BGS INSTITUTE OF TECHNOLOGY

(Affiliated to Visvesvaraya Technological University, Belgaum)
BG Nagar, Nagamangala Taluk, Mandya-571448

DEPARTMENT OF MECHANICAL ENGINEERING

CERTIFICATE

Certified that the project work entitled **"PERFORMANCE EVALUATION OF DIESEL ENGINE OPERATED WITH DIESEL & DIESEL- ETHYL TERT BUTYL ETHER BLENDS"** carried out by **Mr. Sanjay H G (4BW14ME044), Mr. Ramu C R (4BW15ME037), Mr. Nihal Jain D P (4BW16ME028), Mr. Sumanth M Dev (4BW16ME042)** bonafide students of BGS Institute of Technology, B G Nagar in partial fulfilment for the award of **Bachelor of Engineering** in **Mechanical Engineering** of the, **Visvesvaraya Technological University, Belagavi** during the year **2019-2020**. It is certified that all corrections/suggestion indicated for Internal Assessment have been incorporated in the report deposited in the department library.

The project work has been approved as it satisfies the academic requirements in respect of project work prescribed for the said degree.

Signature of the Guide	Signature of the HOD	Signature of the Principal
Dr. Ranganatha Swamy L	**Dr. S H Manjunath**	**Dr. B K Narendra**

Head of the Department
Department of Mechanical Engineering
BGSIT B G Nagar-571448

External Viva

Name of the examiners — Signature

1. Dr. Ranganatha Swamy. L
2. Dr. Girisha K.B.

VISVESVARAYA TECHNOLOGICAL UNIVERSITY

“Janna Sangama”, Belgaum – 590018

A PROJECT REPORT ON

“PERFORMANCE EVALUATION OF DIESEL ENGINE OPERATED WITH DIESEL & DIESEL- ETHYL TERT BUTYL ETHER BLENDS”

SUBMITTED IN PARTIAL FULFILLMENT FOR THE AWARD OF THE DEGREE

BACHELOR OF ENGINEERING
IN
“MECHANICAL ENGINEERING”

Submitted By

Sanjay H G (4BW14ME044)
Ramu C R (4BW15ME037)
Nihal Jain D P (4BW16ME028)
Sumanth M Dev (4BW16ME042)

Under the guidance of

Dr. RANGANATHA SWAMY L
Associate Professor,

DEPARTMENT OF MECHANICAL ENGINEERING
BGS INSTITUTE OF TECHNOLOGY
BG Nagar, Nagamangala Taluk, Mandya-571448

2019-2020

BGS INSTITUTE OF TECHNOLOGY

(Affiliated to Visvesvaraya Technological University, Belgaum)
BG Nagar, Nagamangala Taluk, Mandya-571448

DEPARTMENT OF MECHANICAL ENGINEERING

CERTIFICATE

Certified that the project work entitled **"PERFORMANCE EVALUATION OF DIESEL ENGINE OPERATED WITH DIESEL & DIESEL- ETHYL TERT BUTYL ETHER BLENDS"** carried out by **Mr. Sanjay H G (4BW14ME044), Mr. Ramu C R (4BW15ME037), Mr. Nihal Jain D P (4BW16ME028), Mr. Sumanth M Dev (4BW16ME042)** bonafide students of BGS Institute of Technology, B G Nagar in partial fulfilment for the award of **Bachelor of Engineering** in **Mechanical Engineering** of the**, Visvesvaraya Technological University, Belagavi** during the year **2019-2020**. It is certified that all corrections/suggestion indicated for Internal Assessment have been incorporated in the report deposited in the department library.

The project work has been approved as it satisfies the academic requirements in respect of project work prescribed for the said degree.

Signature of the Guide	Signature of the HOD	Signature of the Principal
Dr. Ranganatha Swamy L	**Dr. S H Manjunath**	**Dr. B K Narendra**

External Viva

Name of the examiners — Signature

1. ____________________ ____________________
2. ____________________ ____________________

CHAPTER 1

INTRODUCTION

Diesel engine is the most popular prime mover among the internal combustion engines widely used in transportation, farming, power generation and many more industrial applications due to their superior fuel economy, durability and reliability.

In spite of its several advantages, the diesel engine is inherently dirty and is the vital contributor of NOx and particulate matter, both of which cause serious public health problems. Particulate Matter (PM) emissions from diesel combustion contribute to urban and regional hazes. NOx emissions from diesel vehicles play a major role in ground- level ozone formation. Ozone is a lung and respiratory irritant causes a range of health problems related to breathing, including Chest pain, coughing, and shortness of breath. Particulate matter has been linked to premature death, and increased respiratory symptoms and diseases. In addition, NOx, and Particulate matter adversely affect the environment in various ways, including crop damage, acid rain, and visibility impairment.

In view of increased concerns regarding the effects of diesel engine particulate and NOx emissions on human health and the environment, reducing the NOx and Particulate emission from diesel engines is one of the most significant challenges today due to continuing stringent emission requirement. A lot of research work has taken up in this direction to develop techniques to mitigate the tailpipe NOx emission and NOx formation in the cylinder respectively.

1.1 NOx and PM mitigation Techniques

Exhaust Gas Recirculation (EGR) is a NOx emission reduction technique, in which portion of an engine's exhaust gas re- circulates back to the engine inlet manifold, where it dilutes the incoming air, reducing amount of excess oxygen available and lowering the peak combustion temperature. EGR tends to reduce the amount of fuel burned in the power stroke, which leads to increased Particulate Matter (PM) emission and specific fuel consumption.

Injection of Hydrogen Peroxide (H_2O_2) in to the combustion chamber of diesel engine is a well-known emission reduction technique, where H_2O_2 forms OH radicals at higher temperature, which accelerates the oxidation of diesel soot and thus reduce the diesel soot. No major contribution from this method to reduce NOx emission.

In-cylinder water injection in to combustion chamber of a diesel engine is one well approved method of reducing NOx and smoke emission, where water/fuel emulsion or water alone is injected into the intake manifold. Significant reduction in NOx could be achieved in this technique and no considerable reduction in smoke could be observed; In addition, water does not contribute appreciably to the energy release.

From the review of the above techniques, notable interest is focused on the use of oxygenated fuels either as, neat fuel or as an additive to reduce emissions from diesel engine with no loss of efficiency during combustion.

1.2 Oxygenated fuels

Oxygenated fuels are the attractive class of synthetic fuels in which Oxygen atoms are chemically bound within the fuel structure. This Oxygen bond in the oxygenated fuel is energetic and provides a chemical energy that result in no loss of efficiency during combustion.

The oxygenates commonly used are either alcohols or ethers.

1.2.1 Alcohols

- Methanol (MeOH)
- Ethanol (EtOH)
- Isopropyl alcohol (IPA)
- N-butanol (BuOH)
- Gasoline grade t-butanol (GTBA)

1.2.2 Ethers

- Methyl tetra-butyl ether (MTBE)
- Tertiary amyl methyl ether (TAME)
- Tertiary hexyl methyl ether (THEME)
- Ethyl tertiary butyl ether (ETBE)
- Tertiary amyl ethyl ether (TAEE)
- Di-isopropyl ether (DIPE)
- Di-n-butyl ether (DBE)

1.3 Statement of the problem

The diesel engine is inherently dirty and is the most significant contributor of NOx and particulate matter, both of which contribute to serious public health problems. Particulate

Matter (PM) emissions from diesel combustion contribute to urban and regional hazes. NOx emissions from diesel vehicles play a major role in ground- level ozone formation. In this connection, significant interest is focused on the use of oxygenated fuels either as, neat fuel or as an additive to reduce emissions from diesel engine.

The present work is to evaluate the performance of a diesel engine operated with diesel and diesel-Ethyl tert-butyl ether (ETBE) blends.

1.4 Objectives

In the present research work, it is proposed to carry out the experimentation on a computerized test rig with pure diesel and diesel-ETBE blends to evaluate the performance and emission characteristics. It is also intended to perform the experimentation by varying the operating parameter like load. The results are analyzed to establish the diesel/oxygenated fuel ratio, that would impart the reduced emissions preserving high efficiency.

1.5 Scope of the study

- To check feasibility of different diesel-ETBE blends.
- The scope extends towards developing suitable operating parameters to tune an existing CI engine to operate on oxygenated fuel.
- The scope of study also includes analysis of engine performance and exhaust emissions with different diesel-ETBE ratios.

1.6 Justification of the project

This project is justified in the present context of increased concerns regarding the effects of diesel engine particulate and NOx emissions on human health and the environment, reducing the NOx and Particulate emission from diesel engines is one of the most significant challenges today due to continuing stringent emission requirement.

1.7 Limitations of the study

- A relative performance study between different oxygenated agent fuels is not taken up.
- Performance study conducted does not include ETBE more than 20%.

1.8 Organization of dissertation

Chapter 1 deals with general introduction, statement of the problem, scope and limitations of the study.

Chapter 2 consists of review of literature made on oxygenated fuels.

Chapter 3 includes experimental setup along with its specifications. Precautions and procedures to be followed while conducting experimentation have been discussed.

Chapter 4 presents the results and discussion.

Chapter 5 offers significant conclusions along with future work to be done.

Textbooks and published papers referred have been given in Reference.

CHAPTER 2

LITERATURE REVIEW

The survey examined the following technical literature available on the topic of using oxygenated fuels as transportation fuel.

Noboru Miyamoto et al. [1] investigated the combustion and emissions of diesel with four kinds of oxygenates viz. Diethylene glycol dimethyl ether, Ethylene glycol mono-n-butyl ether, 2-ethylhexyl acetate and Di-n- butyl ether as main fuel on single cylinder, four stroke cycle, DI diesel engine. The results showed that significant improvements in smoke, particulate matter, NO_X, HC, engine noise and thermal efficiency were simultaneously obtained with the oxygenates.

Manuel A. Gonzalez D et al. [2] objective of their study was to select most promising oxygenate compounds as blending components in diesel fuel for an advanced engine testing for reducing particulate emissions in the exhaust. The results have shown that PM emission reductions were proportional to the oxygen content of the fuel. Both Tripropylene Glycol Mono-Methyl Ether and Di Butyl Maleate oxygenated test fuels contained 7% wt. oxygen and their total PM emissions were similar.

David L. Hilden et al. [3] evaluated a reference and five blends containing oxygenates under steady-state conditions using a prototype 3-cylinder four-valve common–rail DI diesel engine. The experimental results have shown that oxygenated fuels reduced PM and NO_X under some operating conditions, but produced little effect on either HC or CO emissions. Aliphatic oxygenates at 6 wt. percent oxygen in the reference fuel reduced PM emissions by 15-27 %.

Mitsuo Tamanouchi et al. [4] conducted a study of the effects of engine technology and fuel properties on diesel exhaust gas emissions. The effect of fuel properties on exhaust gas emissions was examined using four D.I Diesel engines equipped with an oxidation catalyst, high-pressure injection, turbocharger and natural aspiration fuel charging. In addition, oxidation catalysts were installed on the two turbocharged and natural aspirated engines to examine their effects on reducing exhaust emissions. It was found that the installation of oxidation catalyst clearly had an effect on reducing the level of hydrocarbons carbon monoxide (CO) and particulate matter (PM). The high-pressure injection engine was found to have a low level of PM and not be affected by the type of fuel. It was clearly shown that engine technology has a greater effect on reducing exhaust emissions than fuel properties.

James P Wallace et al. [5] the objective of this study was to select the most promising oxygenate compounds as blending components in diesel fuel for advanced engine testing. A fuel matrix was designed to consider the effect of molecular structure and boiling point on the ability of oxygenates to reduce engine out exhaust emissions from a modern diesel engine. Nine test fuels including low sulfur (1ppm), low aromatic hydrocracker base fuel and 8 oxygenated fuels were formulated to contain 7% weight of oxygen. A Daimler Chrysler OM 611CICI engine for light duty vehicles was controlled with a SWRI Rapid prototyping Electronic Control System. The base fuel was evaluated in four speed load Modes oxygenated blends only in one mode.

M. Alam et al. [6] conducted an experiment with a direct injection diesel engine operate with neat dimethyl ether (DME) to investigate the performance of the catalyst. The experimental results have shown that total hydrocarbon emission was much less than the conventional diesel engine.

K.A. Subramanian et al. [7] carried out experimental investigations to assess the effect of using diethyl ether to improve performance and emissions of a DI diesel engine running on water- diesel emulsion. It was found that use of neat water diesel emulsion significantly lower NO_X and smoke levels as compared to neat diesel operation. It also increases the brake thermal efficiency at high outputs. However, there is a rise in HC, CO emissions and ignition delay. Use of 10% diethyl ether along with water diesel emulsion can significantly help in lowering HC and CO levels without adverse effects on NO_X and smoke, particularly at high outputs. However, the HC and CO levels are still higher than diesel operation.

From the review of literatures, significant interest is focused on the use of oxygenated fuels either as, neat fuel or as an additive to reduce emissions from diesel engine with no loss of efficiency during combustion.

CHAPTER 3

METHODOLOGY AND EXPERIMENTAL SET UP

The aim of the experiment is to "Evaluate the performance of a diesel engine operated with diesel and an oxygenated fuel Ethyl Tert-Butyl Ether (ETBE)- Diesel blends.". Experiment is carried out at constant rated speed, comparing the performance of C.I engine by varying injection pressure on diesel and oxygenated fuel [Diesel-Ethyl Tert-Butyl Ether (ETBE)]. The ETBE of 50, 100, 150 and 200 ml is added to diesel and tested at three particular injection pressures separately. The samples are prepared by using the 1000 ml measuring jar and a graduated test tube.

3.1 Preparation of blend

- Diesel, ETBE, 1000 ml measuring jar and a 10 ml graduated test tube are the components required for making blend.
- The measuring jar and graduated test tube thoroughly washed and cleaned dry.
- Diesel was taken in the measuring jar and poured into container. Now 50, 100, 150 and 200 ml of ETBE was added to it.
- Now the mixture in the container is thoroughly mixed for about 10- 15 minutes for proper blending.
- The ETBE-diesel blends thus obtained is checked for stability.

3.2 Experimental setup

Schematic diagram of the engine test rig is shown in Fig. 3.1. The engine test was conducted on four-stroke single cylinder direct injection water cooled compression ignition engine connected to eddy current dynamometer loading. The specification of the engine is given in table 6.1. The engine was always operated at a rated speed of 1500 rev/min. The engine was having a conventional fuel injection system. The injection nozzle had five holes of 0.2 mm diameter with a spray angle of 120º. A piezoelectric pressure transducer was mounted with cylinder head surface to measure the cylinder pressure. It is also provided with temperature sensors for the measurement of jacket water, calorimeter water, and calorimeter exhaust gas inlet and outlet temperatures. An encoder is fixed for crank angle record. The signals from these sensors are interfaced with a computer to an engine indicator to display P-ϴ, P-V and fuel injection pressure versus crank angle plots. The provision is also made for the measurement of volumetric fuel flow. The built-in program in the system calculates brake power, thermal efficiency and brake specific fuel consumption. The software package is fully configurable and averaged P-ϴ diagram, P-V plot and liquid fuel injection pressure diagram can be obtained for various operating conditions.

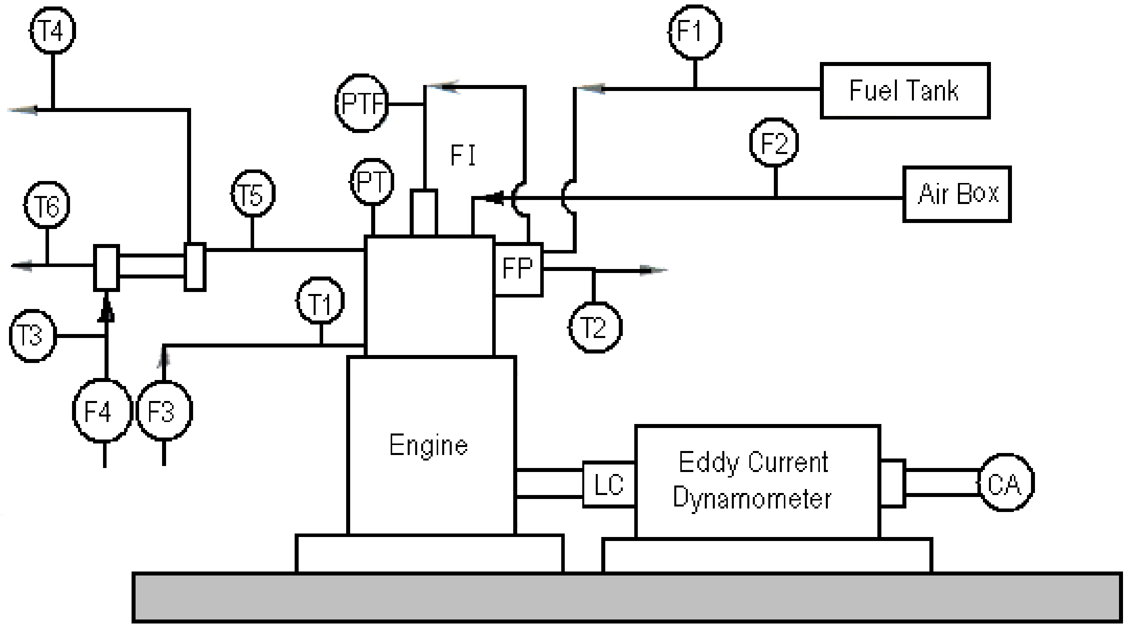

Fig. 3.1 Schematic Diagram of the Experimental Set-up

PT - Combustion Chamber Pressure Sensor

PTF - Fuel Injection Pressure Sensor

FI - Fuel Injector

FP - Fuel Pump

T1- Jacket Water Inlet Temperature

T2- Jacket Water Outlet Temperature

T3 - Calorimeter Water Outlet Temperature

T4 - Calorimeter Water Outlet Temperature

T5 - Exhaust Gas Temperature before Calorimeter

T6 - Exhaust Gas Temperature after Calorimeter

F1 - Liquid fuel flow rate

F2- Air Flow Rate

F3 -Jacket water flow

F4 -Calorimeter Water flow rate

LC -Load Cell

CA- Crank angle Encoder

EGC- Exhaust Gas Calorimeter

Fig. 3.2.1 Diesel Engine View

Fig. 3.2.2 View of Eddy Current Dynamometer

Fig. 3.2.3 PC Based Diesel Engine View

Fig. 3.2.4 View of Data retrieving

Table 3.1 Engine Specifications

Sl. No	Engine Parameters	Specification
01	Machine supplier	INLAB Equipments. Bangalore.
02	Engine Type	TV1(Kirloskar, Four Stroke)
03	Number of cylinders	Single Cylinder
04	Number of strokes	Four-Stroke
05	Rated power	5.2KW (7 HP) @1500RPM
06	Bore	87.5mm
07	Stroke	110mm
08	Cubic Capacity	661cc
09	Compression ratio	17.5:1
10	Rated Speed	1500 RPM
11	Dynamometer	Eddy Current dynamometer, make SAJ
12	Type of cooling	Water cooling
13	Fuel injection Pressure	175bar
14	Fuel	Diesel
15	Load Measurement	Strain gauge load cell
16	Speed Measurement	Rotary encoder
17	Temperature Indicator	Digital, PT-100 type temperature sensor
18	Cylinder Pressure Measurement	Piezo-Sensor, range 2000 Psi, make PCB USA
19	Fuel Injection Pressure Measurement	Piezo Sensor, range 5000 Psi, make PCB USA

20	Water flow Measurement	Rota meter

3.3 Measurement system

The test bed is fully instrumented to measure the various parameters such as flow measurement, load measurement, pressure measurement, etc. during the experiments on the engine.

3.3.1 Flow measurement

Air flow measurement is done by the flow sensors, a conventional U- tube manometer as well as air intake differential pressure transducers unit present in the control panel. There are two parallel air suction arrangements, one for U- tube manometer having arranged of 100-0- 100 mm and another for pressure differential unit, which senses the difference in pressure between suction and atmospheric pressure. This difference in pressure will be sent to transducer which will give the DC volt analog signal as output which in turn will be converted into digital signal by analog to digital converter and fed to the engine software.

For liquid fuel flow rate measurement, the fuel tank in the control panel is connected to the burette for manual measurement and to a fuel flow differential pressure unit for measurement through computer.

Cooling water flow to the engine and calorimeter is measured by means of a calibrated Rota meter with stainless steel float.

3.3.2 Load measurement

The eddy current dynamometer is provided to test the engine at different loading conditions. A strain gauge type load cell mounted beneath the dynamometer measures the load. The signals from the load cell are interfaced with analog to digital converter to give Torque in N-m. The dynamometer is loaded by the loading unit situated in the control panel.

3.3.3 Pressure measurement

A water-cooled piezoelectric transducer mounted on the cylinder head surface measures the cylinder dynamic pressure and a piezoelectric transducer mounted on the fuel line near the injector measures the fuel injection pressure.

3.3.4 Engine speed measurement

Engine speed is sensed and is indicated by an inductive pickup sensor in conjunction with a digital RPM indicator, which is a part of the eddy current dynamometer control unit. The dynamometer shaft rotating close to inductive pickup rotary encoder sends voltage pulses whose frequency is converted to RPM and displayed by digital indicator in the control panel, which is calibrated to indicate the speed directly in number of revolutions per minute.

3.3.5 Temperature measurement

Chromium-aluminum thermocouples connected to digital panel meter are positioned at different locations to measure the following temperatures.

- Jacket water inlet temperatures (T1)
- Jacket water outlet temperatures (T2)
- Calorimeter inlet water temperature (T3)
- Calorimeter inlet water temperature (T4)
- Exhaust gas temperature before calorimeter (T5)
- Exhaust gas temperature after calorimeter (T6)

All the sensors which sense the temperature of respective locations are connected to the control panel, which gives the digital reading of the respective temperatures.

3.4 Emission testing

INDUS model PEA205 is a 5-gas analyzer meant for monitoring CO, CO_2, HC, O_2 and NO in automotive exhaust. It meets OIML Class-I specifications. CO, CO_2 and HC (Hydrocarbon residue) are measured by NDIR technology and O_2 and NO by electrochemical sensors. It is also supplied as a 4-gas analyzer which can be upgraded easily to 5-gas version by the addition of a NO sensor. It has many control features to prevent faulty measurements. A built-in dot matrix printer is provided to print out a hard copy of the results. It conforms to CMVR 115/116 and is certified by ARAI, Pune.

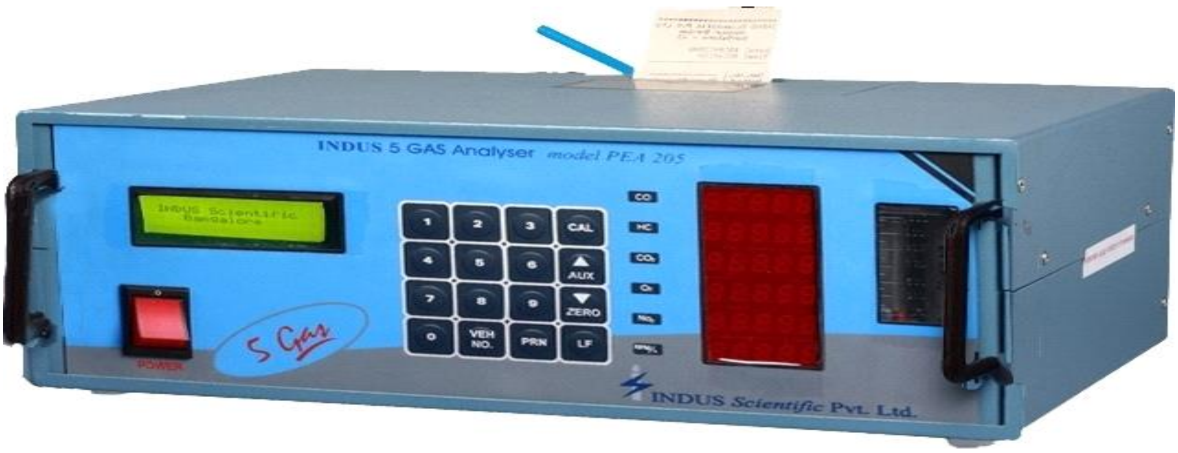

Fig. 3.3 Gas Analyzer

- Features selection of fuel type.
- Automatic fresh air intake during Auto Zero.
- Line leak check facility.
- Lambda for Petrol and CNG Engines.

- CO Correction.

3.4.1 Emission measurement

- ❖ Automotive exhaust monitor (Indus smoke meter model OMS103)
  - o Range- 0 to 100% opacity in HSU; 0 to ∞ in k (1/m)
  - o Resolution-0.1% in HSU, 0.01 (1/m) in k
- ❖ Automotive exhaust monitor Indus five gas Analyzer model PEA-205

  Range- CO: 0 to 15%,

  HC: 0 to 30000 PPM as hexane,

  O_2: 0 to 25%,

  CO_2: 0 to 20% &

  NO_x: 0 to 5000 PPM

  Data resolution- CO: 0.001%,

  O_2 & CO_2: 0.01%,

  HC & NO_x: 1 PPM

3.5 Experimental procedure

- ❖ Switch on the mains of the control panel and set the supply voltage from servo stabilizer to 220 volts.
- ❖ The main gate valve is opened, the pump is switched ON and the water flow to the engine cylinder jacket (300 liters/hour), calorimeter (50 liters/hour), dynamometer and sensors are set.
- ❖ Engine is started by hand cranking and allowed to run for 20 minutes to reach steady state condition.
- ❖ The engine software is used for taking readings.

The engine has a compression ratio of 17.5 and a normal speed of 1500 rpm controlled by the governor. An injection pressure of 175 bar is used for the best performance as specified by the manufacturer. The engine is first run with neat diesel at torque conditions such as 6.5, 13, 19.5 and 26 N-m. Between two toque trials, the engine is allowed to become stable by running it for 3 minutes before taking the readings. At each loading condition performance parameters namely speed, exhaust gas temperature, brake power, peak pressure is measured under steady state conditions. The experiments are repeated for various combinations of diesel oxygenated fuel and biodiesel blends. With the above experimental results, the parameters such as total fuel consumption, brake specific fuel consumption, brake specific energy consumption, brake thermal efficiency are calculated. Finally, graphs are plotted for brake specific fuel consumption, brake thermal efficiency with respect to torque conditions for diesel and oxygenated fuel. From these plots, performance characteristics of the engine are determined.

3.6 Experimentation

The experiments were conducted on a direct injection compression ignition engine for various torque and Ethyl tertiary butyl ether (ETBE) of 50, 100, 150 and 200 ml blend with pure diesel for base piston. Performance parameters like Specific Fuel Consumption (SFC) and Brake Thermal Efficiency (BTE) are analyzed and emission characteristics like CO, CO_2, HC, and NOx are evaluated.

CHAPTER 4

RESULTS AND DISCUSSION

This chapter visualize the impact of blending an oxygenated agent with diesel in varied proportions on diesel engine performance. The experimental investigations were performed with four different blends ET5 (5% oxygenate and 95% diesel by volume), ET10 (10% oxygenate and 90% diesel by volume), ET15 (15% oxygenate and 85% diesel by volume) and ET 20 (20% oxygenate and 80% diesel by volume). The engine was operated on ETBE blends with diesel under different loads and its performance was correlated with neat diesel operation. Diesel- ETBE blend supplemented with 2% Ethyl acetate to retain homogeneity and prevent the interfacial tension between two liquids. During these tests, injection timing of 23˚ BTDC, injection pressure of 205 bar, compression ratio of 17.5, injector of 5 holes of 0.2 mm with toroidal combustion chamber have been set for engine as these being optimized engine conditions for all injected fuel blend operation.

4.1 Performance parameter

This section provides the performance of engine in terms of BTE when it is fuelled with blends of ETBE with diesel.

4.1.1 Brake thermal efficiency

Figure 4.1 shows the variation of BTE with different engine loads for different blends of ETBE with diesel. BTE increases with an increase in load for all blends of the oxygenates. It is observed from the figures that as the proportion of oxygenate in the mixture is increased, enhancement in brake thermal efficiency can be noticed comparatively to that of neat diesel fuel operation. This is due to improved combustion indicated by increased brake thermal efficiency and availability of ample oxygen, which ensures higher combustion efficiency. With ETBE-diesel fuel blends operation, the higher latent heat of vaporization observed with ETBE produce more cooling effect that results in lower exhaust gas temperature which tends to lower the heat loss through exhaust and hence higher brake thermal efficiency is obtained. In addition, the longer ignition delay due to lower cetane number of ETBE involves a rapid rate of released energy which further reduces the heat loss from the engine because there is not enough time for this heat to leave the cylinder through heat transfer to the coolant.

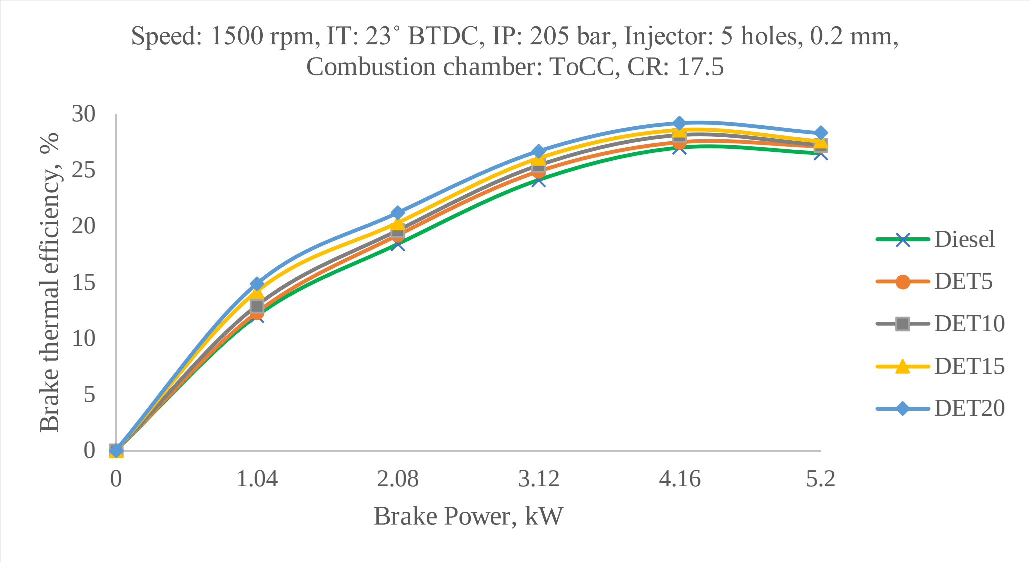

Figure 4.1 Variation of BTE with load for different ETBE blends percentage

4.2 Emission parameters

In this section, variation of emission parameters is presented for the engine fuelled with oxygenates-diesel blends in different proportions.

4.2.1 Smoke emissions

Figure 4.2 illustrates smoke emission variations with engine loads for different oxygenate blend percentage. Smoke is direct indication of incomplete combustion occurring in the engine. Smoke emission is higher at low loads, which may be due to short combustion cycle, long delay period and shortage of oxygen which may be due to improper mixing or usage of rich fuel. At high loads, the flame temperature is high, which results in low smoke emission with ETBE blends than the base fuel.

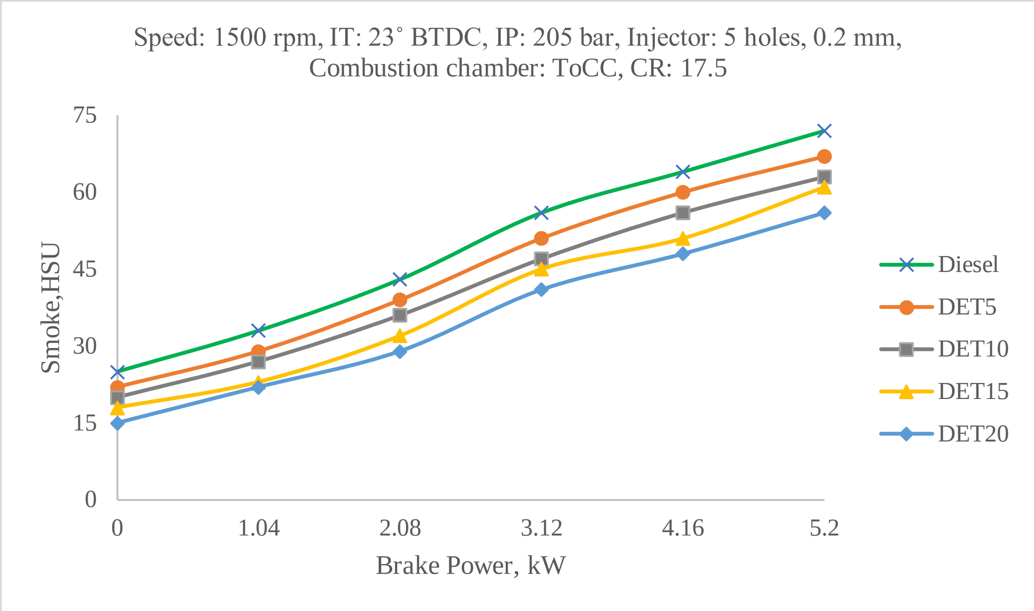

Figure 4.2 Variation of smoke emission with load for different ETBE blend percentage

4.2.2 HC and CO emissions

Figure 4.3 illustrates the variation of HC with load for blends with varied oxygenate percentage. At lower loads, HC emissions for all different blends of ETBE are comparable with diesel fuel due to low cetane number of blends that promotes quenching effect and could be the main cause for the increase in THC emissions. At higher load, HC emissions with all blends were significantly reduced compared to diesel.

Figure 4.4 shows the variation of CO with load for blended fuel combinations. Inadequate combustion is the main cause for CO formation. ETBE has lower cetane number and higher latent heat of vaporization than the diesel which results in not enough vaporization and hence very less time is available to burn fuel completely that results in considerable increase in CO emissions at lower load. At higher loads, enough time is available for combustion to occur, and better mixing and inbuilt fuel oxygen together results in complete combustion and hence insignificantly declined CO emissions were observed for all blends of oxygenates at high load.

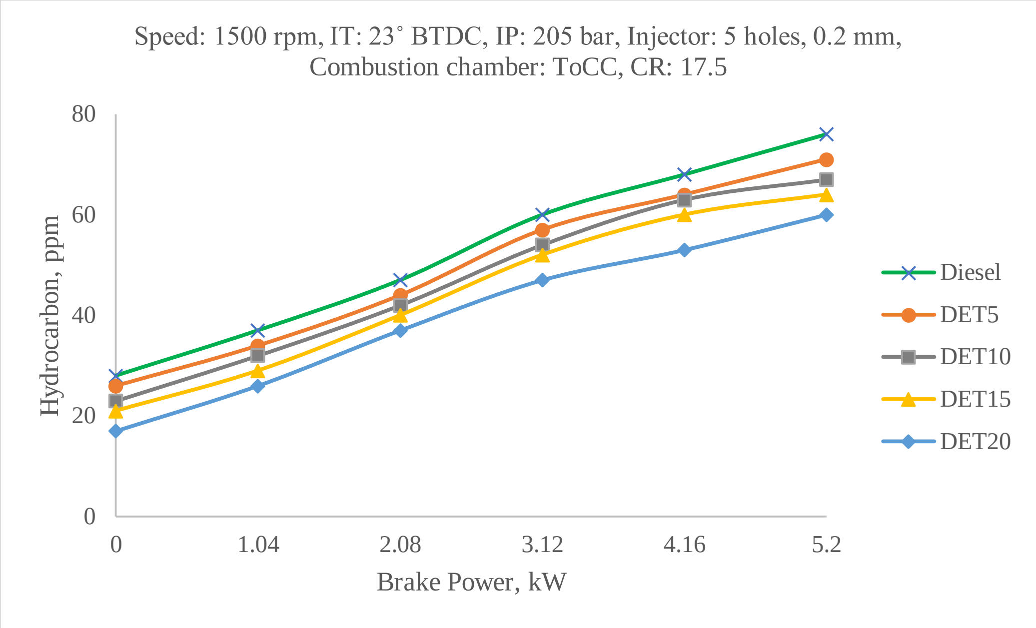

Figure 4.3 Variation of HC emission with load for different ETBE blend percentage

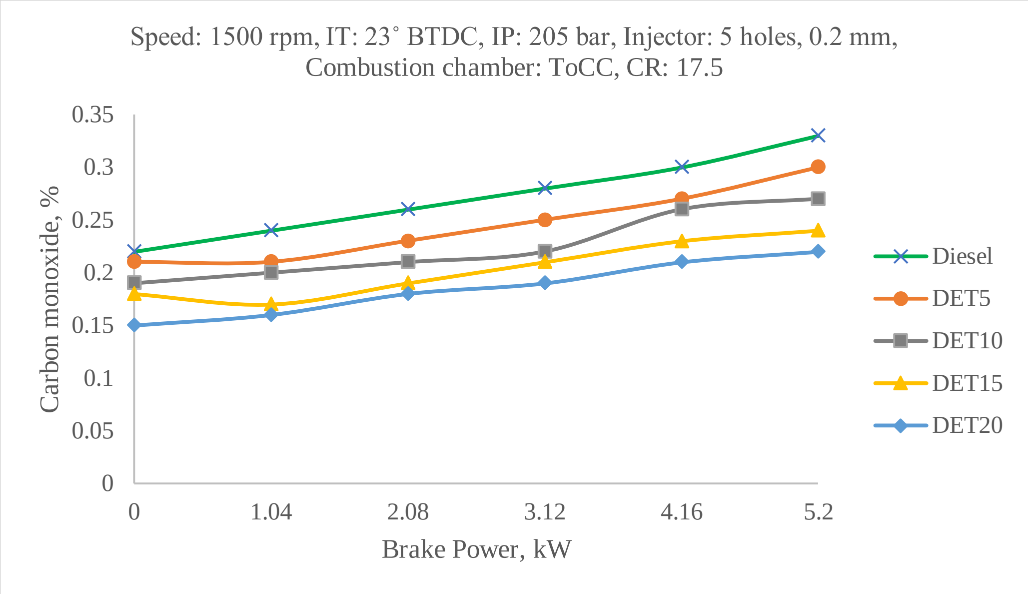

Figure 4.4 Variation of CO emission with load for different ETBE blend percentage

4.2.3 NO_X emissions

Figure 4.5 presents uncertainties of NOx emissions with engine loads for different oxygenate blended fuel combinations used. The formation of NOx is primarily a function of flame temperature, the residence time at that temperature, and the availability of oxygen in combustion chamber. NOx emission intensified with the engine load. The possible reason for this could be the higher gas temperature prevailed in the cylinder as a result of bulk of fuel injected and combusted in the cylinder with increased load. It also can be seen that NOx emission is insignificantly raised with all oxygenate blended fuels comparatively to that of diesel at all loads.

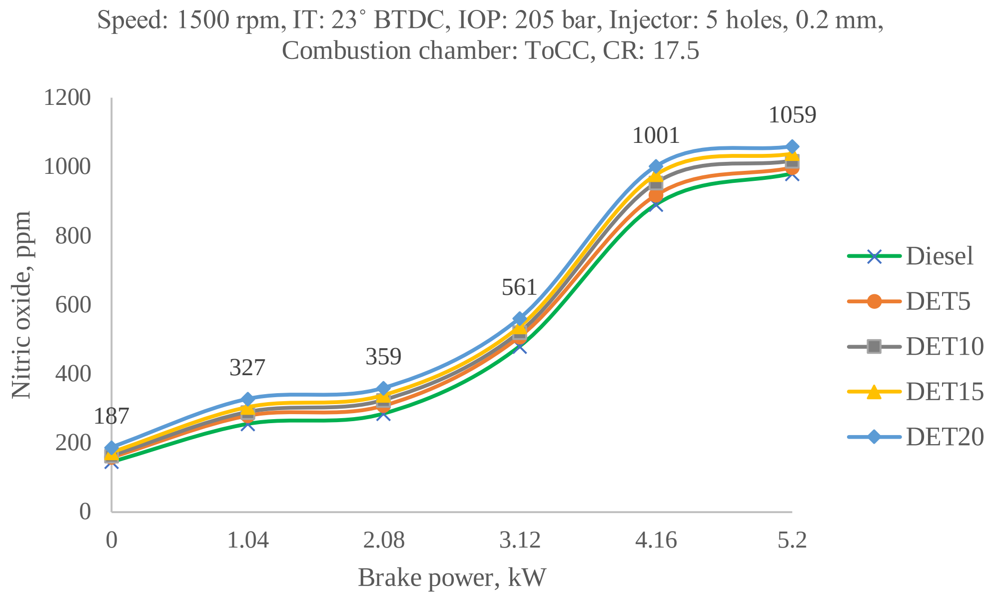

Figure 4.5 Variation of NOx emission with load for different ETBE blend percentage

4.3 Combustion parameters

In this section, different combustion parameters at higher load conditions are presented in the form of graphs. The results are analyzed, discussed and compared with diesel fuel operation.

4.3.1 Peak pressure

Figure 4.6 shows the variation of peak pressure with brake power for different oxygenates-diesel blends and was found to be higher than the neat diesel operation. Auto ignition temperature of the fuel is a predominant element which causes variations in the shape of the curve in the pressure angle diagram of engine. Due to combustion of diesel with lower self -ignition temperature, peak pressure is obtained initially, and then a depression is formed due to continuous heat absorption by ETBE in their blends due to their higher latent heat for vaporization. When auto ignition condition of ETBE is reached in the cylinder, combustion occurs and hence sudden rise of temperature and pressure is observed.

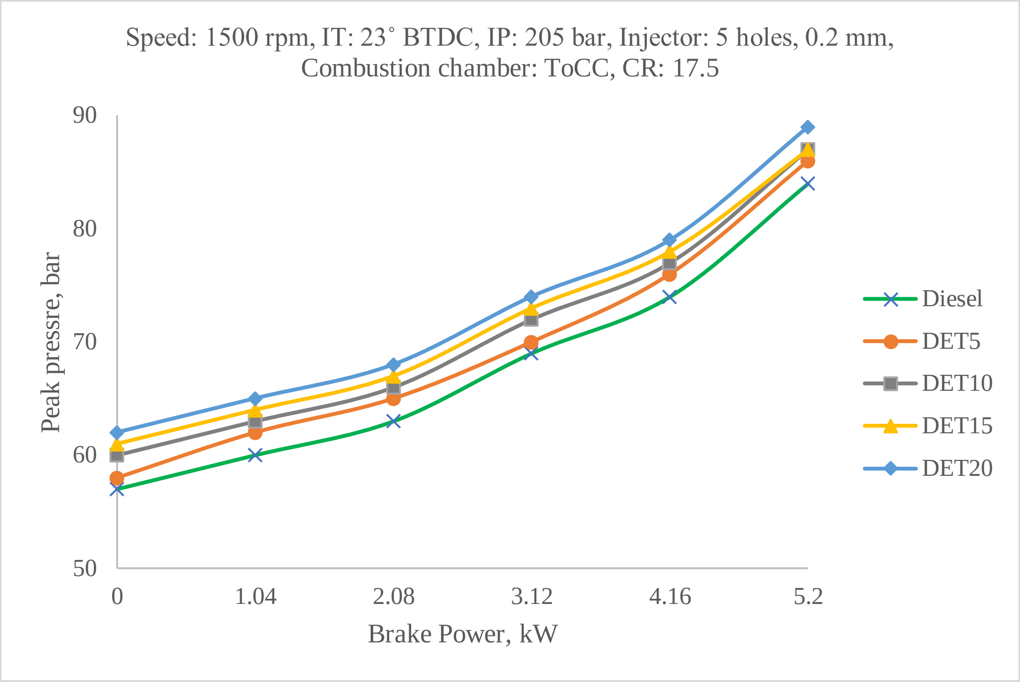

Figure 4.6 Variation of peak pressure with load for different ETBE blend percentage

4.3.2 Combustion duration

Figure 4.7 depicts the effect of different oxygenate blends in varied percentages with diesel on combustion duration. Combustion duration increased with load and ETBE blend percentage. The trend could be due to the higher auto ignition temperature, higher latent heat of evaporation and lesser cetane number of ETBE compared to diesel.

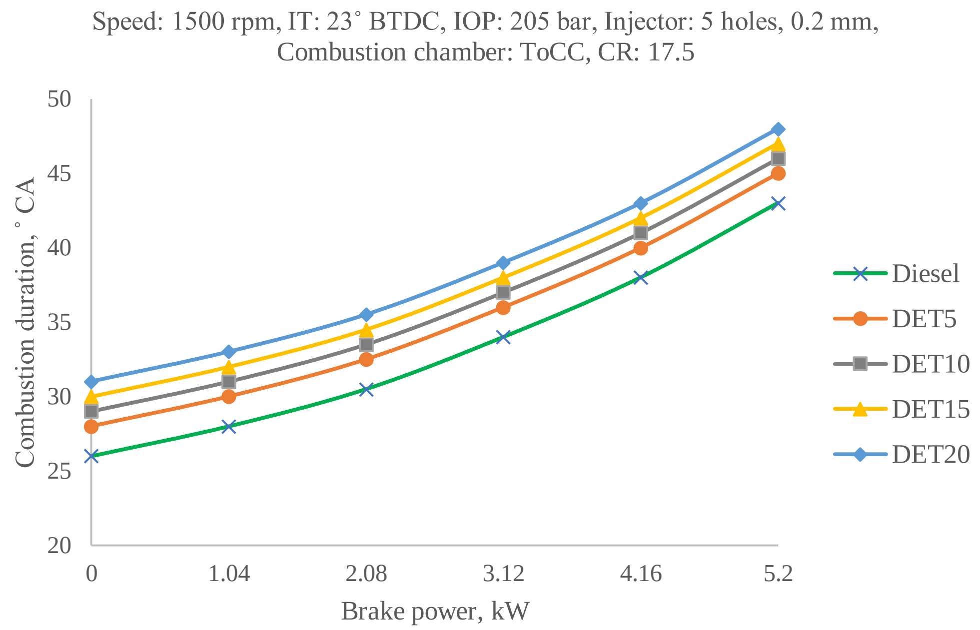

Figure 4.7 Variation of combustion duration with load for different ETBE blend percentage

4.3.3 Ignition delay

Figures 6.22 to 6.24 shows the variation of ignition delay with brake power for different oxygenate blend percentage with diesel. Ignition delay decreased with load and increased with ETBE blends percentage. The trend could be due to the higher auto ignition temperature, higher latent heat of evaporation as well as lower cetane number of ETBE comparatively to that of diesel.

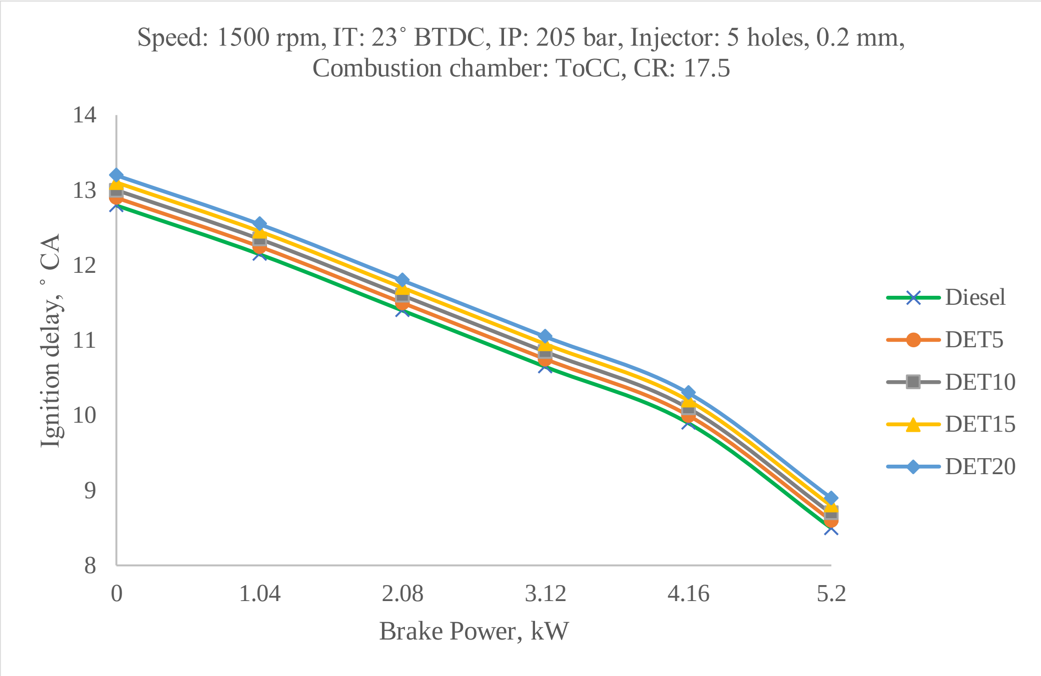

Figure 4.7 Variation of ignition delay with load for different ETBE blend percentage

4.4 Suggestion for future work

- The research work can be extended to assess effect of high injection pressures of 1500 bar with Common Rail Direct Injection (CRDI) facility on engine performance using different oxygenates additives in diesel.

REFERENCES

1) Noboru Miyamoto, Hideyuki Ogawa, Nabi Md.Nurun, Kouichi Obata and Teruyoshi Arima, "*Smokeless, Low NOX, High Thermal Efficiency and Low Noise Diesel Combustion with Oxygenated Agents as Main Fuel*," SAE Paper No.1998-980506.
2) Manuel A.Gonzalez D, William Piel, Tom Asmus, Wendy Clark, John Garbak, Eleanor Liney, Mani Natarajan and James P. Wallace III, "*Oxygenates screening for advanced Petroleum- based Diesel Fuels: Part 2. The Effect of Oxygenate Blending Compounds on Exhaust Emissions*", SAE Paper No.2001-01-3632.
3) David L. Hilden, John C. Eckstrom and Leslie R. Wolf, "*The Emissions Performance of Oxygenated Diesel Fuels in a Prototype DI Diesel Engine*", SAE Paper No. 2001-01-0650.

4) Mitsuo Tamanouchi, Hiroki Morihisa, Jihei Lida, and Takanobu "*Effect of properties on exhaust emission for Diesel with and without oxidation catalyst and high-pressure injection*" SAE paper 970758
5) James P. Wallace, Mani Natarajan, John Garbak, Wendy Clark, and Tom Asmus "*Oxygenates screening for advanced petroleum- Based fuels: Part 2. The effect of oxygenate blending compounds on exhaust emissions*" SAE paper 2001-01-3632
6) K.A. Subramanian and A. Ramesh, "*Use of Diethyl Ether Along with Water-Diesel Emulsion in a Di Diesel Engine*," SAE Paper No.2002-01-2720.