بسم الله الرحمن الرحيم

Palestine polytechnic university

College of engineering

Mechanical Engineering Department

The effect of variable compression ratio (VCR) on the performance parameters of a gasoline engine

Project team

Amjad Nassar Mohammed Shahatit

Supervisor

Dr. Zuhdi Salhab

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Abstract

The compression ratio of an internal combustion engine is an important control parameter for effective engine design. A project study to simulate the effect of variable compression ratio on the performance of an engine. In this project the various performance parameters were studied at various compression ratios. The study carried out using a simulation software Diesel RK version 4.3.0.189 it is internal combustion engine simulation software, and ECM titanium mapping software version 1.61, to get the engine maps from the control unit file for Volkswagen Golf 2.0 TFSI and engine control module number (1K0907115K).

The performance parameters considered for the simulation are Brake Torque, Engine power, indicated mean effective pressure (IMEP), Brake mean effective pressure (BMEP), Specific fuel consumption (SFC), Cylinder Pressure and Cylinder Temperature. The graphs for these parameters against the engine speed at different compression ratios.

An increase in compression ratio cause increases in Indicated mean effective pressure (IMEP), Brake mean effective pressure (BMEP), Brake torque, piston engine power, cylinder pressure and cylinder temperature and reduction in the specific fuel consumption.

Dedication

إلى السنبلة الذهبيّة في بِلادي و بيّارات البرتقال .....

إلى كروم العنب و غصن الزيتون ......

. و دَم الشهداء و دَمعة الأطفال

إلى رغيف الطابون و ريح ال َزعتر ......

إلى الشموع التي احترقت لتصنع لنا غدا أفضل .... .إلى (فِلسطين). تِلك التي َصنعتني َكي أكون ُهنا
.إلى القابعين خلف القضبان لننعم بطعم الحرية.....(أسرانا البواسل) (شهداء الحرية)

الى من كان دعائها سر نجاحي ...الى معنى الحب و الى معنى الحنان و التفاني....الى بسمة الحياة و سر الوجود و حنانها بلسم جراحي الى اغلى الحبايب...(امي الحبيبة)

الى من كلله الله بالهيبة و الوقار....الى من علمني العطاء بدون انتظار....الى من احمل اسمه بكل افتخار..ارجو من الله ان يمد في عمرك لترى ثمارا قد حان قطافها بعد طول انتظار و ستبقى كلماتك نجوم اهتدي بها اليوم و في الغد و الى الابد...(والدي العزيز)

إلى من تحلو بالإخاء وتميزوا بالوفاء والعطاء إلى ينابيع الصدق الصافي......(أصدقائي)

) .إلى الذين أجدهم معي في السراء والضراء ..... (أقاربي الأعزاء

إلى من سرنا سوياً ونحن نشق الطريق معاً نحو النجاح والإبداع إلى... (زملائي)

).إلى أولئك الذين يحملون على كاهلهم بناء جيل المستقبل....(أساتذتنا الكرام

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وقال رسول الله صلى الله عليه وسلم : " من وضع إليكم معروفا فكافئوه ، فإن لم تجدوا ما تكافئونه به فادعوا له حتى تروا أنكم كافأتموه " ..رواه ابو داوود.

أنني بكامل شكري وامتناني ووفاءا وتقديرا واعترافا مني بالجميل أتقدم بجزيل الشكر لأؤلائك المخلصين الذين لم يألوا جهدا في مساعدتنا في مجال هذا البحث العلمي ،

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Chapter 1: Introduction

1.1 Overview

1.2 Importance of the Project

1.3 Problem Statement

1.4 Objectives of the Project

1.5 Methodology

1.6 Literature review

1.7 Time Table

1.1 Overview

Combustion, also known as burning, is the basic chemical process of releasing energy from a fuel and air mixture. In an internal combustion engine (ICE), the ignition and combustion of the fuel occurs within the engine itself. The engine then partially converts the energy from the combustion to work. [1]

The performance of spark ignition engines is a function of many Factors (Compression ratio, Fuel chemical structure, Air-fuel ratio, ignition timing, flame speed etc. ……). One of the most important ones is Compression ratio. Also it is one of the most important parameters for optimizing efficiency and fuel consumption. [1]

1.2 Importance of the Project

With increasing demands for better engine performance and improved fuel economy has led to much advancement in the automotive industry. One of those advancements is the concept of variable compression ratio VCR. The concept of VCR proved in increasing the engine performance with also proved in improving the fuel economy. [2]

1.3 Problem Statement

The higher the compression ratio, the more compressed the air is in the cylinder. When the air is compressed, you get combustion from the air-fuel mixture and more fuel being used and thus higher the efficiency. Conventional engines operate at a fixed compression ratio. Thus there might be a chance that the engine is running at a lower efficiency than when it is to be operated at any other compression ratio. So an engine with variable compression ratio is needed so that the compression ratio of the engine can be changed according to different load and speed conditions. [3]

1.4 Objectives of the Project

- This project theoretically investigates the effect of variable compression ratio on the performance of a gasoline engine - spark-ignition (SI).

- This project simulation investigates engine parameters with different engine speed and change of compression ratio in four stroke four-cylinder engine by take some parameters and calculate others.

- Simulation the Break Torque, Engine Power, indicated mean effective pressure (IMEP), Brake mean effective pressure (BMEP), Specific fuel consumption (SFC), Cylinder Pressure and Cylinder Temperature. The graphs for these parameters against the engine speed at different compression ratios.

1.5 Methodology

With the increasing cost and demand of energy resources such as diesel and gasoline there is continuous need for engines having high efficiency and lowest fuel consumption as these resources are on the verge of depletion. Therefore, an engine with variable compression ratio is needed which provides best performance and also reduces the consumption of fuel. Thus further reducing the environmental damage and benefitting the manufacturers by satisfying the strict emission control norms. In this project a four-cylinder gasoline engine (The 2.0l FSI engine with turbocharger AXX) has been taken into account for carrying out the simulation. The study carried out using a simulation software Diesel RK version 4.3.0.189.

The performance parameters considered for the simulation are Break Torque, Engine Power, indicated mean effective pressure (IMEP), Brake mean effective pressure (BMEP), Specific fuel consumption (SFC), Cylinder Pressure and Cylinder Temperature, were studied distinctly for every case. An optimum value of compression ratio has been found at which engine is running at best efficiency and lowest fuel consumption. The range of compression ratio considered for studying engine was (8.5 - 12.5).

1.6 Literature review

The first study:

The Effect of Compression Ratio upon the Performance and Emission of spark ignition engine (Mohammed Kadhim Allawi) 2016.

Introduction

The goal of this research to improve the performance of the gasoline engine (SI) by Increasing the compression ratio (CR) below detonating values, to improve the performance by use the experimental analysis the performance of SI engine operating with variable compression ratios 6, 7, 8 and 9.

Procedure

The research was performed using engine test: a single cylinder, variable compression ratio engine type GR used in the experiments. It made by the " Prodit" Company, 4 strokes; has popped overhead valve and connected to a hydraulic dynamometer. it adapted to run on an SI engine. The exhaust gas analyzer type (TEXA) was used to analyze the emissions of exhaust. The analyzer the CO-CO2-HC-O2 emissions contents. The Compression Ratio measured by the cylinder-head position and it varies from (4 to 17).

Result

The research evaluates the Effect of Compression Ratio upon the Performance and Emission like as Brake Thermal Efficiency, f Brake specific fuel consumption, HC & CO emissions in the exhaust gases. [4]

The second study:

Influence of compression ratio on the performance characteristics of a spark ignition engine (Aina T., Folayan C. O. and Pam G. Y.) 2012.

Introduction

The goal of this research to improve the performance of the gasoline engine (SI) by Increasing the compression ratio (CR) below detonating values, to improve the performance by use an experimental and theoretical analysis the performance of the Ricardo variable compression ratio spark ignition engine. Compression ratios of 5, 6, 7, 8 and 9, and engine speeds of 1100 to 1600 rpm.

Procedure

experimental is realized using test engine (Ricardo variable compression ratio engine with direct current electric dynamometer is a four stroke water-cooled single cylinder petrol engine). Variation of the compression ratio was achieved by raising the cylinder head up in order to decrease the compression ratio and by lowering it down to increase the compression ratio and theoretical is realized by equation and calculation.

Result

The research evaluates the Effect of Compression Ratio upon the Performance and efficiencies like as brake power, brake thermal efficiency, brake mean effective pressure and specific fuel consumption. [5]

The third study:

Effect of Compression Ratio on Performance and Emissions of a Single Cylinder Four Stroke Diesel Engine (Yogesh S. Awate , Madhu L. Kasturi , K. S. Gharge , A. T. Pise) 2017.

Introduction

The goal of this study and experiment is to work was conducted to evaluate the effect of compression ratio on performance and emission by using conventional diesel fuel on the single cylinder four stroke variable compression ratio (VCR) engine.

Procedure

The engine specification uses for experimental: Variable Compression Ratio, Single cylinder Engine diesel, 4 stroke, connected with Dynamometers. Dynamometer Type: eddy current, air cooled with loading unit, Load measurement Direct coupling, strain gauge, manual loading, Exhaust Gas Calorimeter Type shell and tube, K type thermocouple, water cooling. The exhaust gas analyzer Model AVL was used to analyze the emissions of exhaust.

Result

The study evaluates the Effect of Compression Ratio upon the Performance, emission and efficiencies like as brake thermal efficiency, specific fuel consumption, and Exhaust Gas Temperature (EGT) with emission HC, CO & NOx. [6]

1.7 Time Table

The time table that will spend during the summer semester as shown in table 1.1

Table 1.1 Time Table for the summer semester

Number of weeks / Task	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Select the idea								
Select the software								
literature review								
Writing report								
Make presentation								

The time table that will spend during the first semester as shown in table 1.2

Table 1.2 Time Table for the first semester

Number of weeks / Task	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Select engine																
Engine specification																
Make simulation and get a results																
Make report																
Make presentation																

Chapter 2: Diesel-RK ICE software and ECM TITANIUM Mapping Software

2.1 Introduction

2.2 The theoretical basis for building models of Diesel-RK software

2.3 Features of Diesel RK software

2.4 Applicability of Diesel-RK software

2.5 ECM TITANIUM Mapping Software

2.6 The main features of ECM Titanium

2.1 Introduction

Currently, the researches of internal combustion engines in the world have focused on research and development of software to solve simulation problems and complete the working cycle to solve problems related to the logical organization of the mixture generation process and combustion in IC engines. The demand for such software is very large, while the prices of software from well-known brands Boost (AVL), Wave (Ricardo), GT-Power (Gamma Technologies) are very high, possibly up to hundreds of thousands of dollars. However, the above software does not allow to study in detail the effects of the combustion chamber shape, spray beam direction and other characteristics of the process of creating a mixture to the quality of combustion process.

Diesel-RK is a software for calculating internal combustion engines developed by Bauman Technical University (Russian Federation) experts. It has been used by many facilities specializing in research, development, and production. Diesel-RK software used a multi-zone fire model based on the mixture and combustion model of Razleisev, added and developed by Kuleshov (known as Razleisev-Kuleshov model or RK model). [7]

2.2 The theoretical basis for building models of Diesel-RK software

To build the software, the team of Diesel RK has built and developed computational models of previous scientists and researchers. The main mathematical model of the software is to simulate the engine process. This model was developed based on the research results of GS A. Kuleshov: Simulation and optimization of the working process of internal combustion engines. The working parameters of the mixed-gas in the engine combustion chamber are determined by solving the partial differential equation of energy, mass and state equation for open thermodynamic systems. Multi zone fire models are used to calculate combustion in gasoline and gas engines. The release heat rate is calculated according to the Wiebe method. The mixture formation and combustion process in diesel engines are simulated by the RK model. The method of simulating the RK model was developed by Professor Razleytsev in 1990-1994. Later, the method was modified and supplemented by Dr. Kuleshov. The RK model will take into account: (1) Shape of fuel spray; (2) Fuel particle size; (3) Direction of the fuel sprays in the combustion chamber; (4) The dynamics of the development and decay process of the fuel sprays; (5) Dynamics and shapes of swirls in the combustion chamber; (7) Interaction of fuel particles with swirls and walls of combustion chambers. NOx emission calculation is done in two ways: (1) The model was developed by Professor Zvonov with the use of Zeldovich mechanism on the basis of chemical balance of 18 substances when considering conventional diesel engines; (2) DKM model considers 199 reactions with 33 substances to accurately predict NOx emissions in engines with EGR, multi-nozzle systems and HCCI engines. DKM only supports DIESEL-RK version in Russia, see Figure 2.1 that main window of Diesel rk software.

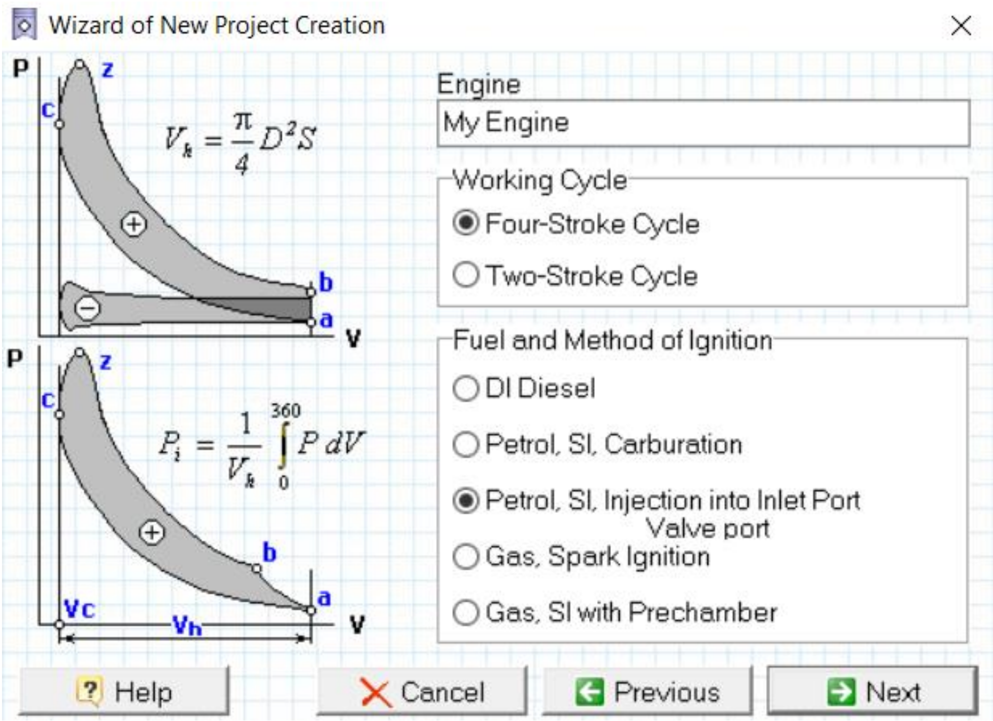

Figure 2.1 Diesel rk software [7]

2.3 Features of Diesel RK software

The main features of DIESEL-RK software are similar to known thermodynamic software. However, along with popular features, DIESELRK has new advanced applications that other programs do not have. DIESEL-RK oriented optimization of the combustion process in engines and ICE analysis and optimization. Assuming the same working of all cylinders in the engine allows a significant increase in operating speed and makes it possible to optimize the complex engine tasks. DIESEL-RK is a software that simulates the thermodynamic cycle of relatively complete engines. The software is designed to simulate and optimize the working processes of combustion engines for 2-stroke engines and 4-stroke engines with a turbocharger. Software can simulate the model of the following types of engines:

(1) DI diesel engine, including PCCI and also biofuel engine.

(2) SI gasoline engine.

(3) SI gas engines include a pre-combustion chamber system, engines can use different gases: methane, propane-butane, biogas, synthetic gas.

(4) Reversible or non-reversing two-stroke engines, reciprocating piston engines (OP motors or Junkers) and OPOC engines.

(5) Dual fuel engine (the engine has an independent fuel injection system for different fuels) (Engine with RCCI).

DIESEL-RK is a thermal and dynamic calculation software for highly reliable internal combustion engines. This software meets different requirements in evaluation design and testing. It is used to perform the following functions:

(1) Allows a detailed review of the impact of the parameters affecting the fuel injection process, forming mixture; dynamic of combustion and formation of pollutants.

(2) Multi-parameter optimization function allows optimization of design, fuel supply process, air exchanges ... to achieve a simultaneous compromise of the two biggest goals is to reduce fuel consumption and to reduce pollution levels (NOx, PM).

(3) Add a suitable model for calculating the NOx emissions of diesel engines working with lean mixes - PCCI (Premixed Compression Ignition) and having a high level of emissions (EGR).

(4) Allows analysis and evaluation of intelligent air distribution systems.

(5) Combined thermodynamic simulation with temperature forecasting of details (piston, cylinder, cylinder head).

(6) Allow to link with other simulation software for overall engine design (check the compatibility of diesel engines with applications of fuel consumption, pollution emissions, ...).

(7) The combustion model of a diesel engine in Diesel-RK software allows calculation of engine simulation when using different types of fuel: diesel fuel (B0), biofuels as well as biofuel mixtures with different mixing ratios. The software also allows users to update the properties of the fuel in the library based on the properties of the actual fuel surveyed.

The RK model is capable of optimizing the bowl piston shape and fuel injection system parameters and developing multi-point injection technology and controlling Common Rail throughout all operating modes. [8]

2.4 Applicability of Diesel-RK software

Software can be applied to solve problems in diesel engines:(1) Predicting torque graphs and engine performance; (2) Predict and optimize fuel consumption; (3) Analysis and optimization of combustion and emission processes;(4) Prediction knock; (5) Optimize working time of valves; (6) Analysis and optimization of EGR system; (7) Optimizing the combination of turbocharged turbines and emissions; (8) Research and optimize fuel spray characteristics of both multi-nozzle system including spray shape and spray position as well as optimize crown piston shape; (9) Convert diesel engine into gas engine; (10) Analysis of engines using dual fuel .

The fast data processing speed has allowed DIESEL-RK to solve optimization tasks well, including optimizing the crown piston shape and fuel injection system to achieve low NOx and smoke emissions. [9]

Publications that was used diesel RK

Andrey Kuleshov, Khamid Mahkamov, Andrey Kozlov, Yury Fadeev, 2014, “Simulation of dual-fuel diesel combustion with multi-zone fuel spray combustion model,” ASME 2014 Internal Combustion Engine Division Fall Technical Conference ICEF2014-5700, October 19-22, 2014, Columbus, IN, USA, 14 p.

Andrey Kuleshov, Leonid Grekhov "Multidimensional Optimization of DI Diesel Engine Process Using Multi-Zone Fuel Spray Combustion Model and Detailed Chemistry NOx Formation Model", SAE Paper No 2013-01-0882, 2013.

A.S. Kuleshov, A.V. Kozlov, K. Mahkamov "Self-Ignition delay Prediction in PCCI direct injection diesel engines using multi-zone spray combustion model and detailed chemistry" 2010.

A.S. Kuleshov: "Multi-Zone DI Diesel Spray Combustion Model for Thermodynamic Simulation of Engine with PCCI and High EGR Level", SAE Paper No 2009-01-1956, 2009.

Kuleshov, A. and Mahkamov, K. Multi-zone diesel fuel spray combustion model for the simulation of a diesel engine running on biofuel. // Proc. Mechanical Engineers Vol. 222, Part A, Journal of Power and Energy. pp. 309 – 321. 2008.

SAE Paper No 2005-01-2119, 2005

SAE Paper No 2006-01-1385, 2006

SAE Paper No 2007-01-1908, 2007

SAE Paper No 2009-01-1956, 2009

SAE Paper No 2010-01-1960, 2010

SAE Paper No 2013-01-0882, 2013

ASME ICEF2014 - 5700, 2014

SA SAE Paper No 2015-01-1791, 2015

SAE Paper No 2015-01-1859, 2015 [10]

2.5 ECM TITANIUM Mapping Software

ECM Titanium is the mapping software that allows you to interpret and modify the files of the control unit easily and with accuracy. It is compatible with all the original files of cars, motorbikes, trucks, tractor and boats; it does not need other files or additional information as all are already included in the software.

To each original file corresponds a driver, supplied by Alientech, that decodes and makes available the parameters of the engine performance, for example: spark advance, engine revolves, acceleration percentage and turbo pressure. In this way you can edit the related parameters modifying the performance of the engine, see Figure 2.2 ECM TITANIUM Mapping Software.

Figure 2.2 ECM TITANIUM Mapping Software

2.6 The main features of ECM Titanium

DRIVER SEARCH

The driver search is the exclusive feature that will allow you to automatically find all the necessary info to remap the original file you loaded in ECM Titanium. You will not need to purchase or to search for additional information to edit the parameters of the engine performance.

MAP LIST

In the section dedicated to the map list you will find all the necessary information to manage at your best any kind of ECU and TCU. Maps are divided in categories like: intake control, advance, turbo, engine torque, limiters and deactivations. Beside the map categories, you will also find all the available unit of measurement for each single function.

TABLE VIEW

Thanks to the table view you have the exact representation in real values used to manage the engine. You can then create your own strategy to edit the maps in the drivers. For example, you can use the interpolation feature that permits to modify the parameters in a proportional way to a selected area of the map.

3D VIEW

The 3D view will allow the form and the development of the map; you can so linearise the representation, modifying the values point by point so to make the engine response more uniformed and smooth. You will be also able to increase or decrease specific areas to improve the vehicle performance.

2D VIEW

Through the 2D view, you will have the chance to explore the entire original file to search for one or more maps you want. You will be able to modify any parameter in the loaded map. And thanks to the feature Memo addresses you can memorize the addresses of the maps so that you will easily find them again later.

INTERNAL DATABASE

Our internal database will allow you to save all the files on ECM Titanium inside the flash drive so to have them always with you and work on many different Pc. If you select the desired original file you will find all the associated mod files you created. [11]

Chapter 3: Engine Specification and Performance

3.1 Introduction

3.2 Fuel Stratified Injection (FSI)

3.3 Ignition system

3.4 BorgWarner K03 turbocharger

3.5 Engine Performance

3.1 Introduction

The 2.0l turbocharged FSI engine was first installed in the Volkswagen Golf GTI ,see Figure 3.1 that show The 2.0l FSI engine with turbocharged and Figure 3.2 that show Torque and power graph for 2.0 TFSI engine,and Table 3.1 show Engine specification [12]

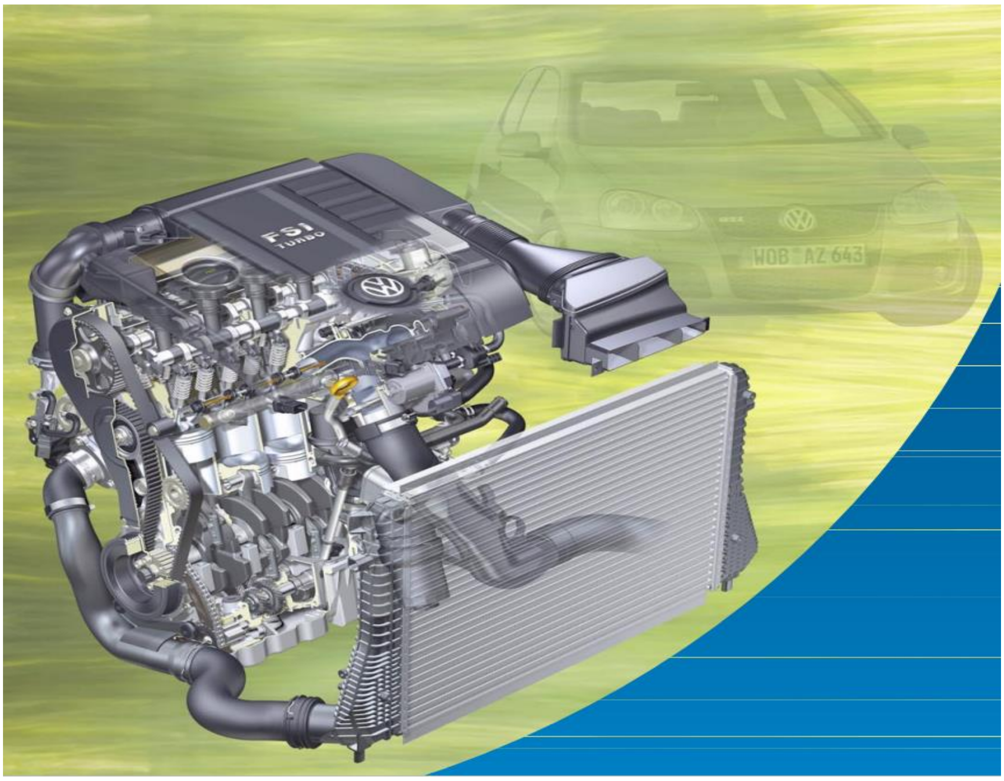

Figure 3.1 The 2.0l FSI engine with turbocharged [12]

Table 3.1 Engine specification [12]

Engine code	AXX
Engine type	4 cylinder in line engine
Capacity	1984
Bore	82.5
Stroke	92.8
Compression ratio	10.5 : 1
Max power	147 Kw at 5700 rpm
Max torque	280 Nm at 1800 - 4700 rpm
Engine management	Bosch motronic MED 9.1
IVO - intake valve opening, degreeBTDC	28
IVC - intake valve closing, degree.ABDC	38
EVO - open degree exhaust valve. BBDC	38
EVC - exhaust valve shutdown. ATDC	8
IV_Lift - intake valve lift, mm	10.7
EV_Lift - exhaust valve lift, mm	10
Intake valve head diameter (mm)	33.85
exhaust valve head diameter (mm)	28

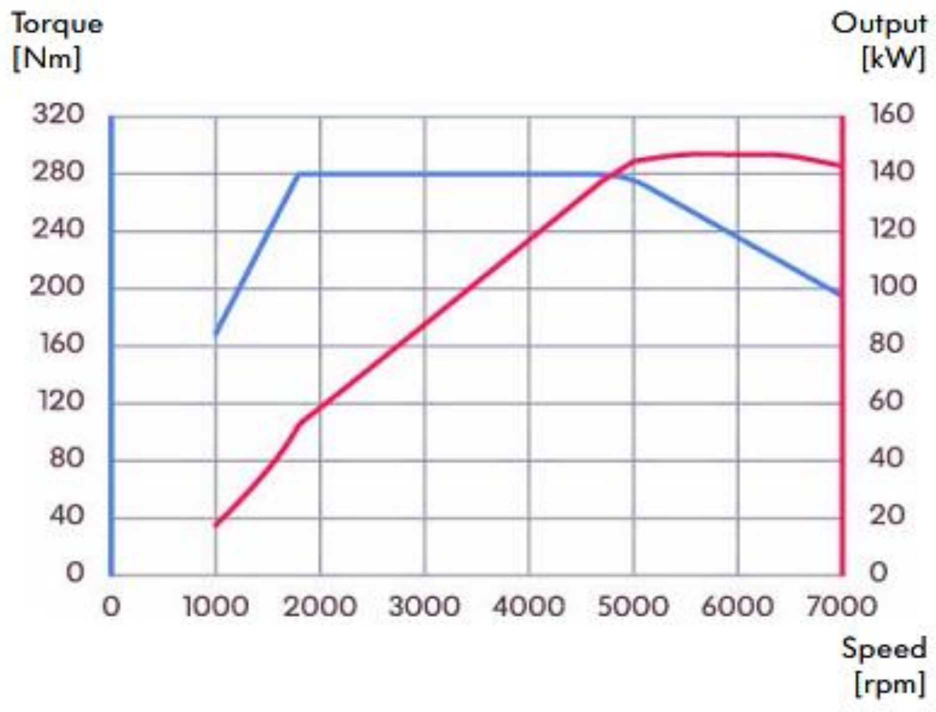

Figure 3.2 Torque and power graph for 2.0 TFSI engine [12]

3.2 Fuel Stratified Injection (FSI)

The 2.0 TFSI engine had Volkswagen's Fuel Stratified injection or FSI which directed fuel directly into the combustion chamber (as opposed to port injection which injected fuel upstream of the chamber) at a pressure of up to 110 bar. The high pressure fuel pump was driven by a four-fold cam on the exhaust camshaft. Fuel was only injected in the piston's compression phase (lather than the conventional induction phase) and was directed into the intake a stream as it moved towards the spark plug. the injection occurred on the intake stroke at approximately 300 degrees before top dead center (TDC) of ignition and the fuel distributed itself homogeneously. The Figure 3.3 show injection timing map X axis represent engine load and Y axis represent engine speed. [12]

RPM|Load	7	14	21	29	36	43	50	57	64	71	79	86	93	100
700	124	124	124	126	127	128	132	132	132	132	132	132	132	132
1100	124	124	124	126	127	128	132	132	132	132	132	132	132	132
1500	125	125	125	128	127	129	127	127	127	127	127	127	127	127
1900	126	126	126	128	128	127	128	127	127	127	127	127	127	127
2300	126	126	126	128	128	128	128	128	128	129	129	129	129	129
2700	127	127	127	128	128	130	128	129	128	128	128	128	128	128
3100	125	125	125	126	128	128	129	128	128	129	129	129	129	129
3600	125	125	125	127	128	129	129	129	129	129	129	129	129	129
4000	125	125	125	127	128	128	127	128	129	129	129	129	129	129
4400	123	123	123	128	128	129	128	129	128	128	128	128	128	128
4800	123	123	123	127	127	128	128	128	128	128	128	128	128	128
5200	121	121	121	127	127	127	128	128	128	129	129	129	129	129
5600	121	121	121	127	126	128	127	127	127	129	129	129	129	129
6000	120	120	120	125	125	126	127	127	129	129	129	129	129	129

Figure 3.3 injection timing map (X axis is engine load and Y axis is engine speed)

3.3 Ignition system

The 2.0 TFSI engine had four single spark ignition coils and cylinder-selective anti-knock control that was controlled by the Bosch Motronic MED 9.1 engine management system. Furthermore, the 2.0 TFSI engine had a compression ratio of 10.5.1. The Figure 3.4 show Ignition timing map X axis represent engine load and Y axis represent engine speed [12]

RPM|Load	8	17	25	33	42	50	58	67	75	83	92	100
700	27	27	27	8	-3	-5	-8	-10	-12	-13	-14	-15
1100	28	32	32	13	6	-2	-6	-8	-10	-12	-13	-14
1400	30	32	32	24	16	5	-3	-5	-8	-10	-12	-13
1800	35	43	38	34	28	19	11	3	-4	-7	-10	-12
2100	45	45	43	37	32	22	15	9	1	-4	-7	-10
2500	47	47	44	39	34	25	19	13	6	0	-4	-7
2800	47	47	43	41	36	27	21	14	7	2	-2	-5
3200	51	51	43	44	35	29	23	16	10	4	1	-2
3500	51	53	48	42	37	33	24	18	12	10	6	2
3900	43	43	48	45	38	35	27	20	16	12	8	4
4200	43	43	45	42	37	33	28	23	19	14	10	6
4600	43	43	44	41	35	33	30	25	21	17	13	9
4900	43	43	43	39	35	33	30	27	23	19	15	11
5300	43	43	44	40	35	33	31	29	25	21	18	13
5600	43	43	47	39	37	33	32	30	28	25	22	17
6000	43	43	45	40	38	35	33	33	32	29	25	20

Figure 3.4 Ignition timing map (X axis is engine load and Y axis is engine speed)

3.4 BorgWarner K03 turbocharger

The 2.0 TFSI had a single water-cooled turbocharger that was integrated with the exhaust manifold into a single unit. For the AXX, BWA and BPY engines which produced peak power of 147 kW. The Table 3.2 show Turbocharger dimension and The figure 3.5 BorgWarner K03 Turbocharger map X axis is air volume flow and Y axis is pressure ratio and The Figure 3.6 show Boost pressure map X axis represent engine load and Y axis represent engine speed. [13]

Table 3.2 Turbocharger dimension [13]

AXX / BWA / BPY EA113: K03 turbocharger		
Turbine	Blade diameter (inducer/exducer)	40 mm / 45 mm
	Number of blades	11
Compressor	Blade diameter (inducer/exducer)	41 mm / 54 mm
	Number of blades	6 + 6

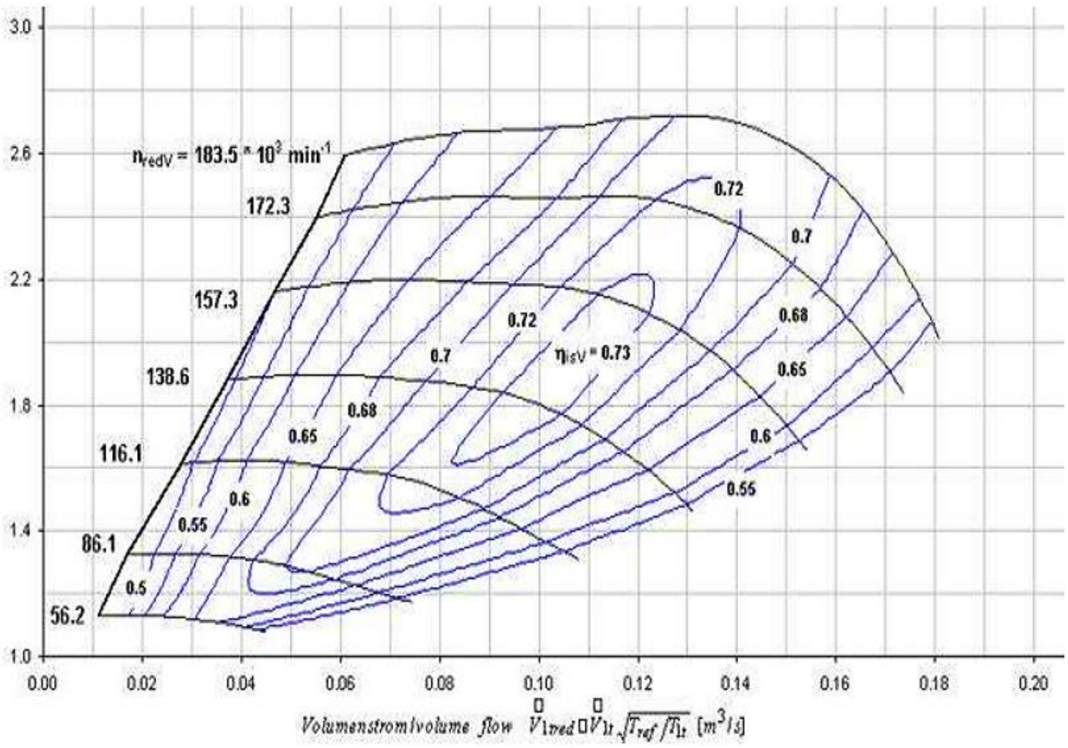

Figure 3.5 BorgWarner K03 Turbocharger map (X axis is air volume flow and Y axis is pressure ratio) [14]

RPM|Load	10	20	30	40	50	60	70	80	90	100
700	0	3200	3400	4000	5400	7600	10600	14000	18000	19000
800	0	3800	4400	5400	7000	9400	11800	15200	18000	19000
900	0	4200	5600	7200	8600	11000	13200	16200	18000	19000
1100	0	4800	7400	9000	10600	12400	14400	16800	18000	19000
1200	0	5000	8400	10200	11800	13400	15000	17000	18000	19000
1400	0	5000	8400	10400	12000	13400	14600	16200	18000	19000
1700	0	5000	8200	10400	12000	13200	14600	15800	18000	19000
1900	0	5000	8200	10400	12000	13200	14800	15800	17000	19000
2200	0	5200	8200	10200	12000	13200	14800	15800	17000	19000
2500	0	5400	8400	10400	12000	13600	14800	16000	17000	19000
2900	0	5800	8600	10600	12000	13600	15000	16400	18000	19000
3400	0	6200	8800	10800	12200	13800	15600	17000	19000	19000
3900	0	6800	9200	11000	12600	14200	16400	17400	19000	19000
4500	0	7400	9600	11000	12800	14600	16800	17800	19000	19000
5200	0	7600	9800	11000	12800	14800	17000	18000	19000	19000
6000	0	7600	9800	11000	12800	14800	17000	18000	19000	19000

Figure 3.6 Boost pressure map (X axis is engine load and Y axis is engine speed)

3.5 Engine Performance

1-Torque

in simple terms, is 'Twisting or Turning Force'. It is the tendency of a force to rotate an object about an axis. In automotive terms, it is the measure of rotational effort applied on engine crankshaft by the piston.

Torque = force * distance (N.m)

2-Brake Power (BP)

The brake power of an engine is the actual power delivered by the crankshaft and is measured by the means of an electric dynamometer. It is an important factor for calculating the mechanical efficiency of an engine.

3-Mean Effective Pressure (MEP)

The mean effective pressure is the hypothetical Pressure which is assumed to be acting on the piston during the power stroke.

4-Indicated Power (IP)

The indicated power of an engine is the actual power developed within the cylinder during the combustion process. It is always greater than the brake power. The sum of brake power and friction power gives the indicated power. The indicated power of a single cylinder engine is determined by using the following formulae
Where,

$$IP = \frac{IMEP \times L \times A \times N}{60}$$

IMEP = Indicated Mean Effective Pressure (Pa)
L = Length of stroke (m)
A = Area of cylinder (m^2)
N = Number of working strokes per minute

5-Friction Power (FP)

The friction power is the power that is required to overcome the loss of power due to friction in an engine. Friction power increases in relation to engine speed and it is calculated by subtracting the brake power from the indicated power.

$$FP = IP - BP$$

6-Specific Fuel Consumption (SFC)

It is defined as the amount of fuel consumed per unit of power developed per hour.

7-Brake Specific Fuel Consumption (BSFC)

It is a measure of the fuel efficiency of an engine that burns fuel and develop power. It is obtained by using the formulae

$$BSFC = \frac{M}{BP}$$

Where, M = Weight of fuel (Kg/hr.).

8-Indicated Specific Fuel Consumption (ISFC)

It is the ratio of amount of fuel used by an engine to the indicated power of an engine. It is obtained by using the formulae

$$ISFC = \frac{M}{IP}$$

Where, M = Weight of fuel (Kg/hr.) [15]

Chapter 4 Procedure

4.1 Introduction

4.2 Procedure

4.1 Introduction

The results discussed in this chapter were obtained using the RK Diesel simulation software described in the second chapter of the project by selecting an engine with the specifications mentioned in the third chapter of the project, following certain procedures. Based on this simulation, a set of curves describing The effect of compression ratio on engine performance parameters such as Indicated mean effective pressure (IMEP), Brake mean effective pressure (BMEP), Brake torque, Specific fuel consumption (SFC), piston engine power, cylinder pressure and cylinder temperature(average).

4.2 Procedure

To determine the optimum value of the compression ratio the specifications of the four-cylinder gasoline engine is entered into the simulation software Diesel RK: Bore, Stroke, Nominal speed, Compression ratio, No. of valves, No. of cylinders. That was taken from the third chapter. Figure 4.1 which contains the engine specification information, Figure 4.2 and figure 4.3 which contains intake and exhaust valve dimension and timing, select from fuel injection system window the petrol fuel direct injection with high pressure 110 bar show in Figure 4.4.

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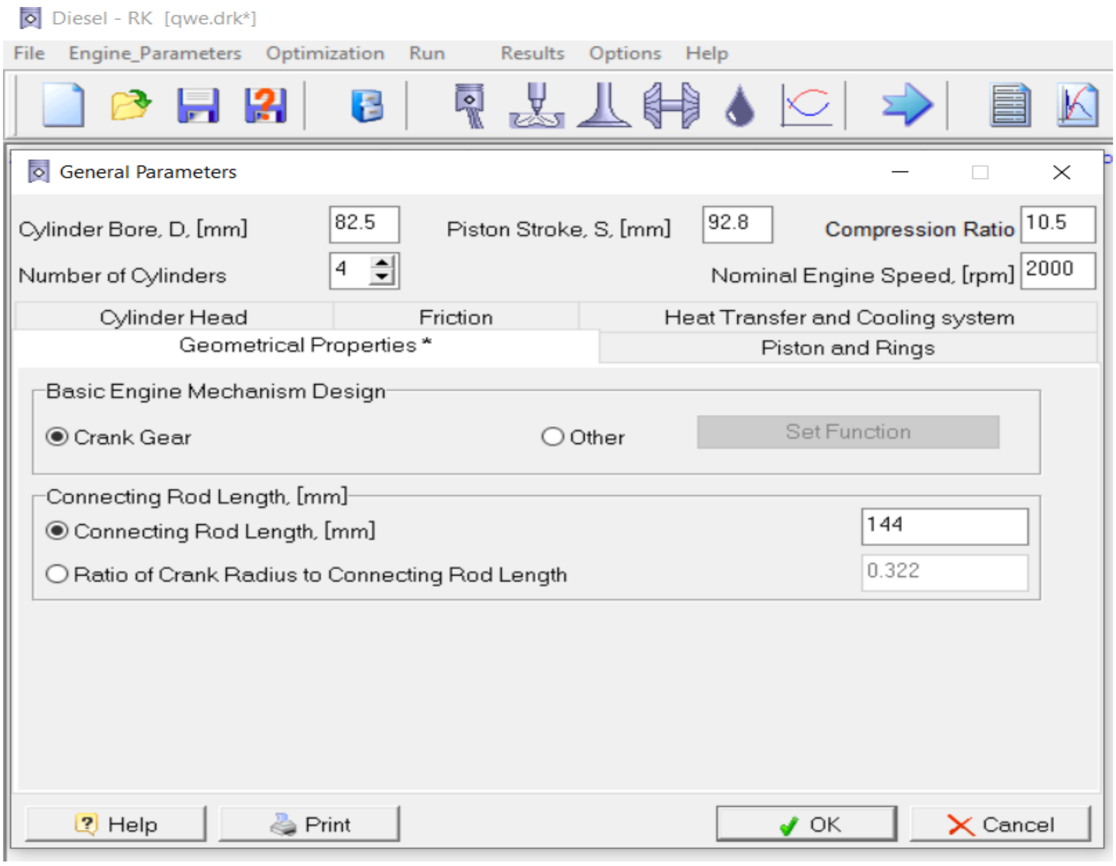

Figure 4.1 General parameter from software Diesel RK

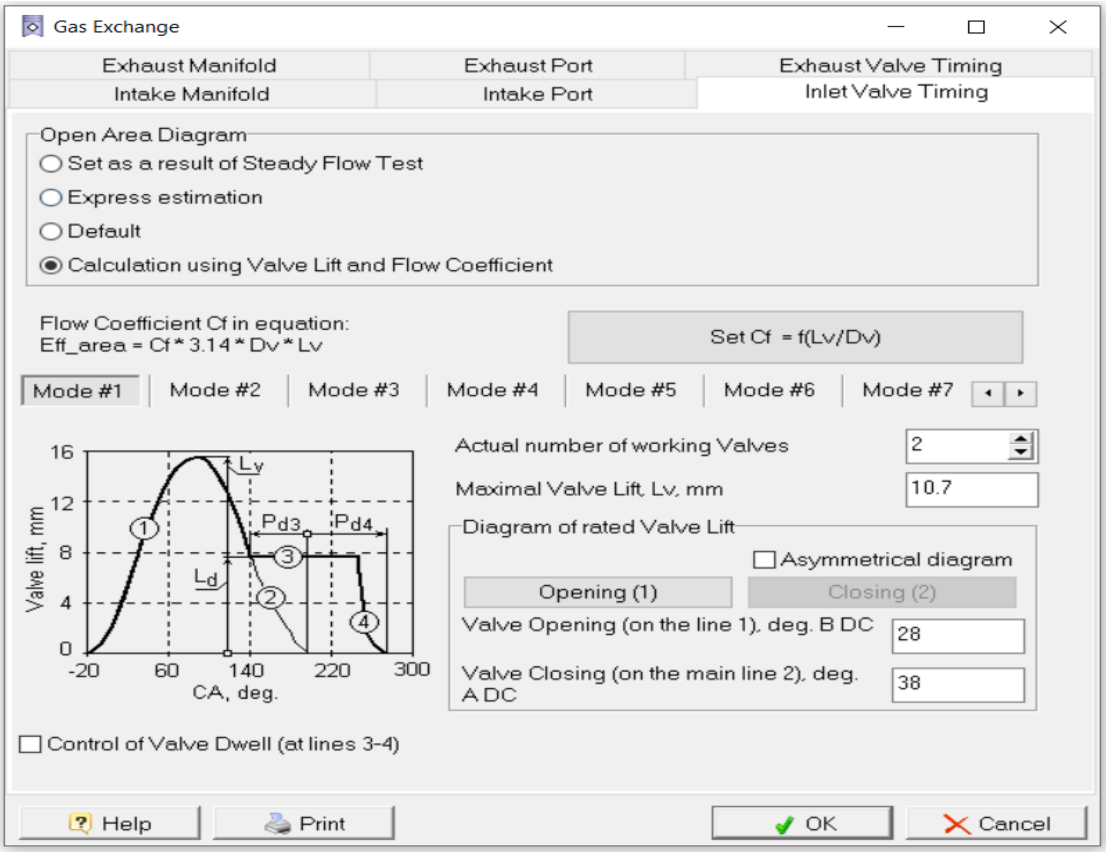

Figure 4.2 Inlet valve timing from software Diesel RK

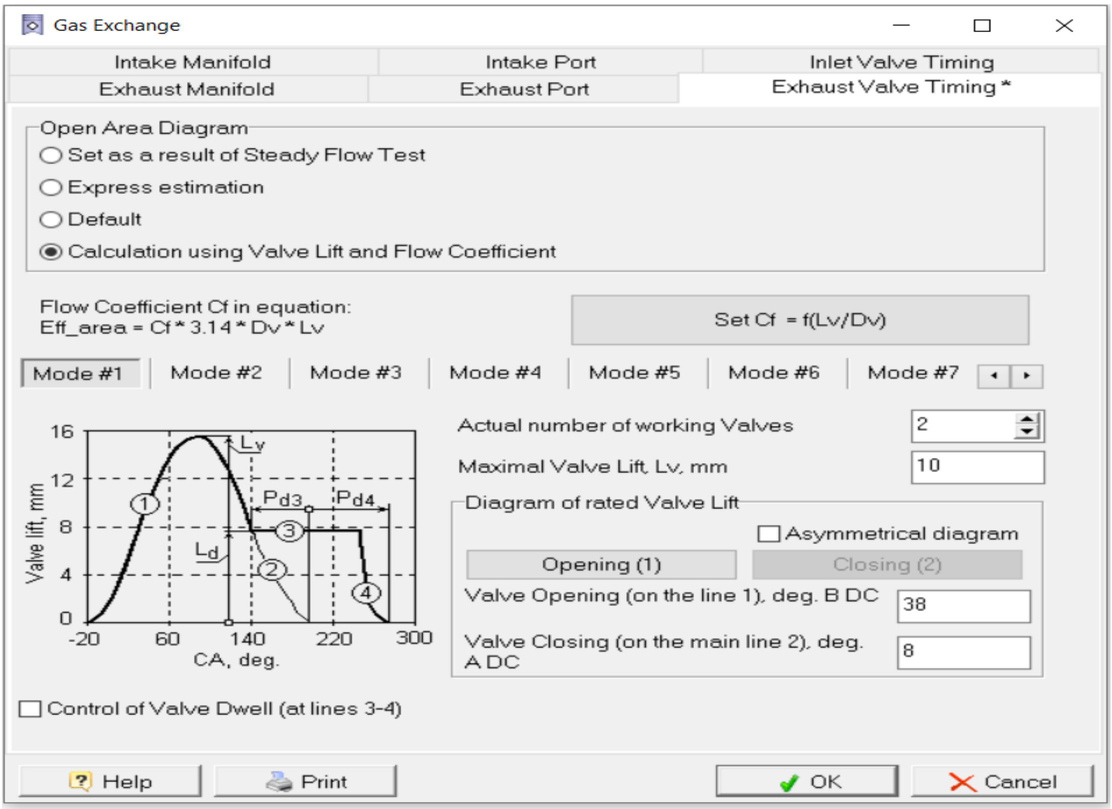

Figure 4.3 exhaust valve timing from software Diesel RK

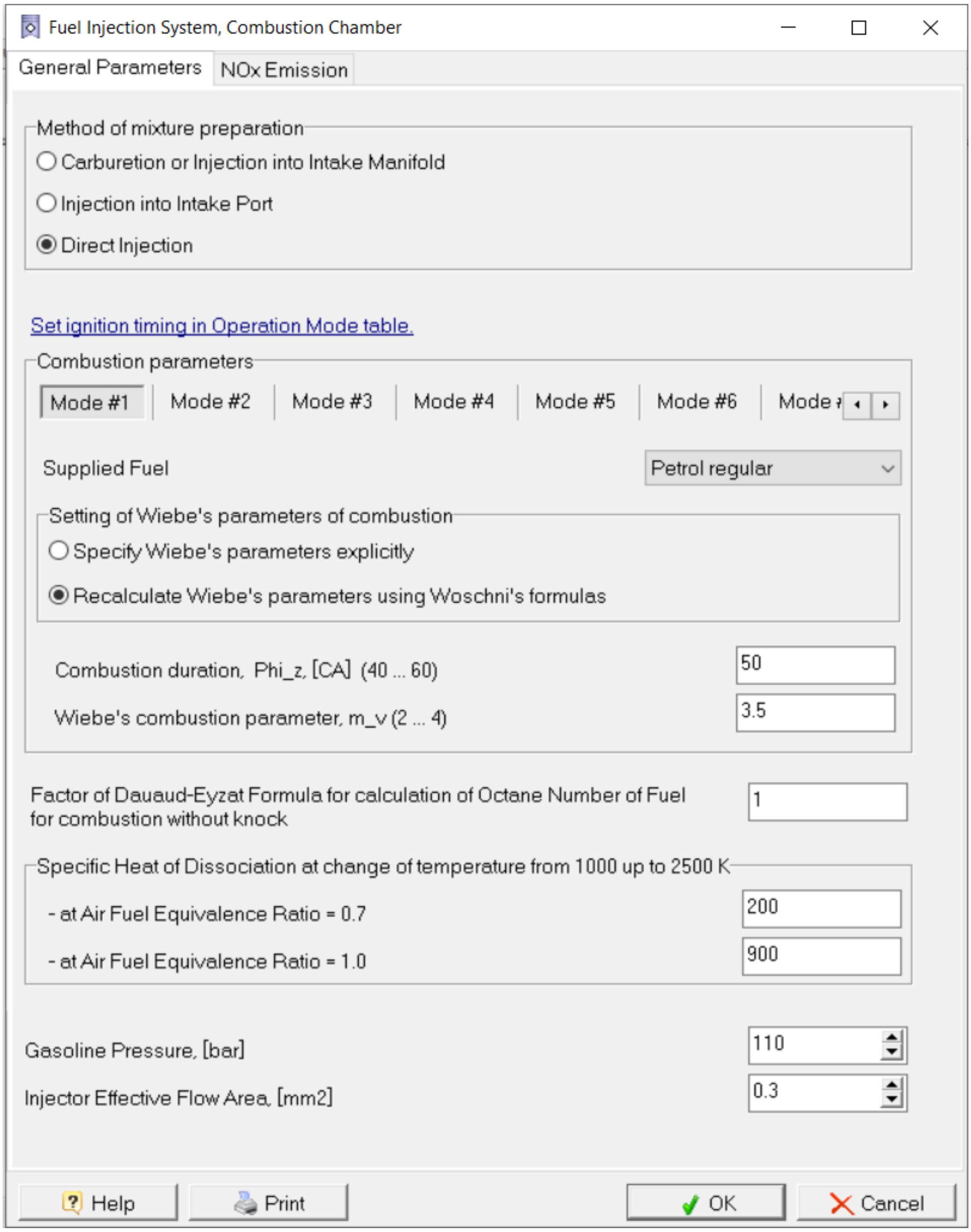

Figure 4.4 fuel injection system

Then select the turbo charger dimension and specification of the single water-cooled turbocharger that was integrated with the exhaust manifold into a single unit which see in figure 4.5 and 4.6 which contain turbine and compressor specification.

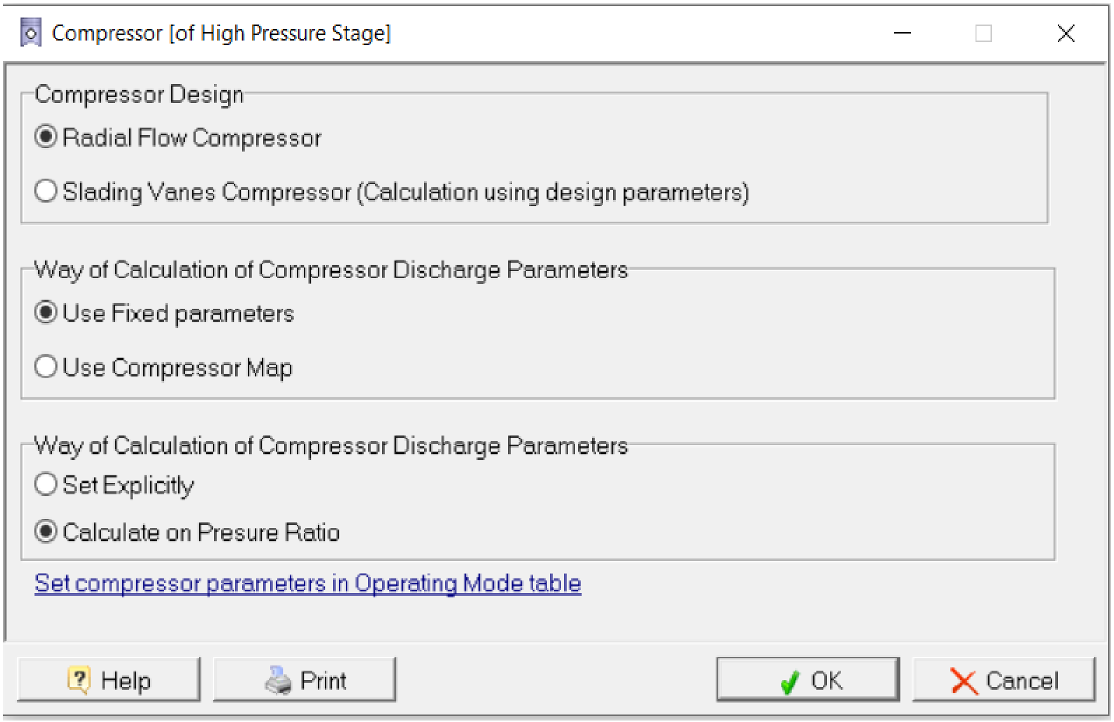

Figure 4.5 Turbocharger compressor specification

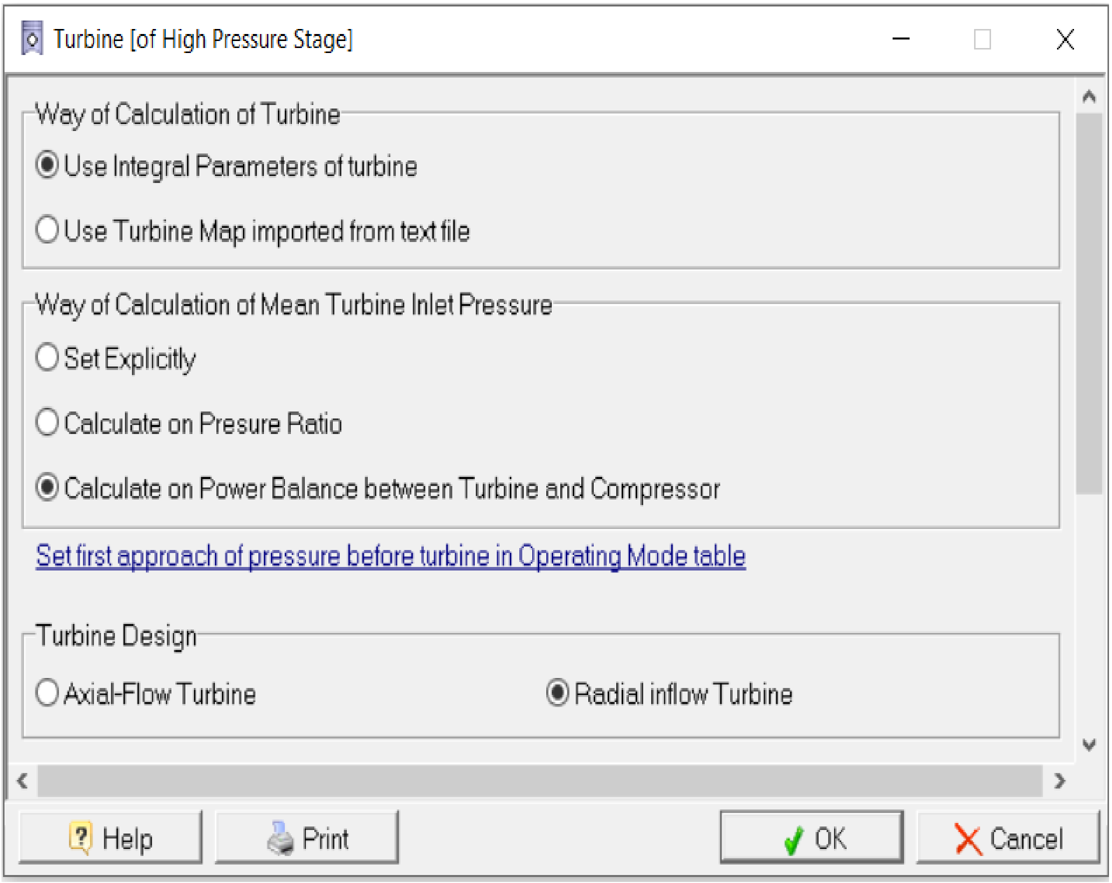

Figure 4.6 Turbocharger turbine specification

Select operating mode window and fill operating engine speed from 800 to 6000 rpm, pressure ratio, gasoline injection timing, ambient temperature and pressure and ignition timing all that show in Figure 4.7.

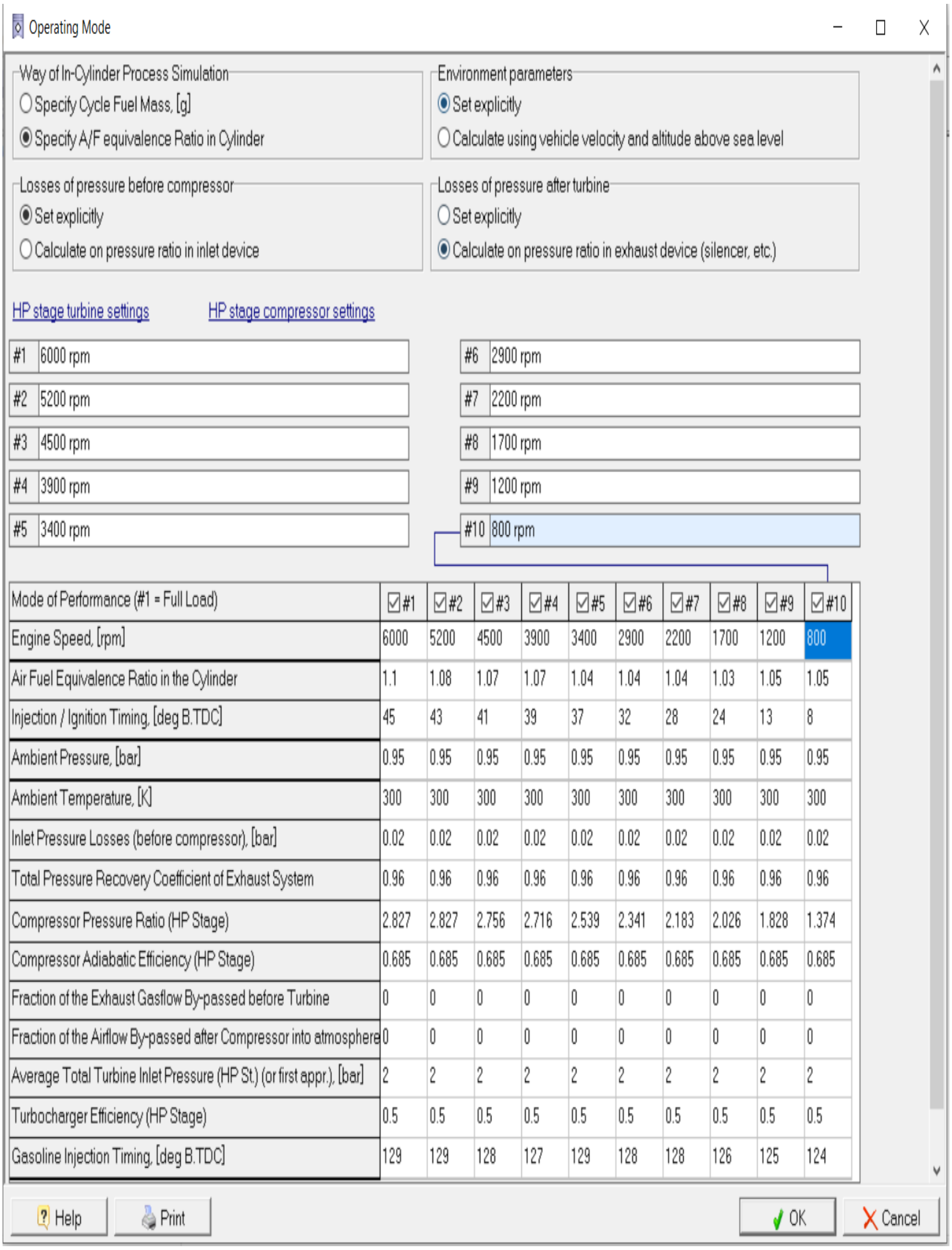

Figure 4.7 Operating mode

After inputting these values, the software runs a simulation. After successful simulation, results for different parameters are obtained. By taking into account the results obtained graphs are plotted for different compression ratios which are as follows

1. Brake Torque VS Engine Speed
2. Brake Mean Effective Pressure VS Engine Speed
3. Specific Fuel Consumption VS Engine Speed
4. Piston Engine Power VS Engine Speed
5. Indicated Mean Effective Pressure VS Engine Speed
6. Cylinder Pressure VS Crank Angle
7. Cylinder Temperature VS Crank Angle

Chapter 5: Results

5.1 Result

5.2 Comparison between our study and Literature reviews

5.3 Percentage error between actual torque and power and simulation torque and power

5.4 Conclusion

5.1 Result

After successful simulation results are obtained for different parameters such as Indicated mean effective pressure (IMEP), Brake mean effective pressure (BMEP), Brake torque, Specific fuel consumption (SFC), piston engine power, cylinder pressure and cylinder temperature.

These results are then plotted into graphs against the engine speed& crank angle. The graphs show variations of parameters with engine speed at different compression ratios. These graphs help in determining at which compression ratio the engine works best for the different parameters. A value is then selected at which all these Parameters are at their highest and lowest.

1. **Brake torque**

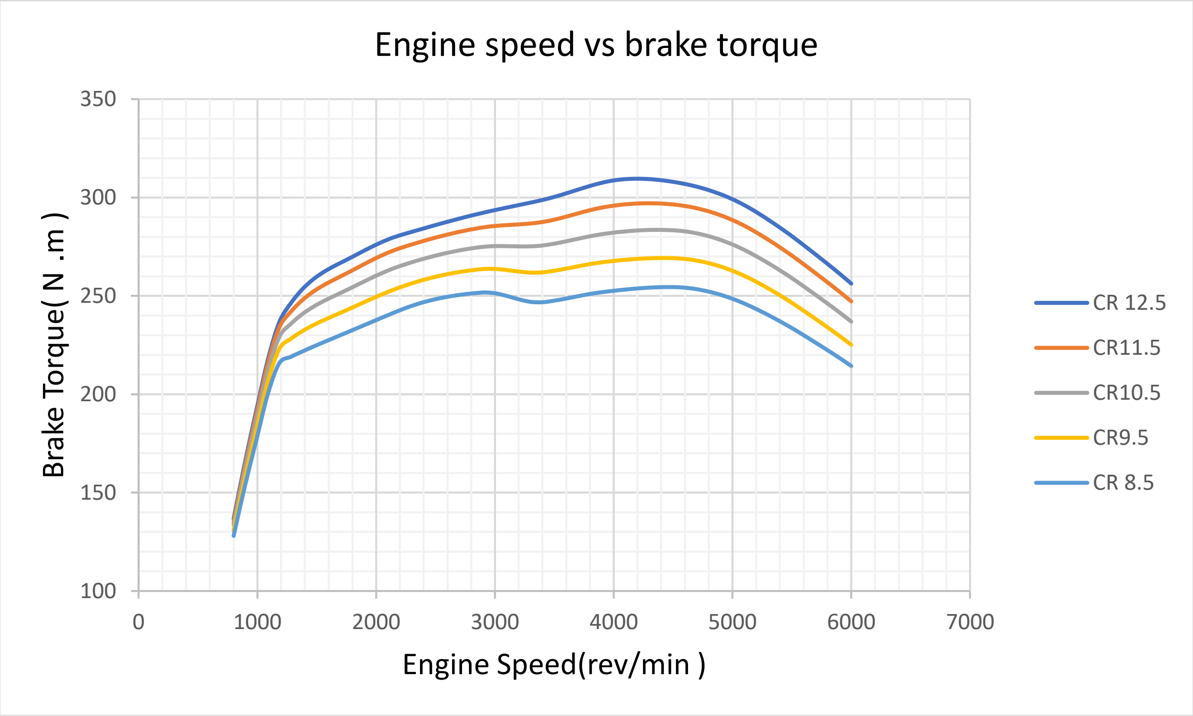

Figure 5.1 Variation of Brake torque with Compression Ratio for different engine speeds.

The figure 5.1 shows brake torque increases as the compression ratio increases until reash maximum after that decrease at higher speeds it becomes more difficult to ingest a full charge of air. Increase in compression ratio induces greater turning effect on the cylinder crank. That means that the engine is giving more push on the piston, and more torque is generated. The highest Brake torque was recorded for the compression ratio 12.5 while the least was for 8.5.

2. Piston engine power

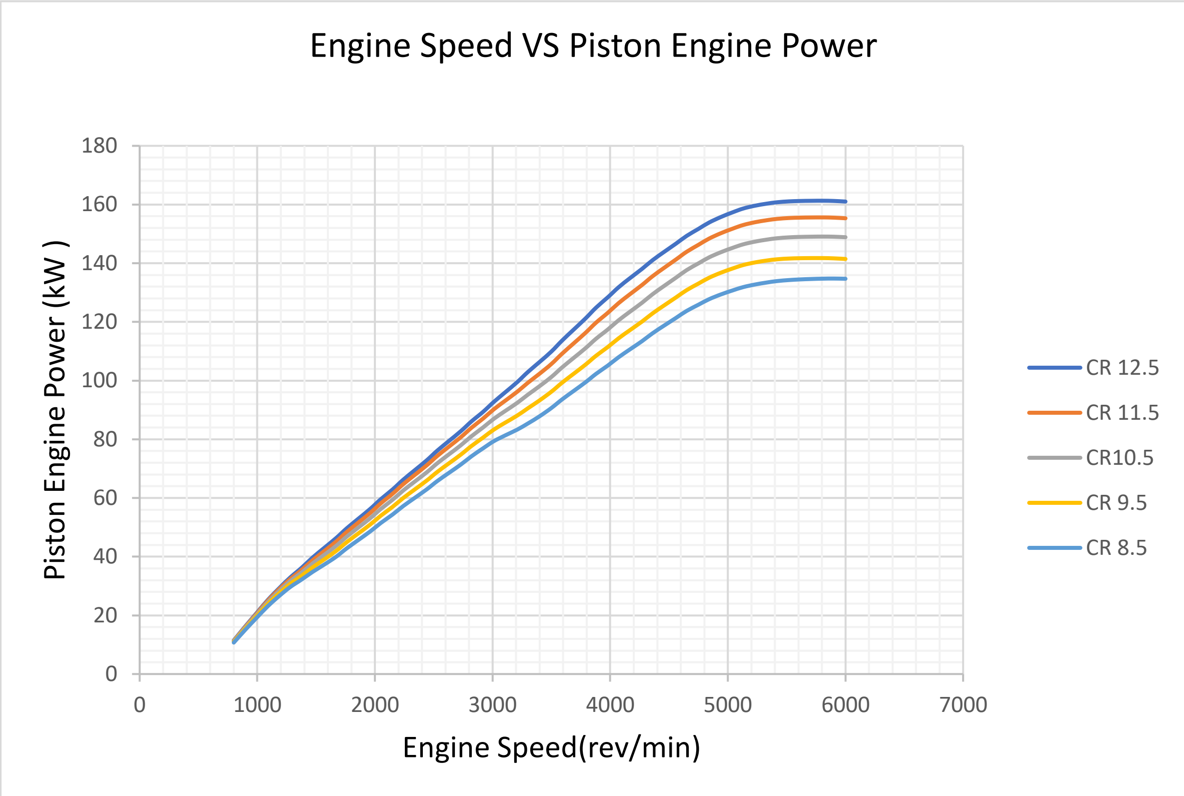

Figure 5.2 Variation of Piston engine power with Compression Ratio for different engine speeds.

The figure 5.2 shows piston engine power increases as the compression ratio and engine speed increases. This is due to the increase in compression ratio increases the peak pressure and temperature produce a greater force acting through a large part of the power stroke and hence, increase the power output of the engine. The highest Piston engine power was recorded for the compression ratio 12.5 while the least was for 8.5.

3. Brake Mean Effective Pressure (BMEP)

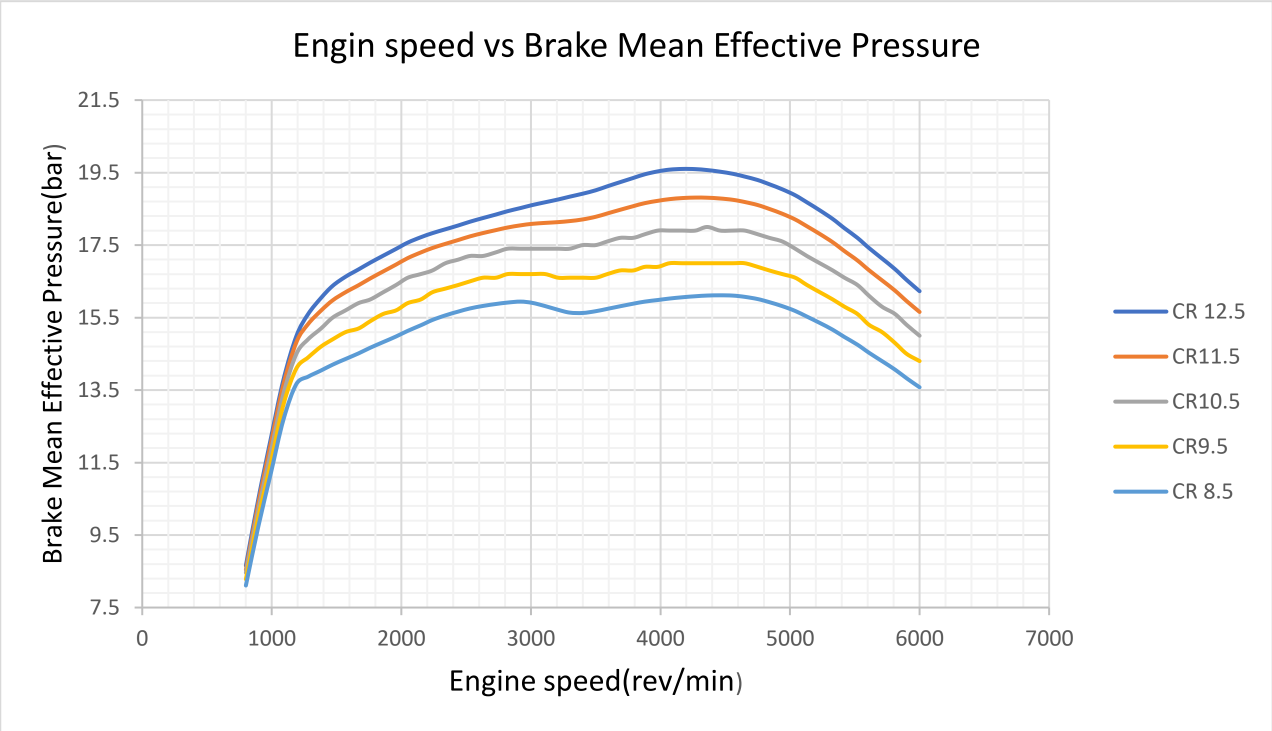

Figure 5.3 Variation of Brake mean effective pressure with Compression Ratio for different engine speeds.

The figure 5.3 shows Brake Mean Effective Pressures were found to be increasing with the increase in engine speed until reach at beak value after that goas to decrease and increase with the compression ratio increase its due to reduces the clearance volume and therefore increases pressure and temperature and the total combustion duration is reduced. The highest Indicative Mean Effective Pressures was recorded for the compression ratio 12.5 while the least was for 8.5.

4. Indicated Mean Effective Pressure (IMEP)

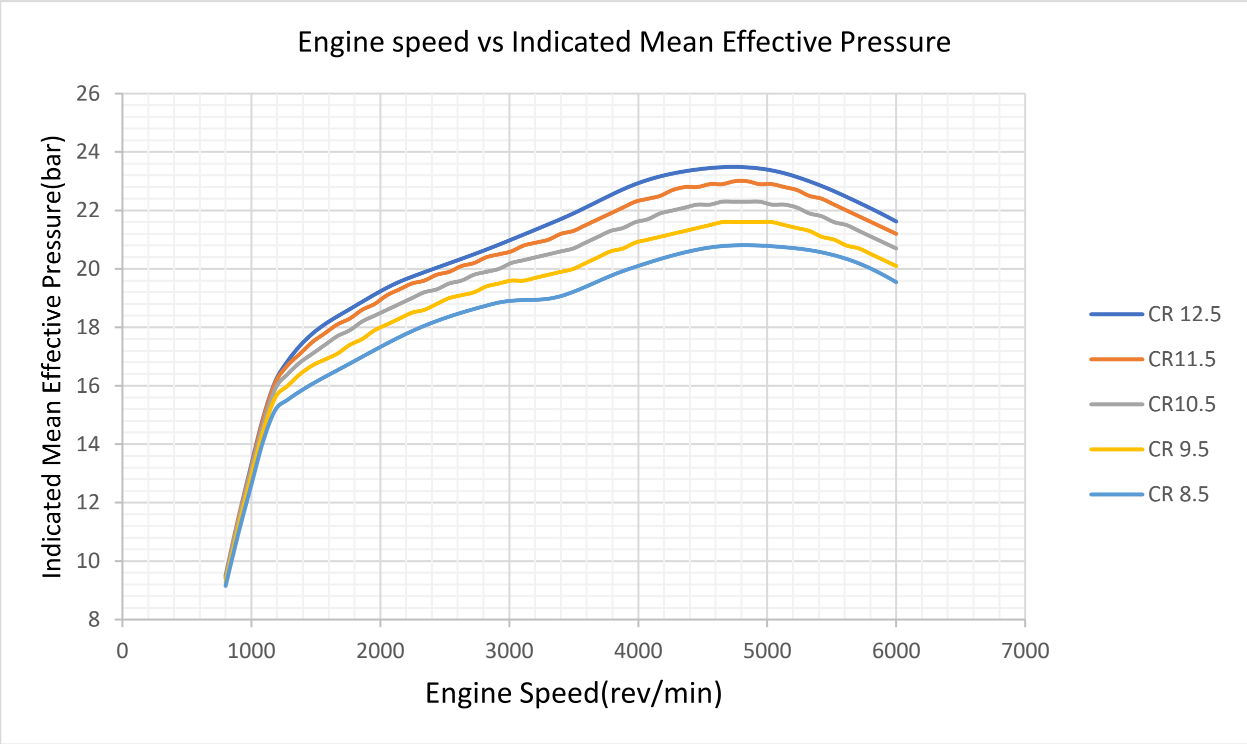

Figure 5.4 Variation of Indicated Mean Effective Pressure with Compression Ratio for different engine speeds.

The figure 5.4 shows Indicated Mean Effective Pressures were found to be increasing with the increase in engine speed until reach at beak value after that goas to decrease and increase with the compression ratio increase. The highest Indicative Mean Effective Pressures was recorded for the compression ratio 12.5 while the least was for 8.5.

5. Specific Fuel Consumption (SFC)

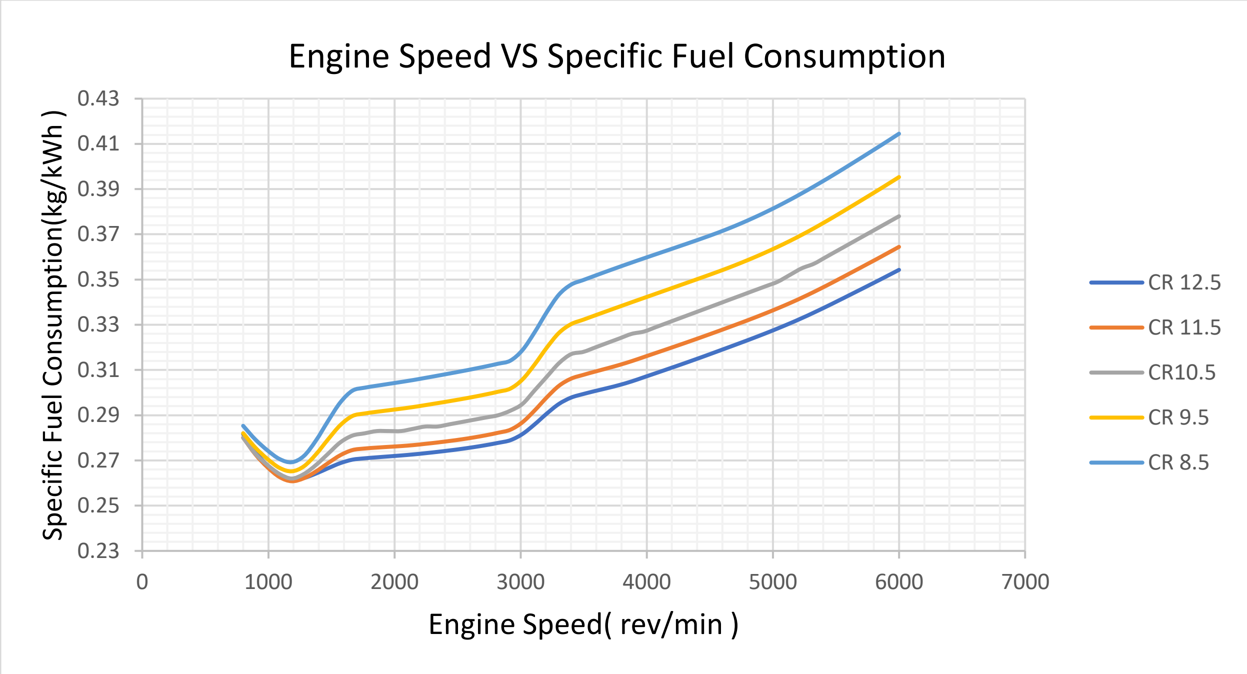

Fig 5.5 Variation of Specific Fuel Consumption with Compression Ratio for different engine speeds.

The figure 5.6 shows Specific fuel consumption decrease as the compression ratio increases due to increase combustion temperature also increases resulting in better combustion, As a result, the thermal efficiency rises .spicific fuel consumption increase with increase engin speed This is due to the increased friction(At lower speeds spicific fuel consumption the increases due to increased time for heat losses from the gas to the cylinder and piston wall). The highest spicific fuel consumption was recorded for the compression ratio 8.5 while the least was for 12.5.

6. Cylinder pressure

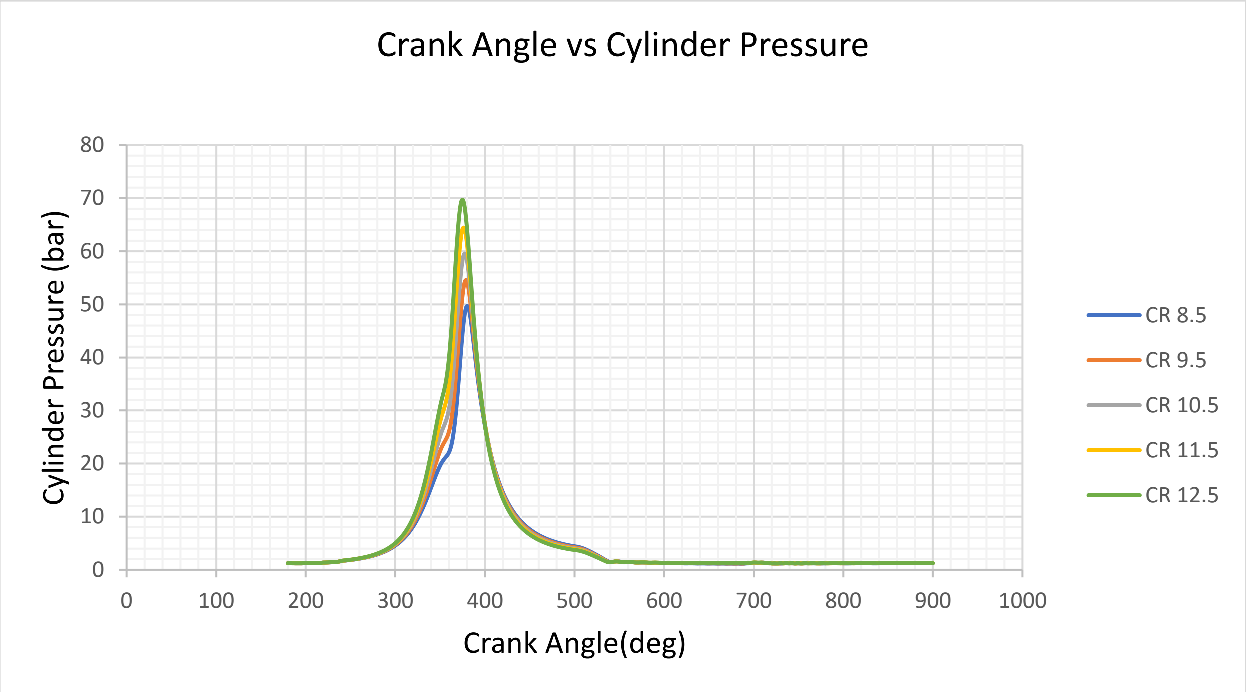

Figure 5.6 Variation of cylinder pressure with compression ratio for different crank angle.

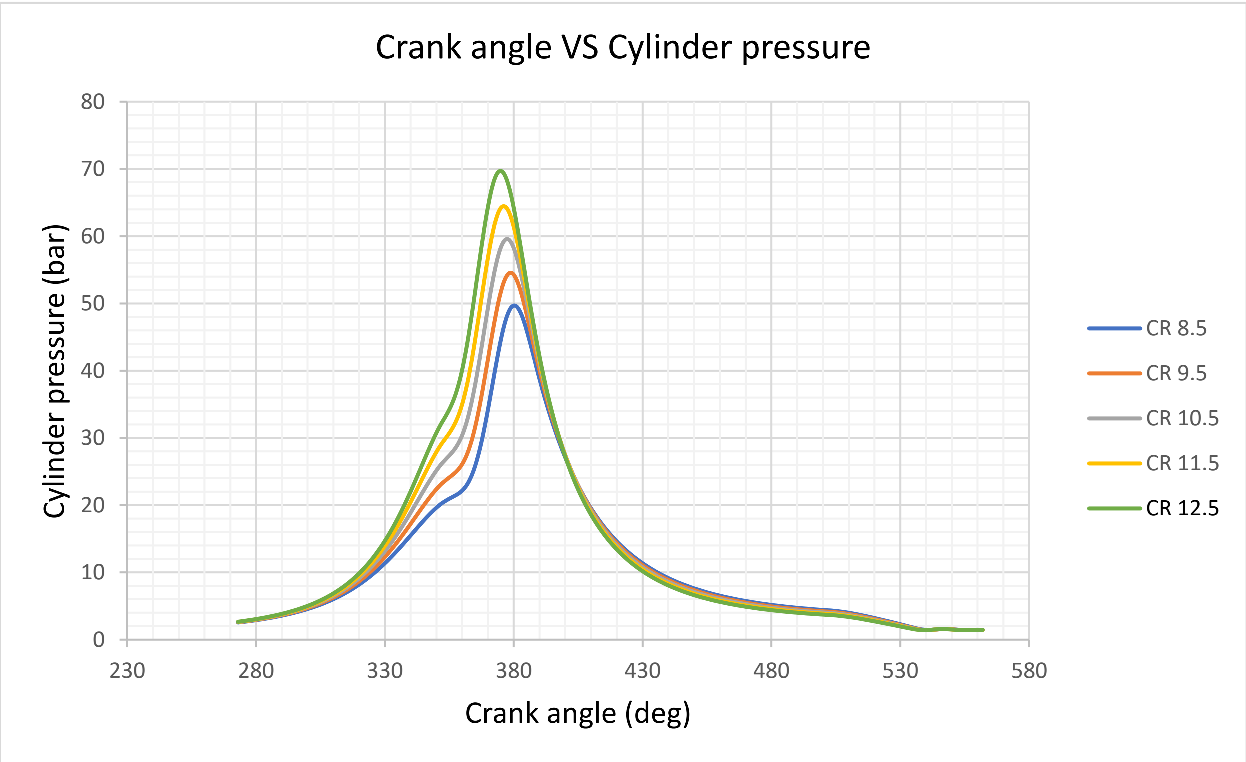

Figure 5.7 Variation of cylinder pressure with compression ratio for different crank angle.

7. Cylinder Temperature (average)

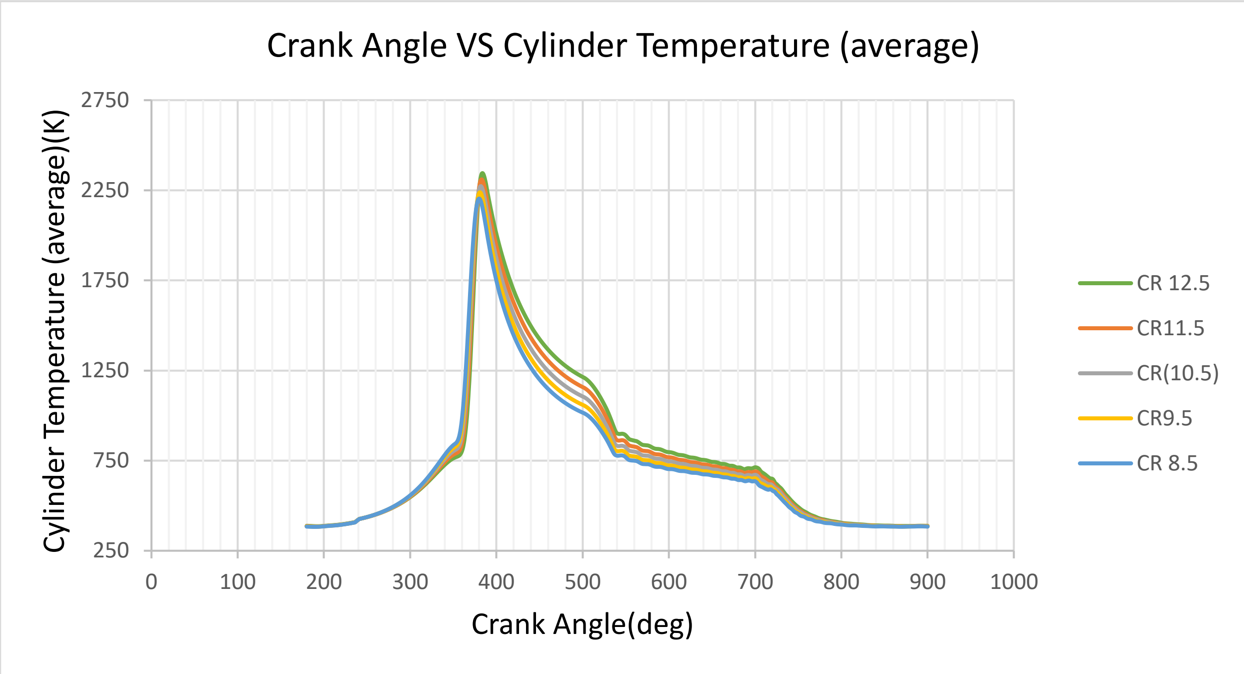

Figure 5.8 Variation of Cylinder Temperature (average)with compression ratio for different crank angle.

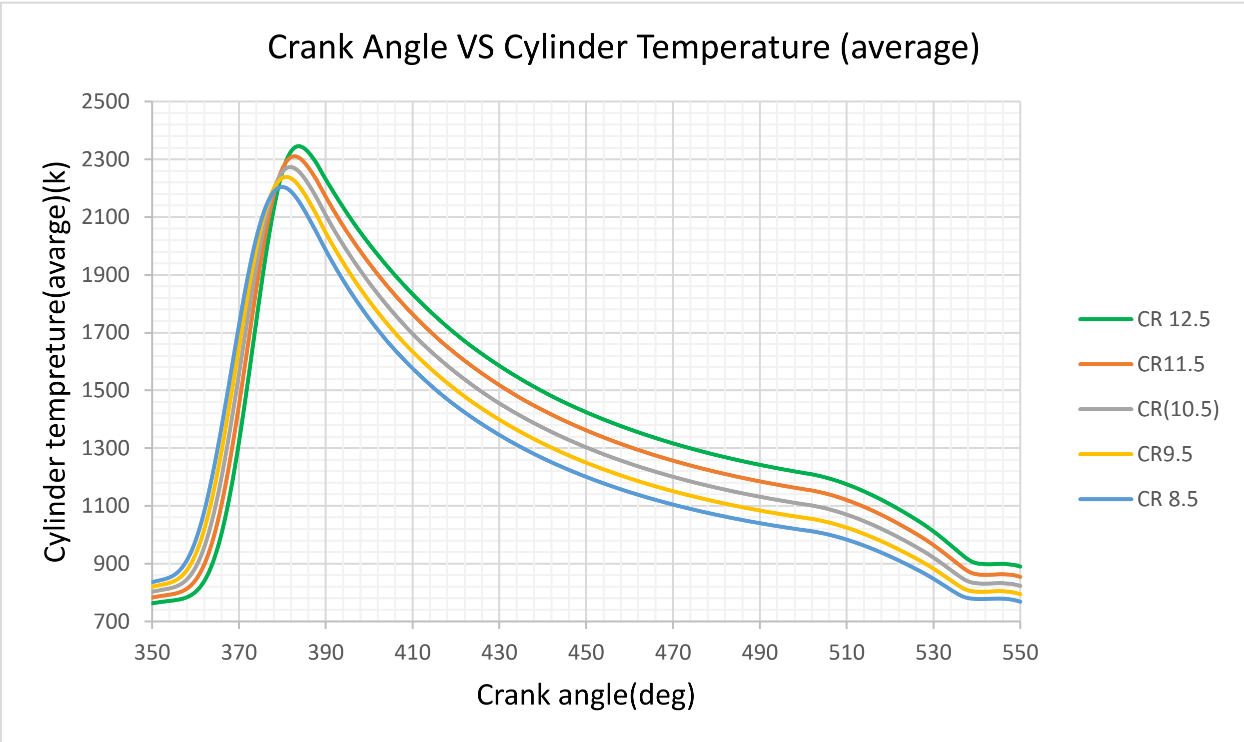

Figure 5.9 Variation of Cylinder Temperature (average)with compression ratio for different crank angle.

Both figure 5.7 & figure 5.9 shows an Increased compression ratio reduces the clearance volume and therefore increases the density of the cylinder gases during burning. increases the peak pressure and temperature and the total combustion duration is reduced. The highest pressure and temperature s was recorded for the compression ratio 12.5 while the least was for 8.5

5.2 Comparison between our study and Literature reviews

A comparison between our study and Literature reviews. The comparison was made based on the results obtained within this project and the results that they obtained within their studies.

The first study:

The Effect of Compression Ratio upon the Performance and Emission of spark ignition engine (Mohammed Kadhim Allawi) 2016.

The research evaluates the Effect of Compression Ratio upon the Performance and Emission like as Brake Thermal Efficiency, Brake specific fuel consumption, HC & CO emissions in the exhaust gases.

increase in compression ratio on the variable compression ratio engine increases the brake thermal efficiency. increase in compression ratio on the variable compression ratio engine decreases the emission CO, HC and Brake specific fuel consumption. [4]

The second study:

Influence of compression ratio on the performance characteristics of a spark ignition engine (Aina T., Folayan C. O. and Pam G. Y.) 2012.

The research evaluates the Effect of Compression Ratio upon the Performance and efficiencies like as brake power, brake thermal efficiency, brake mean effective pressure and specific fuel consumption.

Increase in compression ratio on the Ricardo variable compression ratio engine increases the brake power such as the figure 5.10, brake thermal efficiency, brake mean effective pressure, and reduction in the specific fuel consumption. [16]

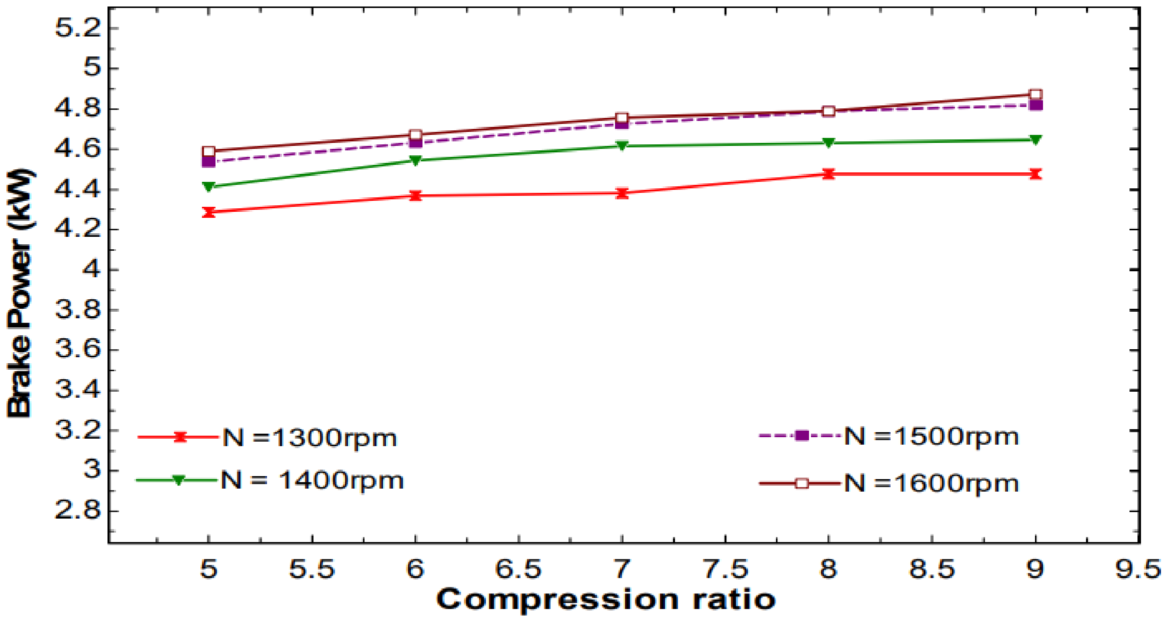

Figure 5.10 Variation of brake power with compression ratio. [16]

Our project:

The effect of variable compression ratio on the performance parameters of a gasoline engine.

Our study evaluates the Effect of Compression Ratio upon the performance parameters such as Indicated mean effective pressure (IMEP), Brake mean effective pressure (BMEP), Brake torque, Specific fuel consumption (SFC), piston engine power, cylinder pressure and cylinder temperature(average).

Increase in compression ratio cause increase in Indicated mean effective pressure (IMEP), Brake mean effective pressure (BMEP), Brake torque, piston engine power in figure 4.11, cylinder pressure and cylinder temperature(average)and reduction in the specific fuel consumption.

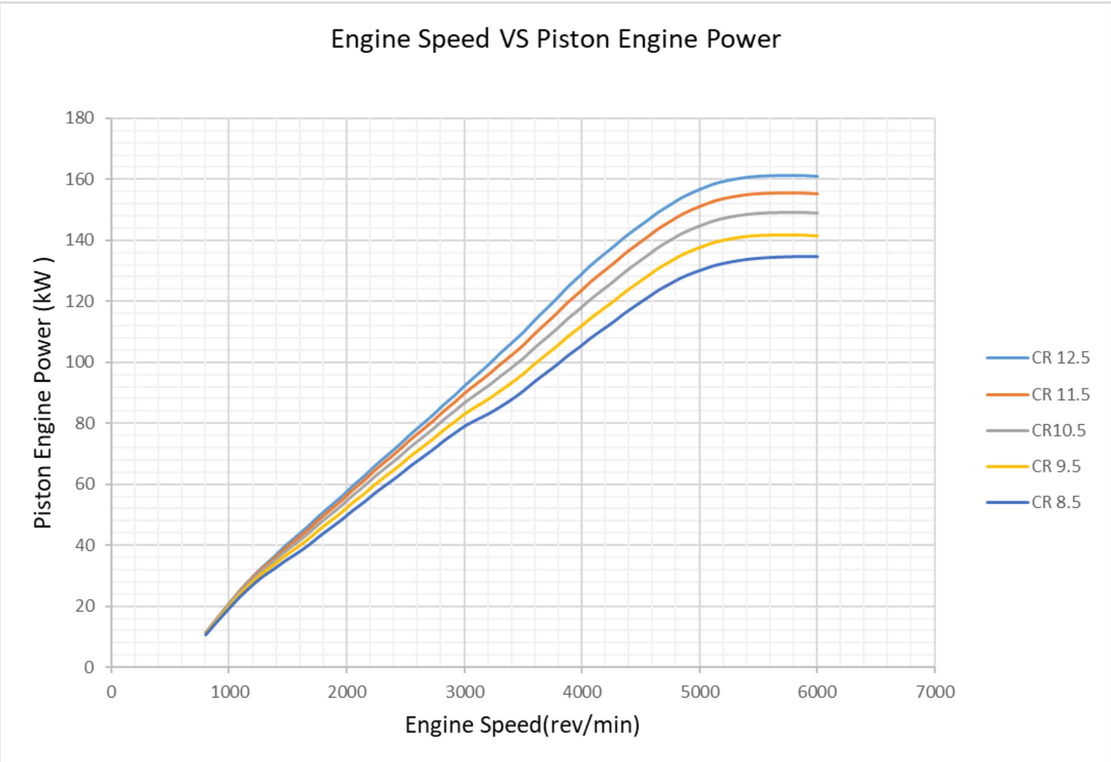

Figure 5.11 Variation of engine power with Compression Ratio for different engine speeds.

5.3 Percentage error between actual torque and power and simulation torque and power.

To ensure the accuracy of the results given by the software that used (diesel rk), calculated the percentage error between actual torque and power and simulation torque and power, that show in table 5.1.

Table 5.1 percentage error between actual torque and power and simulation torque and power

engine speed	actual torque	simulation torque	percent error (T)	actual power	simulation power	percent error (P)
6000	240	235.00	2.083	147	147.64	0.435
5200	275	270.12	1.775	147	147.08	0.054
4500	280	283.23	1.154	130	133.46	2.662
3900	280	281.30	0.464	117	114.88	1.812
3400	280	275.55	1.589	100	98.10	1.898
2900	280	274.82	1.850	84	83.45	0.650
2200	280	265.10	5.321	62	61.07	1.500
1700	260	251.23	3.373	50	44.72	10.556
1200	200	230.73	15.365	20	28.99	44.960

Simulate the power and torque at compression ratio 10.5 and comparison between actual torque and power in figure 5.12 and simulation torque and power in figure 5.13 and from the attached table 5.1 that the percentage error between actual torque and power and simulation torque and power is small, and this indicates the validity and accuracy of the software diesel RK.

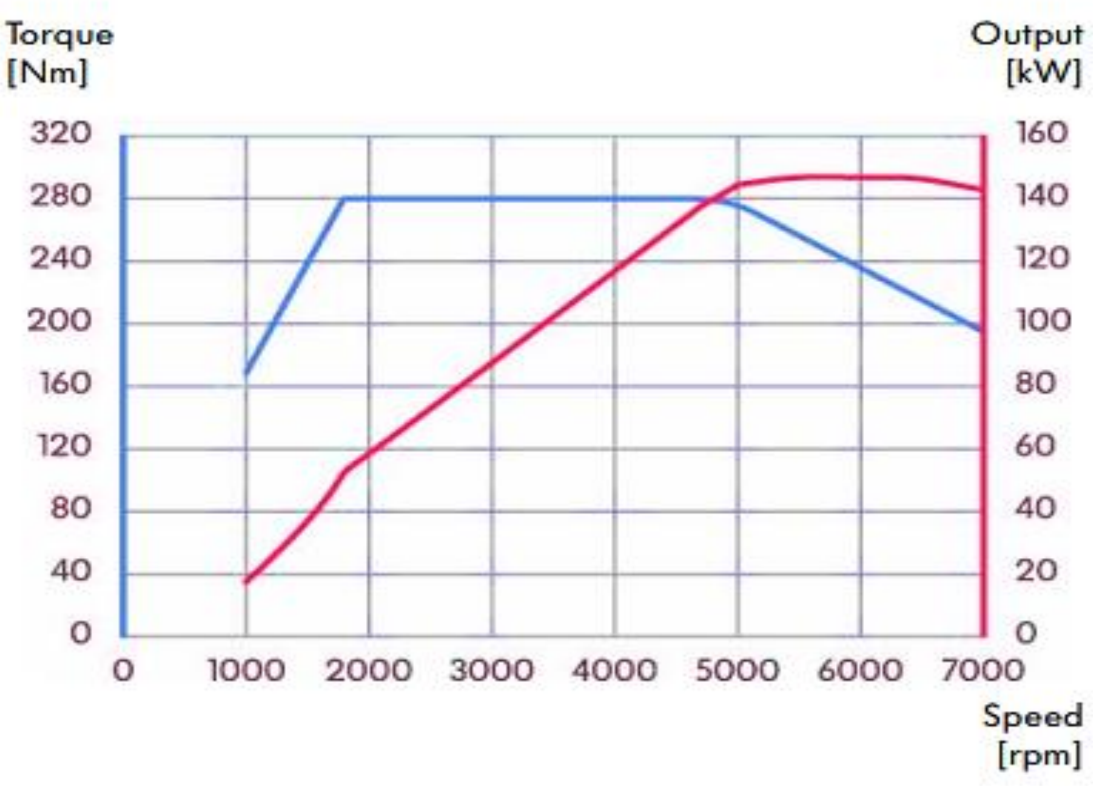

Figure 5.12 Actual engine power & torque vs engine speed (CR 10.5) [12]

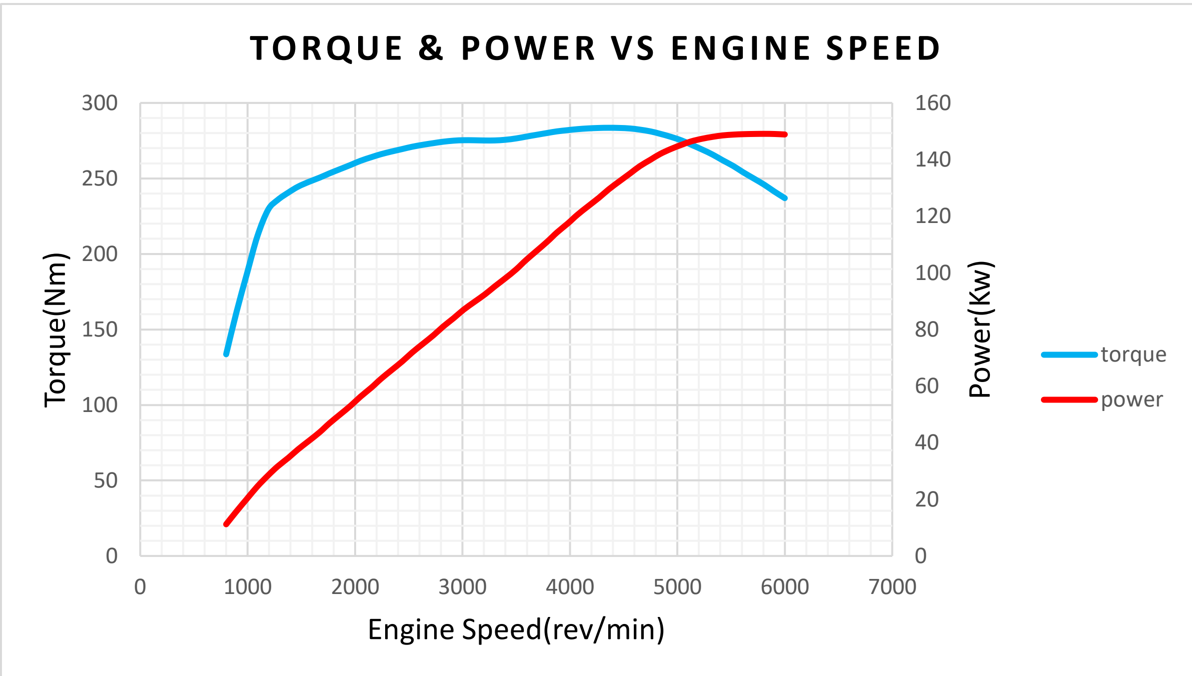

Figure 5.13 Simulation engine power & torque vs engine speed (CR 10.5)

5.4 Conclusion

Following conclusions can be drawn from the simulate diesel RK software carried out on the IC engine with gasoline at various compression ratios.

Increase in compression ratio cause increase in Indicated mean effective pressure (IMEP), Brake mean effective pressure (BMEP), Brake torque, piston engine power, cylinder pressure and cylinder temperature(average)and reduction in the specific fuel consumption.

The percentage error between actual torque and power and simulation torque and power is small, and this indicates the validity and accuracy of the software diesel RK.

Engine with variable compression ratio is needed so that the compression ratio of the engine can be changed according to different load and speed conditions. VCR engines proved in increasing the engine performance with also proved in improving the fuel economy.

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