,135	0,78	0,0166	0,0190	0,123	0,14	706,13	145,908	0,00	0,00
1900	1903	1000	1403	198	3,8	0,00002	5,033	302,000	0,0839	830	0,9879	0,8064	0,1979	0,2454	4,0507	16432,85	42.538	34488195,9606	0,0151	302	0,083889	0,78	0,0166	0,0118	0,198	0,14	706,13	90,667	0,42	334,25
1900	1896	2000	1401	195	7,9	0,00002	3,300	198,000	0,0550	830	0,9902	1,6473	0,3018	0,1832	8,2705	33551,86	42.538	46191356,9988	0,0099	198	0,055	0,78	0,0166	0,0077	0,302	0,14	706,13	59,444	0,27	205,51
1900	1899	3000	1392	190	11,8	0,00002	2,100	126,000	0,0350	830	0,9822	2,4168	0,4743	0,1962	12,1785	49405,63	42.538	43124643,0377	0,0063	126	0,035	0,78	0,0166	0,0049	0,474	0,14	706,13	37,828	0,25	189,22
1900	1900	4000	1384	184	15,4	0,00002	1,500	90,000	0,0250	830	0,9761	3,0738	0,6640	0,2160	15,4647	62737,12	42.538	39177091,8254	0,0045	90	0,025	0,78	0,0166	0,0035	0,664	0,14	706,13	27,020	0,26	191,86
2000	2003	0	1479	218		0,00002	5,367	322	0,0894	830	0,9894	0,0000	0,1856	0,0000	0,0000	0,00	42.538	0,0000	0,0161	322	0,089444	0,78	0,0166	0,0126	0,186	0,14	706,13	96,671	0,00	0,00
2000	2003	1000	1474	212	4,1	0,00002	3,167	190	0,0528	830	0,9861	0,9333	0,3145	0,3370	4,4518	18059,92	42.538	25112526,8891	0,0095	190	0,052778	0,78	0,0166	0,0074	0,315	0,14	706,13	57,042	0,49	372,00
2000	2001	2000	1468	209	8,4	0,00002	2,300	138	0,0383	830	0,9831	1,8909	0,4330	0,2290	9,0194	36589,72	42.538	36953818,5517	0,0069	138	0,038333	0,78	0,0166	0,0054	0,433	0,14	706,13	41,431	0,30	226,71
2000	2002	3000	1465	201	12,6	0,00002	1,700	102	0,0283	830	0,9806	2,7347	0,5859	0,2142	13,0574	52971,15	42.538	39502706,6029	0,0051	102	0,028333	0,78	0,0166	0,0040	0,586	0,14	706,13	30,623	0,27	195,67
2000	2000	4000	1462	198	16,5	0,00002	1,333	80	0,0222	830	0,9795	3,5314	0,7470	0,2115	16,8530	68369,30	42.538	40008786,1177	0,004	80	0,022222	0,78	0,0166	0,0031	0,747	0,14	706,13	24,018	0,25	183,48
2100	2102	0	1552	230		0,00002	4,100	246	0,0683	830	0,9894	0,0000	0,2429	0,0000	0,0000	0,00	42.538	0,0000	0,0123	246	0,068333	0,78	0,0166	0,0096	0,243	0,14	706,13	73,855	0,00	0,00
2100	2103	1000	1547	225	4,4	0,00002	3,267	196	0,0544	830	0,9857	1,0634	0,3049	0,2867	4,8335	19608,52	42.538	29517111,4672	0,0098	196	0,054444	0,78	0,0166	0,0076	0,305	0,14	706,13	58,844	0,42	320,33
2100	2101	2000	1540	220	9	0,00002	2,267	136	0,0378	830	0,9822	2,1345	0,4394	0,2059	9,6971	39339,13	42.538	41109581,9702	0,0068	136	0,037778	0,78	0,0166	0,0053	0,439	0,14	706,13	40,830	0,27	202,91
2100	2101	3000	1537	210	13,4	0,00002	1,367	82	0,0228	830	0,9803	3,0395	0,7288	0,2398	13,8217	56071,70	42.538	35295859,4023	0,0041	82	0,022778	0,78	0,0166	0,0032	0,729	0,14	706,13	24,618	0,29	208,97
2100	2102	4000	1531	205	17,4	0,00002	0,900	54	0,0150	830	0,9760	3,8697	1,1067	0,2860	17,5973	71388,47	42.538	29592933,6601	0,0027	54	0,015	0,78	0,0166	0,0021	1,107	0,14	706,13	16,212	0,32	232,78
2200	2199	0	1623	242		0,00002	3,333	200	0,0556	830	0,9890	0,0000	0,2988	0,0000	0,0000	0,00	42.538	0,0000	0,01	200	0,055556	0,78	0,0166	0,0078	0,299	0,14	706,13	60,044	0,00	0,00
2200	2197	1000	1619	240	4,7	0,00002	2,367	142	0,0394	830	0,9875	1,2095	0,4208	0,3479	5,2551	21318,69	42.538	24322839,9805	0,0071	142	0,039444	0,78	0,0166	0,0055	0,421	0,14	706,13	42,632	0,46	347,44
2200	2204	2000	1617	230	9,6	0,00002	1,533	92	0,0256	830	0,9831	2,3780	0,6496	0,2732	10,3414	41953,10	42.538	30982902,2674	0,0046	92	0,025556	0,78	0,0166	0,0036	0,650	0,14	706,13	27,620	0,33	243,75
2200	2202	3000	1609	224	14,3	0,00002	1,167	70	0,0194	830	0,9791	3,4639	0,8537	0,2465	15,0156	60915,41	42.538	34338158,1692	0,0035	70	0,019444	0,78	0,0166	0,0027	0,854	0,14	706,13	21,016	0,29	208,69
2200	2201	4000	1603	218	18,5	0,00002	0,600	36	0,0100	830	0,9759	4,3756	1,6600	0,3794	18,9849	77017,76	42.538	22307498,5474	0,0018	36	0,01	0,78	0,0166	0,0014	1,660	0,14	706,13	10,808	0,41	295,00

Modifikasi Yanmar TF 85 MH-di pada Kompresi Rasio 1:16 Berbahan Bakar Pertamina DEX

Beban (watt)	Putaran Aluminator (rpm)	Alternator			Volume Bahan Bakar (m3)	Waktu			Densitas (Kg/m3)	Massa Masuk Bahan Bakar (Kg)	Effisiensi Slip	Daya		Nilai Kalor (KJ/Kg)	FCR (Kg/h)	SFC (Kg/kwh)	SEC (Kg/kwh)	Torsi (Nm)	BMEP (N/m2)	LHV (KJ/kg)	Eff. Thermal (%)
		Tegangan (Volt)	Arus (Ampere)	Load Factor (%)		Menit	Detik	Jam				kW	HP								
0	1328	188	0	0,85	0,00002	2,333	140	0,0389	830	0,0166	0,989	0,0000	0,0000	706,1308	0,4269	0,0000	0,0000	0,0000	0,00	42538	0,0
1000	1327	183	3,6	0,85	0,00002	1,800	108	0,0300	830	0,0166	0,985	0,7081	0,9495	706,1308	0,5533	0,7815	551,8148	3,7479	15204,64	42538	10829720,8
2000	1326	180	7,4	0,85	0,00002	1,600	96	0,0267	830	0,0166	0,986	1,4303	1,9181	706,1308	0,6225	0,4352	307,3196	7,5835	30764,81	42538	19445555,4
3000	1326	180	11,1	0,85	0,00002	1,267	76	0,0211	830	0,0166	0,988	2,1407	2,8707	706,1308	0,7863	0,3673	259,3712	11,3753	46147,21	42538	23040339,3
4000	1318	173	14,5	0,85	0,00002	0,933	56	0,0156	830	0,0166	0,981	2,7085	3,6321	706,1308	1,0671	0,3940	278,2124	14,3684	58289,75	42538	21479989,5
0	1401	198	0	0,85	0,00002	3,167	190	0,0528	830	0,0166	0,988	0,0000	0,0000	706,1308	0,3145	0,0000	0,0000	0,0000	0,00	42538	0,0
1000	1400	197	3,8	0,85	0,00002	2,033	122	0,0339	830	0,0166	0,986	0,8040	1,0782	706,1308	0,4898	0,6092	430,1863	4,0410	16393,51	42538	13891656,5
2000	1398	194	7,9	0,85	0,00002	1,367	82	0,0228	830	0,0166	0,983	1,6502	2,2129	706,1308	0,7288	0,4416	311,8505	8,2849	33610,22	42538	19163027,0
3000	1398	190	11,9	0,85	0,00002	1,033	62	0,0172	830	0,0166	0,985	2,4307	3,2595	706,1308	0,9639	0,3965	280,0150	12,1904	49454,11	42538	21341710,5
4000	1391	185	15,5	0,85	0,00002	0,833	50	0,0139	830	0,0166	0,981	3,0965	4,1525	706,1308	1,1952	0,3860	272,5515	15,5546	63101,74	42538	21926133,2
0	1471	215	0	0,85	0,00002	2,900	174	0,0483	830	0,0166	0,985	0,0000	0,0000	706,1308	0,3434	0,0000	0,0000	0,0000	0,00	42538	0,0
1000	1476	212	4	0,85	0,00002	2,000	120	0,0333	830	0,0166	0,988	0,9089	1,2188	706,1308	0,4980	0,5479	386,9209	4,3395	17604,35	42538	15445018,9
2000	1472	210	8,5	0,85	0,00002	1,433	86	0,0239	830	0,0166	0,984	1,9212	2,5763	706,1308	0,6949	0,3617	255,4075	9,1683	37194,11	42538	23397899,4
3000	1467	203	12,6	0,85	0,00002	1,167	70	0,0194	830	0,0166	0,981	2,7609	3,7024	706,1308	0,8537	0,3092	218,3457	13,1562	53371,98	42538	27369436,6
4000	1455	198	16,4	0,85	0,00002	0,600	36	0,0100	830	0,0166	0,973	3,5322	4,7367	706,1308	1,6600	0,4700	331,8543	16,8399	68316,05	42538	18007902,3
0	1552	230	0	0,85	0,00002	2,500	150	0,0417	830	0,0166	0,990	0,0000	0,0000	706,1308	0,3984	0,0000	0,0000	0,0000	0,00	42538	0,0
1000	1545	225	4,4	0,85	0,00002	1,800	108	0,0300	830	0,0166	0,984	1,0648	1,4279	706,1308	0,5533	0,5197	366,9503	4,8421	19643,25	42538	16285585,2
2000	1528	220	9	0,85	0,00002	1,400	84	0,0233	830	0,0166	0,973	2,1553	2,8903	706,1308	0,7114	0,3301	233,0793	9,7919	39723,56	42538	25639340,7
3000	1536	215	13,5	0,85	0,00002	0,933	56	0,0156	830	0,0166	0,978	3,1416	4,2128	706,1308	1,0671	0,3397	239,8624	14,2589	57845,31	42538	24914283,7
4000	1535	210	17,4	0,85	0,00002	0,667	40	0,0111	830	0,0166	0,977	3,9594	5,3096	706,1308	1,4940	0,3773	266,4432	17,9795	72939,03	42538	22428792,1
0	1601	249	0	0,85	0,00002	2,333	140	0,0389	830	0,0166	0,974	0,0000	0,0000	706,1308	0,4269	0,0000	0,0000	0,0000	0,00	42538	0,0
1000	1623	240	4,8	0,85	0,00002	1,500	90	0,0250	830	0,0166	0,988	1,2344	1,6554	706,1308	0,6640	0,5379	379,8223	5,3536	21718,66	42538	15733673,8
2000	1618	235	9,7	0,85	0,00002	1,100	66	0,0183	830	0,0166	0,985	2,4502	3,2857	706,1308	0,9055	0,3695	260,9468	10,6358	43147,39	42538	22901223,6
3000	1606	229	14,2	0,85	0,00002	0,733	44	0,0122	830	0,0166	0,977	3,5246	4,7265	706,1308	1,3582	0,3853	272,1019	15,2997	62067,78	42538	21962364,2
4000	1600	220	18,3	0,85	0,00002	0,533	32	0,0089	830	0,0166	0,973	4,3801	5,8738	706,1308	1,8675	0,4264	301,0639	18,9961	77063,24	42538	19849606,1

Modifikasi Yanmar TF 85 MH-di Berbahan Bakar Pertamina DEX dan CNG 1 L/min pada Kompresi Rasio 1:16

Putaran Engine		Beban	Putaran Aluminator	Alternator			Volume Bahan Bakar (m3)		Waktu			Densitas (Kg/m3)		Masa Masuk Bahan Bakar (Kg)		Effisiensi	Daya		FCR (Kg/h)		Nilai Kalor	SFC	SEC	Torsi	BMEP	LHV (KJ/kg)		Eff. Thermal (%)
(rpm) kontrol	(rpm) aktual	(watt)	(Rpm)	Tegangan (Volt)	Arus (Ampere)	Load Factor (%)	Pertamina DEX	CNG	Menit	Detik	Jam	Pertamina DEX	CNG	Pertamina DEX	CNG	Slip	kW	HP	Solar	CNG	(KJ/Kg)	(Kg/kwh)	(kJ/kWh)	(Nm)	(N/m2)	Pertamina DEX	CNG	
1800	1803	0	1326	189	0	0,85	0,00002	0,0046667	4,667	280	0,0778	830	0,78	0,0166	0,0036400	0,9855	0,0000	0,0000	0,2134	0,046800	734,152	0,0000	0,0000	0,0000	0,00	42.538	7.698	0,0000
1800	1805	1000	1326	183	3,5	0,85	0,00002	0,0037667	3,767	226	0,0628	830	0,78	0,0166	0,0029380	0,9844	0,6889	0,9238	0,2644	0,046800	728,748	0,4518	329,2150	3,6506	14809,85	42.538	7.698	44887787758,9132
1800	1803	2000	1338	181	7,5	0,85	0,00002	0,0024333	2,433	146	0,0406	830	0,78	0,0166	0,0018980	0,9944	1,4454	1,9383	0,4093	0,046800	720,742	0,3156	227,4342	7,6509	31038,14	42.538	7.698	60841407745,0478
1800	1799	3000	1319	180	11	0,85	0,00002	0,0016	1,600	96	0,0267	830	0,78	0,0166	0,0012480	0,9825	2,1339	2,8615	0,6225	0,046800	715,738	0,3137	224,4939	11,3075	45872,17	42.538	7.698	59059496199,3501
1800	1801	4000	1316	172	14,4	0,85	0,00002	0,0012	1,200	72	0,0200	830	0,78	0,0166	0,0009360	0,9791	2,6784	3,5917	0,8300	0,046800	713,336	0,3274	233,5217	14,2242	57704,68	42.538	7.698	55596596495,4769
1900	1904	0	1404	205	0	0,85	0,00002	0,0041333	4,133	248	0,0689	830	0,78	0,0166	0,0032240	0,9881	0,0000	0,0000	0,2410	0,046800	730,949	0,0000	0,0000	0,0000	0,00	42.538	7.698	0,0000
1900	1901	1000	1396	200	3,8	0,85	0,00002	0,0029667	2,967	178	0,0494	830	0,78	0,0166	0,0023140	0,9840	0,8178	1,0966	0,3357	0,046800	723,944	0,4678	338,6427	4,1035	16647,03	42.538	7.698	20614078,4066
1900	1901	2000	1395	198	7,9	0,85	0,00002	0,002	2,000	120	0,0333	830	0,78	0,0166	0,0015600	0,9833	1,6843	2,2586	0,4980	0,046800	718,140	0,3235	232,2881	8,4650	34340,89	42.538	7.698	28622994,5093
1900	1903	3000	1391	190	11,9	0,85	0,00002	0,0015333	1,533	92	0,0256	830	0,78	0,0166	0,0011960	0,9795	2,4442	3,2776	0,6496	0,046800	715,338	0,2849	203,8061	12,2840	49833,75	42.538	7.698	31844444,5741
1900	1899	4000	1384	182	15,3	0,85	0,00002	0,00105	1,050	63	0,0175	830	0,78	0,0166	0,0008190	0,9766	3,0191	4,0485	0,9486	0,046800	712,435	0,3297	234,8877	15,1574	61490,27	42.538	7.698	26935551,5751
2000	2001	0	1480	219	0	0,85	0,00002	0,0039333	3,933	236	0,0656	830	0,78	0,0166	0,0030680	0,9911	0,0000	0,0000	0,2532	0,046800	729,748	0,0000	0,0000	0,0000	0,00	42.538	7.698	0,0000
2000	1998	1000	1471	211	4,2	0,85	0,00002	0,0026667	2,667	160	0,0444	830	0,78	0,0166	0,0020800	0,9866	0,9511	1,2754	0,3735	0,046800	722,143	0,4419	319,1163	4,5413	18423,02	42.538	7.698	21551036,8705
2000	2001	2000	1468	209	8,5	0,85	0,00002	0,0019333	1,933	116	0,0322	830	0,78	0,0166	0,0015080	0,9831	1,9134	2,5659	0,5152	0,046800	717,739	0,2937	210,8030	9,1496	37117,97	42.538	7.698	31432423,3023
2000	2005	3000	1462	201	12,6	0,85	0,00002	0,0015667	1,567	94	0,0261	830	0,78	0,0166	0,0012220	0,9771	2,7444	3,6803	0,6357	0,046800	715,538	0,2487	177,9554	13,1038	53159,39	42.538	7.698	36533820,5195
2000	1996	4000	1458	198	16,4	0,85	0,00002	0,0008333	0,833	50	0,0139	830	0,78	0,0166	0,0006500	0,9788	3,5126	4,7104	1,1952	0,046800	711,135	0,3536	251,4447	16,7382	67903,34	42.538	7.698	24872285,0329
2100	2102	0	1552	230	0	0,85	0,00002	0,0035	3,500	210	0,0583	830	0,78	0,0166	0,0027300	0,9894	0,0000	0,0000	0,2846	0,046800	727,146	0,0000	0,0000	0,0000	0,00	42.538	7.698	0,0000
2100	2098	1000	1546	228	4,5	0,85	0,00002	0,0024833	2,483	149	0,0414	830	0,78	0,0166	0,0019370	0,9874	1,1002	1,4753	0,4011	0,046800	721,042	0,4071	293,5310	5,0006	20286,36	42.538	7.698	23214709,5228
2100	2103	2000	1543	220	9,2	0,85	0,00002	0,0016	1,600	96	0,0267	830	0,78	0,0166	0,0012480	0,9832	2,1797	2,9230	0,6225	0,046800	715,738	0,3071	219,7719	9,9263	40269,09	42.538	7.698	29633893,6691
2100	2097	3000	1536	215	13,5	0,85	0,00002	0,0010667	1,067	64	0,0178	830	0,78	0,0166	0,0008320	0,9815	3,1311	4,1988	0,9338	0,046800	712,536	0,3132	223,1403	14,2249	57707,68	42.538	7.698	28378735,9779
2100	2103	4000	1532	209	17,5	0,85	0,00002	0,0007667	0,767	46	0,0128	830	0,78	0,0166	0,0005980	0,9762	3,9672	5,3200	1,2991	0,046800	710,734	0,3393	241,1272	18,0749	73326,32	42.538	7.698	25843796,0017
2200	2201	0	1622	245	0	0,85	0,00002	0,0023333	2,333	140	0,0389	830	0,78	0,0166	0,0018200	0,9875	0,0000	0,0000	0,4269	0,046800	720,141	0,0000	0,0000	0,0000	0,00	42.538	7.698	0,0000
2200	2198	1000	1626	240	4,8	0,85	0,00002	0,0018667	1,867	112	0,0311	830	0,78	0,0166	0,0014560	0,9913	1,2305	1,6501	0,5336	0,046800	717,339	0,4717	338,3390	5,3438	21668,71	42.538	7.698	19516919,8670
2200	2199	2000	1618	235	9,7	0,85	0,00002	0,0015	1,500	90	0,0250	830	0,78	0,0166	0,0011700	0,9860	2,4480	3,2827	0,6640	0,046800	715,137	0,2904	207,6500	10,6407	43167,02	42.538	7.698	31200564,2737
2200	2203	3000	1607	229	14,3	0,85	0,00002	0,0009667	0,967	58	0,0161	830	0,78	0,0166	0,0007540	0,9775	3,5472	4,7568	1,0303	0,046800	711,935	0,3037	216,1850	15,4119	62522,79	42.538	7.698	29136123,1545
2200	2205	4000	1600	220	18,3	0,85	0,00002	0,0007	0,700	42	0,0117	830	0,78	0,0166	0,0005460	0,9723	4,3841	5,8791	1,4229	0,046800	710,334	0,3352	238,1208	19,0133	77133,20	42.538	7.698	26076259,9921

Modifikasi Yanmar TF 85 MH-di Berbahan Bakar Pertamina DEX dan CNG 2 L/min pada Kompresi Rasio 1:16

Putaran Engine		Beban (watt)	Putaran Aluminator (Rpm)	Alternator			Volume Bahan Bakar (m3)		Waktu			Densitas (Kg/m3)		Massa Masuk Bahan Bakar (Kg)		Effisiensi Slip	Daya		FCR (Kg/h)		Nilai Kalor (J/gr)	SFC (Kg/kwh)	SEC (kJ/kWh)	Torsi (Nm)	BMEP (N/m2)	LHV (KJ/kg)		Eff. Thermal (%)
(rpm) kontrol	(rpm) aktual			Tegangan (Volt)	Arus (Ampere)	Load Factor (%)	Pertamina DEX	CNG	Menit	Detik	Jam	Pertamina DEX	CNG	Pertamina DEX	CNG		kW	HP	Pertamina DEX	CNG						Pertamina DEX	CNG	
1800	1803	0	1330	190	0,0	0,85	0,00002	0,00907	4,53	272,0	0,0756	830	0,78	0,0166	0,0	0,988	0,00	0,00	0,22	0,09	760,6	0,000	0,00	0,0	0	42538	7698	0,0
1800	1799	1000	1327	187	3,5	0,85	0,00002	0,00680	3,40	204,0	0,0567	830	0,78	0,0166	0,0	0,988	0,70	0,94	0,29	0,09	747,0	0,551	411,82	3,7	15072	42538	7698	20255067,2
1800	1798	2000	1329	182	7,4	0,85	0,00002	0,00553	2,77	166,0	0,0461	830	0,78	0,0166	0,0	0,990	1,44	1,93	0,36	0,09	739,4	0,315	232,94	7,6	31019	42538	7698	33846170,1
1800	1805	3000	1323	180	11,1	0,85	0,00002	0,00407	2,03	122,0	0,0339	830	0,78	0,0166	0,0	0,982	2,15	2,89	0,49	0,09	730,5	0,271	197,88	11,4	46432	42538	7698	37213996,0
1800	1801	4000	1317	173	14,5	0,85	0,00002	0,00253	1,27	76,0	0,0211	830	0,78	0,0166	0,0	0,980	2,71	3,63	0,79	0,09	721,3	0,325	234,16	14,3	58205	42538	7698	29173549,1
1900	1901	0	1401	202	0,0	0,85	0,00002	0,00860	4,30	258,0	0,0717	830	0,78	0,0166	0,0	0,988	0,00	0,00	0,23	0,09	757,8	0,000	0,00	0,0	0	42538	7698	0,0
1900	1902	1000	1396	200	3,7	0,85	0,00002	0,00667	3,33	200,0	0,0556	830	0,78	0,0166	0,0	0,984	0,80	1,07	0,30	0,09	746,2	0,493	367,52	4,0	16243	42538	7698	22564226,0
1900	1901	2000	1397	195	7,9	0,85	0,00002	0,00500	2,50	150,0	0,0417	830	0,78	0,0166	0,0	0,985	1,66	2,22	0,40	0,09	736,2	0,297	218,66	8,3	33754	42538	7698	35186194,8
1900	1905	3000	1395	191	11,8	0,85	0,00002	0,00400	2,00	120,0	0,0333	830	0,78	0,0166	0,0	0,981	2,43	3,26	0,50	0,09	730,1	0,243	177,62	12,2	49585	42538	7698	41328631,4
1900	1897	4000	1389	185	15,4	0,85	0,00002	0,00273	1,37	82,0	0,0228	830	0,78	0,0166	0,0	0,981	3,07	4,12	0,73	0,09	722,5	0,267	193,27	15,4	62554	42538	7698	35703025,3
2000	2001	0	1474	215	0,0	0,85	0,00002	0,00927	4,63	278,0	0,0772	830	0,78	0,0166	0,0	0,987	0,00	0,00	0,21	0,09	761,8	0,000	0,00	0,0	0	42538	7698	0,0
2000	2005	1000	1478	212	4,1	0,85	0,00002	0,00660	3,30	198,0	0,0550	830	0,78	0,0166	0,0	0,988	0,93	1,25	0,30	0,09	745,8	0,424	316,50	4,4	18047	42538	7698	26125131,3
2000	1999	2000	1461	205	8,4	0,85	0,00002	0,00467	2,33	140,0	0,0389	830	0,78	0,0166	0,0	0,979	1,86	2,50	0,43	0,09	734,2	0,280	205,24	8,9	35989	42538	7698	36911134,3
2000	2003	3000	1468	200	12,6	0,85	0,00002	0,00320	1,60	96,0	0,0267	830	0,78	0,0166	0,0	0,982	2,72	3,64	0,62	0,09	725,3	0,264	191,18	13,0	52679	42538	7698	36936887,6
2000	1998	4000	1458	196	16,3	0,85	0,00002	0,00220	1,10	66,0	0,0183	830	0,78	0,0166	0,0	0,978	3,46	4,64	0,91	0,09	719,3	0,289	207,74	16,5	66941	42538	7698	32333982,7
2100	2101	0	1553	232	0,0	0,85	0,00002	0,00893	4,47	268,0	0,0744	830	0,78	0,0166	0,0	0,990	0,00	0,00	0,22	0,09	759,8	0,000	0,00	0,0	0	42538	7698	0,0
2100	2099	1000	1546	228	4,4	0,85	0,00002	0,00573	2,87	172,0	0,0478	830	0,78	0,0166	0,0	0,987	1,08	1,44	0,35	0,09	740,6	0,410	303,48	4,9	19854	42538	7698	26215162,2
2100	2098	2000	1538	220	9,0	0,85	0,00002	0,00380	1,90	114,0	0,0317	830	0,78	0,0166	0,0	0,982	2,13	2,86	0,52	0,09	728,9	0,289	211,02	9,7	39409	42538	7698	34455044,9
2100	2103	3000	1537	214	13,4	0,85	0,00002	0,00233	1,17	70,0	0,0194	830	0,78	0,0166	0,0	0,979	3,10	4,16	0,85	0,09	720,1	0,306	220,04	14,1	57276	42538	7698	30733756,6
2100	2105	4000	1532	208	17,4	0,85	0,00002	0,00140	0,70	42,0	0,0117	830	0,78	0,0166	0,0	0,975	3,93	5,27	1,42	0,09	714,5	0,386	275,76	17,9	72351	42538	7698	23371621,2
2200	2199	0	1625	246	0,0	0,85	0,00002	0,00747	3,73	224,0	0,0622	830	0,78	0,0166	0,0	0,990	0,00	0,00	0,27	0,09	751,0	0,000	0,00	0,0	0	42538	7698	0,0
2200	2201	1000	1618	240	4,7	0,85	0,00002	0,00427	2,13	128,0	0,0356	830	0,78	0,0166	0,0	0,985	1,21	1,63	0,47	0,09	731,7	0,462	338,26	5,3	21371	42538	7698	21978306,5
2200	2201	2000	1616	232	9,6	0,85	0,00002	0,00280	1,40	84,0	0,0233	830	0,78	0,0166	0,0	0,984	2,40	3,21	0,71	0,09	722,9	0,336	242,81	10,4	42210	42538	7698	28513519,1
2200	2198	3000	1605	226	14,2	0,85	0,00002	0,00233	1,17	70,0	0,0194	830	0,78	0,0166	0,0	0,978	3,47	4,66	0,85	0,09	720,1	0,273	196,45	15,1	61154	42538	7698	34425567,3
2200	2203	4000	1601	218	18,4	0,85	0,00002	0,00127	0,63	38,0	0,0106	830	0,78	0,0166	0,0	0,974	4,36	5,85	1,57	0,09	713,7	0,382	272,68	19,0	76907	42538	7698	23470087,5

Modifikasi Yanmar TF 85 MH-di Berbahan Bakar Pertamina DEX dan CNG 3 L/min pada Kompresi Rasio 1:16

Putaran Engine		Beban	Putaran Aluminator	Alternator			Volume Bahan Bakar (m3)		Waktu			Densitas (Kg/m3)		Massa Masuk Bahan Bakar (Kg)		Effisiensi Slip	Daya		FCR (Kg/h)		Nilai kalor	SFC	SEC	Torsi	BMEP	LHV (J/kg)		Eff. Thermal
(rpm) kontrol	(rpm) aktual	(watt)	(Rpm)	Tegangan (Volt)	Arus (Ampere)	Load Factor (%)	Pertamina DEX	CNG	Menit	Detik	Jam	Pertamina DEX	CNG	Pertamina DEX	CNG		kW	HP	Pertamina DEX	CNG	(J/gr)	(gr/kwh)	(kJ/kwh)	(Nm)	(N/m2)	Pertamina DEX	CNG	(%)
1800	1795	0	1331	185	0	0,85	0,00002	0,0167	5,567	334	0,0928	830	0,78	0,0166	0,013	0,9936	0,0000	0,0000	0,1789	0,1404	806,4	0,0000	0,0	0,0000	0,00	42.538	7.698	0,0
1800	1801	1000	1328	182	3,4	0,85	0,00002	0,0125	4,167	250	0,0694	830	0,78	0,0166	0,010	0,9881	0,6631	0,8892	0,2390	0,1404	781,2	0,5722	447,0	3,5295	14318,42	42.538	7.698	23476836,9
1800	1802	2000	1320	180	7,2	0,85	0,00002	0,0087	2,900	174	0,0483	830	0,78	0,0166	0,007	0,9816	1,3980	1,8747	0,3434	0,1404	758,4	0,3461	262,5	7,4162	30086,08	42.538	7.698	34448374,6
1800	1798	3000	1321	178	11	0,85	0,00002	0,0063	2,100	126	0,0350	830	0,78	0,0166	0,005	0,9845	2,1058	2,8239	0,4743	0,1404	744,0	0,2919	217,2	11,1649	45293,75	42.538	7.698	37575410,4
1800	1805	4000	1317	170	14,4	0,85	0,00002	0,0045	1,500	90	0,0250	830	0,78	0,0166	0,004	0,9777	2,6511	3,5551	0,6640	0,1404	733,2	0,3034	222,5	14,0872	57148,74	42.538	7.698	33789283,6
1900	1901	0	1401	200	0	0,85	0,00002	0,0136	4,533	272	0,0756	830	0,78	0,0166	0,011	0,9876	0,0000	0,0000	0,2197	0,1404	787,8	0,0000	0,0	0,0000	0,00	42.538	7.698	0,0
1900	1897	1000	1402	198	3,8	0,85	0,00002	0,0091	3,033	182	0,0506	830	0,78	0,0166	0,007	0,9903	0,8044	1,0787	0,3284	0,1404	760,8	0,5827	443,3	4,0429	16401,34	42.538	7.698	20733523,9
1900	1901	2000	1390	194	7,8	0,85	0,00002	0,0082	2,733	164	0,0456	830	0,78	0,0166	0,006	0,9798	1,6352	2,1929	0,3644	0,1404	755,4	0,3087	233,2	8,2358	33411,02	42.538	7.698	37978790,3
1900	1905	3000	1391	190	11,7	0,85	0,00002	0,0053	1,767	106	0,0294	830	0,78	0,0166	0,004	0,9784	2,4056	3,2259	0,5638	0,1404	738,0	0,2927	216,0	12,0903	49047,70	42.538	7.698	36111606,4
1900	1899	4000	1386	182	15,4	0,85	0,00002	0,0035	1,167	70	0,0194	830	0,78	0,0166	0,003	0,9780	3,0344	4,0691	0,8537	0,1404	727,1	0,3276	238,2	15,2184	61737,97	42.538	7.698	30080532,1
2000	2001	0	1474	215	0	0,85	0,00002	0,0139	4,633	278	0,0772	830	0,78	0,0166	0,011	0,9871	0,0000	0,0000	0,2150	0,1404	789,6	0,0000	0,0	0,0000	0,00	42.538	7.698	0,0
2000	2005	1000	1477	212	4,1	0,85	0,00002	0,0096	3,200	192	0,0533	830	0,78	0,0166	0,007	0,9871	0,9323	1,2503	0,3113	0,1404	763,8	0,4844	370,0	4,4516	18059,26	42.538	7.698	25350612,6
2000	2003	2000	1469	208	8,4	0,85	0,00002	0,0061	2,033	122	0,0339	830	0,78	0,0166	0,005	0,9828	1,8824	2,5243	0,4898	0,1404	742,8	0,3348	248,7	8,9701	36389,90	42.538	7.698	32523347,2
2000	2003	3000	1463	200	12,6	0,85	0,00002	0,0052	1,733	104	0,0289	830	0,78	0,0166	0,004	0,9787	2,7262	3,6558	0,5746	0,1404	737,4	0,2623	193,4	13,0037	52753,31	42.538	7.698	40151718,1
2000	1999	4000	1461	195	16,4	0,85	0,00002	0,0031	1,033	62	0,0172	830	0,78	0,0166	0,002	0,9794	3,4575	4,6365	0,9639	0,1404	724,7	0,3194	231,5	16,4919	66904,23	42.538	7.698	30357524,7
2100	2110	0	1548	230	0	0,85	0,00002	0,0105	3,500	210	0,0583	830	0,78	0,0166	0,008	0,9831	0,0000	0,0000	0,2846	0,1404	769,2	0,0000	0,0	0,0000	0,00	42.538	7.698	0,0
2100	2112	1000	1544	225	4,3	0,85	0,00002	0,0087	2,900	174	0,0483	830	0,78	0,0166	0,007	0,9796	1,0457	1,4023	0,3434	0,1404	758,4	0,4627	350,9	4,7351	19209,17	42.538	7.698	25767985,7
2100	2101	2000	1543	220	9	0,85	0,00002	0,0056	1,867	112	0,0311	830	0,78	0,0166	0,004	0,9841	2,1303	2,8568	0,5336	0,1404	739,8	0,3164	234,0	9,6370	39095,33	42.538	7.698	33789126,9
2100	2103	3000	1535	212	13,3	0,85	0,00002	0,0035	1,167	70	0,0194	830	0,78	0,0166	0,003	0,9781	3,0524	4,0932	0,8537	0,1404	727,1	0,3257	236,8	13,8804	56310,04	42.538	7.698	30258686,0
2100	2105	4000	1535	208	17,5	0,85	0,00002	0,0021	0,700	42	0,0117	830	0,78	0,0166	0,002	0,9771	3,9442	5,2892	1,4229	0,1404	718,7	0,3963	284,9	17,9191	72694,12	42.538	7.698	23460000,9
2200	2199	0	1625	250	0	0,85	0,00002	0,01	3,333	200	0,0556	830	0,78	0,0166	0,008	0,9902	0,0000	0,0000	0,2988	0,1404	766,2	0,0000	0,0	0,0000	0,00	42.538	7.698	0,0
2200	2201	1000	1615	240	4,6	0,85	0,00002	0,0084	2,800	168	0,0467	830	0,78	0,0166	0,007	0,9832	1,1889	1,5943	0,3557	0,1404	756,6	0,4173	315,7	5,1654	20954,86	42.538	7.698	28285216,1
2200	2201	2000	1612	232	9,6	0,85	0,00002	0,0052	1,733	104	0,0289	830	0,78	0,0166	0,004	0,9814	2,4029	3,2223	0,5746	0,1404	737,4	0,2976	219,4	10,4305	42314,35	42.538	7.698	35390051,3
2200	2205	3000	1610	228	14,2	0,85	0,00002	0,0033	1,100	66	0,0183	830	0,78	0,0166	0,003	0,9784	3,5037	4,6984	0,9055	0,1404	725,9	0,2985	216,7	15,2088	61699,17	42.538	7.698	32747901,5
2200	2204	4000	1610	220	18,5	0,85	0,00002	0,002	0,667	40	0,0111	830	0,78	0,0166	0,002	0,9789	4,4025	5,9037	1,4940	0,1404	718,1	0,3712	266,6	19,0758	77386,46	42.538	7.698	24938696,2

ABOUT THE AUTHOR

The author was born on 1st January 1996 in Bontang East Kalimantan and resides in Bontang. The author is the first child of 2 siblings born with the name of Faishal Afif Herfanda commonly called Afif. His father is Aries Joko Susanto, his mother is Ida Ratnawati and his sister is Arum Dwi Safitri. The author has completed formal education at SD Vidatra Bontang, SMP Vidatra Bontang, and SMA Vidatra Bontang. In 2014 the authors continue their studies for a bachelor degree in Marine Engineering Double Degree program of Institut Tekonlogi Sepuluh Nopember (ITS) and Hochshcule Wismar, with student number 04211441000035 and take the field of expertise in Marine Power Plant (MPP). As a student the writer is not only active in the academic field but also active in the non-academic field. The authors are active in various activities and organizations such as being part of HIMASISKAL FTK ITS 2015/2016 and 2016/2018, Marine Marine Assembling (MDA) committee Marine Icon 2016, Creative Market staff from ITS Expo 2015, Staf Berani Bem ITS 2015/2016 and became one of the members at the Marine Power Plant Laboratory (MPP). During the course of the author has conducted job training in PT. Samudra Marine Indonesia, Banten and Medco E&P Natuna Ltd, Jakarta. Institut Tekonlogi Sepuluh Nopember (ITS) and especially Marine Engineering Department is very special place for writers, because in this place the writer learn various science both hard skill and soft skill as stock to prepare for a better future. Regarding the clarity of this thesis information can contact the email address that has been listed.

Faishal Afif Herfanda
Marine Engineering Department Student
herfandafif@gmail.com

"Take only pictures, leave only bubbles-diver"