بسم الله الرحمن الرحيم

Sudan University of science and Technology

College of graduate studies

Prediction of NOx emission from turbocharged bio fuel engine

التنبؤ بانبعاث NOx من محرك الشحن ألعنفي العامل بالوقود الحيوي

Thesis submitted in partial fulfillment of requirement for the degree of M.Sc. in Mechanical Engineering (Power)

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الآية

بسم الله الرحمن الرحيم

قال نعالى:

﴿ إن في خلق السموات والأرض واختلاف الليل والنهار والفلك التي تجري في

البحر بما ينفع الناس وما أنزل الله من السماء من ماء فأحيا به من كل دابة

وتصريف الرياح والسحاب المسخر بين السماء والأرض لآيات لقوم يعقلون﴾

صدق الله العظيم

(سورة آل عمران-الآية 85)

Dedication

I want to dedicate this thesis to my parents who give me the greatest support in my life and study.

Acknowledgements

First, I would like to express my gratitude to Allah for enable me the guiding to complete this work, and to express my gratitude to my parents, who made my life fruitful and my family for their invaluable support during my work.
A further special thanks to my, Dr. Eihab Abdelraouf Mustafa for his constant guidance and support throughout this work. I would also like to thank all my committee members for their encouragement and support of my thesis work.
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I would like to express my sincerest appreciation to my brothers and colleagues at Mechanical engineering.

Abstract

NOx emission reduction is the most commonly required one in all the researches on the vehicle engines but they are too hard to manipulate with the primary methods. The objective of this research was to determine the reason for the higher levels of NOx emissions from biodiesel fueled engines, to predict the emission of NOx, to reduce NO_X emission concentrations, to reduce fuel consumption and to choose a suitable method circuits and software programming. This research includes Mechanism of NOx formation, NOx Reduction Techniques and diesel-Rk (advantage, type of engine can applying on it the company uses historical). It was determined that a change in compression ratio and engine speed caused by changes in fuel properties between diesel fuel and biodiesel might be the source of the NOx increase, Using the engine specification to get value of NOx emission was simulated in diesel-Rk software and the measured and simulation results of NOx emission were compared with the value of NOx that given from prediction equation and shows maximum error of 12%.

المستخلص

يعتبر خفض اكاسيد النيتروجين هو الاكثر شيوعا في البحوث المتعلقة بمحركات الوكبات ولكن من الصعب جدا التعامل معها بالطرق الاساسية. الهدف من هذا البحث هو تحديد سبب ارتفاع مستويات أكاسيد النيتروجين المنبعثة من محركات الديزل التي تعمل بالوقود الحيوي، التنبؤ بانبعاث أكاسيد النتروجين،الحد من تركيز انبعاث أكاسيد النيتروجين في البيئة المحيطة، تقليل استهلاك الوقود، اختيار الدورة المناسبة و اختيار برنامج الكتروني لمحاكاة النموزج. هذا البحث يحتوي على آلية تشكيل أكاسيد النتروجين، تقنيات الحد من انبعاث أكاسيد النيتروجين، برنامج المحاكاة الديزل -RK (المميزات، نوع المحرك الذي يمكن التطبيق عليه). تقرر أن التغير في نسبة الاحتراق وسرعة المحرك الناجمة عن التغيرات في خصائص الوقود بين وقود الديزل والديزل الحيوي قد يكون مصدر زيادة أكاسيد النيتروجين، وقد تمت محاكاة ذلك باستخدام مواصفات المحرك للحصول على قيمة لانبعاثات أكاسيد النيتروجين في برامج الديزل-RK و تمت مقارنة نتائج القيا س والمحاكاة لانبعاثات لأكاسيد النتروجين مع قيمة أكاسيد النتروجين الناتجة عن معادلة التنبؤ وتبين أن الحد الأقصى لنسبة الخطأ 12٪

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APPERVIATION

NOx	Mono nitrogen oxides
CR	Compression Ratio
PR	Pressure Ratio
RPM	Revelation per Unit
TWC	three way converters
EGR	Exhaust Gas Recalculation
NA	Natural Stagnation
SPSS	program for statistical analysis
EPA	Environmental Protection Agency
ARF	Air Fuel Ratio
0D	Zero Dimension
ppm	Part Pre Million
CAD	Computer Analysis Diagram
PCCI	Piston Cycle Combustion Engine
ICE	Internal Combustion Engines
DOS	Diesel Operation System
DI	direct injection

CHAPTER I

Introduction

CHAPTER I

Introduction

1-1 Introduction

NO_X is the one of the main pollutant emission to the atmosphere in the recently with the increase in different fuel engines.

Oxides of Nitrogen are one of the most undesirable pollutant constituents of automotive transport because of its connection with the formation of photochemical smoking the atmosphere.

NOx formation pathway includes three methods, i.e., thermal NOx, fuel NOx, and prompt NOx. Even though the degree of the emission release amount varies, each of the three pathways of NOx formation contributes to the overall NOx emission to the environment.

NOx is one of the basic pollutants emitted from combustion processes, NOx is a common term for mono nitrogen oxides (NO and NO_2).Lastly the Scientific studies discovered that NOx was adding to smog (a significant form of air pollution) and ozone production. It combines with moisture in the atmosphere to produce HNO3 (a component of acid rain), it lead to increases the risk of respiratory diseases, and it causes pulmonary and respiratory problems. In the past the manufacturers were designing their engines for lower HC and CO emissions. Unfortunately the resulting slope air-fuel mixtures and higher engine operating temperatures put forward NOx in the exhaust.

After realizing the harmful effects of NOx, the Environmental Protection Agency (EPA) added NOx to its list of regulated items. Environmental regulations are the driver forcing industry to implement NO_X control techniques Standards for the control of NO_X have been established as part of the Clean Air Act.

Future economic growth shall crucially depend on long term availability of energy in increasing quantities from sources that are dependable, safe and environment friendly

Diesel engines are typically more efficient due to higher compression ratio and also find significant use in transportation portion irrigation part and small captive power plant engine because of its higher thermal efficiency and lower fuel consumption but it emits higher NOx which is one of the most unwanted pollutants.

Table 1-1 Summary of alternative fuels candidates

Candidates	Advantages	Disadvantages
Hydrogen	High lower heating value. "Zero" pollutant by emission Potentially renewable energy source	Refilling problem. Safety issue due to high pressure tank
DME	Less PM &NOx emission. High cetane number.	Worse lubrication than diesel. Safety issue due to high pressure tank.
Coal	Large accessible reserve.	Injection problem. Lubrication contamination
Biodiesel	Low HC and CO emission. Potentially renewable energy source	Low energy content. Uncertain effect on NOx

1-1-1 Biodiesel as an alternative fuel

In the previous different decades, it has been found thaw1t biodiesel (esters derived from vegetable oils) is a very favorable one. The most common blend is a mix of 20% biodiesel and 80% petroleum diesel, called "B20". The widespread use of biodiesel is based on the following advantages [2]

1. Biodiesel is potentially renewable and non-petroleum-based
2. 2-Biodiesel combustion produces less greenhouse gases

3. Biodiesel is less toxic and biodegradable
4. Biodiesel can reduce tailpipe emissions of PM, CO, HC, air toxics, etc
5. 5-Little modifications are needed for the traditional CI engine to burn biodiesel.

1-1-2 Biodiesel also has some negative attributes [2]

1- Lower heating value, higher viscosity
2- Lower storage stability, material compatibility issue
3- Slightly higher NOx emission

Through the above feature of biodiesel, the higher NOx emissions from biodiesel fueled engines are a main concern due to more and restrict regulations, and therefore it serves as the main motivation of this work.

1-1-3 Use of the engine cycle simulation to study a biodiesel fueled engine

In modern engine research and study, using small's experiments single would be very costly, and time-consuming, and more cause and effect relationships implicit in the test results are often hard to explain. On the other side, modeling and simulation approaches, although less precise in predicting the outcome of a specific test, could effectively isolate one changeable at a time and conduct parametric studies on it. Therefore simulation could point out cause-effect relationships more clearly, and a support model could be a very useful tool to study new type of engines or engines running with new type of fuels. Since people still don't have a very clear understanding on the effect of using biodiesel on a diesel engine, together with experimental study, a simulation study of the biodiesel engine is necessary.

Engine cycle simulation models could be divided into three maine divisions:

Zero-dimensional models, quasi-dimensional, multi-zone models and multi-dimensional models. Zero-dimensional models have been successfully used to predict engine performance and fuel economy, but they are too simplified to predict the engine emission carefully. On the other side, though multi-dimensional models could provide the most careful prediction due to more detailed geometry modeling, the safely increased computation time becomes a major limiting factor of applying multi-dimensional models.

Among them, quasi-dimensional, multi-zone models could be effectively used as an engine development tool because they combine some of the advantages of zero-dimensional and multi-dimensional models. Therefore, quasi-dimensional, multi-zone model would be a good choice for this biodiesel engine study.

1-2 Problem Statement

Diesel exhaust emission influence air pollution significantly, specially NOx and today most researcher in the world focus on how to use technology to prediction with the pollutant emissions like NO_X in internal combustion engines there are much emissions in the exhaust due to the engine work.

And to solve this problem you should to search to the technique to use it, one of the methods to predict with these emissions are software simulation (Diesel RK).

1-3 Research Objectives

1- 1-To predict the emission of NOx under variable (CR, PR rpm …..ect)
2- 2- To reduce NO_X emission concentrations.
3- To reduce fuel consumption

1-4 Significant of Study

Minimizing pollution by reducing NOx emission to preserve the environment and achieving safe and stable operation for the end user.

Make volume of flame constant, hence the combustion temperature will be constant that led to reduce NO_X emission reducing fuel consumption by optimize combustion

CHAPTER II

Literature Review

CHAPTER II

Literature Review

2-1 Literature review

A review of recent biodiesel fueled engine research activities is presented here.

Activities can be roughly divided into two aspects: engine experimental studies and numerical studies.

Both of these types of studies focus on the performance and emission Characteristics of biodiesel fueled engines and comparison to the conventional diesel engine [3].

2-2 Mechanism of NO_X formation

A main obstacle in understanding the mechanism of formation and controlling its emission is that combustion is strongly varied and transient in diesel engines.

While NO and NO2 are bloc together as NOx, there are some special differences between these two pollutants.

NO is a colorless and odorless gas, while NO2 is a reddish brown gas with sharp door. Both gases are considered toxic, but NO2 has a level of toxicity 5 times greater than that of NO. Although NO2 is in generable formed from oxidation of NO, attention has been given on how NO can be controlled before and after combustion (Levendis et al 1994).

NO is formed during the post flame combustion process in a high temperature region. The most quite accepted mechanism was suggested by Zeldovich (Heywood 1988). The major source of NO formation is the oxidation of the nitrogen existing in atmospheric air. The nitric oxide formation chain reactions are initiated by atomic oxygen, which forms from the dissociation of oxygen molecules at the high temperatures reached during the combustion process. The essential reactions governing the formation of NO from molecular nitrogen are,

$$N_2 + O \rightarrow NO + N,$$

$$N + O_2 \rightarrow NO + O,$$

$$N + OH \rightarrow NO + H.$$

Chemical balance considerations denote that for burnt gases at typical flame temperatures; NO_2/NO ratios should be negligibly small. While empirical data show that this is true for spark ignition engines, in diesels, NO_2 can be 10 to 30% of total exhaust emissions of oxides of nitrogen.

A reasonable mechanism for the stability of NO_2 is as follows. NO formed in the flame zone can be rapidly transformed to NO2 via reactions like

$$NO + HO_2 \rightarrow NO_2 + OH.$$

Thereafter, conversion of this NO_2 to NO occurs via

$$NO_2 + O \rightarrow NO + O_2,$$

But the NO_2 formed in the flame is irrigated by mixing with cooler fluid. This explanation is consistent with the highest NO_2/NO ratio circulating at high load in diesels, when cooler regions which could prime the conversion back to NO are diffused wood 1988).

2-2-1 Where does NOx come from?

Automobiles and other mobile sources contribute about half of the NOx that is emitted.

Electric power plant boilers produce about 40% of the NOx emissions from stationary sources.

Additionally, substantial emissions are also added by such anthropogenic sources as industrial boilers, incinerators, gas turbines, reciprocating spark ignition and Diesel engines in stationary sources, iron and steel mills, cement manufacture, glass manufacture, petroleum refineries, and nitric acid manufacture. Biogenic or natural sources of nitrogen oxides include lightning, forest fires, grass fires, trees, bushes, grasses, and yeasts.1 these various sources produce differing amounts of each oxide. The anthropogenic sources are approximately shown

Table 2:1 primary sources of NOx emission

Mobile Sources	Electric Power Plants	Everything Else
50%	20%	30%

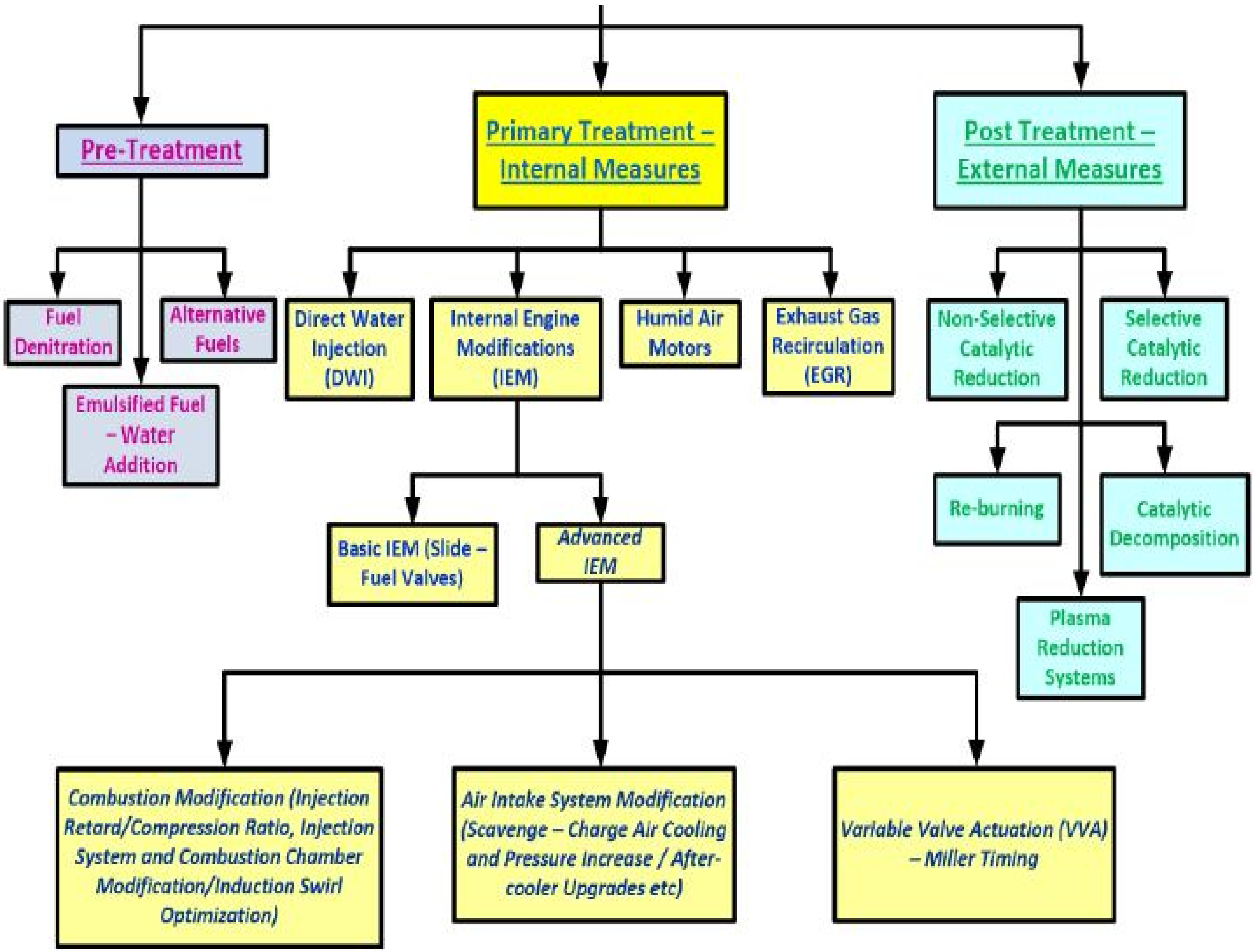
This shows a graphic illustration of the emissions of our two greatest sources of NOx If we could minimize the NOx emissions from just these two leading categories, we might be able to live with the rest. However, don't anticipate either of these categories to become zero in the foreseeable future. We cannot anticipate the car, truck, bus, and airplane to disappear. The zero-emission car is still on the drawing board and not on the production line. Also, social customs will have to change before consumption of electricity can be reduced.

In all combustion there are three opportunities for NOx formation. They are:

1- Thermal NOx - The concentration of "thermal NOx" is controlled by the nitrogen and oxygen molar concentrations and the temperature of combustion. Combustion at temperatures well below 1,300^{o}C (2,370^{o}F) forms much smaller concentrations of thermal NOx.

2- Fuel NOx - Fuels that contain nitrogen (e.g., coal) create “fuel NOx” that results from oxidation of the already-ionized nitrogen contained in the fuel.

3- Prompt NOx - Prompt NOx is formed from molecular nitrogen in the air combining with fuel in fuel-rich conditions which exist, to some extent, in all combustion. This nitrogen then oxidizes along with the fuel and becomes NOx during combustion, just like fuel NOx. The abundance of prompt NOx is disputed by the various writers of articles and reports - probably because they each are either considering fuels intrinsically containing very large or very small amounts of nitrogen, or are considering burners that are intended to either have or not have fuel-rich regions in the flame.



Fighter 2-1 show the Marine Diesel-Emitted NOx Reduction Methods

2-3 NO_X Reduction Techniques

The engine operating parameters such as air-to-fuel ratio spark timing, compression ratio, engine speed, engine power, engine temperature, engine cleanliness etc. impact the amount of NOx emissions from the combustion process. Also engine design parameters such us surface to volume ratio, exhaust back pressure, valve overlap, and fuel injection have an influence on the NOx emissions. Apart from adjusting these parameters to reduce the NOx emissions, the techniques like exhaust gas recirculation (EGR) and catalytic converter are used to reduce the amount of NOx emissions [8]

From the knowledge of parameters affecting the NO_X emissions, some of the methods to reduce the NO_X emissions can be suggested.

2-3-1 De rating

NOx consistence fundamentally depends on temperature conditions in the cylinder.

The pressure and thereby temperature in the cylinder can be reduced by operating the engine using a minimal supply of fuel (diesel engine) or by using a lean air-fuel mixture [8].

For spark ignited, the impact of retarding or advancing the spark timing may be important. If the spark timing is advanced, the overall temperatures during the cycle tend to go up and NOx emissions will therefore increase. Retarding the spark timing tends to lower oxides of nitrogen but may not reduce hydrocarbon emissions marginally [10].

2-3-2 Air fuel Ratio (AFR) Adjustment

In a stoichiometric air-fuel ratio, the oxygen in the air-fuel mixture should completely oxidize the fuel. However, the oxygen content in the stoichiometric state has been specified to be 1 percent by volume of oxygen in the exhaust gas. Under lean-burning conditions, the air-fuel ratio is higher than that in the stoichiometric state. Therefore, an engine operating in the lean burning conditions contains more than 1 percent by volume of oxygen in the exhaust gases consequently NOx emissions will be higher, but HC and CO emissions are decreased. The air-fuel ratio is lower in the rich burning conditions than that in the stoichiometric state. The exhaust gases from a rich-burning engine contain less than 1 percent by volume of oxygen, NOx emissions will be lower, but HC and CO emissions are increased.

If the air-to-fuel ratio is decreased to obtain the rich-burning state, NOX formation will drop readily, there being incomplete oxygen for combustion; and HC and CO emissions will increase accordingly [11].

2-3-3 Turbocharger with Intercooler (For Diesel Engines)

Turbocharger is the arrangement in which the exhaust gases from an engine are guided to a turbine that mobilize a compressor. The compressor compresses the intake air, which is cooled in an intercooler. Because of compression and the lower temperature of incoming air, a major mass of air can be crowded into the air manifold. Given the conditions of higher pressure and major air mass, more fuel can be injected and burned, to product more power for a given size of engine.

The low temperature of the absorption air leads to low peak temperature during combustion and thus to low NOx emissions. It has been notify, that 10 to 30 percent NOx reduction has been achieved from diesel engines with the use of turbocharger with intercooler. Also, HC and CO emissions decrease because the turbocharger increases the air-fuel ratio to that of a lean burning mixture [12].

2-3-4 Reduced Manifold Air Temperature

As mentioned in the prior's technique, the numerous air temperatures can be reduced by using an intercooler upstream of the multiple. Greater air mass can be packed because of the high air density at low air temperature and thereby more fuel can be injected and burned to produce more power. When there is a low air temperature, peak combustion temperature also is low; therefore NOx emissions are low.

But the combustion reactions are slow at very low air temperature, so that HC and CO emissions rise [13].

2-3-5 Water Induction

Water is inserting into the engine either with the intake air or by water injection directly into the cylinder.

The vaporization of this water helps to decrease the peak combustion temperature; thus, NOx emissions are low.

But at low temperatures, hydrocarbons are burned slowly; therefore HC emissions rise, On the other hand, CO emissions are unaffected by water inducement [14, 15].

2-3-6 Combustion Chamber Redesign

Combustion chambers can be adjusted to have a socket at the piston head or to have a bowl shaped cylinder head. Fuel is injected into the socket (formed by a combustion chamber modification) as a rich mixture and ignited. NOx formation is belated as the mixture burns in the absence of excess air. Then the burning mixture enters the main combustion chamber, and is mixed with additional air, to complete the combustion and lower the peak temperature. Therefore NOx emissions, as well as HC and CO emissions, are low [16].

2-3-7 Catalytic Converter

Three way converter (TWC) catalysts are used to reduce NOx, HC and CO emissions. priceless metal catalysts are used to oxidize HC and CO, and rhodium catalyst coverts NOx to N2, By using a TWC catalyst, NOx, HC, and CO can be decreased together [14, 17]

2-4 previous simulation studies

Due to the subtlety and complexity of comparing biodiesel and diesel combustion in direct injection engines, numerical studies (engine simulations) have been applied in addition to experimental studies.

The numerical study in [13] applied a so-called well-mixed balloon model to examine the flame temperature and NOx formation of biodiesel combustion.

Calculation were made using Cantor in a MATLAB environment.

The well-mixed balloon is a sample that simulates the time history of a jet of fuel into a combustion chamber including oxidizer. In the well-mixed balloon, the mass output is zero and thus the balloon grows as mass flows in. In time the balloon grows and the fuel-air mixture in the balloon reaches the ignition conditions and then ignites. This leads to a sudden increase in temperature [13].

Two fuels, methyl but annotate and methyl trans-2-butenoate,9 were simulated, and the results showed that the double bonded methyl trans-2-butaneoate gave a 14K higher flame temperature than the other fuel. The investigator believed that this change in temperature caused an increase in NOx emissions of 159 ppm [13]. Also, the author did the model sensitivity analysis on the influence of the various NOx mechanisms. Results revealed that the thermal NOx mechanism had the most visible contribution to the NOx formation (92%), comparing to other mechanisms such as N_2O mechanism (1%) and Fennimore mechanism (13%) [13].

Due to the over-simplicity of zero-dimensional model, and the long computational time of three-dimensional model, quasi-dimensional multi-zone models are increasingly applied by many investigators [17, 18, 19, and 20]. The study in [17] developed a quasi-dimensional, multi-zone, direct injection (DI) diesel combustion model.

The model was implemented in a full cycle simulation of a turbocharged engine.

The combustion model accounted for transient fuel sprays evolution, fuel-air mixing, ignition, combustion and NO and soot pollutant formation. The results demonstrated that the model can predict the rate of heat release and engine performance with high fidelity, while more effort is needed to enhance the fidelity of emission prediction. Arise et al. [18] reported that the model they developed successfully predicted engine performance and emissions.

In addition, the constants in their sub models remained the same throughout the engine operating range, which enabled this quasi-dimensional multi-zone model to be used for prediction purposes. By using the GT-Power software, [20] also developed a multi-zone model to analyze the performance and emissions of different types of diesel and biodiesel fuels.

The model was calibrated at a default case using normalized burn rate and it was then used to predict pressure diagram, heat release and NOx emissions for soybean based biodiesel, rapeseed based biodiesel and reference diesel. The results showed that three fuels gave almost the same pressure diagram, while the two biodiesel cases gave slightly higher heat release rate than that of diesel case. At two load conditions, results showed 60% higher NOx concentration from the two biodiesels fuel than that of diesel fuel. Since the 10 model has not been well calibrated at all engine operating conditions, these results could be very preliminary.

To obtain more detailed combustion insight, 3D simulation is still applied by some investigators. In [8], a KIVA model was developed and calibrated using the engine data for diesel no.2 and B100 biodiesel. Good agreement between measured and predicted heat release is obtained with some discrepancies associated with the start of combustion. In terms of emissions, the author compared soot vs.

NOx tradeoff between measurement and prediction and the agreement is also quite good. After completing the KIVA model validation, a detailed examination of the impact of engine controls settings on NOx formation due to the lower energy content of the B20 blends was conducted.

Two test cycles (UDDS6K and HWY55) were conducted by the KIVA model. Final results showed that at higher speeds and loads, the change in engine control settings due to the lower energy content of the blended fuel led to a NOx increase on the order of 3-4%.

The author believed that this accounts for the majority of the NOx difference between a B20 blend and its base diesel fuel**.**

A considerable amount of experimental work has been done to fully understand the working of EGR and its deteriorating effects on combustion stability at higher EGR levels.

2-5 Investigation of EGR Effect on Combustion and PM Emissions in a DI SI Engine

It is well known that EGR can effectively put down knock in gasoline fueled internal combustion engines with various researchers in the late 1970s and 1980s investigating this number , identifying that large proportions of EGR have the ability to reduce NOx emissions substantially, along with some improvements in fuel economy. During the late 1990s and early 2000s there was continued concentrate on the use of EGR to repress engine knock. Grand in et al. investigated the effect of low (7%, 9%) and medium (11%, 13%) EGR ratios on KLMBT spark timing, fuel consumption, as well as NOX and HC emissions in a 4-cylinder turbocharged engine with cooled low pressure (LP)-EGR.

Overall they found that considerable knock repression at power outputs comparable with what was achieved by fuel enrichment could be obtained using cooled EGR. By increasing EGR from low (7%) to medium (13%) ratios, they found that the KLMBT spark timing could be advanced by 8 CAD. Similar results were also observed by Refs. .Fuel consumption could be reduced by 0.4% from 254 to 253 g/kW h with the EGR ratio increase, also reported similar or greater improvements. Increasing EGR from zero to medium levels (10%) NOx emissions could be significantly reduced by 43% from 3000 to 1700 rpm, with similar results reported greater reductions of

NOx of up to 90%. HC emissions remained stable, which was similarly reported by Refs. Diana et al. investigated the effect of EGR on engine performance parameters in a 4-cylinder, 1.25 l gasoline engine.

They observed similar reductions in fuel consumption, and NOX emissions as. However at the three tested engine loads of 5, 7, and 9bar, HC emissions were observed to increase significantly by 12.0%, 9.1%, and 4.8% for the three respective loads, unlike who observed steady HC. Refs. Also observed a significant HC emissions increase across the EGR range [3].

Poteau investigated the use of cooled EGR to reduce knocking using 0D simulations and a 2 l, 4-cylinder turbocharged engine. They found that at 1500 rpm engine speed with a BMEP of 11.3 bar, the exhaust gas temperature was reduced significantly by up to 100 C also reported significant reductions in exhaust gas temperatures with EGR addition. Similar to Ref. they also observed significant reductions in fuel consumption and an advanced KLMBT spark timing[3].

There has been somewhat little published work quantifying the effect of EGR on PM emissions from gasoline engines. Alger et al. investigated the effect of high levels (up to 40%) of cooled LP-EGR on PM in a turbocharged PFI engine. They observed that PM mass and number reduced safely as EGR reduced the need for enrichment to reduce exhaust gas temperatures, they also observed benefits at rich conditions [3].

EGR was observed to reduce PM emissions at medium engine loads, particularly in the medium–high load range; observed similar findings. They proposed that the formation of soot, even from rich regions, can be reduced or even eliminated, with the use of EGR Like they observed significant NOx emission reductions and similar to, they observed that HC emissions increased with increasing EGR, particularly at the highest tested engine load

CHAPTER III

Design Methodology

CHAPTER III

Design Methodology

3-1 Methodology

This chapter is interested in how to summarize NOx emission operation and Diesel RK software steps and the engine used in the present investigation is a four-cylinder, four-stroke, turbo-charged, water-cooled and direct-injection CI engine.

3-2DIESEL-RK Software

The DIESEL-RK is vocational thermodynamic full-cycle engine simulation software. On a market, there is little well recognized thermodynamic engine simulation material from different contractor.

These tools cover wide range of practice tasks: from general engine connotation analysis up to design engine systems. The kernels of engine simulation models of other programs are focused mainly on non-steady 1D gas dynamic phenomena.

DIESEL-RK is concentrate on advanced diesel combustion simulation and emission formation simulation, one has not such specific functions as analysis of engine passing behavior or analysis of difference between engine cylinders operation. Usage of DIESEL-RK is effective if customer deals with engine combustion optimization and emissions control, port timing, EGR and turbo charging optimization as well.

The major concentrates of DIESEL-RK are below The DIESEL-RK is professional thermodynamic full-cycle engine simulation software. On a market, there are few well known thermodynamic engine simulation tools from different contractor. These tools cover wide range of practice tasks: from general engine concept analysis up to design engine systems.

The kernels of engine simulation models of other programs are concentrating fundamentally on non-steady 1D gas dynamic phenomena. DIESEL-RK is concentrate on advanced diesel combustion simulation and emission formation simulation, one has not such specific functions as analysis of engine passing behavior or analysis of difference between engine cylinders operation. Usage of DIESEL-RK is effective if customer deals with engine combustion optimization and emissions control, port timing, EGR and turbo charging optimization as well. The main features of DIESEL-RK are below:

Thermodynamic test of Diesels fueled by diesel oil, methanol, bio-fuels and mixtures of bio fuels with diesel oil, HCCI / PCCI concepts and Dual fuel systems are supported.

Thermodynamic test of SI petrol engines and gas engines, including pre chamber engines, and engines fueled by Natural gas (Methane), Pipeline gas (Propane-Butane), Biogas, Wood gas, Syngas with arbitrary composition (Producer gas), by any gas having arbitrary composition as well.

Thermodynamic test of Two- and Four-stroke engines, Junkers engines with reverse pistons; Crank case scavenged engines, etc.

3-3 Simulation and optimization of Mixture Formation and Combustion in diesel

Fuel injection optimization of sprayer design and location, injection pressure, injection timing rate shaping, split / multiple injection strategy PCCI test including Low Temperature Combustion phase, etc. personal diameters and direction of nozzles of few injectors, having separate control (own fuel and own injection profiles) are accounted and may be optimized.

Detail Chemistry is simulated for Ignition Delay prediction at PCCI and HCCI for Diesel Fuel, Methanol and for Bio-Fuel.

1- Common Rail control algorithm development; Automatic optimization of Injection profile fronts shape.
2- Effect of Combustion Chamber Geometry modification.
3- Fuel Sprays Evolution visualization.
4- Nitrogen Oxides, Soot and Particles formation simulation. Detail Kinetic Mechanism for NO_X formation at large EGR and multiple injections.
5- Simulation of effects of Turbo charging Intake and Exhaust Port flows, Bypasses, and EGR.
6- Valve and Port Timing optimization. VVA optimization with the dwell of the valves.
7- Multipart metric optimization of engines parameters, Conjoint optimization of NO_X, PM and SFC, including Pareto optimization.

DIESEL-RK is full cycle thermodynamic engine simulation software. One is designed for simulating and optimizing working processes of two and four stroke internal combustion engines with all types of support. The program can be used for modeling the following types of engines:

1- DI Diesel engines, including PCCI and engines fueled by bio-fuels.
2- SI petrol engines.
3- SI gas engines including pre chamber systems, and engines fueled by different gases: Methane, Propane-Butane, Biogas, Wood gas, Syn gas, etc.
4- Two-stroke engines with uniflow and loop scavenging, opposed piston engines (OP or Junkers engines) and OPOC engines.

5- Dual fuel engines (engines having few independent fuel injection systems for different fuels).

The DIESEL-RK is thermodynamic software: engine cylinders are considered as open thermodynamic systems.

3-4 Representative applications include:

1- Fuel consumption prediction and optimization.

2- Torque curve and other engine performances predictions.

3- Combustion and emission analysis, including PCCI.

4- Dual fuel engine mixture formation and combustion analysis.

5- Knock prediction.

6- Valve timing optimization, including VVA optimization for every operating mode.

7- EGR analysis and optimization.

8- Turbocharger and bypasses matching and optimization.

9- Conversion of diesel engines into gas engines.

10- Cooperation with different modeling tools: Simulink, IOSO NM, etc. DIESEL-RK solver can be run under the control of other applications [22-25].

In order to run DIESEL-RK kernel under the control of external codes intended for optimization or for simulation of vehicle where the engine has been used, the special interface is developed. The interface includes text files with input data and output data. The DIESEL-RK solver may be run by external code via batch file

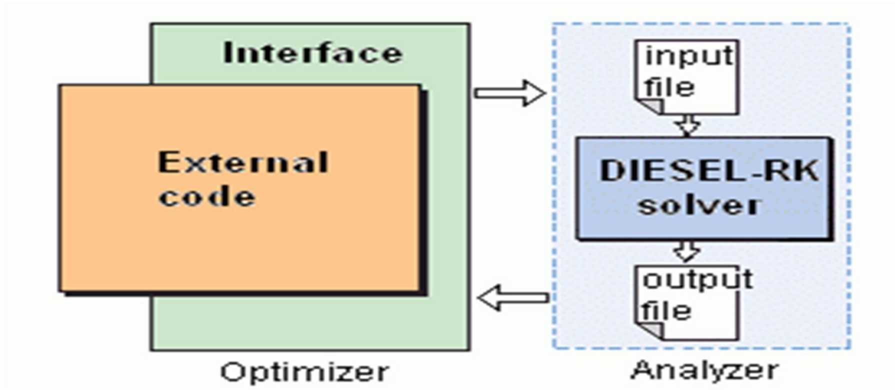


Figure 3:1Selection of engine models used in the DIESEL-RK

Selection of engine models used in the DIESEL-RK is stipulated by the requirements of a high accuracy of results, high rate of calculation and generality. The last condition is a reason of refusal from empirical equations, which are correct only in narrow boundaries. Authors have preferred frequently laborious methods which consider the physical nature of phenomena in engines. A number of calculation methods were developed by authors of this project

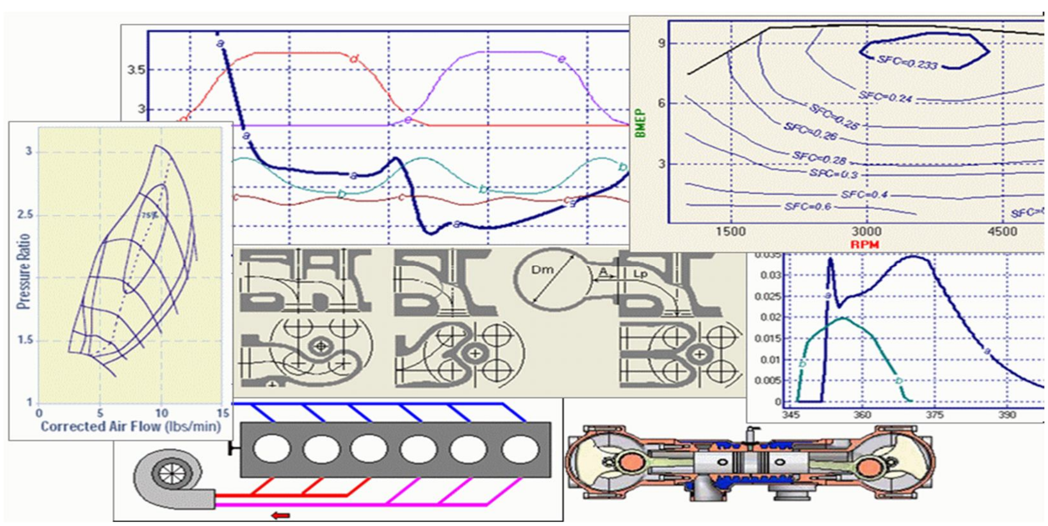


Figure 3:2 DIESEL-RK with other Simulation Tools

3-5 History of the program

Development of the DIESEL-RK software core has been started in 1981-82 in the department of Internal Combustion Engines (Piston Engines), Bauman Moscow State Technical University. From its very beginning the software was devised as a tool for optimization research and, therefore, a particular emphasis was made on the adequacy and operating speed of the mathematical models and algorithms applied, many of those being original authors' codes.

All these years the work has been constantly carried out in touch with engineers and computational research performed was to the order of different manufacturers of Internal Combustion Engines (ICE). In this time the software adequacy has been tested to fit dozens of engines of various types and purposes. Many computational procedures and options were introduced into the software to suit the demand of industrial enterprises – software users including biggest engine manufacturers of Russia.

The software is intended primarily for ICE developers and researchers; hence much attention is given to provide the product of convenient use for an engineer. The input and output data therefore are organized in a way to suit the industrial demand.

The first software version with a convenient interface and functions of multi parametrical optimization was issued in 1991 owing to financial support of A.Surin, to whom the project leader is truly grateful. The first DIESEL software was in use among leading motor manufacturers of Russia because of its convenient interface and core with the realized and at that time modern combustion model of the compression ignition engine.

In 1993-1994 based on the novel computational code of mixture formation and combustion in diesels, developed by professor of the Kharkov Polytechnic Institute N.Razleytsev, a new software generation was developed and issued: DIESEL-4t software and its modification DIESEL-2t for two-stroke engines. Being a DOS application, the programs were equipped with a window interface reminding a Window application by appearance. For visualization of the mixture formation process and combustion in a diesel Fuel Jet Visualization code was included as part of DIESEL-RK software. In late 90s remote access to the software via INTERNET was organized. The software was intensively used not only within industrial enterprises but in the educational process at the department of ICE (Piston Engines), Bauman University, as well.

The year 2002 gave start to the development of the new Window NT-oriented DIESEL-RK software. The software core was considerably improved and included the up-to-date procedure for calculating toxic emissions with account of the EGR system, multiphase injection research, what provides and expands the potentialities of the diesel performances calculation. As a result of hard work of the workers' team the first version of DIESEL-RK software has been issued in 2004.

As a professional product, DIESEL-RK software can be successfully used by the beginners: students and PhD students of higher schools. To make the process of numerous input data setting (being at times very time-consuming) easier, and empirical coefficients setting easier, the software comprises specific tools – settings wizards. The wizards will create data files automatically on the basis of most general information on the engine to be studied, using common technical solutions accepted in the motor-building industry. Thus, the process of input data setting is considerably simplified, and the most elaborate stage of computational research – calculation model calibration – is simplified as well. The latter fact is special importance to students having little experience, time and experimental date for customizing the software with the engine, and also for the needs of researchers performing quick examination of a particular engine design.

Multipart metrical optimization used in the software ensures a radically increased efficiency of numerical research aimed at improving the technical level of engines.

Over the course of its development DIESEL software has been always using advanced mathematical models of combustion in a diesel. In the present software version the RK-model is realized, taking into account specific injection features and fineness of fuel spraying, dynamics of fuel sprays evolution, interaction of sprays with air swirl and with the walls as well as orientation of sprays in the piston bowl. In this case the model accounts for conditions of each fuel spray evolution and thus generated near-wall flows as well as their interaction.

Calculation of NOx emission is realized by the latest techniques: with Zeldovich scheme and with Detail Kinetic Mechanism.

The software includes “Fuel Spray Visualization” code. This code allows a user in pictorial form to analyze the animation picture of fuel sprays evolution, their interaction with the piston bowl walls as well as with swirl and among themselves. The code is helpful in designing the piston bowl shape and in making a proper choice of diameter, number and directions of injector nozzles for a particular fuel supply characteristic and swirl intensity.

3-6 The Customers

A lot of research projects was carried out with codes DIESEL under the contracts with many companies-manufacturers and researchers of engines in Russia and Euro Union.

Table3-1 below show that the company using DIESEL -Rk and their country.

Country	**Customers**	**Russian Customers**
GERMANY	Robert Bosch GmbH *	JSC "Kolomna plant" (Kolomna)
ITALY	LOMBARDINI srl *	JSC "GAZ" (N.Novgorod) *
HUNGARY	ESPA AGENT Kft.*	JSC "KamAZ" (NaberezhnieChelny) *
UK	WDL Ltd.*	JSC "ZIL" (Moscow) *
USA	General Motors *	JSC "Zavolzhsky Engine Plant" (Zavolzhie) *
UK	PTL Power train Technology *	JSC "Vladimir plant" (Vladimir) *
GERMANY	HEINZMANN GmbH *	JSC "Auto diesel" (Yaroslavl) *
GERMANY	Astremo Power train AG	JSC "Altai Precision Components Plant" (Barnaul) *
NETHERLANDS	RDA *	JSC "RUMO" (N. Novgorod)
SWEDEN	FT Engineering AB *	JSC " Penz diesel mash" (Penza)*
FINLAND	Aumet OY *	JSC "Ufa Motor" (Ufa) *
ITALY	Istitu to Motor i -CNR *	TsAGI (Moscow)
UK	Sir Joseph Swan Centre for Energy Research	JSC "Rybinsk Motors" (Rybinsk)
	Newcastle University *	JSC "Liulka-Saturn" (Moscow) *
SWISS	WARTSILA *	JSC "OKB Sukhoy" (Moscow)

3-7 Calculation models used in the DIESEL-RK

Selection of engine models used in the DIESEL-RK is stipulated by the requirements of a high accuracy of results, high rate of calculation and generality. The last condition is a reason of refusal from empirical equations, which are correct only in narrow boundaries. Authors have preferred frequently laborious methods which consider the physical nature of phenomena in engines.

3-8 SPSS:

The Spss is the approach of mathematical dealing collection, analysis interpretation, and organization of data.

The Spss is a widely used program for statistical analysis in social science it is also used by marked researcher, health researcher …etc.

And it has much application for a lot of purpose and in this case we focus abut that relate to our search.

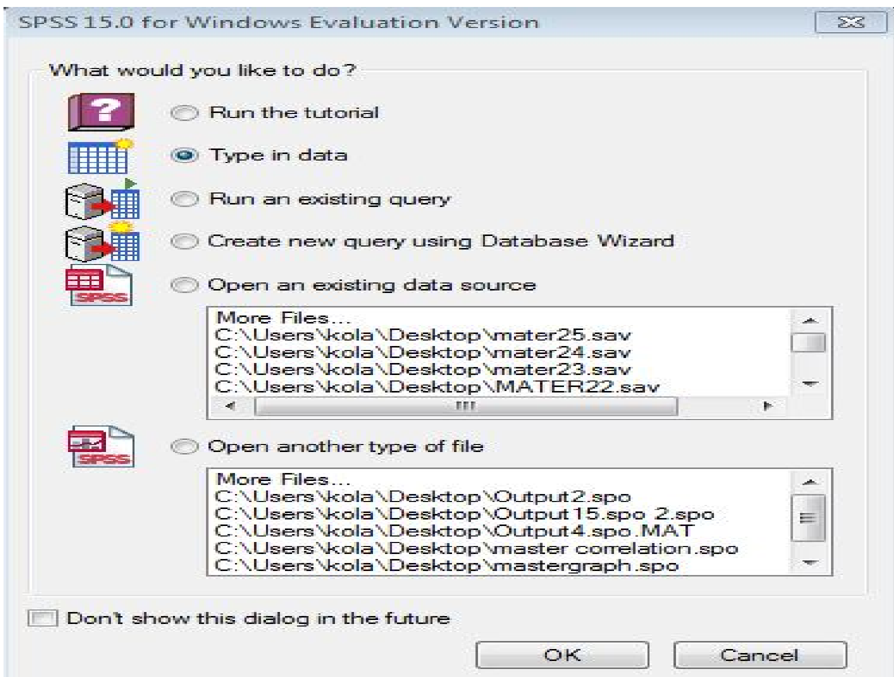


Figure 3:3 show that main window of the program

Common goal for a statistic research project is to investigate causality and in particular to draw a conclusion in the effect of change in the values of predictor or independent variables on dependent variable.

And we used in this section to create correlation between parameter that used and get prediction equation.

3-9 Liner regression:

In the statistics the Liner regression is an approach for modeling relationship between the scalar dependant variable one or more and independent variable.

Liner regression is fairest type of regression analysis to be studies rigorously and to be used extensively in particular application.

Liner regression has much particular use one of them is prediction ore error prediction.

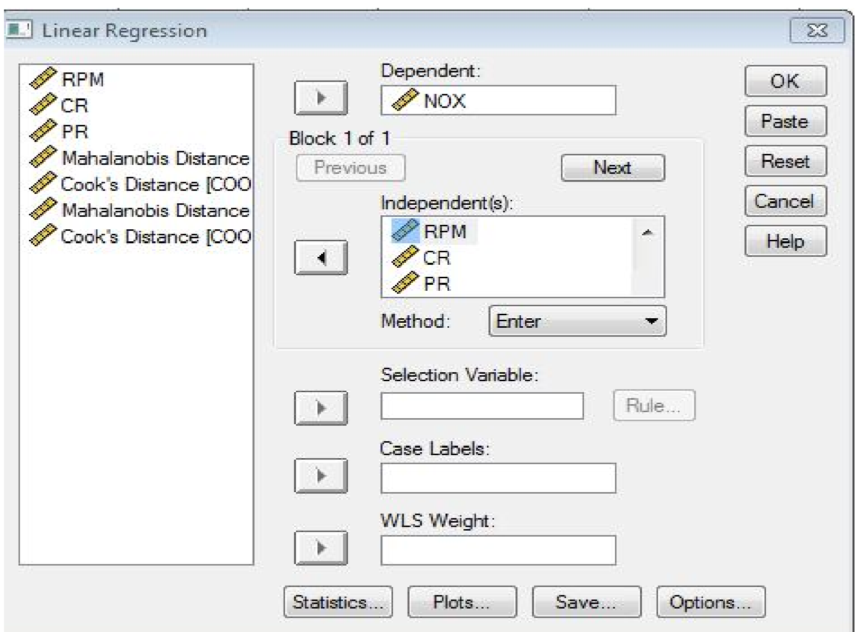


Figure 3:4 main window of the Liner regression

Table 3-2 Characteristics of engine Parameters Specification

Engine type	Turbo charged diesel engine
Number of cylinders	4
Bore	103mm
Stroke	132mm
Compression ratio	18.3
Number of valves	16
Injection system	direct injection
Displacement	4.399 liter
Cooling system	Water

3-10 Engine Parameter Test in Diesel RK

When you open the program window appears containing several options, we select (create new project)

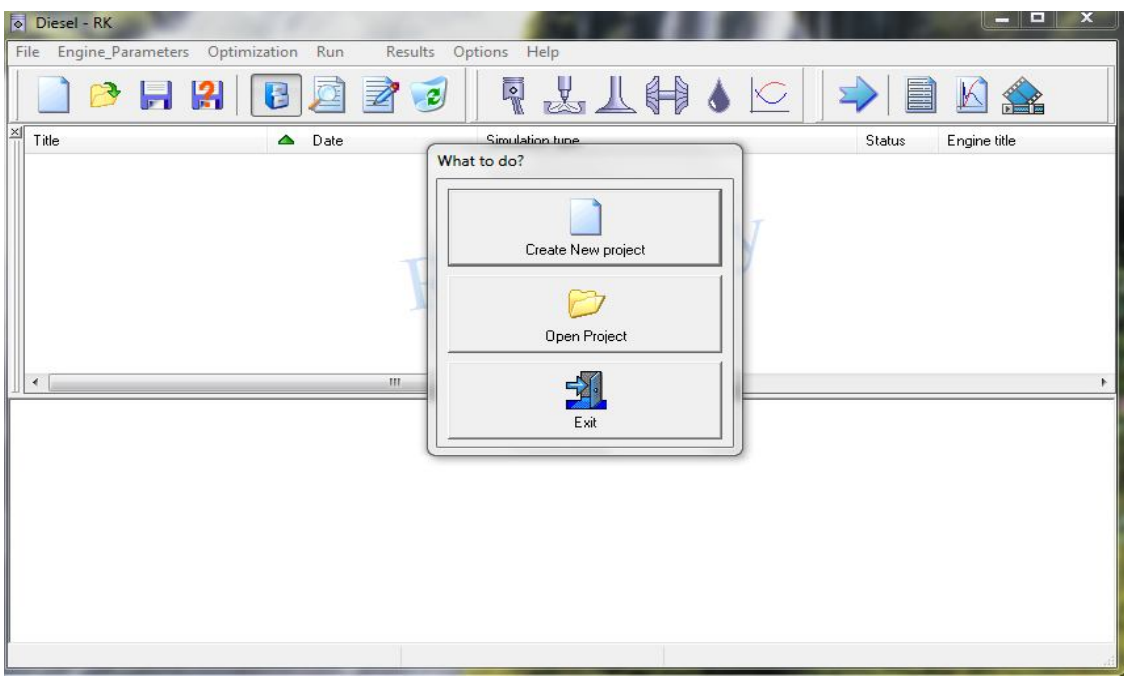


Figure 3.5 show the select of new project step 1

Another window appears, and then chooses (NEXT).

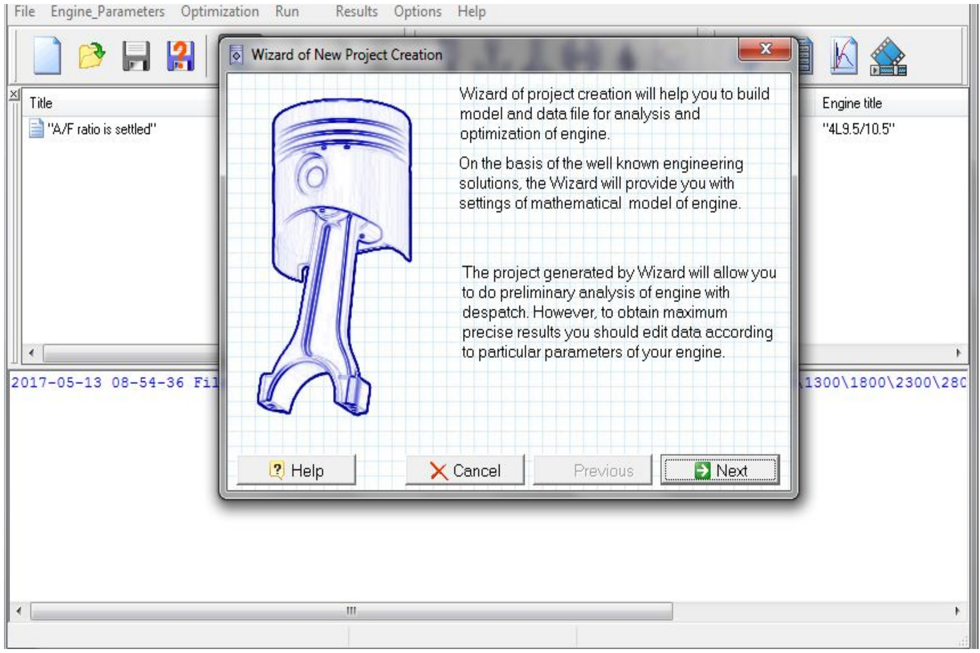


Figure 3.6 show the cylinder shape step 2

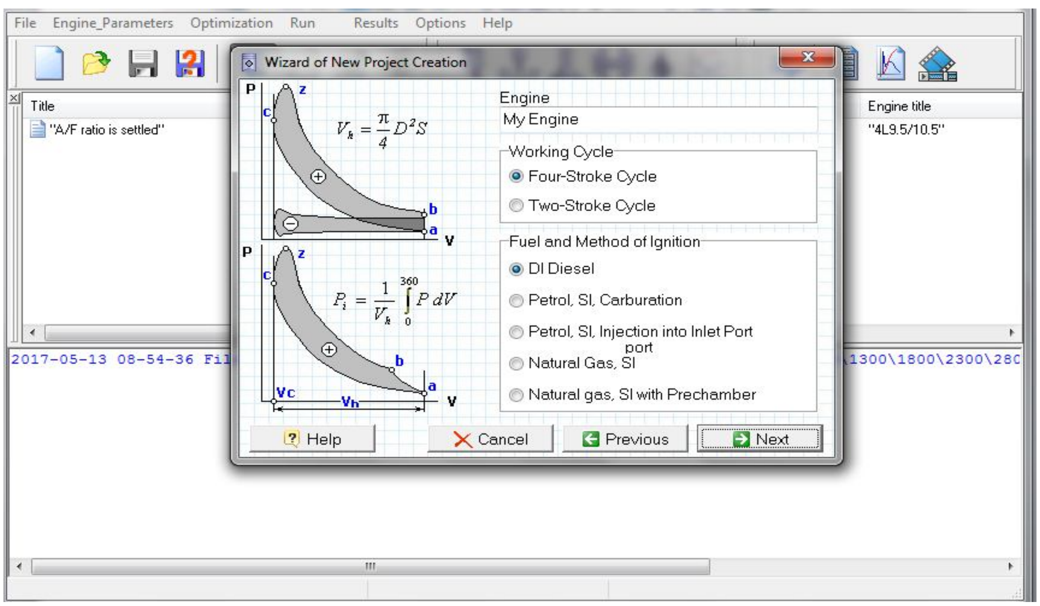


Figure 3.7 define the type of basic engine design step 3.

In the new window we select the name of the engine (a project name) and then determine the type of working cycle choose (Four-Stroke Cycle) after that we choose the fuel and method of ignition (DI Diesel) then press (NEXT)

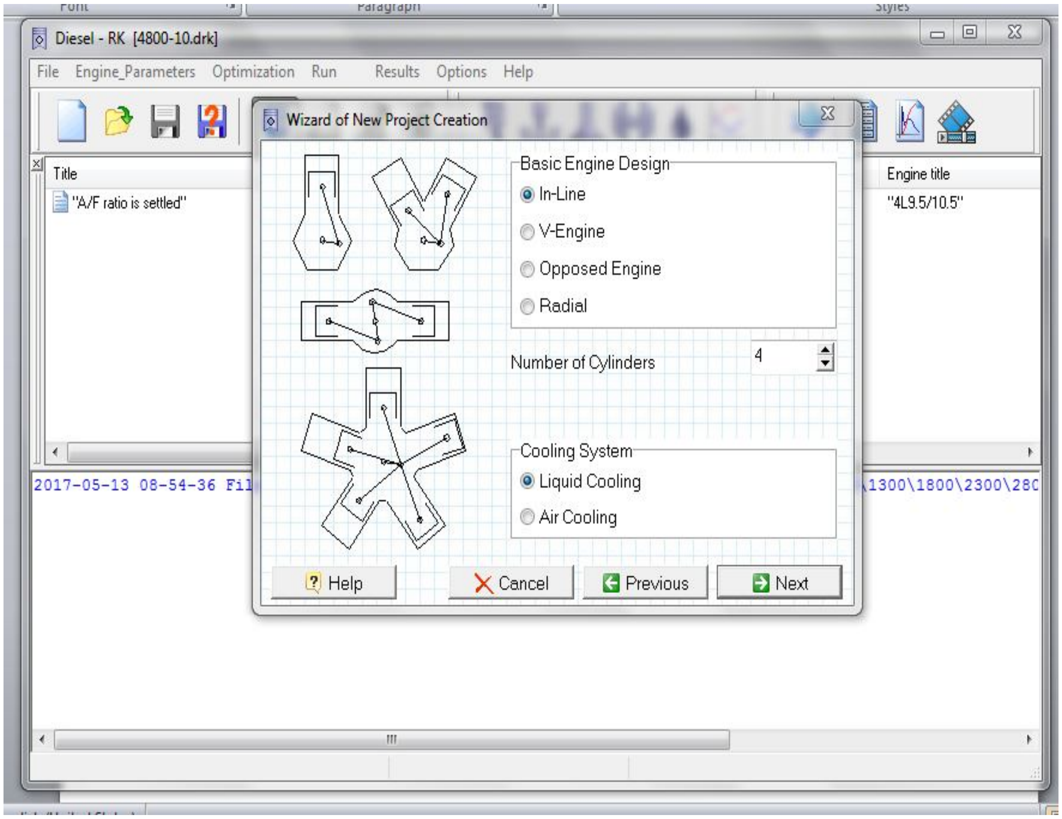


Figure 3.8 show step 4.

In the new window define the type of basic engine design we choose (In-Line) then we determine number of cylinder choose (0), and cooling system (Liquid Cooling) then press (NEXT)

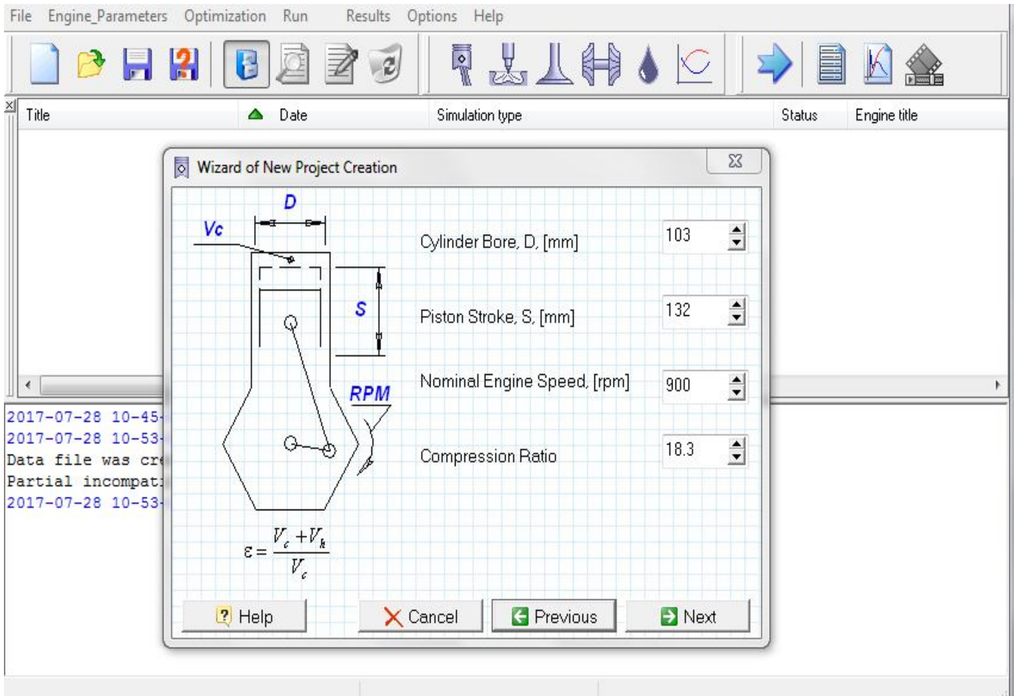


Figure 3.9 show step 5.

In the new window we determine the cylinder bore (103 mm) and piston stroke (132mm) then determine the nominal engine speed (900 rpm), and compression ratio (18.3) and number of cylinder then press (NEXT)

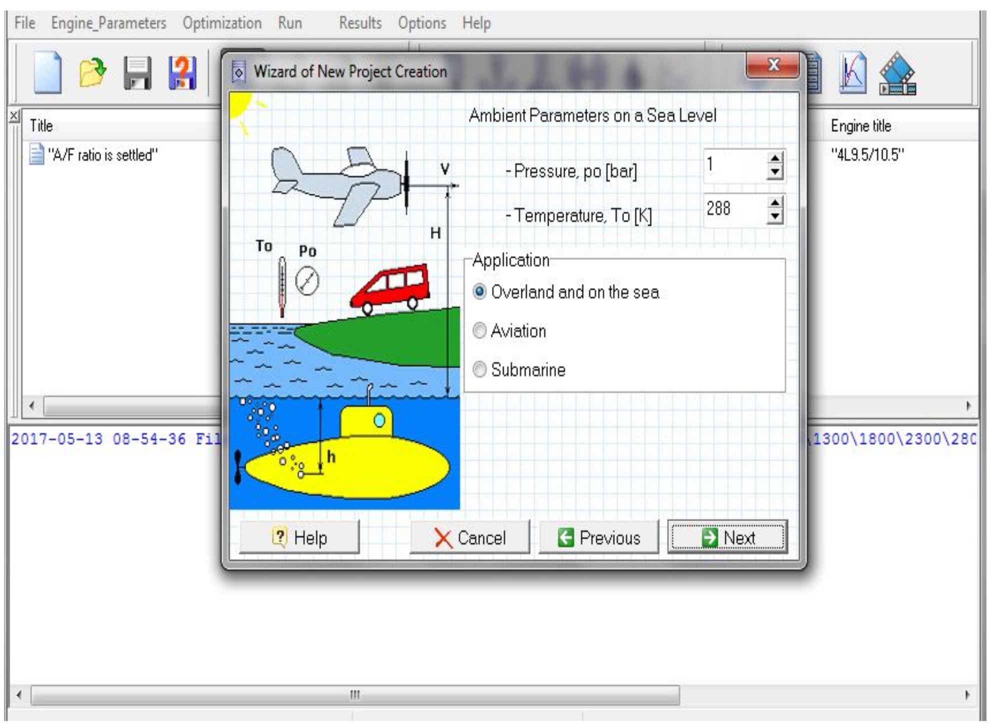


Figure 3.10 show step 6

Ambient parameter on sea level window appears then choose the pressure value (1 bar), and temperature value (288 K) and determine the application type so we choose (Over land and on the sea), then press (NEXT)

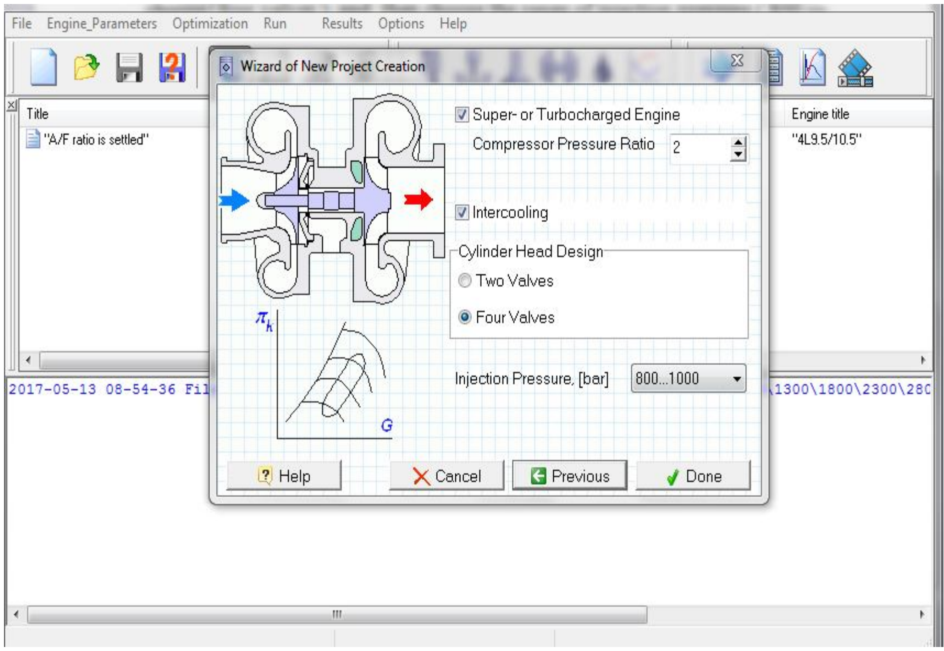


Figure 3.11 the turbo charger (step 7)

In new window we choose super – or turbocharged engine , then choose Inter cooling , according to cylinder head design we determine the number of valves we choose (four valves), and then choose the range of injection pressure (800 --- 1000 bar) ,then press (Done).

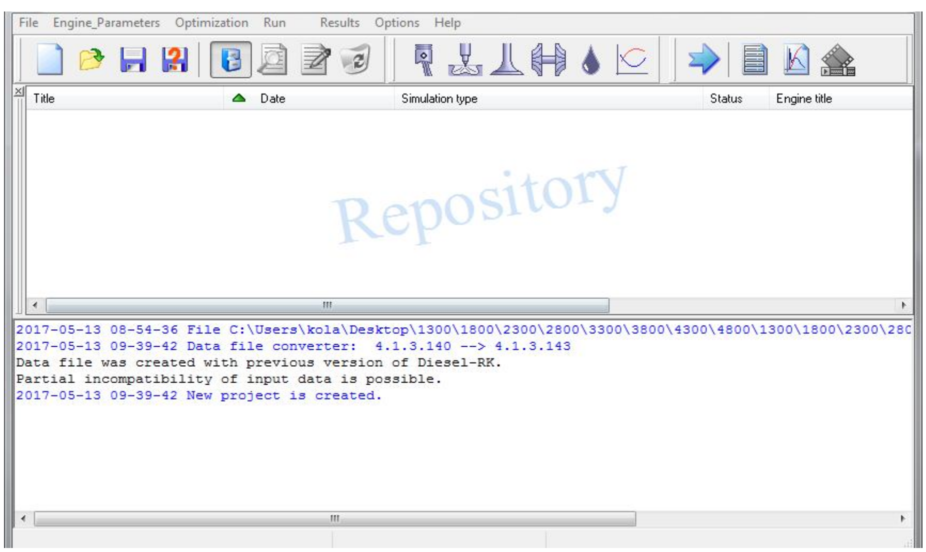


Figure 3.12 save the result file (step 8).

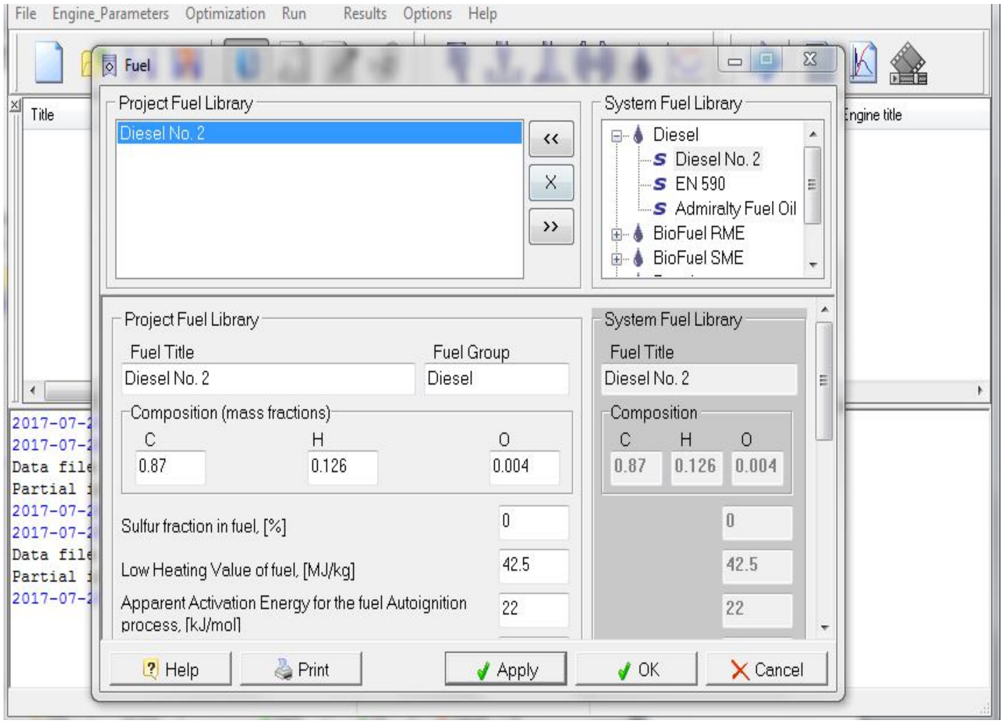


Figure 3.13 other fuel input (diesel No.2)

In a second experiment, we do the same steps but use different fuel (methane gas, and gasoline)

CHAPTER IV

Results and discussion

CHAPTER IV

Results and discussion

4-1 Preface

This section is considered the most important because it deals with equation of prediction of NOx emission and values obtained from program and compare them to get proportion of error required noting that the value set in the round was taken as a model of many values for clarification and modified prediction obtained from program of statistical analysis.

After make correlation and compare the predict value with numerical value and compeer them and get error we explain the relation between the parameter by using chart.

4-2 Effect of rpm on NOx emission

NOx directly result of very high in cylinder temperature.

High engine load cusses in high in cylinder temps as rpm increase, the load goes down even though the engine is making more torque so peak temperature start decreasing as rpm increasing and hence reduction in NOx emission.

Increase in rpm $\longrightarrow$ reduction in engine load $\longrightarrow$ reduction in NOx emission.

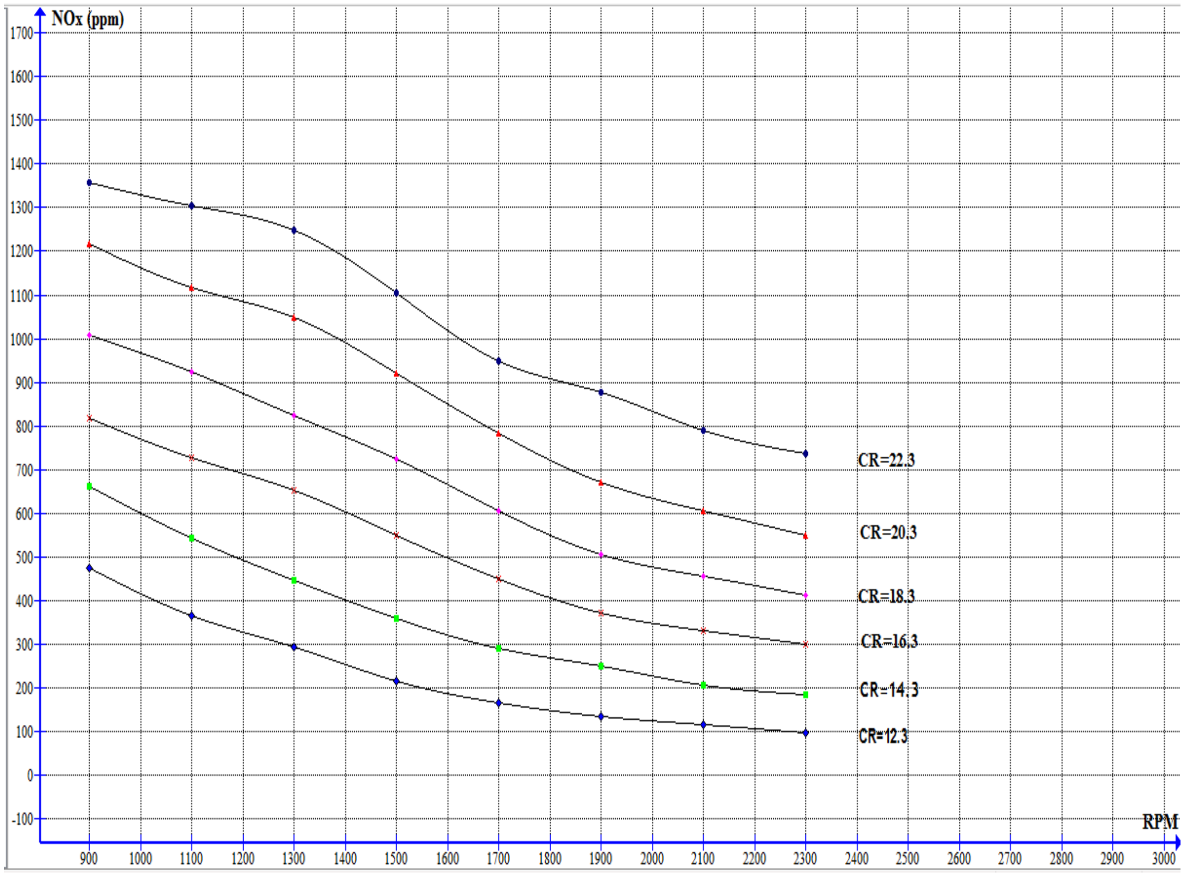


Figure 4-1 The relation between the NOx and rpm

4-3 **Effect of CR on NOx emission**

The simulation has been corrected out for compression ratio the analysis of simulation result show that the higher compression ratio result in higher cylinder pressure and higher heat release rate as well as slower ignition delay.

The NOx emission increase at higher compression ratio due to the higher pressure and temperature.

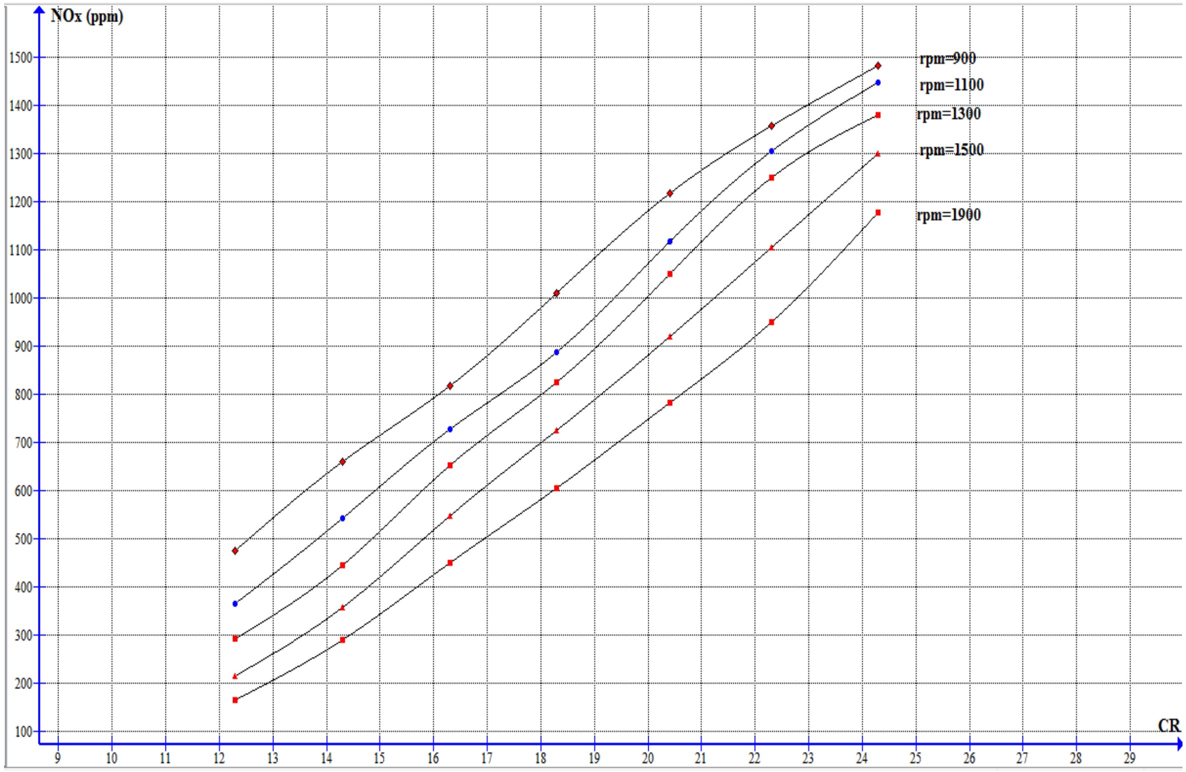


Figure 4-2 Relation between the NOx and compression ratio

4-4 Effect of PR on NOx emission

The simulation correct out the propose of turbo charger for the engine and the result emission are compared to the naturally aspirated engine and the level of NOx are higher in term of their concentration in the exhaust with the naturally and same time the emission produced by turbo charged engine are respectively lower and higher than those the naturally aspirated engine It seen that the relation between them is not constant that depended on air observed.

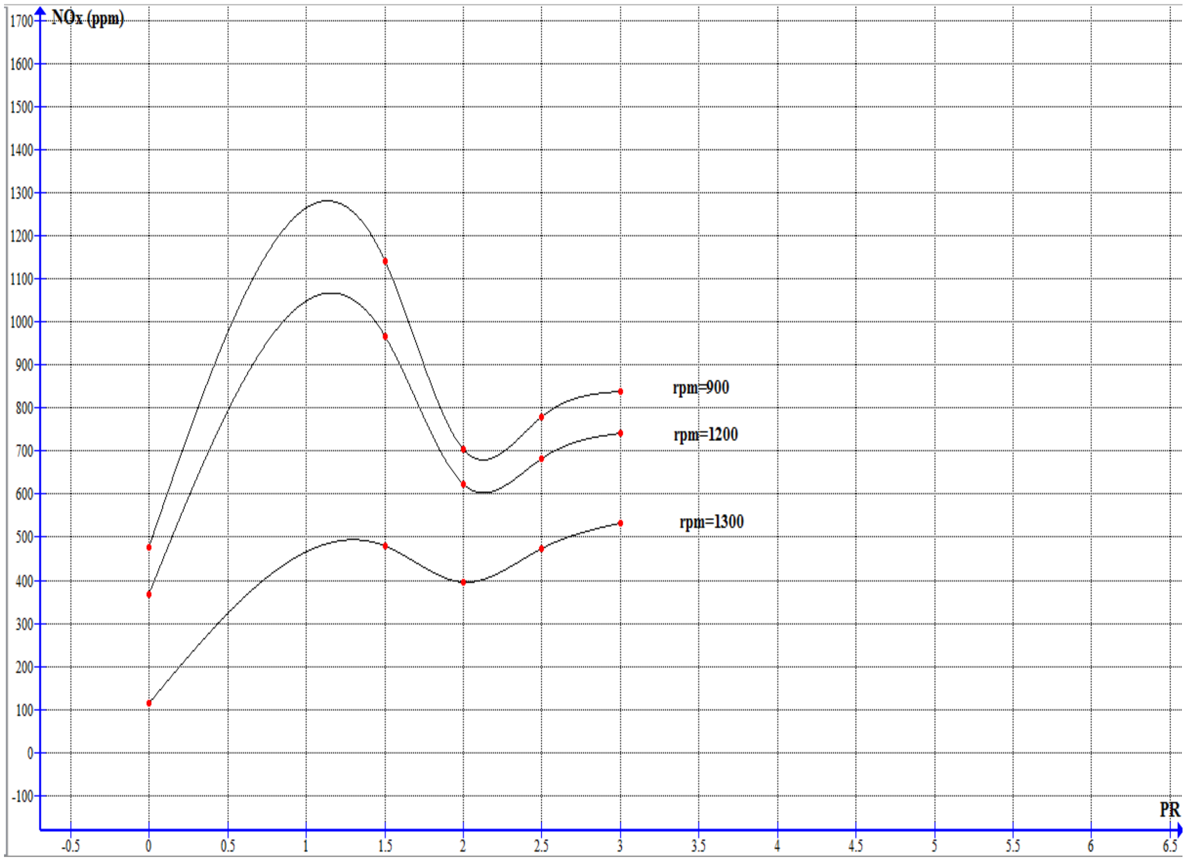


Figure 4-3 The relation between the NOx and pressure ratio

4-5 NOx prediction

To predict the NOx emission from the measured in-cylinder pressure using engine parameter, the cylinder pressure and the cylinder temperature characteristics of the combustion are described.

The comparison of the cylinder pressure and cylinder temperature of diesel and biodiesel fuel is also discussed in detail. Finally the predicted NOx emissions values from cylinder pressure measurement were compared with measured NOx emission for both diesel and biodiesels fuel.

The beauty of the new NOx prediction method is that the parameters which can be used for the NOx predictions are already a must measure parameters during engine development and calibration for combustion and performance analysis. Furthermore, the correlation between engine parameter and NOx emission would be integrated with the non-destructive engine dynamics data, e.g. vibration and acoustic emission, to enable prediction of NOx emission by dynamics data in future work

4-6 Prediction equation

To predict with NOx emission that emitted from internal compassion engine we make correlation between our parameter by using SPSS program to create equation by interring the values that in the table below.

Prediction of NOX = 451.00-0.4RPM+50.865CR+92.547PR

The table 4-1 below show that the value that given from Diesel-RK program when applying the properties of engine comparing with predicted value and error

CR=20.3& PR=NA			
Speed(rpm)	Predicted	Measured	Error%
900	1126.3	1216.80	-8.035
1100	1046.3	1115.50	-6.595
1300	966.3	1048.40	-8.496
1500	886.3	919.64	-3.762
1700	806.3	782.98	2.892
1900	726.3	671.55	7.538
CR=24.3& PR=1.5			
900	1561.6675	1365.00	12.59
1100	1481.6675	1313.40	11.375
1300	1401.6675	1292.00	7.824
1500	1321.6675	1215.50	8.88
1700	1241.6675	1184.60	4.596
1900	1161.6675	1151.90	.0841
CR=18.3& PR=2			
900	1209.394	1111.30	8.11
1100	1129.394	1034.30	8.42
1300	1049.394	977.69	6.83
1500	969.394	936.40	3.4
1700	889.394	868.99	2.29
1900	809.394	806.10	0.41
CR=22.3& PR=2.5			
900	1499.668	1328.30	11.8
1100	1379.668	1276.30	7.5
1300	1299.668	1254.20	3.5
1500	1219.668	1169.50	4.11
1700	1139.668	1134.10	0.49
1900	1059.668	1109.70	-4.72
CR=16.3& PR=3			
900	1505.941	1426.70	5.26
1100	1425.941	1381.30	3.31
1300	1345.941	1337.80	0.506
1500	1256.941	1302.00	-3.586
1700	1185.941	1257.40	-6.03
1900	1105.941	1190.10	-7.61

Reveal that the NOx predicted and NOx Measured in the turbo charging engine is analysis and comparing to get error that required.

Comparison of predict and measure engine out NOx trend of the selected compression ratio change shown in fighter -4 the formulated model able to predict the NOx emission trend at both speed relative error of NOx prediction with the respect to the measure NOx values are within -8.035% to 7.538% which considered as a good NOx emission prediction see that in fig 4-4

The above result show that the NOx emission trend at both speed relative error of NOx prediction with the respect to the measure NOx values are within 12.59% to .0841% which considered as a good NOx emission prediction see that in fig 4-5

In fighter 6 we show that result show that the NOx emission trend at both speed relative error of NOx prediction with the respect to the measure NOx values are within 8.11% to 0.41% which considered as a good NOx emission prediction see that in fig 4-6.

In fighter 7 we show that result show that the NOx emission trend at both speed relative error of NOx prediction with the respect to the measure NOx values are within 11.8% to -4.72% which considered as a good NOx emission prediction see that in fig 4-7.

In fighter 6 we show that result show that the NOx emission trend at both speed relative error of NOx prediction with the respect to the measure NOx values are within 5.26% to -7.61% which considered as a good NOx emission prediction see that in fig 4-8.

The above result show that the comprehensive model has potential to predict the NOx emission

Similarly, compression of predict and measure shown in figure above is also able to predict the NOx emission trend at both speeds, the relative error are in range of 12.59% to -7.61%this shows that formulated model is capable of predicting of NOx emission with different of compression ratio see that in fig 4-9.

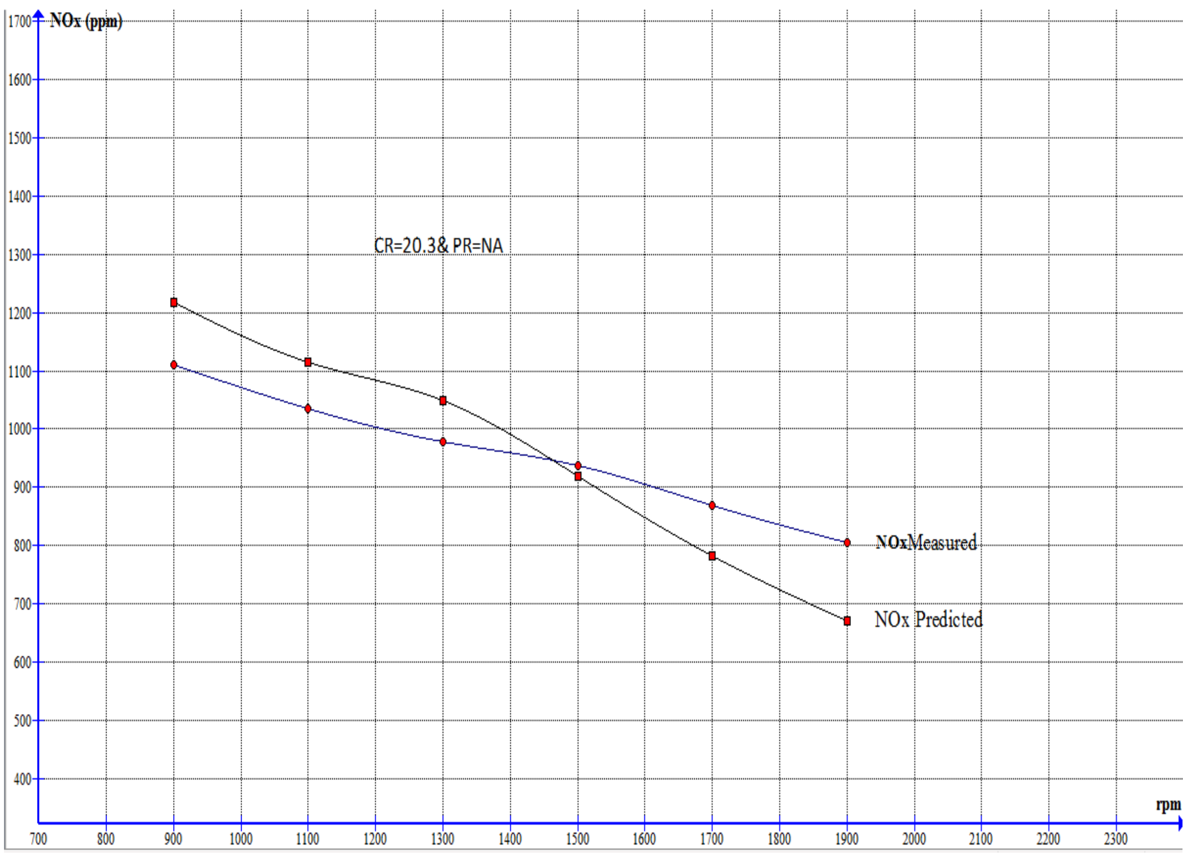


Figure 4-4 Comparison of predict NOx and measure result when compression ratio is 20.3 and pressure ratio is NA.

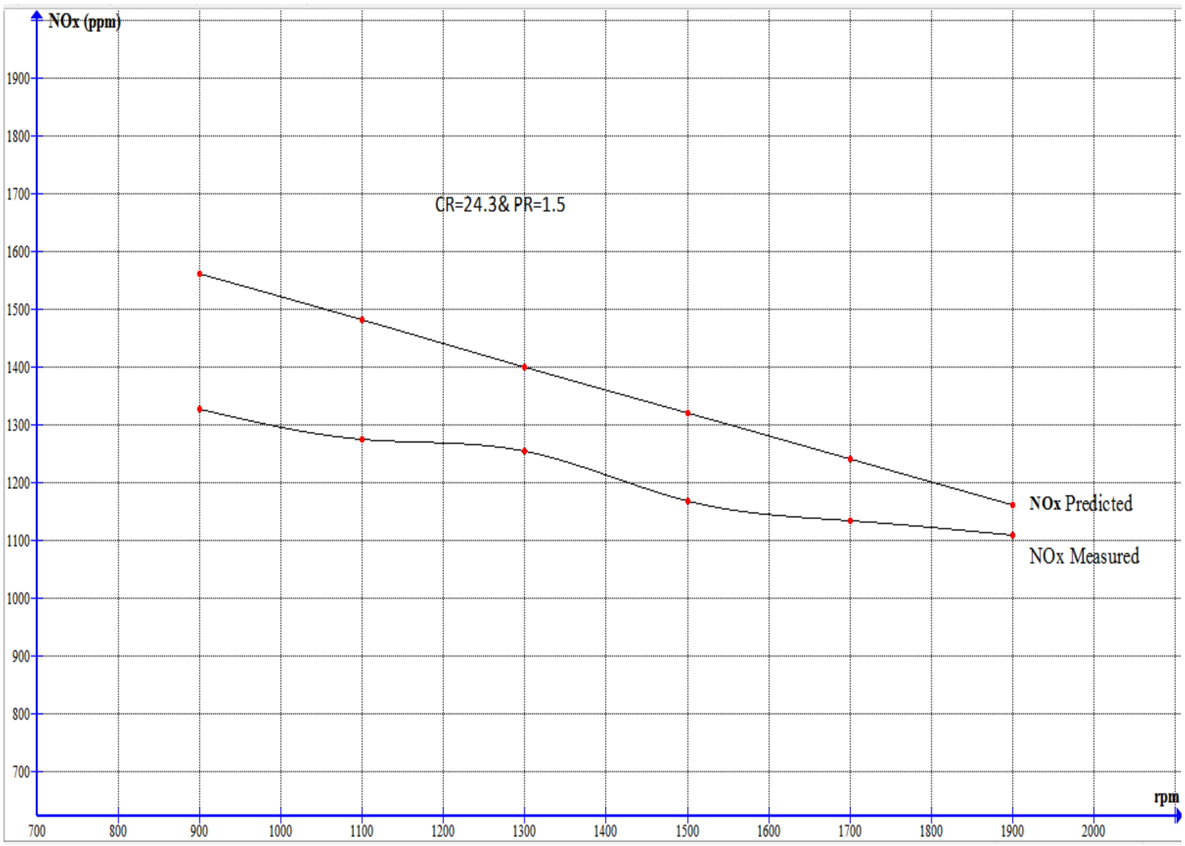


Figure 4-5 The relation between the NOx Predicted and measured when compression ratio is 24.3 and pressure ratio is 1.5.

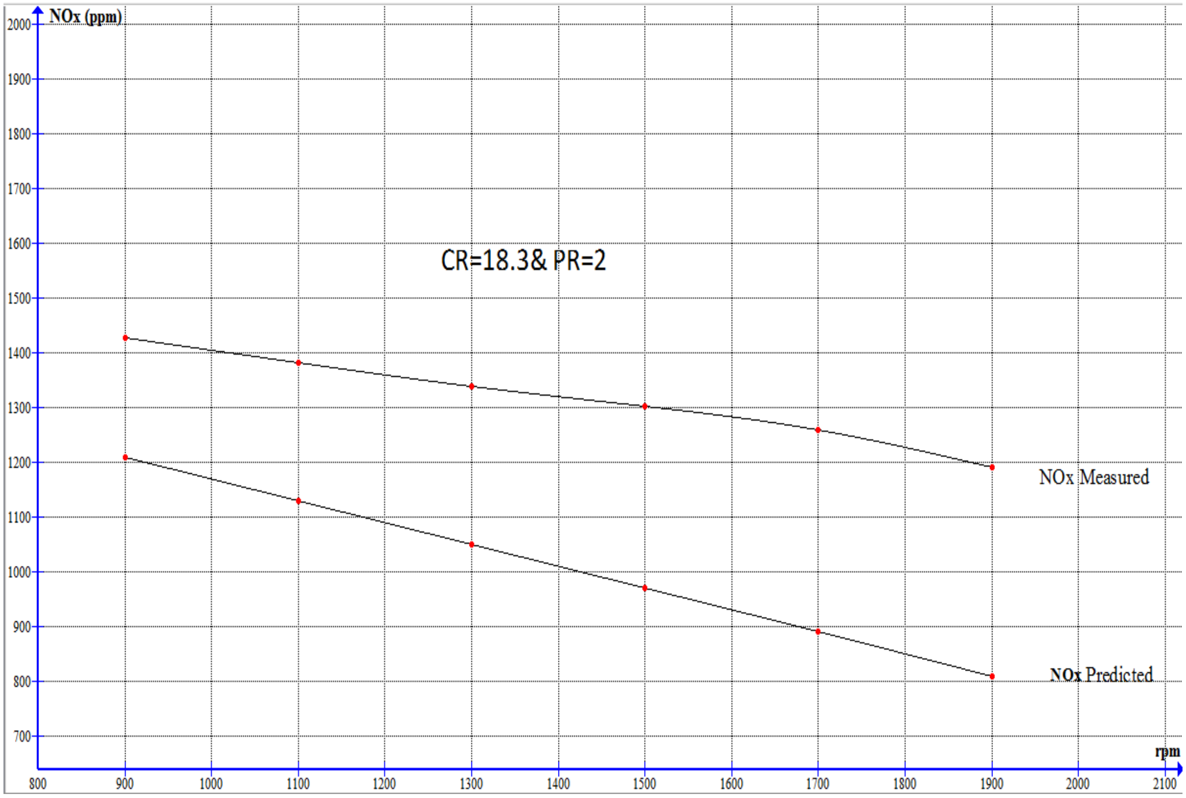


Figure 4-6 Relation between the NOx Predicted and measured when compression ratio is 18.3 and pressure ratio is 2.

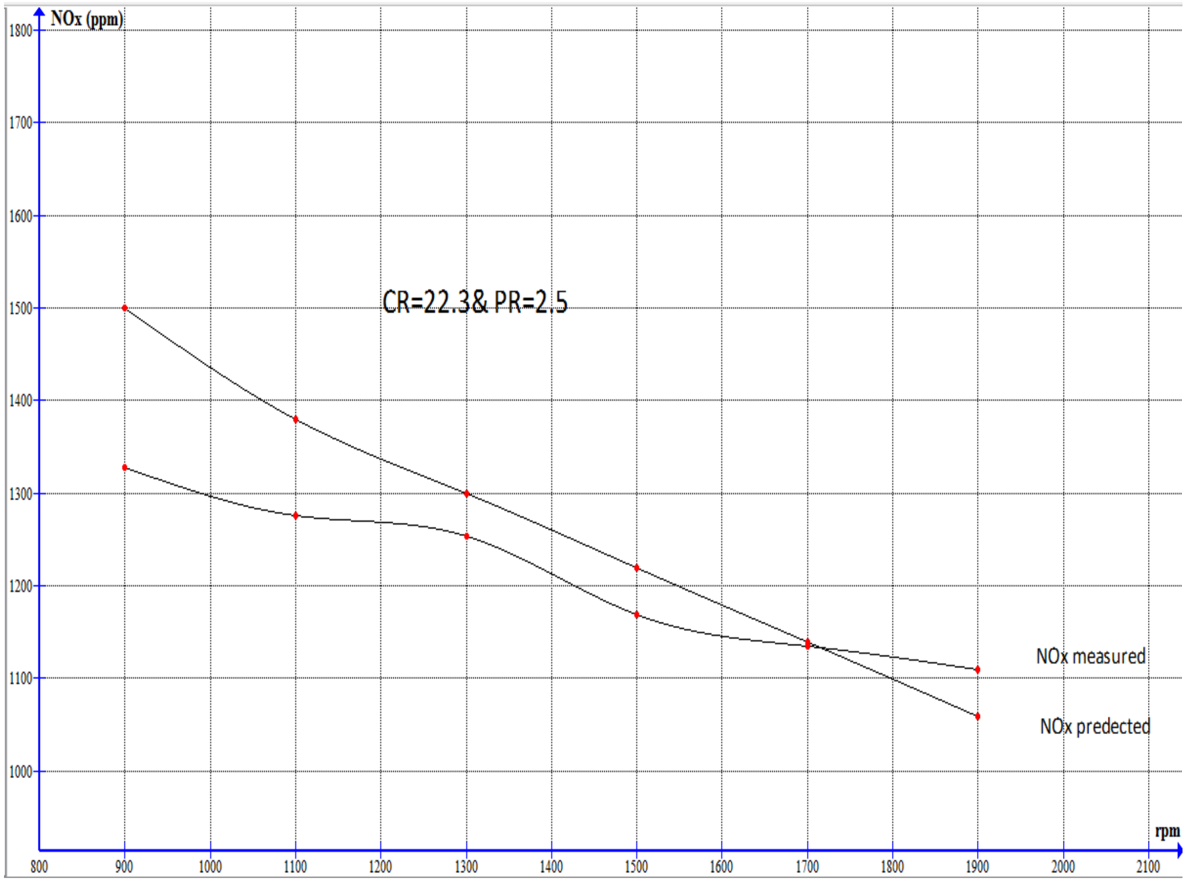


Figure 4-7 Relation between the NOx Predicted and measured when compression ratio is 22.3 and pressure ratio is 2.5.

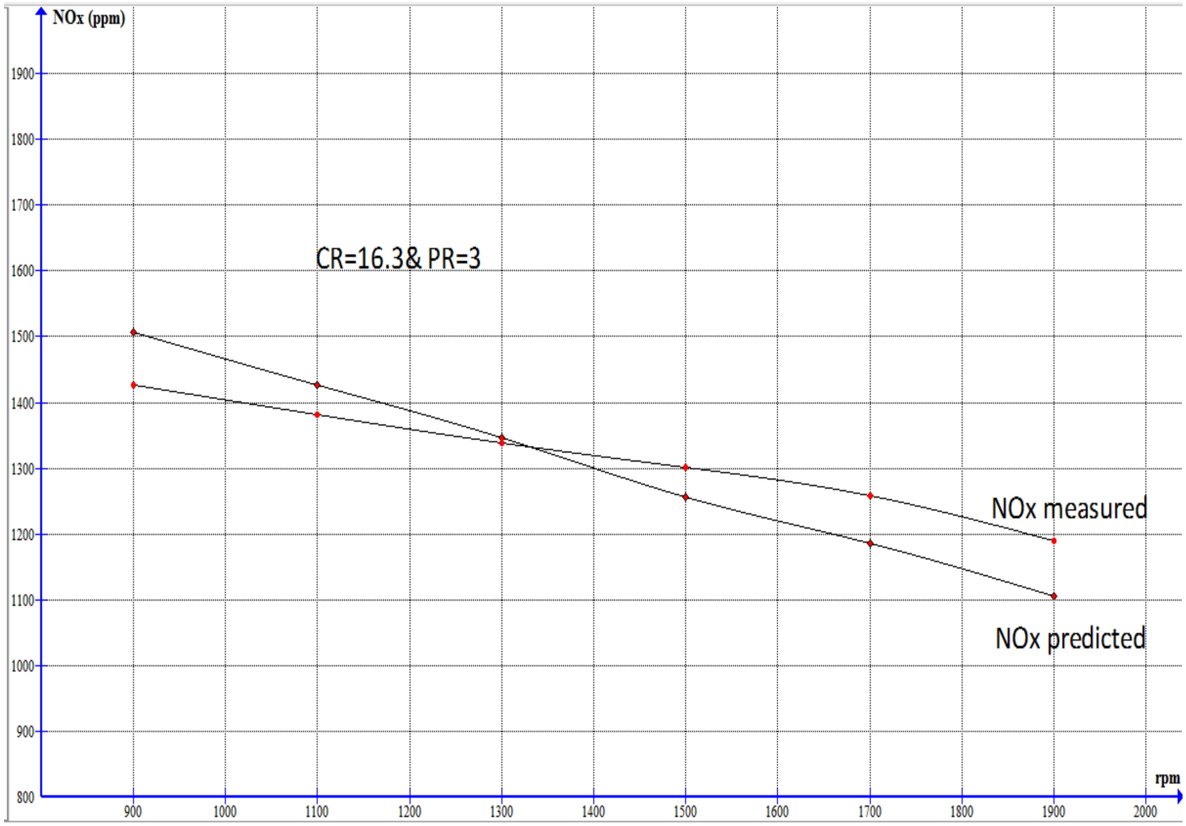


Figure 4-8 Relation between the NOx Predicted and measured when compression ratio is 16.3 and pressure ratio is 3.

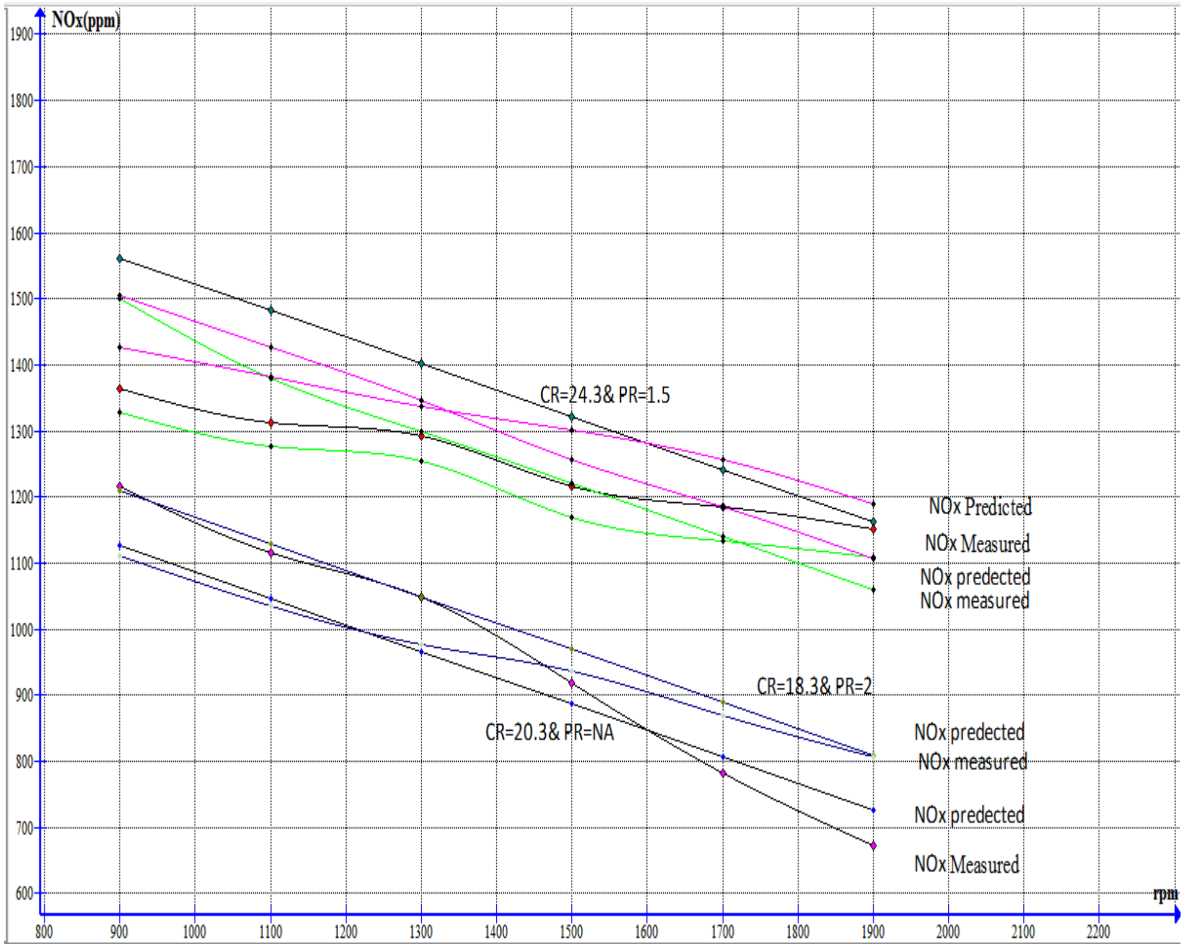


Figure 4-9 Relation between the NOx Predicted and measured

CHAPTER V

Conclusion and Recommendation

CHAPTER V

Conclusion and Recommendation

5-1Conclusion

In this study, the performance of using the specification of diesel engine to predict the NOx emission has been investigated based on a specification of diesel engine running with different values including revulsion per minute, compression ratio and turbo charger

The NOx emission is predicted firstly using the specification of diesel engine by DIESEL-RK programming software and using the prediction equation to predict the NOx emission.

The measured and prediction results of NOx emission are compared and it has been shown that the deviation of the values obtained from the model from the measured values is less than to12% based on the predication.

In this study the prediction of Nox emission from vehicles was investigated numerically, to figure out how change in compression ratio and rpm is useful to reduce NO_X emission and reduce the fuel consumption, the results obtained are summarized as follows:

1- Finally, through this research we find that the change in rpm and compression ratio and turbo charger effect on NOx emission
2- Decrease the NO_X emission and fuel consumption to format depend on high rpm and less CR, hence NO_X emission decreases with increasing rpm and decreases compression ratio.
3- The DIESEL-RK method is most effective and gives good result in a few times and it doesn't cost.
4- We get good result whenever we run alt of test

Recommendation

1. We recommend that this project can applied experimentally and by another program software such as CFD , Mat lab, EGR … etc , and can use for high load vehicles such as trucks …etc
2. We recommend that the researcher to use diesel-Rk soft ware instead of empirical test to invest the time and money and effort
3. 3-Enacting strict laws that prevent NOx emissions
4. Conversion of nitrogen oxides into more moderate compounds and attention to vegetation and renewable energy.
5. 5-The researcher they wont to applying the diesel-Rk software you should to knew they have a good network before to starting so as not waste their time because the program is online calculation.

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