UNIVERSITY OF TURKISH AERNAUTICAL ASSOCIATION

INSTITUTE OF SCIENCE AND TECHNOLOGY

EXPERIMENTAL INVESTIGATION OF THE EFFECTS OF USING ETHANOL-GASOLINE 750 ADN 450 ON THE PERFORMANCE AND EXHAUST EMISSION OF SPARK IGNITION ENGINE IN IRAQ

MASTER THESIS

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Institute of Science and Technology

Mechanical and Aeronautical Engineering Department

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HUSSEIN Al-GBURI

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IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE

DEGREE OF MASTER OF SCIENCE IN MECHANICAL AND AERONAUTICAL ENGINEERING

Supervisor: Assist. Prof. Dr. Munir ElFarra

CO. Supervisor: Dr. Kadhim Fadhil Nasir

بسم الله الرحمن الرحيم

الله لا اله الا هو الحي القيوم لاتأخذه سنه ولانوم له مافي السموات وما في الأرض من ذا الذي يشفع عنده الا بأذنه يعلم مابين ايديهم وما خلفهم ولايحيطون بشيء من علمه الا بما شاء الله وسع كرسيه السموات والارض ولايؤده حفظهما وهو العلي العظيم.

(صدق الله العظيم)

Türk Hava Kurumu Üniversitesi Fen Bilimleri Enstitüsü'nün 1403730036 numaralı Yüksek Lisans öğrencisi "Hussein AL-Gburi" ilgili yönetmeliklerin belirlediği gerekli tüm şartları yerine getirdikten sonra hazırladığı "EXPERIMENTAL INVESTIGATION OF THE EFFECTS OF USING ETHANOL-GASOLINE750ADN450 ON THE PERFORMANCE AND EXHAUST EMISSION OF SPARK IGNITION ENGINE IN IRAQ" başlıklı tezini, aşağıda imzaları bulunan jüri önünde başarı ile sunmuştur.

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Hussein AL- Gburi
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March 2017 Hussein Al-Gburi

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Abstract

Experimental investigation the effects of using ethanol-gasoline 750 and 450 on the performance and exhaust emission of spark ignition engine in Iraq

Hussein Al- Gduri

Master. Department of Aeronautics and Mechanical Engineering

Supervisor: Assist. Prof. Dr. Munir Elfarra

March 2017, 75 Pages

Abstract:

In this study, the effects of adding pure ethanol 99.9% (0%E, 10%E, 20%E, 30%E, 40%E, 50%E) to gasoline 750, 450 blends on the performance of engine and characteristic emission of SI engine are analyzed. In the experiment, the ICE includes single cylinder and four stroke spark ignitions. Performance tests were performed for brake power (Bp), brake specific fuel consumption (Bsfc), brake thermal efficiency (η_{bth}), volumetric thermal efficiency (η_V) and for carbon dioxide (Co2), carbon-monoxide (CO) and hydrocarbon born (HC) emissions. The measurements were achieved under various engine speeds (1500- 2500 rpm) for two cases, the first one with load and the second case without load. Ethanol- gasoline750 and 450 blends fuel increase the brake power, brake thermal efficiency and volumetric efficiency. Also, the (Bsfc) slightly decreases by using the mentioned blends. Increasing the ethanol-gasoline750 and 450 blends fuel decrease the CO and HC emissions. It was detected that the exhaust gas temperature increases as engine speed increases for all fuel types.

Keywords: Ethanol, Gasoline 750 and 450, engine performance, emission characteristics

ÖZET

750 ve 450 etanol benzin kullanımının Irak'ta kıvılcım ateşlemeli motorun performansı ve egzoz emisyonu üzerindeki etkilerinin deneysel incelemesi

Al- Gduri Hussein. E
Yüksek Lisans Tezi, Makine Mühendisliği Anabilim Dalı
Tez Danışmanı: Yrd. Doç. Dr. Monier El-Farra
2017, 75 sayfa

ÖZET:

Bu çalışmada, 750 ve 450 benzin karışımlarına 99.9 % saf etanol eklemenin (0%E, 10%E, 20%E, 30%E, 40%E, 50%E,) motor performansı ve kıvılcım ateşlemeli (SI) motorun karakteristik emisyonu üzerine etkileri araştırılmaktadır. Deneyde kullanılan içten yanmalı motor (ICE) tek silindir ve dört fazlı kıvılcım ateşlemesi ihtiva etmektedir. Performans testleri fren gücü (BP), fren özgül yakıt sarfiyatı (Bsfc), fren ısıl verimi, hacimsel ısıl verim (η_{bth}), volumetrik verim (η_V) ile karbondioksit (CO2), karbonmonoksit (CO) ve hidrokarbon (HC) kaynaklı emisyonlar için yapılmıştır. Ölçümler iki vaka için farklı motor devirleri altında (1500-2500 rpm), ilk vaka yüklemeli, ikincisi ise yüklemesiz yapılmıştır. Etanol 750 ve 450 benzin karışımları fren gücünü, fren ısıl ve hacimsel verimini arttırmaktadır. Ayrıca, fren özgül yakıt sarfiyatı hafif bir oranda azalmaktadır. Etanol 750 ve 450 benzin karışımlarını arttırmak karbondioksit yoğunluğunun arttığı yerde karbonmonoksit ve hidrokarbon emisyonlarını azaltmaktadır. Bütün yakıt türleri için motor hızı arttıkça egzoz gazı ısısının arttığı fark edilmiştir

Anahtar Kelimeler: Etanol, 750 ve 450 benzinleri, motor performansı, emisyon özellikleri

List of symbols

Symbols	Subscripts Meaning	
1-D	Combustion Model	
4-S	Four Stroke	
AFR-1	Mass ratio of air to fuel present in engine	
ASTM	Method test	
AV-1	Open fuel value fully	
AVL	Di- gas analyzer	
BDC	Bottom dead center	
BHP	Brake horse power	
BP	Brake power	kw
BSFC	Brake specific fuel consumption	kg/kw.sec
BTE	Brake thermal efficiency	
CC	Cubic Capacity	
CFD	Computational fluid dynamics	
CIB	Control interface box	
CO	Carbon monoxide	%
CO2	Carbon dioxide	%
DAD	Data acquisition board	
Di	Digital inputs	
DMA	Direct memory access	
Do	Digital outputs	
E	Ethanol	
E0	Pure ethanol	
E10	10 percentage by volume ethanol	
E20	20 percentage by volume ethanol	
E30	30 percentage by volume ethanol	
E40	40 percentage by volume ethanol	
E50	50 percentage by volume ethanol	
EDIBON	Name company	
EGT	Exhaust gas Temperature	
G	Gasoline	
HOV	Higher Evaporation heat	
HU	Hydrocarbon burn	ppm
ICE	Internal combustion engine	
IROX 2000	Machine examination octane number	
KTEC	Kawasaki engine combustion	
LHV	Lower heat of value	kj/kg
LmL-GRAPTOR	Engine type	
Mc Clure brand	Types dynamometer	
MPEI	Engine type	
MTBE	Methyl tertiary butyl ether	
NOx	Oxides of nitrogen	%
PCL	Peripheral Component Interconnect	
RON	Octane number	
RPM	Revolution per Minuit	

RVP	Reid vapor pressure	
SAJ	Eddy current dynamometer type	
SC-2	Out gases flow	m^3/h
SC-3	Fuel flow	ml/min
SCADA	System control + Data Acquisition + Software	
SI	Spark ignition	
SP-1	Environment pressure inlet pressure	mbar
ST-1	Inlet air temperature	C^0
ST-2	Exhaust gases temperature	C^0
ST-3	Fuel temperature	C^0
ST-4	Refrigeration Air temperature	C^0
ST-5	Sump oil temperature	C^0
SV-1	Engine speed	rpm
T85 D	Engine type	
TBMC -12	Name device	
TDC	Top dead center	
Vd	Swept or Displacement volume	m^3
VLT- 3600	Model analyzer	
W-L	With load (Ethanol- Gasoline750)	
WO-L	With load (Ethanol- Gasoline450)	
WOT	Wide Open Throttle	

Symbols

ma	Mass air	m^3/h
ρ_a	Air density	m^3/kg
λ	Lamb	
η_V	Volumetric efficiency	%
η_{thb}	Brake thermal efficiency	%
η_m	Mechanical efficiency	%
R	Gas constant for air	kj/kg.k
P_a	Air Pressure	
$\dot{m}f$	Mass flow rate	kg/sec
Ø	Ratio equivalent	
ρa	Air density	$\frac{Pa}{T\times R}$
ηthb	Brake thermal efficiency	$\frac{Bp}{(LHV)\times\dot{m}f}$
Hv	Volumetric efficiency	$\frac{ma}{\rho\times Vd}$
Bsfc	Brake specific fuel consumption	$\frac{\dot{m}f}{Bp}$
Ø	Ratio equivalent	$\frac{1}{\lambda}$

Chapter One

Introduction

1.1 Background

Background Alternative fuels may be utilized to actively improve both emission pollution and the performance of (SI) engine [1]. It becomes increasingly important to really know what kind of fuel is being used to run the engine. Using the wrong kind of fuel may result in many troubles with the engine running. For instance, gasoline is the fuel designed for spark-ignition engines. Some of these alternative fuels include ethanol, methanol, methyl-tertiary, butyl-ether (MTBE) [2, 3, 4]. Due to the soaring crude oil prices in the world in general and gasoline in particular, and the direction of crude output fields in the next forty years, it has been necessary to look for an alternative to relieve the increasing burden demand on gasoline derived from crude oil as a consequence of the increasing number of autos in the world. Consequently, and in order to decrease fuel consumption the procedure of adding ethanol added to gasoline is being performed. The choice of materials to produce ethanol such as wheat, corn and barley are obtained from the nature. Ethanol is resistant to the knock phenomenon in Internal Combustion Engine (ICE) that operate using spark ignition. Also, latent heat value is high and ethanol contains high amount of octane. The existence of octane helps to increase the efficiency rates of the engine.Ethanol can highly be compressed because of its lower steam pressure so it can easily be stored and transported. It contains oxygen atom in its chemical structure which has a positive influence on the environment by reducing the proportion of the carbon-monoxide (CO) and hydrocarbons (HC) emissions when burning fuel that contains a percentage of ethanol [5,6,7]. The first attempts of mixing fuel with ethanol to run vehicles were between 1880s-

1890s. Henry Ford introduced ethanol as the fuel of choice for many autos during the early stages of development [8].The use of bioe-thanol is also recommended as an alternative fuel for (SI) engines because of the severe pollution standards at the present time, this requires minimizing (NOx) and CO2 emissions. The use of bioethanol can reduce the level of (NOx) emissions by 50-60% [9, 10, 11]. According to many reports ethanol–gasoline blends can be used as fuel in order to replace some part of gasoline in engine applications. Using gasoline–ethanol blends including ethanol at low concentrations could get better engine performance and characteristic emissions [12, 13]. Due to the decrease in the peak temperature within the cylinder, alcohol can be burned with lower flame temperature and luminosity also both NOx emissions and heat loss will be reduced. The vaporization of ethanol usually possesses a high latent heat. This latent heat normally lowers the temperature of the intake air and therefore, increases both density and volumetric efficiency. However, the oxygen found in ethanol helps to reduce the Heat Value (HV) more than gasoline. It is evident that in SI engines ethanol could be used as a fuel [14, 15].

1.2 Comparison between Ethanol and Gasoline Combustion Properties

1-The ethanol's vaporization heat is relatively high and three times higher than that of gasoline. This relatively increased heat of vaporization provides a good cooling to the air-fuel mixture and reduces the temperature in the engine.

2- Thermal value of ethanol is lower than in gasoline, which requires the burning of larger amounts of ethanol in order to get a similar energy.

3- Ethanol can be recognized by its high-Octane Number (RON), which means that it can work at a maximum compression ratio. By adding ethanol to gasoline, the RON of gasoline will be increased.

4-Theoretical amount of air required for the combustion of ethanol is lower than the amount required for the combustion of gasoline.

5- The freezing degree in ethanol is rather low which prevents fuel freezing especially in cold regions.

6- The combustion outputs of ethanol are less pollutants due to the existence of fourth ethylated lead which is being added to gasoline to raise the RON and also the employ of ethanol-gasoline reduces the carbon-monoxide and nitrogen dioxide

7- Ethanol melts completely in the water. On the other hand, gasoline is not dissolvable in water

9- Ethanol is a nontoxic substance **[**16, 17].

1.3 Alcohol fuel Industry

The ethanol industry started early in times of man as a consequence of chemical processes. The natural fermentation of any botanical substance produces alcohol in different concentrations. Chinese were the first who started the distillation process through which they have discovered the flammability of alcohol. Most of ethanol produced in USA is an outcome of hydrogenation using assistant factors to ethylene and fermentation of sugar, grain and corn. The possibility of butanol alcohol production from fermentation of living substances is currently studied. This production procedure takes place in insulation atmosphere and it produces ethanol and acetone as secondary outputs. Ethanol is made by fermenting sugar cane, various cereals and dates. The production processes do not require high temperatures. Brazil is considered as a leading country in producing alcohol ethanol fuel from sugar cane in which its annual production is nearly twenty billion gallons of ethanol[18].

1.4 Alcohol Production in Iraq

Iraq is considered as an important a resource of sugar represented by Al- Zahdy dates which contain 54% of the sugar material. This is a very high rate of sugar noting that the sugar amount in sugar cane normally does not exceed 11%.The dates industry in Iraq is growing and developing and will reach very high production rates in the coming years. The ethanol is produced in Iraq from Al-Zahdy dates in different stages as below:

1. Production sugary juice**:** the dates enter into a cylindrical device which contains a rotating turbine. With the help of water steam the dates turn into sugary juice mixed with nuclei and fibers.

2. The sugary juice is brewed by adding a special type of yeast in anaerobic conditions and a diluted alcohol of 10% degree is obtained.

3. After obtaining the alcohol, it enters into distillation section at high temperature and depending on the difference between boiling temperatures, the concentrated alcohol is produced. The separation of alcohol is done in four distillation towers as shown below:

1-The disposal of the sugars in alcohol.

2-This tower is called acceleration tower in which alcohol purification of impurities is accomplished by a hot water.

3- This tower is call purification tower in which alcohol is more purified and its concentration increases to about 95%.

4- Alcohol is extracted at high concentrations [18].

1.5 The Objective

1- Study the effects of various mixtures of an environmental friendly alternative fuels(Ethanol) on the execution of internal combustion engine.

2- Study the effects of various mixtures of an environmental friendly alternative fuels (Ethanol) on the release of internal combustion engine.

Chapter Two

Literature Review

2.1 Introduction

There is an increasing usage of ethanol mixtures in SI engine operation. Therefore, many researchers have been done to model the engine performance and emission to predict the experimental performance of different blends of ethanol and gasoline. This chapter presents a summary of many researches and investigations that have been conducted in the area of ethanol blends and its effects on the engine performance and emission.

W. Hsieh, et al. (2002) [19] have investigated experimentally the engine performance and pollutant emission of SI engine using ethanol–gasoline blended fuels with various blended rates (0%, 5%, 10%, 20%,30%). Fuel properties of ethanol–gasoline blended fuels were first examined by the standard ASTM methods, as shown in table (2-1).

Table 2-1 Properties of different ethanol- gasoline blends [19]

Property item	E0	E5	E10	E20	E30
Density (kg/l at 15.51C)	0.7575	0.7591	0.7608	0.7645	0.7682
RON (octane number)	95.4	96.7	98.1	100.7	102.4
RVP (kPa at 37.81C)	53.7	54.3	58.3	58.3	56.8
Sulfur (wt%)	0.0061	0.0059	0.0055	0.0049	0.0045
Washed gum (mg/100 ml)	0.2	0.2	0.2	0.6	0.2
Unwashed gum (mg/100 ml)	18.8	18.6	17.4	15	14.4
Corrosively (3 h at 501C)	1 a	1 a	1 a	1 a	1 a
10 vol%	54.5	49.7	50.8	52.8	54.8
50 vol%	94.4	88.0	71.1	70.3	72.3
90 vol%	167.3	167.7	166.4	163.0	159.3
End point	197.0	202.5	197.5	198.6	198.3
Heating value (cal/g)	10176	9692	9511	9316	8680
Carbon (wt%)	86.60	87.70	86.70	86.70	86.00
Hydrogen (wt%)	13.30	12.20	13.20	12.30	13.90
Residue (vol%)	1.7	1.5	1.5	1.5	1.5
Color	Yellow	Yellow	Yellow	Yellow	Yellow

It was discovered that with the increasing in ethanol content, the Reid vapor pressure of the blended fuels initially increases to a maximum value at 10% addition of ethanol and then decreases. According to their study, they found that by using ethanol–gasoline blended fuels, CO and HC emissions may be reduced from 10 % to 90% and 20 % to 80% respectively. While CO2 emission increases from 5% to 25% depending on the engine conditions. It was observed that NOx emission has a close relationship to the equivalence ratio, such that NOx emission reaches a maximum near the stoichiometric condition (λ=1) and that NOx emission rely upon the engine operating condition rather than the ethanol content.

S.Pai, at el. (2002)[20] have also studied the influence of ethanol blends on SI engine performance and emission. The experiments were executed on a single cylinder,4- stork, and SI engine, as shown in table(2-2) properties specifications, with pure gasoline and from 10% to 80% ethanol – gasoline blend. The experiment was accomplished at a constant speed 3000 RPM but with various loads of 25%, 50%,75%, and 100%. The emission was analyzed.

Table 2-2 Properties of gasoline, ethanol and mixture of 10% and 20% (by volume) [20]

Property	**Gasoline**	**Ethanol**	**(E10-90G)**	**(E20-80G)**
Specific Gravity 15.5 C^0	0.72-0.75	0.79	0.73-0.76	0.735-0.765
Heating Value(Mj/kg)	43.5	27.0	41.9	40.0
Appox Reid vapor pressure 37.8C^0kpa	59.5	17	64	63.4
Stoichiometric A/F ratio	14.6	9	14	13.5
Oxygen content (% by weight)	0.00	3.5	3.5	7.0

It was found that with blends, the engine operated smoothly. The blends burn more efficiently and generated lower emissions of NO_X, CO and CO2.Various parameters for example: BP, BSFC, η_{bth}, HC, and NO_x during combustion process under varying load conditions are analyzed. For ethanol –gasoline blended fuels, great enhancements in performance of the SI engine under partial load and a full load operation were noticed. It was noticed that the BTE for E20 blend has increased about 10.915 % compared to standard gasoline. They have also discovered that BSFC has increased with the increasing in the ethanol percentage but has decreased with increasing the load. Also, it was noticed that the E100 volumetric efficiency is higher in comparison to gasoline with increasing the ethanol percentage.

M.Al-Hasan. (2003)[21]presented the effects of ethanol in unleaded gasoline on the performance and exhaust emissions in a spark-ignition engine. Conducted tests for equivalence air–fuel ratio, fuel consumption, volumetric efficiency, brake thermal efficiency, brake power, engine torque and brake specific fuel consumption were investigated. Also, the exhaust emissions for CO, CO2 and HC were analyzed. The tests were done by using unleaded gasoline–ethanol blends with different percentages of fuel at three-fourth throttle opening position and with variable engine speed ranging from 1000 to 4000 rpm, as shown in Figure (2.1). Researcher discovered that Ethanol addition results in an increase in each of the following: BP, η_{bth}, η_V and fuel consumption by about 8.3%, 9.0%, 7% and 5.7% mean average values, respectively. Both brake specific fuel consumption and equivalence air–fuel ratio have decreased by about 2.4% and 3.7% mean average value, respectively.

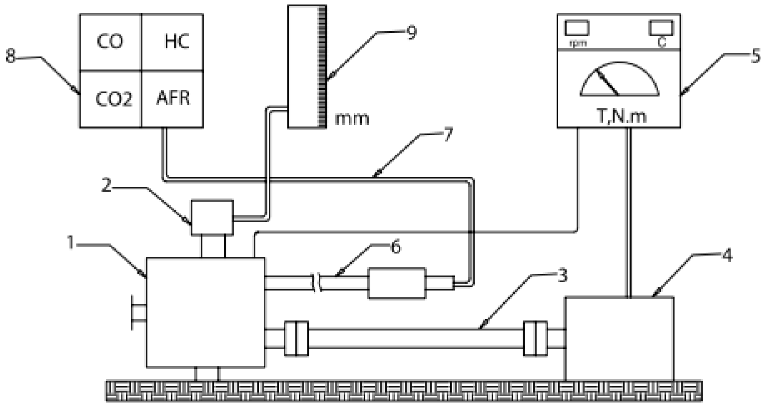

Figure 2.1 Engine Diagram and Instrumentation [21]

1-Engine 2-Caburetter 3-Drive Shaft 4-Dynamometer 5- Dynamometer Panel 6-Exhuast Pipe 7-Simpling Tube 8-Gas Analyzer 9-Fuel Burette

Using an ethanol–unleaded gasoline blend leads to a considerable reduction in exhaust emissions by about46.5% and 24.3% of the mean average values of CO and HC emissions, respectively, for all engine speeds. The 20% ethanol fuel blend showed the best results of the engine performance and exhaust emissions.

F. Yüksel and B. Yüksel. (2004)[22]have examined the use of ethanol–gasoline blend as a fuel in an SI engine. They conducted test performance on a 4-cylinder SI engine with compression ratio 8:1. In the experiments, the concentrations of CO, CO2, HC and O2 in the exhaust gas were measured by the analyzer of VLT-3600 with pre-calibration. With the operating conditions (throttle valve opening 25%, 50%, 75%, and 100%, various engine speed, various fuels up to 60% ethanol – gasoline blend by volume), torque output, fuel consumption rate, engine speed, intake air quantity and concentrations of CO, CO2, HC and O2 emissions were recorded for the analysis. Experimental results specified that using ethanol–gasoline blended fuel, the torque output consumption of the engine increased slightly, the CO and HC emissions decreased dramatically because of the leaning effect caused by the ethanol addition, and the CO2 emission increased as a result of the enhancement in

Combustion. It was found that in using ethanol–gasoline blended fuel, the CO and HC emissions would be reduced approximately by80% and 50%, respectively, while the CO2 emission increases 20% depending on the engine conditions.

M.A. Ceviz and F. Yüksel. (2005)[23]focused on the impact of ethanol–unleaded gasoline blends on cyclic variability and emissions in an SI engine. They have investigated the impacts of ethanol–unleaded gasoline blends on cyclic variability and emissions in a spark-ignited engine. This study has presented the following results: the use of ethanol–unleaded gasoline blend as a fuel leads to a significant reduction in exhaust emissions by about20.2% and 30.01% for HC and CO emissions, respectively, at 10% ethanol ratio compared to pure gasoline experiments. Using a blend of ethanol–unleaded gasoline as a fuel decreased the coefficient of variation in indicated mean effective pressure, CO and HC emission concentrations, while increased CO2 concentration at 10% ethanol in fuel blend. The 10 % (by volume) ethanol in fuel blend show the best results.

H. Bayrab. (2005)[24]has showed the outcome of adding ethanol to unleaded gasoline and its use in internal combustion engines that operate spark ignition on the engine performance and the amount of pollutants emitted from it. His work included both theoretical and experimental investigations. In the theoretical part, the researcher used the equations of the first law of thermodynamic using system simulation to represent the combustion and provide flame within the combustion chamber. In the practical part, the researcher used ethanol purity of 93% added to unleaded gasoline at proportions of different size between (1.5% -21%), and an increase of 1.5% every time. The researcher used the compression ratio of (8.25:1, 7.75%) when the ignition (10°BTDC) and 1500rpm speed of rotation. The experimental results presented that adding

7.5% ethanol to unleaded gasoline is the best for the engine's performance and also the emission of pollutants. On the other hand, the theoretical outcomes presented that the theoretical ratio of 16.5% ethanol was the best, and the mathematical model being used in the theoretical segment of the research was acceptable.

M. Koç, et al. (2009) [25] studied the influence of ethanol–unleaded gasoline blends on both engine performance and exhaust emissions in a spark-ignition engine. They conducted test performance on a single cylinder, 4-stroke, SI engine, engine test bed with a McClure brand dynamometer and a gas analyzer, as presented in Figure (2.2) and in table (2-3).The experiments used 8 different engine speeds ranging from 1500 rpm to 5000 rpm with addition of 500 rpm increments each time at two different compression ratios (10:1 and11:1) and with the (WOT) operating conditions after completion of a standard warm up procedure. Three different fuels (E0, E50 and E85) were tested with each speed value. The used fuels were unleaded gasoline (E0), gasoline–ethanol blends. E50 and E85.Each of the following: fuel consumption, Engine torque and pollutant emissions (HC, CO and NOx) have been measured throughout the experiment.

Table 2-3 Test Engine [25]

Engine Kind	Hydra, overhead camshaft, with fuel injection, spark ignited
Number of cylinder	One cylinder
Bore × Stroke	80.26 mm×88.9 mm
Compression Ratio	(5:1 to 13:1)
Maximum speed	1000 to 5400 rpm
Maximum Power	15kw
Ignition timing range	70^0 BTDC - 20^0 ATDC

The results obtained showed that, torques as a result of blended fuels (E50 and E85) were found to be much higher than those of base gasoline (E0) in all the speed range. The reason for that is the higher latent heat of evaporation of ethanol addition and oxygenated fuel. The lower energy content of ethanol–gasoline fuel, depending on percentage of ethanol in the blend, can cause an increment in brake specific fuel consumption of the engine. A noticeable decrease in HC emissions was detected due to the leaning effect and additional fuel oxygen caused by the addition of ethanol. But, at higher compression ratio, HC emissions increased, and that is due to higher surface to volume ratio. Reduction in NOx emissions was achieved with ethanol addition and the reason for that is the higher latent heat of vaporization of ethanol. By comparing two compression ratios (11:1 and11:0) results showed that NOx emissions were higher at the 11:1 ratio than 11:0. It was also discovered that compression ratio can be increased without knock occurrence by using ethanol–gasoline blends.

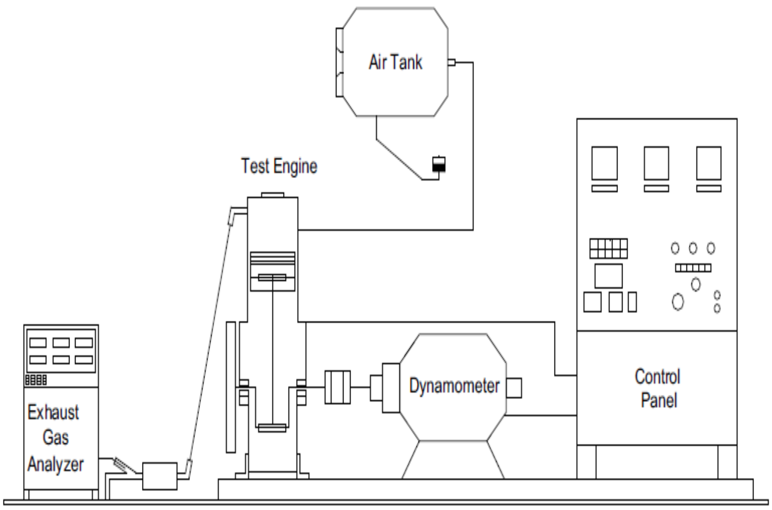

Figure 2.2 Schematic view of the engine Test [25]

H.Saeed, A. R. Habboo. (2010)[26] presented the result of adding ethanol purity of 99.2% to unleaded gasoline on the performance of spark ignition engine. As well as, the amount of pollutants discharged from it. The researchers used different size ratios of ethanol (% 10, %20, %30, % 40 and% 50) to unleaded gasoline. The properties of the blends are shown in table (2-4).

Table 2-4 Properties of blended fuels [26]

NO	Blend	Density (kg/m^3)	Octane number
1	E0	728.2	76
2	E10	731.8	83
3	E20	737.8	89
4	E30	745.9	95
5	E40	746.9	99
6	E50	758.3	101

The experiments were accomplished at various compression ratios (9:1,10:1, 11:1), while the time has been changed to give ignition by 5 degrees' crankshaft and by fixing the rotation speed to 2000 RPM and has a ratio equivalent (ϕ = 1). The researchers noticed that the torque of the engine increases with providing a spark timing ignition significantly, and has full compression ratios. It was noticed that the featured fuel consumption has decreased while providing time ignition for all sorts of fuel used. Results also showed a substantial reduction in exhaust emission for higher percentage ethanol – gasoline blends. In addition, all blending ethanol with gasoline allows engine to operate at high compression ratio without knock occurrence.

M.A.R. Sadiq et al. (2011)[27]reviewed the influences of ethanol – gasoline blends on exhaust and noise emissions from 4- stroke SI engine. In their experiment ethanol purity 99.9% was added to gasoline blends to engine type T85D carbureted single-cylinder 4-stroke SI engine with bore and stroke 70mm, 66mm, respectively and swept volume 254 cm^3, is presented in Figure (2.3).In their research, they studied the influence of adding ethanol to gasoline on the exhaust emissions and noise level at different engine loads.

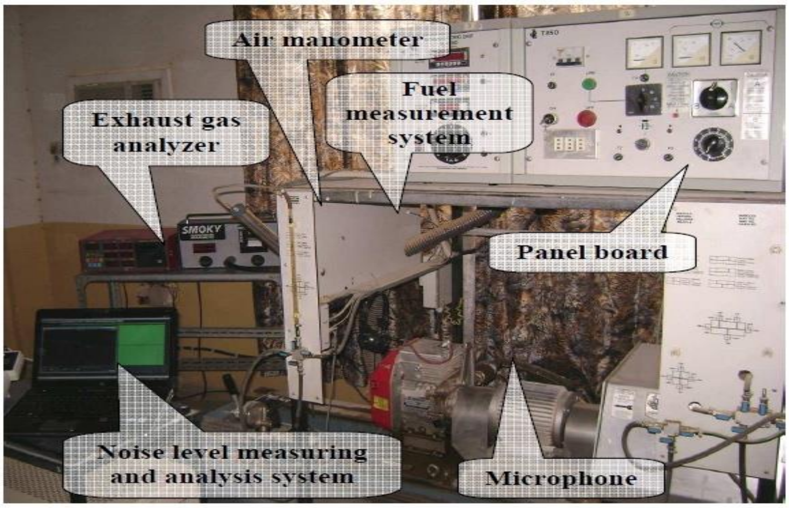

Figure 2.3 Test Engine [27]

Results of the engine test showed that utilizing ethanol-gasoline fuels that will increase the power output of the engine dramatically (up to 50%). Both the CO and HC emissions decrease, as a result of the leaning effect presented by the ethanol addition whereas the CO2 emission increases due to the enhancement of ignition. In addition, noise level has been increased slightly and that is due to the increase of ethanol content. Finally, calculations showed that ethanol can be used as a complementary fuel to gasoline in engines without major changes, and it can help to create a green environment free from toxic pollutants and to save a considerable portion of the available oil.

V. S. Kumbhar, et al. (2012) [28] Realized the outcomes of lower ethanol gasoline blends purity 99.9 (up to 20% by volume) on the performance and emission properties of the Bajaj Kawasaki Engine Combustion (KTEC) model single cylinder four stroke SI engines, as presented in Figure (2.4). The engine specifications are shown in Table (2-5). Tests were performed for different mixes based on size. The ethanol was added to gasoline at a concentration of 5%, 10% and 20%. The power, fuel consumption, torque, and brake mean effective pressure were achieved. The exhaust emission analysis of CO, CO2, and HC using various gasoline-ethanol blends on the basis of the size of the open throttle at speeds ranging between 4000 to8000 rpm were done

Table 2.5 Engine Specifications [28]

No	Particulars	Data
1	*Manufacturer*	*Bajaj Kawasaki*
2	Model	K TEC
3	No. of cylinder	01
4	Cubic capacity	100
5	Bore	50mm
6	Stroke	50.6mm

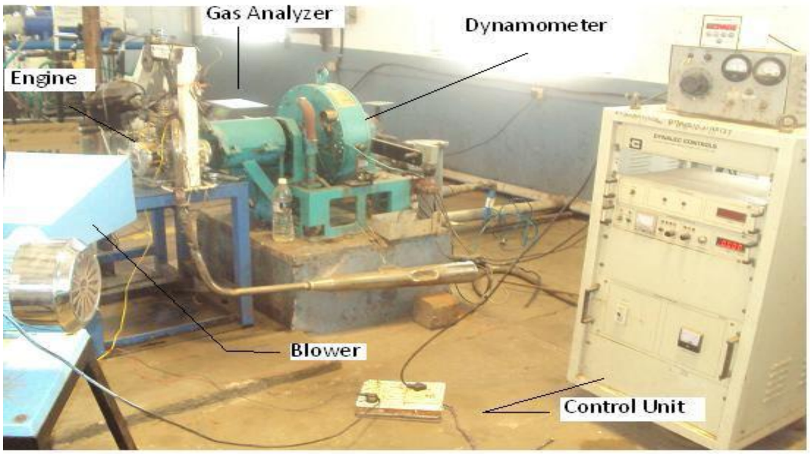

Figure 2.4 Experimental Setup [28]

The results were compared with pure gasoline. It was presented that the influence of the speed of 4000-6000 rpm. There is an escalation in torque, up to 4.77% at 6000rpm with E20.The HC emissions of CO2was reduced for all blends because of combustion improvement and CO being converted to CO2, thus increasing CO2 emissions.

K. B.Siddegowda and J.Venkatesh.(2013)[29] have focused on the performance and Emission properties of MPFI Engine by Using Gasoline – Ethanol Blends. In this research tests are achieved on MPFI engine, as shown in table (2-6) and Figure (2.5) to study the performance and emission of the ethanol gasoline blended fuel.

Table 2.6 Test Engine Specifications [29]

Item	Specification
Model	Maruti 800cc, MPFI Engine
Manufacturer	Maruti Udyog Ltd
Type	Petrol,3cyl, Inline
Cooling	Water cooled
Displacement	796cc
Compression ratio	7.9:1
Maximum Power	39.5 bhp@5000rpm

Figure 2.5 Experimental Setup [29]

The ethanol is mixed with 0%, 10%, 20%, and 30% by volume with gasoline. The various engine performance characteristics like BTE, BSFC and BSEC and emission parameters like UBHC, CO, CO2, and NOX are measured using 5 different gas analyzers (BOSCH). It was detected that by adding 20% ethanol to gasoline there is an increase in the brake thermal adequacy and decrease in fuel consumption. It was also discovered that there is a great amount of reduction in emission on using ethanol with gasoline. Laboratory results refers that when ethanol-gasoline blend is used, both CO and HC emission in the engine decreases remarkably as an effect of the leaning presented by the ethanol addition, on the other hand, CO2 emission increases due to the combustion improvements.

J. kumar, et al. (2013)[30]investigated performance using ethanol blended gasoline fuel in SI engine. In this study, gasoline is being used as reference where it is blended with ethanol. Physical properties related to the fuel were accomplished for the four blends of gasoline and ethanol. A 4-cylinder, 4-stroke and varying rpm Petrol engine connected to eddy current type dynamometer was run on blends containing 5%,10%, 15% and 20% ethanol and the engine performance characteristics were estimated. This work shows that, the higher blends can substitute gasoline in SI engine. Results showed that because of low calorific value of ethanol than gasoline and also increase in the mechanical efficiency, SFC and air-fuel ratio on blending; there is a reduction in exhaust gases and increase in SFC. It can conclude from the result that using 10% ethanol blend is most effective.

A. Elfasakhany (2014)[31]presented experimentally the results of ethanol-blends on the performance and exhaust emission properties of SI engines. A four stroke, single cylinder SI engine, as presented in table (2-7) and Figure (2.6) was used. Four different blends on a volume basis were applied.

These are E0 (0% ethanol + 100% unleaded gasoline), E3 (3% ethanol + 97% unleaded gasoline), E7 (7% ethanol + 93% unleaded gasoline) and E10 (10% ethanol + 90% unleaded gasoline).

Table 2-7 Engine Specifications [31]

Engine Kind	Spark Ignition
Number of cylinder	Single cylinder
Bore × Stroke	65.1 mm ×44.4mm
Compression Ratio	7:1
Cooling	Air cooling
Output Power	1.5kw
Oil volume	0.6 L
Connecting rod	79.55mm

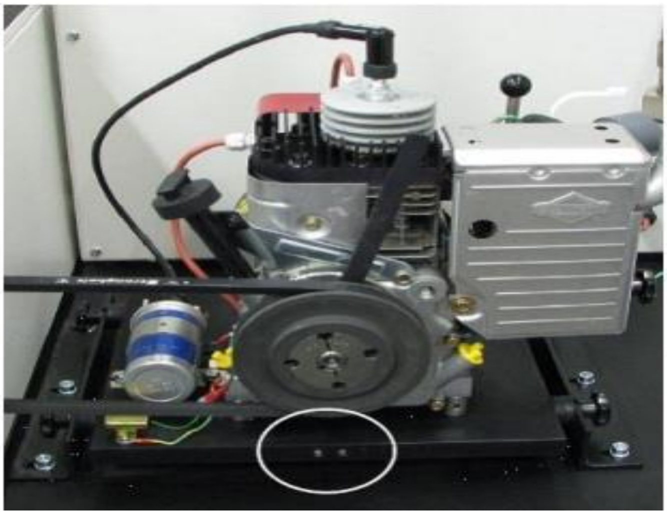

Figure 2.6 Engine Test [31]

Performance tests were conducted for BP, η_V, SFC, engine torque, EGT and cylinder pressure. Also, the exhaust emissions were analyzed for CO, CO2 and UHC, using pure gasoline and gasoline-ethanol blends

With various ratios of ethanol fuel at variable engine speeds, ranging from2600 to 3500 rpm. Research results pointed that blending unleaded gasoline with ethanol will increases the following: BP, torque, η_V, EGT and cylinder pressure, while it decreases the BSFC. It was also noted that when ethanol content is less than 10% blended ratio, fuel consumption will depend mainly on the engine speed rather than the ethanol content. The CO and UHC emissions concentrations in the engine exhaust fall, while the CO2 concentration increases rise. The 10%ethanol in fuel blend shows the best outcomes for all measured parameters at different engine speeds. Finally, this study may confirm that the utilization of ethanol as promising octane blending biofuel with gasoline in current and future gasoline engine technologies.

R.S. Tupkar, et al. (2014) [32] has investigated experimentally 4-stroke SI engines using alcohol petrol blends. A 150 CC 4-S LML GRAPTOR engine, a rope brake dynamometer (Tongue Buckle for loading and unloading purpose), two spring balances (for measuring loads on tight and slack side) and two fuel tanks were used in the experiment. A pulley is directly keyed to output shaft of the engine on which load is applied. Different alcohol petrol blends were applied and the optimum petrol blends for SI engine was found. The different execution parameters such as Bsfc, BP, η_{bth} and torque for 4-stroke engines by using different blends were obtained. Experimental results showed that by using ethanol-gasoline blended fuels, the power output, fuel consumption, η_{bth} and η_V of the engine increase. As a result of the leaning effect caused by the ethanol addition both CO and HC emissions decreased. On the other hand, CO2 emission increases due to the combustion enhancements. They noticed that E15 (Ethanol-15%, Gasoline-85%) is best possible blend that can be utilized in 4-stroke SI engine.

A. Pal.(2014)[33]has studied the impact on SI engine performance and emissions. In this research the performance and emission properties of a 4 stroke,4-cylinder spark ignition MPFI engine, as presented in table(2-8) and Figure(2.7) was investigated with various ethanol gasoline (Gasohol) blends(Desihol) diesel. Ethanol may be used in SI engines as ethanol blended, but because of its rather easy miscibility with gasoline and having a higher-octane number; ethanol is preferably blended with gasoline. Due to the higher ethanol blend usability constraints, in this work the investigation was kept limited to the low (5-15 % ethanol) ethanol gasoline blends. The present work aims at discussing the low ethanol gasoline blends and gasoline (E0/G100), which were tested on a Maruti Suzuki Wagon engine with a SAJ eddy current dynamometer unit.

Table 2.8 Engine Specifications [33]

Characteristics	Value
Make	Suzuki
Number of cylinder	04
Maximum power	44.5 kw @ 5000 rpm
Maximum Torque	59 N.m @ 2500 rpm
Bore	72mm
Displacement	1100mm

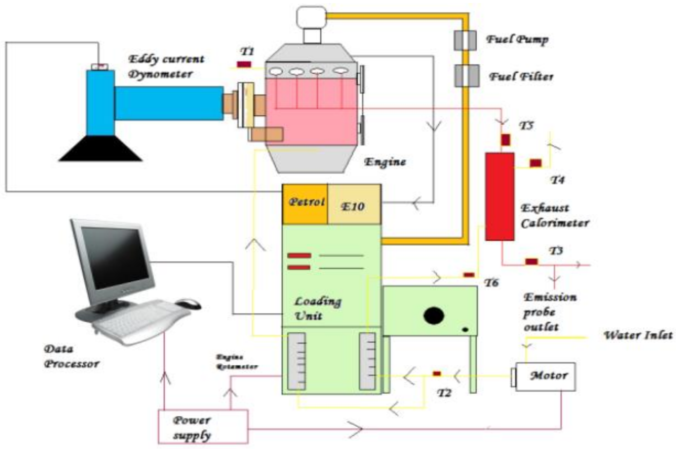

Figure 2.7 Schematic Details of the Test Setup [33]

The different performance parameters such asBP and η_{bth} and exhaust emission parameters like CO, HC, NOx and CO2 have been recorded. The results of this research demonstrate the implementation of low ethanol blended gasoline as clean fuel to lower CO, HC and NOx emissions. Performance parameters show a negligible growth in BHP and η_{bth} and a minor rise in particular fuel consumption, whereas the usefulness of the inherent oxygen content in the ethanol molecule has been proved through the occurrence of a higher peak cylinder pressure and a higher exhaust gas temperature.

L.S.Kuburi et al.(2014) [34] investigated the performance properties of a gasohol fueled SI engine. In this study, the influence of adding ethanol to gasoline on the performance properties of a spark ignition engine at different speeds was analyzed. 20 – 80% of the extracted ethanol was blended with gasoline by adding 20% each interval. Experiments were achieved on a single cylinder petrol engine with various percentage of ethanol as additive to gasoline on their performance indicating characteristics. It is concluded that, by increasing the engine speed as a result an increase in the rate of fuel consumption for control sample will take place. On the other hand, it decreases at higher speed for the blends. In addition, the increasing percentage composition of ethanol may increase the engine power and volumetric efficiency while the highest engine power of 2.7KW and volumetric efficiency of 0.76 were acquired from blend E40. Thus, ethanol could be used as an additive for gasoline engines.

R.S.Bharjand S.Sharma. (2014)[35]studied the parametric evaluation of SI engine with ethanol blended gasoline fuel. The aim of this study is to understand the influence of blending gasoline fuel with ethanol on the performance and emission of SI engine. The thermo-physical characteristics of ethanol are examined by ASTM standards, as displayed in table (2-9). Results reflect that with blending, the HC and CO

Emissions decrease while CO_2 emission increases. NOx emission still unpredictable as it depends upon the engine operation.

Table 2-9 Properties of Different Blends (ASTM) Standards [35]

SR NO.	SAMPLES	Sp.Gr @dec C IS	FLASH POINT (dec c)	ρ @15dec C (kg/m3)	μ@40 dec C (CST) ASTMD 445-06
1.	E10	745.3	<-4	747.8	0.4835
2.	E15	747.3	<-7	749.8	0.4975
3.	E20	750.3	<-5	752.5	0.5306
4.	E25	752.5	<-7	755	0.5483

Bsfc is also confliction between practically obtain results and theoretical calculated ones. Volumetric efficiency, torque output, η_{bth}, RON and density increase considerably with blending. While heating value declines and RVP rises initially and then declines. Heating value of ethanol is less than gasoline so more amount of fuel is needed to obtain same power output. This will also guide to more Bsfc and decreased η_{bth}. Exhaust emissions including CO and HC will decrease due to complete combustion of blended fuel because fuel present is comparatively leaner for same compression ratio and air fuel mixtures and more oxygenated. CO_2 emissions increases again showing complete combustion of fuel present inside. Nox emission slightly depends upon blend rate but majorly depend upon the engine and operation condition of engine.

S.P. Iliev.et al. (2014)[36]developed a 1-D combustion model and studied the engine features using ethanol - gasoline blends. This study's purpose is to obtain a 1- D combustion model of 4- stroke,4-cylinder SI Engine for predicting the influence of different fuel blends(E0, E5, E10, E20, E30, E40, E50) with variable engine speeds, on the performance of fuel consumption at various engine operating conditions. AVL di-gas analyzer boost was used as a computational fluid dynamics simulation Instrument to evaluate the performance and emissions features. For various blends of ethanol gasoline, it was discovered when ethanol percentage increases the HC and CO concentration decline but NOx emission increased with the increase of ethanol percentage and the Bsfc increases also with the increase of ethanol proportion.

A.S. Raja et al. (2015)[37] presented the influence of gasoline-ethanol blends on the performance and emission characteristics of single cylinder air cooled motor bike SI engine. Experiments were performed at partial load and several engine speeds ranging from 3000 to 5000 rpm of a single cylinder 150cc four stroke air cooled spark ignition (SI) engine. Ethanol content was varied from 5 percentages to 20 percentages by volume and four different blends (E5, E10, E15 and E20) were tested. Fuel consumption, engine speed, air fuel ratio, exhaust as temperature and exhaust emissions were calculated throughout each trial. Brake thermal efficiency (η_{bth}), η_{vol}, BSFC and excess air factor were tested for each experiment. BSFC, η_{vol} and excess air factor increased with ethanol percentage in the blend. Carbon-monoxide (CO), hydrocarbon (HC) and (Nox) emissions decreased with blends. Results of the engine test indicated that using ethanol–gasoline blended fuels η_{vol} and excess air factor increased. BSFC was higher for blends due to of the LHV of the blends in comparison to pure gasoline. Finally, the CO, UHC and Nox emissions concentrations in the engine exhaust drop down, while theCO2 concentration increases with ethanol – gasoline ratio in the blends.

Hariram.V. and Athulsasi(2015)[38] reviewed the operation and emission parameter of single-cylinder SI engine with ethanol – gasoline blends. This article deals with the experimental examination of applying gasoline-ethanol blends in a 4-stroke single cylinder overhead cam SI engine for performance and emission characteristics. The performance factors like η_{bth}, BSFC, mechanical efficiency and emission parameters such as UHC, CO and NO_X were analyzed in details. The BTE was found to increase with each addition of ethanol blends which showed 21% at the condition of full load for E20 blend. The mechanical efficiency also showed a similar trend of BTE which consistently increased by 6% to 7% with rise in ethanol blends. The BSEC was found to decrease from 15.5MJ/kWhr to 13.8MJ/kWhr when ethanol blends were increase at the condition of low load and it's exhibited a decreased for the entire operation condition. The UBHC and CO emission were found to decrease by 6% and 11% respectively and NOx increase marginally at full load condition.

2.2 Summary of Previous Researches

This survey displays several of the previous studies about the effect of ethanol - gasoline blended fuel on the engine performance and pollutants emissions. Many experiments were conducted to examine the outcome of blending different rates of ethanol-gasoline. It is clear from the results obtained in the literature study that adding ethanol to gasoline improves the engine performance also decreases the pollutant emissions without significant modifications in the design of the engine. Ethanol could be made from biomass; therefore, it may be considered as renewable energy source which might be an alternative fuel.

Chapter Three

Experimental work

The result of adding ethanol with purity 99.9% to gasoline for SI engine has been tested. In this experimental work, η_{bth}, Bsfc, and η_{vol} characteristic emissions of SI engine have been determined with and without load under different operational conditions**.**

3.1 Experimental Setup

Experimental test rig is illustrated in Figure (3.1). It consists of TBMC 12 created by EDIBON of German (2011). This apparatus has numerous features including advanced real-time SCADA, open control, multicontrol, genuine -time control, specialized EDIBON control software, instruments data acquisition board (250 KS/s), calibration exercises and projector or electronic whiteboard compatibility. The calibration educates the user how to calibrate a sensor and it shows the importance of checking the precision of the sensors before taking measurements. This gadget comprises of the following major parts:

Figure 3.1.Experimental Setup [39]

1. Engine

An internal combustion engine is a device which produces mechanical energy from the chemical energy of the mix fuel-air by means of the combustion process. The combustion engine is fabricated to face multiple conditions and operations. So, it is essential to understand the engine behavior, what is technically known as engine features. The most fundamental factors considered in connection with the engine features are the torque, the power and the fuel consumption in accordance with the revolutions number. In this experiment, the ICE with a single-cylinder 4-stroke SI engine is demonstrated in Figure (3.2). The engine is provided with a combination of air - fuel through carburetor process. The specifications of the engine used in the research are listed in Table (3-1).

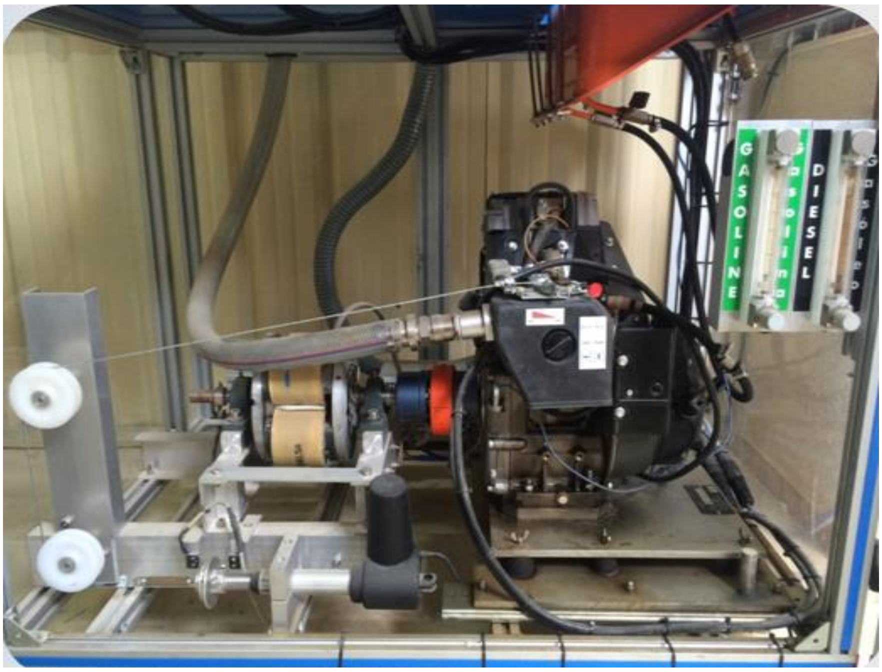

Figure 3.2 Test Engine [39]

Table 3-1 Specification engine used in the Experiment[39]

Engine Type	Spark ignition, four stroke
Number of cylinders	Single cylinder
Bore * Stroke	81 mm *64 mm
Compression Ratio	8.3:1
Cooling	Air cooling
Output Power	11 kw
Swept Volume	0.000329 m^3

2. Dynamometric Brake

The foremost component of the TBMC 12 unit is the dynamometric brake. The equipment established by EDIBON has an eddy current brake, as element carrying out the torque resistant to the engine, also called as Foucault. The dynamometric brakes are accountable for creating a resistant torque. Force transmission from the engine to the brake unit is done using an elastic claw coupling through the shaft. The engine load can be altered by the help of the brake motion. The control of the adjustable braking torque and the speed of the engine is conducted by the use of a computer controlled, as illustrated in Figure (3.3). The torque is measured by measuring the reaction produced in the arm end on a load cell. The properties of the dynamometric brake used in this experiment are:

1- Brake torque is 350Nm
2- Force sensor (torque) range between 0-50 Nm
3- Maximum speed is 3000rpm
4- Arm length is 400mm
5- The cooling system is air

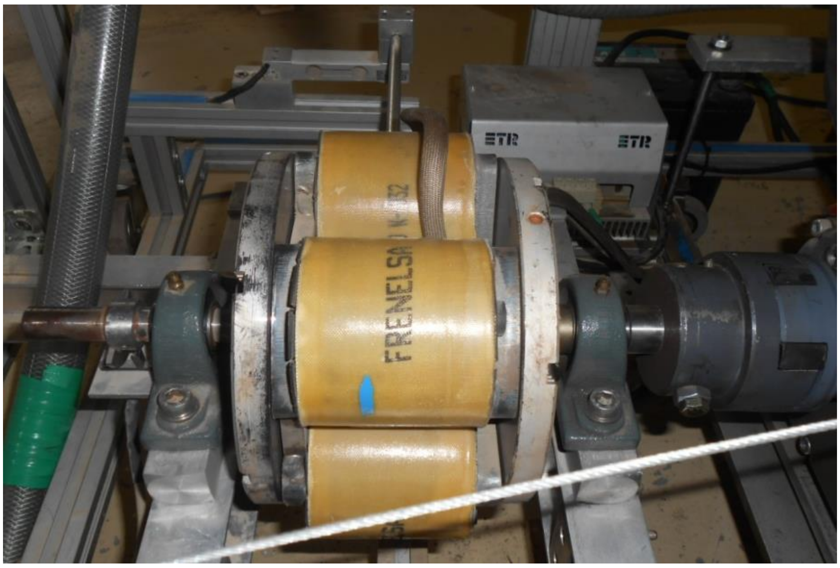

Figure 3.3 Dynamometer Brake[39]

3. Control Interface Box (CIB)

It is an element of the SCADA system. Control interface box with process is drawn at the frontal panel with the location of each element and sensor as clear in Figure (3.4).

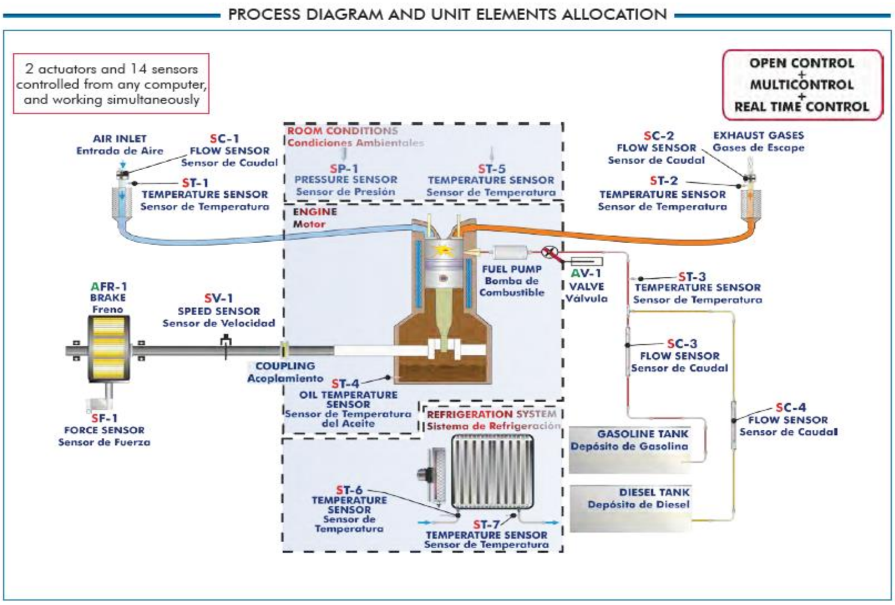

Figure 3.4 Different Elements located in the Unit[39]

In each sensor, with the signals of each, it is manipulated correctly from -10V to + 10V by the computer. Semiconductor sensors in the interface have different pines numbers (2-14). To avoid the bugs, a single cable is connected between the interface box and the computer Control as presented in Figure (3.5). Elements of the console are computer controlled permanently, exclusive of the need for connections or alterations throughout test of the whole process. All the parameters included in the calibration process from all the sensors in the process are conceived at one time by the computer. All the engine values can be altered at any time using the keyboard which allows the analysis about curves and responses of the whole process. All the actuators and sensors values and their responses are displayed on only one screen in the computer. Real-time computer control with flexibility amendments of parameters can be done at any time through this process and all of the data and process results can be stored in a file.

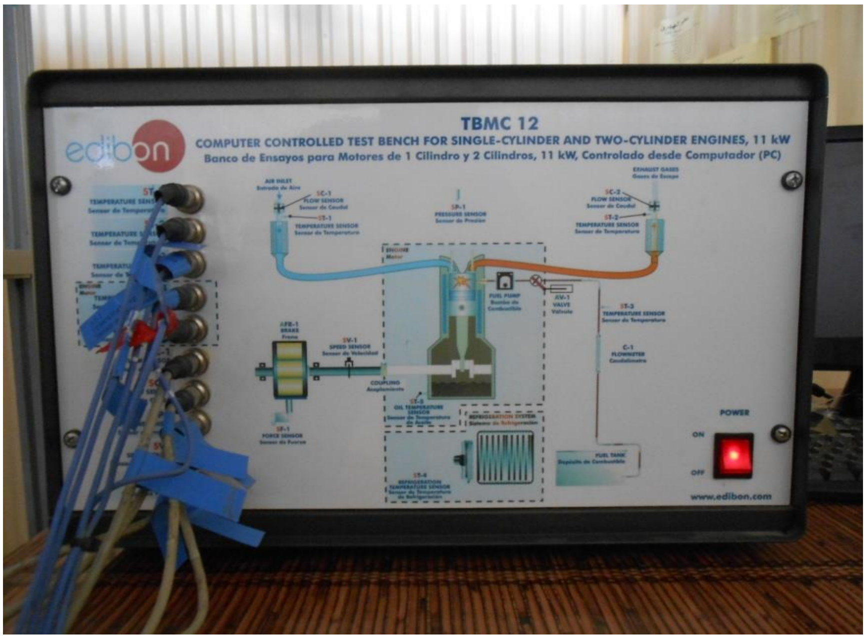

Figure 3.5 Control Interface Box [39]

4.Data Acquisition Board (DAB)

It is a division of the SCADA system.PCI put across data acquisition board (Instruments) to be positioned in a computer slot. Bus PCI Express is shown in Figure (3.6),which consists of:

Analog input

- Quantity of channels=16 single-ended or 8 differentials
- Resolution=16 capabilities, 1 in 65536
- Specimen rate up to 250 KS/s (kilo samples per second),
- Input range (V)=±10 V.
- Observations transfers=DMA, interrupts, programmed I/0, DMA channels=6.

Analog output

- Sum total of channels=2,
- Resolution=16 bits, 1 in 65536,
- max output rate up to 900 KS/s,
- Output range(V)=±10 V,
- Data transfers=DMA, interrupts, programmed I/0.

Digital Input/output

- Number of channels=24 inputs/outputs
- D0 or DI specimen clock frequency 0 to 100 MHz,
- Timing number of counter/timers=4
- Resolution counter/timers 32 bits.

Figure 3.6 Data Acquisition Board[39]

5.Computer Control, Data Management Software and Data Acquisition Board

The actual operation, the drawing simulation and intuitive operation in the screen are consistent with windows operating systems. Also, they are harmonizing with the industry standards, and every conceivable process. The variables change automatically and simultaneously. Open and multi-control software developed with actual windows and the drawing systems, acting simultaneously on all processes and parameters. It also manages treats and compares the data storage. It helps in sampling speed up to 250 Km/s. The system standardization of the sensors participates in this process. Comparative analysis of the data is obtained, and after this process, the conditions during the whole process are adjusted as shown in Figures (3.7) and (3.8).

Figure 3.7 Computer Control [39]

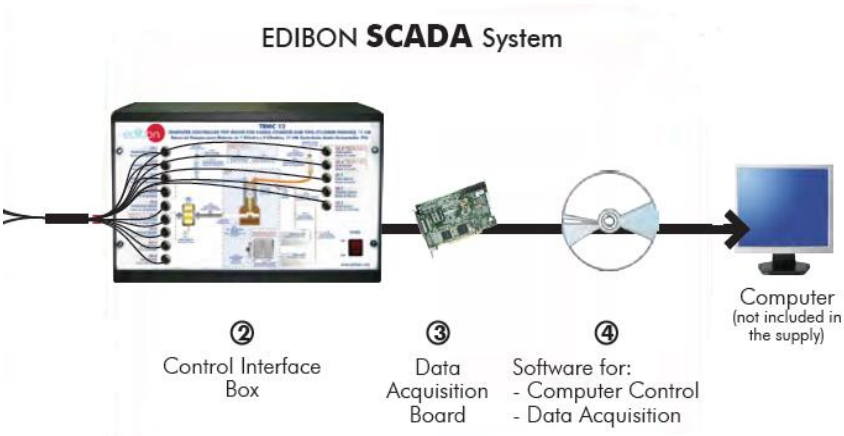

Figure 3.8 Software is part of the SCADA System [39]

6. Exhaust Gas Analyzer:

The exhaust gas analyzer of the type Multigas 488 manufactured in 2001 in Italy is used to examine the exhaust gases emerging from the engine. This instrument measures the percentage of gas carbon-monoxide (%CO) and gas carbon-dioxide (%CO2) and the quantity of hydrocarbon burn emissions (HC ppm). And also, the device is used to establish the percentage of the fuel relative to air (λ Lambda), which represents as the inverse of the equivalence ratio ($\lambda=1/\Phi$). The device, as well as measures the spinning speed of the engine through a special sensor for this purpose. The device is working to collect a sample of the exhaust gases emerging from the ignition chamber by flexible 4 m long tube and is equipped with one of the limbs with a ferric resistant to temperatures. The distance between the combustion chamber to the exhaust end is 1.25m as displayed in Figures (3.9) and (3.10).

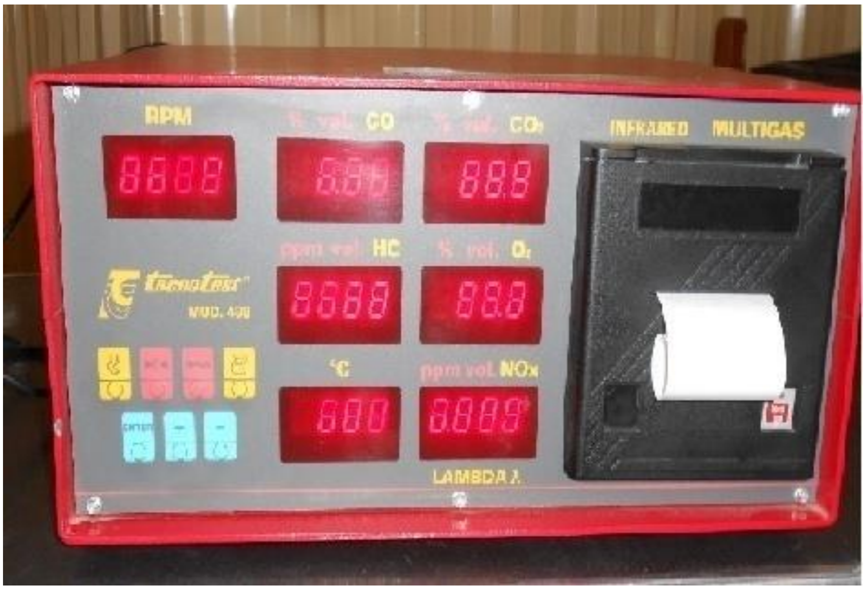

Figure 3.9 Exhaust gas Analyzer

Figure 3.10 Sensor Tube gas

3.2 Experimental Instrumentation

A series of, temperature, pressure and flow sensors are mounted in different points of the test setup. The instrumentation of the engines test bench of EDIBON is composed of the following elements:

3.2.1Temperature Measurement: Thermocouples type J is used with different process

1-Temperature of inlet air (St-1).

2- Temperature of the exhaust gases (St-2).

3- Temperature of the fuel (St-3).

4- Temperature of the engine Air (St-4).

5- Temperature of the engine block oil (St-5).

6- Speed sensor to measure the engine rpm (SV-1).

7- Load cell to measure the torque in Nm (Sf-1).

3.2.2 Orifice plate flow meters:

1- Inlet air the engine (Sc-1).

2-Outlet gases (Sc-2).

3.2.3 Rate of fuel consumption

Flow meter to measure the fuel consumption ranges between 0-42ml/min. It is a glass tube containing two holes, one of them to enter the fuel and the other for the exit of the fuel to the carburetor. It contains the control valve which is in the fuel entry into the carburetor, as shown in Figure (3.11).

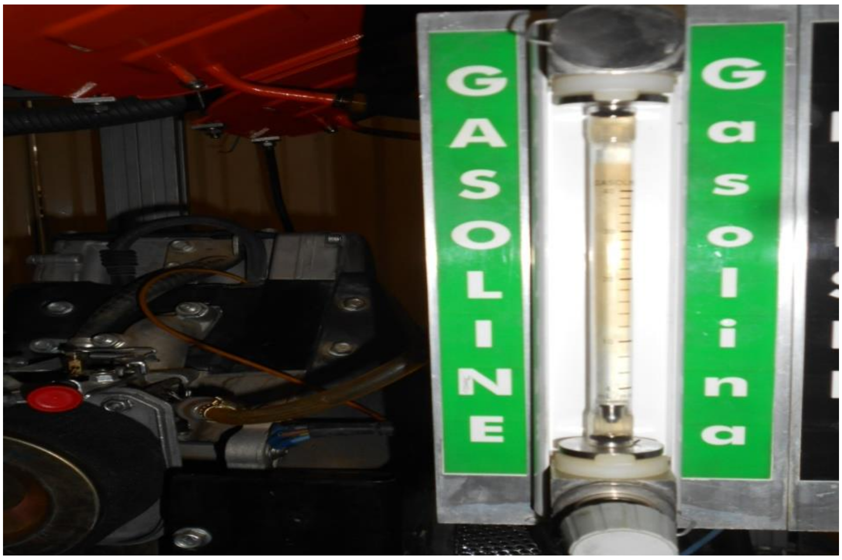

Figure 3.11 Flow Meter[39]

3.3 Fuel Used:

In this research, the outcome of adding ethanol(C2H6OH) with purity 99.9% to gasoline 750(C8H18) and gasoline 450(C6H6) with different volumetric rates (E0, E10, E20, E30, E40, E50) on engine performance and emissions pollutants of SI engine is analyzed. Therefore, it was appropriate to conduct some laboratory tests on the available ethanol-gasoline (750,450). Also, the fuel produced by mixing ethanol - gasoline (750,450) in the proportions mentioned previously. The density, as well as the octane number for each kind of fuel used is known. Use device (IROX2000), machine examination octane number found in the company's central oil products Al-Sada Al-Indian in Babylon. Tables (2a and 2b) show the test results of fuel used and also, Table (3-3) shows the characteristics of ethanol and gasoline.

Table 3-2a Results Tests of fuel

Fuel kind (750)						
	E0	**E10**	**E20**	**E30**	**E40**	**E50**
Density (kg/m^3)	765	767.5	769.8	772.2	774.6	777
Octane Number	91	94.1	95.7	97.3	98.9	101.5

Table 3-2b Results Tests of Fuel

Fuel kind (450)						
	E0	**E10**	**E20**	**E30**	**E40**	**E50**
Density (kg/m^3)	724	730.5	737	743.5	750	756.4
Octane Number	76	80.6	83.7	86.8	89.9	93

Table 3-3 Characteristics of gasoline and ethanol

Property	**Gasoline (450)**	**Gasoline (750)**	**Ethanol**
Formula (liquid)	C_6H_6	C_8H_{18}	C_2H_6OH
Density (kg/m^3)	724	765	785
Heat of vaporization(kJ/kg)	302	305	840
Specific heat (kJ/kg.k)	2.4	2.4	1.7
Heat Value(kJ/kg)	42600	44000	26900
Stoichiometric air –fuel ratio	14.6	15.13	9.00
Octane Number	76	91	107
Freezing Point C^0	-40	-40	-114
Boling Point C^0	78	27-225	27-225

3.4 Experimental Procedure:

Step-1: Before starting, there should be guarantee that there is no oil in the tank engine, because of the influence of oil remaining in the tank on the values of the readings. In this first step, it must be certain that all the connections are correctly stiffened.

Step-2: Supply the first kind of fuel to be tested by a gasoline type 750 (0E) about 1000 ml at the engine tank as shown Figure (3.12). For example to obtain the 10E – 90G mixture, the ethanol is added to the beaker to the level of 100 and gasoline is added to the level 1000. Then the blend is well mixed and the obtained mixture is supplied to the engine tank. The mixing process is a volume mixing.

Figure 3.12 Step-2 Supply the first type of fuel is a test by a gasoline type 750 (0E) about 1000(ml) in the engine tank

Step -3: Start the software SCADA TBMC -12 program before starting the engine to be positive that there is no flaw in the program, as shown in Figure(3.13).

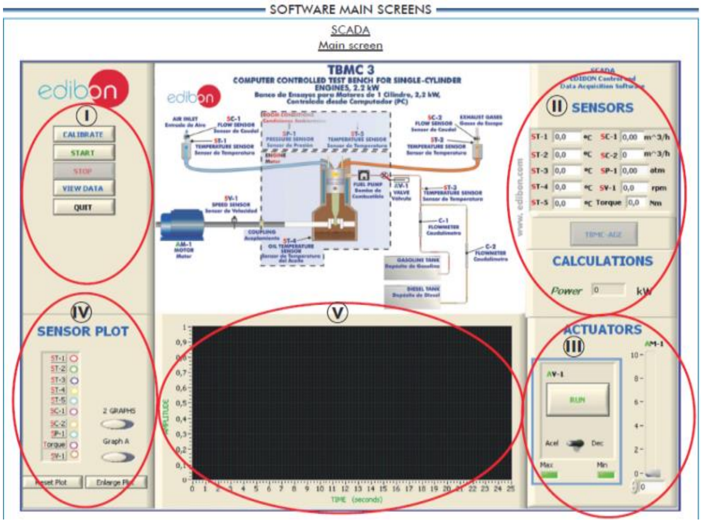

Figure 3.13 Software main Screens [39]

Step-4: Open fuel valve fully (**AV-1**) and then ensure that the fuel has been arrived to the carburetor. Figure (3.14).

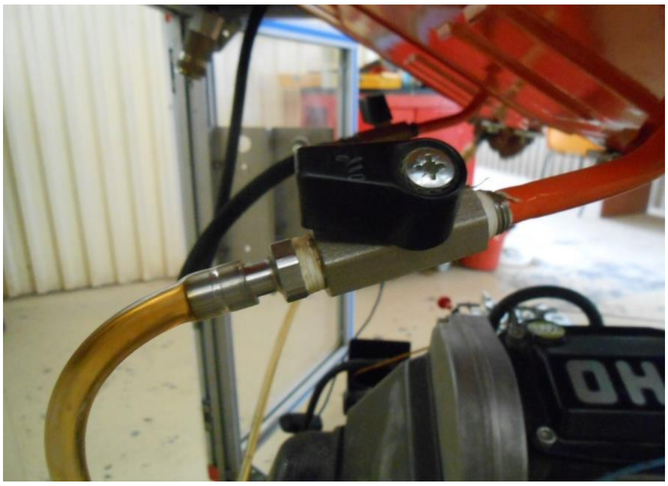

Figure 3.14 Fuel Valve

Step -5: Start the engine by switching on the key in the gray box, and then keep the engine running for (3-5) minutes to steady the combustion process in the engine. When observing that the different sensors maintain their values stable, record them by the software. Also, measure the consumption value of the fuel ($\dot{m}_f$), and the values resulting from the combustion, when speed changes between (1500 to 2500) in case of without load.

Step -6: With load, to do it, activate the actuator AFR-1 during an approximate period of one minute. When observing that the different sensors maintain their values stable, record them by the software. Compute the torque for each position, the Bp and also the fuel consumption ($\dot{m}_f$).Then take a sample of the exhaust gases, show the results on the display device, as in Figure (3.15) and print the results by a printer especially within the exhaust gas analyzer.

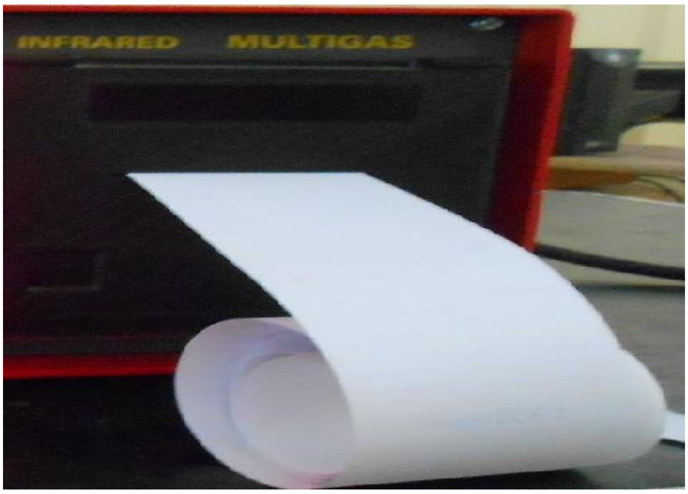

Figure 3.15 Results printerexhausts gas analyzer

Step -7: Repeat all of the steps (1-6) for the other fuel (450) that was mentioned previously.

Step-8: Once the data record is finished, stop the engine by clicking the button (Stop Engine) of the software SCADA- TBMC.

3.5 Performance characteristics:

Brake specific fuel consumption (Bsfc) is defined as the ratio of mass flow rate of fuel to (BP) which calculated as (3-1)[40]:

$$Bsfc = \frac{\dot{m}f}{Bp} \dots\dots\dots\dots \left(\frac{kg}{kws}\right) \dots\dots\dots. (3-1)$$

Brake thermal efficiency (η_{Bth}) is described as the ratio of energy in the brake power to the fuel energy which calculated as (3-2) [40]:

$$\eta thb = \frac{Bp}{(LHV)\times \dot{m}f} \ldots\ldots\ldots\ldots\ldots\ldots (3-2)$$

Volumetric efficiency (η_v) is described as the ratio of the air truly produced at surrounding conditions to the swept volume of the engine which calculated as (3-3)[40,41]:

$$\eta v = \frac{ma}{\rho \times Vd} \ldots\ldots\ldots\ldots\ldots\ldots (3-3)$$

Equivalence ratio (ø) is defined as the actual ratio of fuel-air to ideal or stoichiometric fuel – air or it can find another relation which calculated as (3-4) [40,41]:

$$\emptyset = \frac{1}{\lambda} = \frac{FAa}{FAs} \ldots\ldots\ldots\ldots\ldots\ldots (3-4)$$

Air density which calculated as (3-5)[40,41]:

$$\rho = \frac{Pa}{T \times R} \ldots\ldots\ldots\ldots\ldots (3-5)$$

The brake power can be achieved directly from software.

3.6 Case Study:

Case studies at point at which the produce a higher brake power using (E50-G50) blend (750) load, speed engine 2500 rpm.

Brake specific fuel consumption (Bsfc) using equation (3-1).

$$Bsfc = \frac{\dot{m}f}{Bp}$$

$\dot{m}f$ = 6ml/min unit convert from ml/min to kg/sec for unit homogeneity use this equation

$$\dot{m}f = \frac{Sc3\times 10^{-6}}{60} \times \rho l = \frac{5.2\times 10^{-6}}{60} \times 777 = 6.734\times 10^{-5}\ kg/s$$

$$Bsfc = \frac{6.734\times10^{-5}}{1.30} = 5.18\times10^{-5}\,\frac{\text{kg}}{\text{kw.sec}}$$

Brake thermal efficiency (η_{Bth}) using equation (3-2).

$$\eta thb = \frac{Bp}{(LHV)\times \dot{m}f}$$

$$\eta thb = \frac{1.30}{35450\times6.734\times10^{-5}} = 0.544 = 54.4\%$$

Volumetric efficiency (η_v) using equation (3-3):

$$\eta v = \frac{ma}{\rho\times Vd}$$

ma = 40.10 m^3/h unit convert from m^3/h to kg for unit homogeneity

ma=$3.423\times10^{-4}\ kg$

$$\eta v = \frac{3.423\times10^{-4}}{1.10\times3.29\times10^{-4}} = 0.938 = 93.8\%$$

Equivalence ratio (ø) using equation (3-4)**:**

$$\emptyset = \frac{1}{\lambda}$$

$$\emptyset = \frac{1}{1.001} = 0.999$$

Air density (ρ) using equation (3-5):

$$\rho = \frac{Pa}{T\times R}$$

$$\rho = \frac{100.5}{315.5\times0.287} = 1.109\ \ m^3/kg$$

Chapter Four

Results and Discussion

4.1 Introduction:

This chapter examines the engine performance. The performance of the engine indicates the degree of success in transforming the stored chemical energy in the fuel into mechanical energy. The impact of two different concentrations of the ethanol – gasoline 750 and ethanol – gasoline 450 are studied. Also, the impact of several blends of ethanol-gasoline on the performance and emission characteristics for each of the above concentrations is analyzed. The blends used are as follow:

1- 0% ethanol – 100% gasoline (Pure gasoline case)
2- 10% ethanol – 90% gasoline
3- 20% ethanol – 80% gasoline
4- 30% ethanol – 70% gasoline
5- 40% ethanol – 60% gasoline
6- 50% ethanol – 50% gasoline

All the analysis was executed at two stages. The first stage with load and the second stage without load. Both of the cases are conducted at engine speeds rang between (1500-2500) rpm.

4.2 Engine performance for ethanol-gasoline 750 blends with load:

The calculations of the (Bsfc),(BP), (η_{bth}),(η_V) and (EGT) for ethanol – gasoline 750 blends at variable speeds were obtained.

Figure (4.1), shows the Bsfc at several engine speeds along with load at various blends. It was noticed that with the increase in the ethanol concentration, a decrease in the (Bsfc) may happen. This result is expected for the reason that ethanol has lower latent heat value (LHV) in comparison with gasoline 750, as illustrated in table (3-3). Another notice is that with the increase in engine speed with load, the (Bsfc) will decreases. The minimum (Bsfc)of 5.18×10^{-5} (kg/kw.sec), 5.19×10^{-5} (kg/kw.sec) and 5.39×10^{-5} (kg/kw.sec), were obtained at speed of 2500 for E50, 2250 for E50 and 2000 for E50 respectively. The variation between engine speed and (Bsfc) is almost linear.

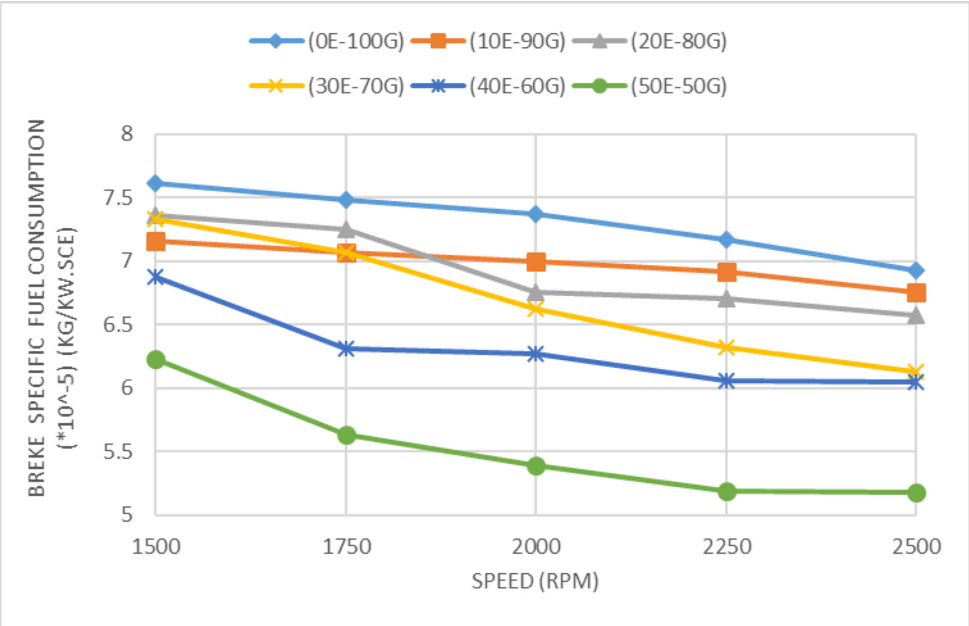

Figure 4.1 Brake specific fuel consumption opposed to engine speed at different blends with load

The power curve of the brake versus various engine speeds with load at several blends is considered as an important factor that validates the functioning of the engine. As displayed in Figure (4.2), ethanol-gasoline 750 blend has an impact on the brake power. The (BP) increases with the increase in the volume proportion of ethanol- gasoline750. It increased by 0.31kw for 10% blend, 0.43 kw for 20% blend, 0.47 kw for 30% blend, 0.51 kw for 40% blend, and 0.51 kw for 50% blend at several engine speeds(1500-2500) rpm. This result is reasonable because of the high evaporation heat (HOV) of ethanol measure up to gasoline (750), as presented in table (3-3). Ethanol's high heat of evaporation could provide cooling sensation for fuel-air charge; hence the density of the blend escalated and more BP might be obtained. Maximum (BP) output of 1.30 kW was obtained at engine speed 2500 rpm for E50. The (BP) begins to increase more as the ethanol content becomes more than 30 % at speed value of 2000 rpm and more.

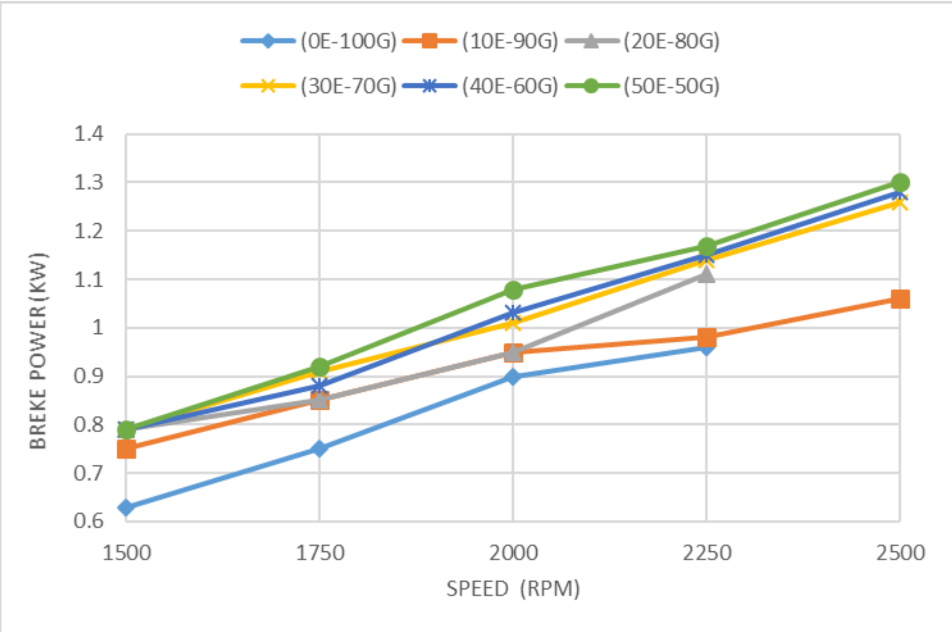

Figure 4.2 Brake power against engine speed at different blends with load

Figure (4.3), presents the η_{bth} against various engine speeds with load at different blends. The influence of ethanol–gasoline750 blends on η_{bth} is very clear. It may be viewed that η_{bth} rises as the engine speed increases for the same blend. Also, η_{bth} grows as the volume percentage of ethanol- gasoline750 increases. It increased by 4% for 10% blend, 5.4% for 20% blend, 6.9% for 30% blend, 5.4% for 40% blend and 9.2% for 50% blend at various engine speeds(1500-2500)rpm. This result is also expected due to the high heat of evaporation for ethanol against gasoline. Maximum η_{bth} was obtained at engine speed of 2500 rpm for E50. When the ethanol content is more than 40 %,η_{bth} begins to increase.

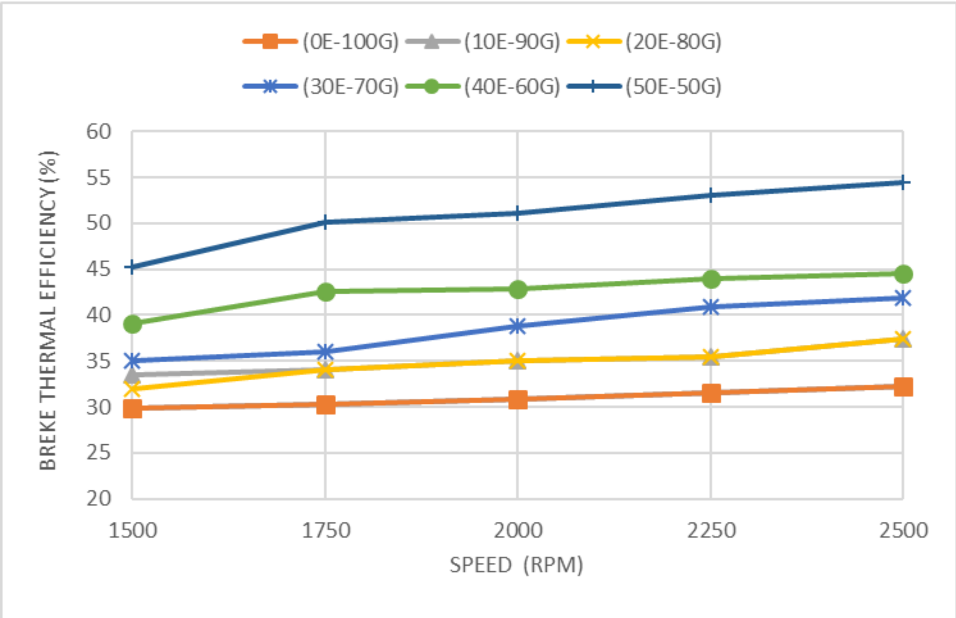

Figure 4.3 Brake thermal efficiency opposed to engine speed at different blends with load

Volumetric efficiency versus different engine speed with load at various blends is illustrated in Figure (4.4). The influence of using different blends ethanol-gasoline750 on η_V is noticed. It can be viewed that η_V increases as the volume percentage of ethanol increases. It increased by 1.1% for 10% blend, 0.6% for 20% blend 1.1% for 30% blend, 1.4% for 40% blend and by 1.5% for 50% blend. Ethanol's heat of vaporization is 2.76 times higher than the gasoline 750, as shown in table (3-3) and this reduces the intake manifold temperature and increases the η_V begins to increase more when ethanol-gasoline 750 blends are at 30%.

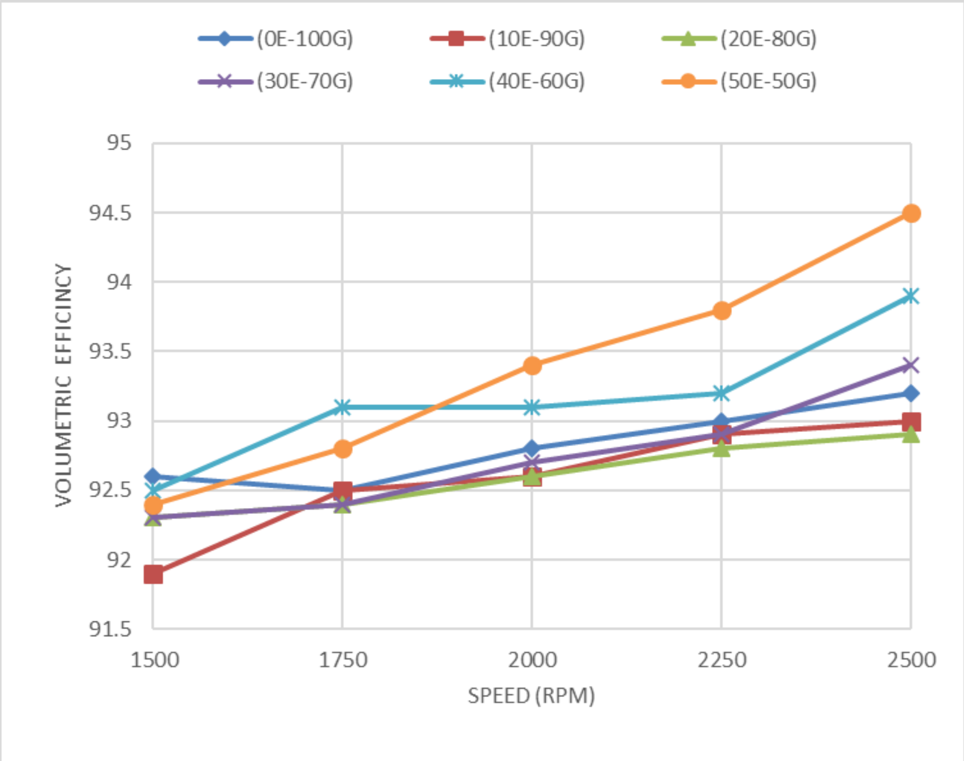

Figure 4.4 Volumetric efficiency versus engine speed at different blends with load

Exhaust gas temperature (EGT) versus various engine speeds with load at different blends is presented in Figure (4.5). The influence of ethanol- gasoline750 blends on EGT at variable engine speeds is clear. It can be noted that EGT increases as engine speed increases for the same blend. It’s became aware that EGT increases slowly at the engine speeds of 2000-2500 rpm, when measure up to pure gasoline 750 (E0). However, at engine speeds between 1750-2500 rpm, the results show an opposite effect where E30 shows the largest increase in EGT. It may indicate that EGT changes proportionally with the greatest cylinder temperature; because of the fact that ethanol has higher latent heat of vaporization than gasoline 750. This interpretation is correct for the speed at the range 2000-2500 rpm. However, for speed range between 1750-2500 rpm, E30 shows great rise in EGT.

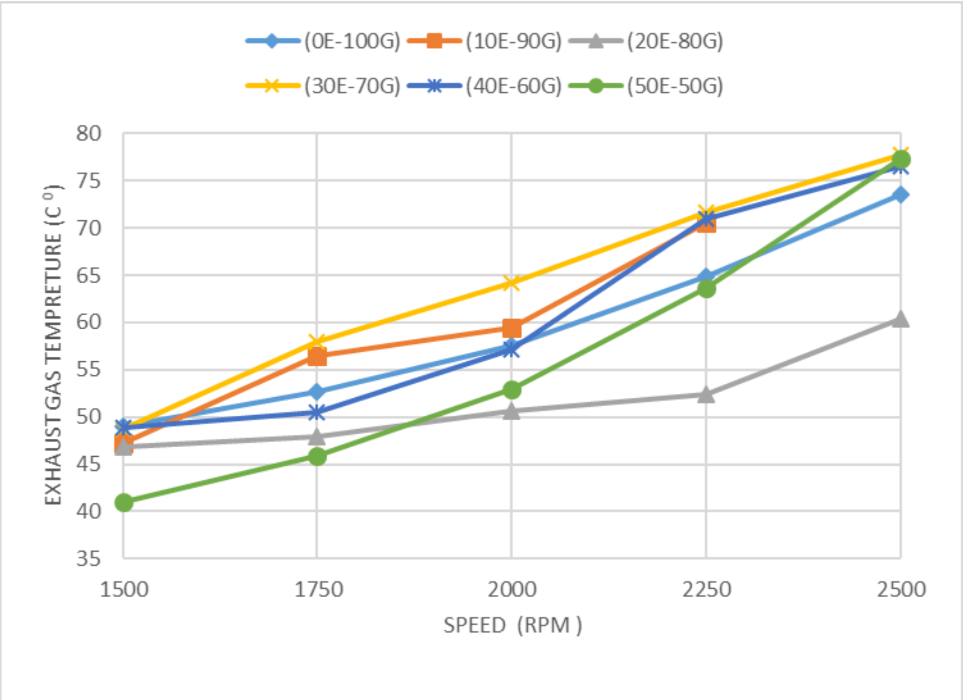

Figure 4.5 Exhaust gas temperatures versus engine speed at different blends with load

4.3 Emission characteristics for ethanol-gasoline750 blends with load:

The result of carbon-monoxide (%CO), carbon-dioxide (% CO2) and amount of hydrocarbon burns (HC ppm) for ethanol- gasoline750 blends versus various engine speeds with load are presented as following.

Carbon-monoxide versus variable engine speeds with load at various blends is presented in Figure (4.6). It can be viewed, that when ethanol–gasoline750 volume percentage increases, the concentrations of CO decreases. Furthermore, it is noticed that with blends between 20E-50E the emission of CO is lower compared with pure gasoline750 (0E) fuel. It can be clarified further more by enrichment of oxygen in ethanol. Ethanol has a high oxygen content that will enhance oxidation through the engine exhaust process. The CO emission begins to decrease when ethanol-gasoline750 at 20% blend and when the engine speed is more than 1750 rpm. Also it is noticed that at 1750 RPM the 10E-90G blend gives the highest value for CO. This result is due to the non-homogeneity between fuel-air normality at engine cycle number.

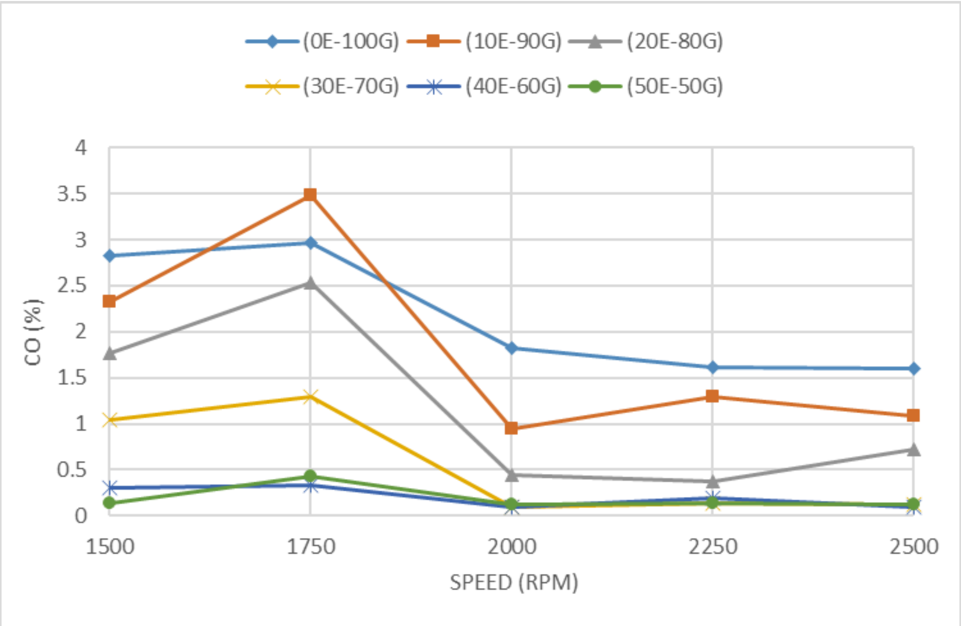

Figure 4.6 Carbon monoxide against engine speed at different blends with load

Carbon-dioxide versus various engine speeds with load at different blends is presented in Figure (4.7).The lowest CO2 emission value is 9.5% which was obtained at a concentration of 50E at 2000rpm. It can be viewed that there is a considerable decrease in concentrations of CO_2 emission when using volume percentage of ethanol- gasoline750 blends in comparison with pure gazoline750. The most noticeable reduction is noticed at E50-G50 blend. Because of the existence of maximum blends of additive in ethanol-gasoline750 blends.

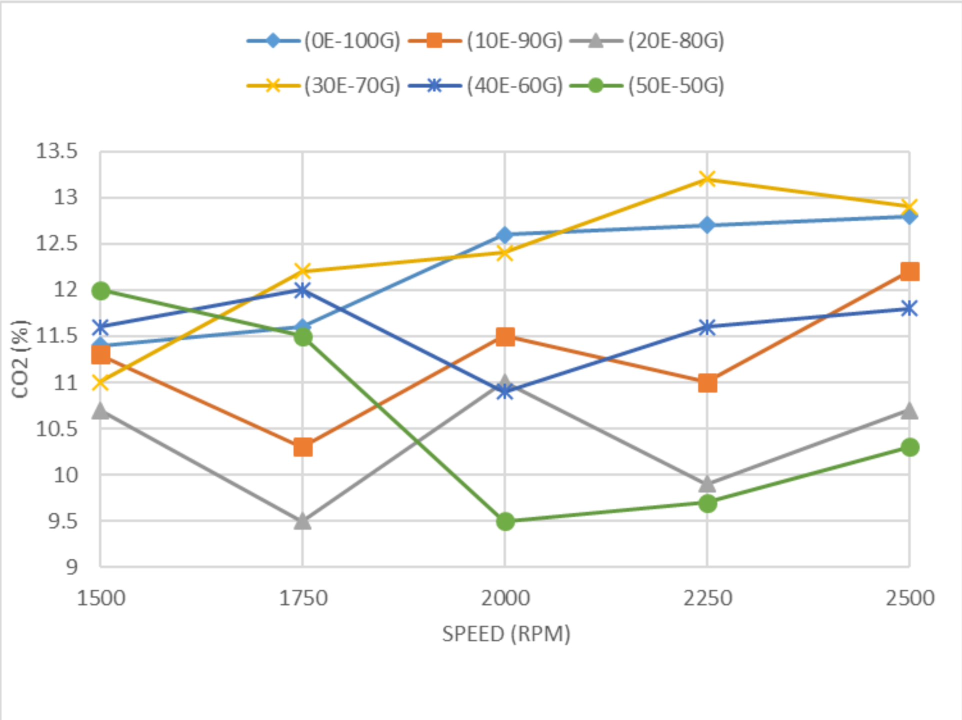

Figure 4.7 Carbon dioxide versus engine speed at different blends with load

Hydrocarbon burns (HC) versus different engine speed with load at different blends is shown in Figure (4.8). It can be seen that when ethanol volume proportion increases the volume of HC decreases as the engine speed increases. The amount of HC emission at all blends percentage is less when compared with pure gasoline750 at all different speeds. Because of the fact that, ethanol contains less flame speed when compared to pure gasoline750 fuel operation. At E30-70G, the volume of the HC emission is 10ppm at 2500rpm which is the lowest obtained value for HC in this experiment.

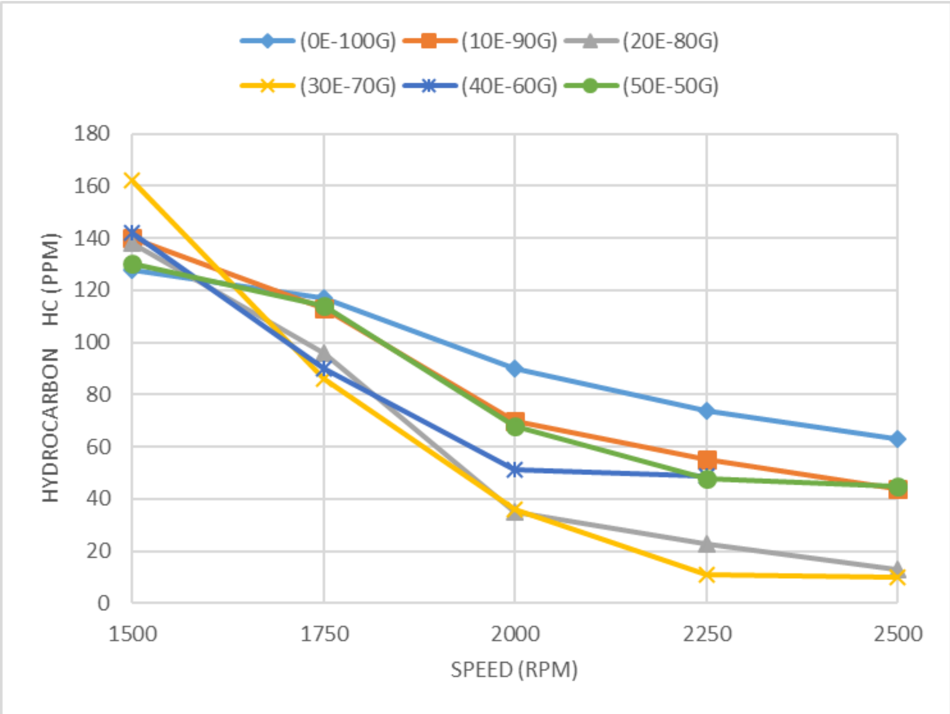

Figure 4.8 Hydrocarbon burn against engine speed at different blends with load

4.4 Engine performance for ethanol-gasoline450 blends with load:

The results of the following: Bsfc, BP, η_{bth}, η_V and EGT for ethanol – gasoline 450 blends at variable speeds were obtained.

Brake specific fuel consumption at different engine speeds with load at different blends is illustrated in Figure (4.9). It can be noticed that Bsfc drops as the engine speed rises due to the LHV of ethanol compared with gasoline450, as indicated in table (3-3). Minimum Bsfc of 5.24×10^{-5} (kg/kw.sec) was obtained for E50 at an engine speed of 2500 rpm. Bsfc has almost a linear relationship with engine speed.

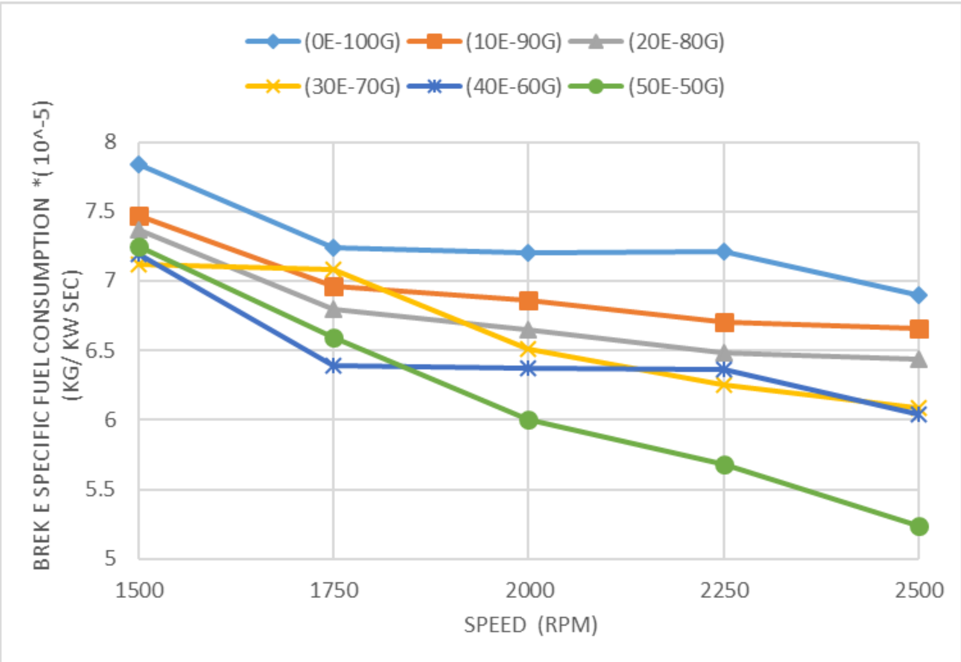

Figure 4.9Brake specific fuel consumption against engine speed at different blends with load

Brake power against different engine speeds with load at different blends is presented in Figure (4.10).BP increases as the volume proportion of ethanol- gasoline450 increases. It increased by 0.36 kw for 10% blend, 0.48 kw for 20% blend, 0.51 kw for 30% blend, 0.50 kw for 40% blend and 0.52 kw for 50% blend at various engine speeds(1500-2500) rpm. Because of the higher heat of evaporation of ethanol in comparison to gasoline 450 as shown in table (3-3). As explained before, the high heat of evaporation could provide cooling for fuel-air charge, hence the blend density increases and eventually, BP increases. Maximum BP output of 1.25 kw was noticed at engine speed of 2500 rpm for E50. BP begins to increase more when ethanol content is more than 20 %.

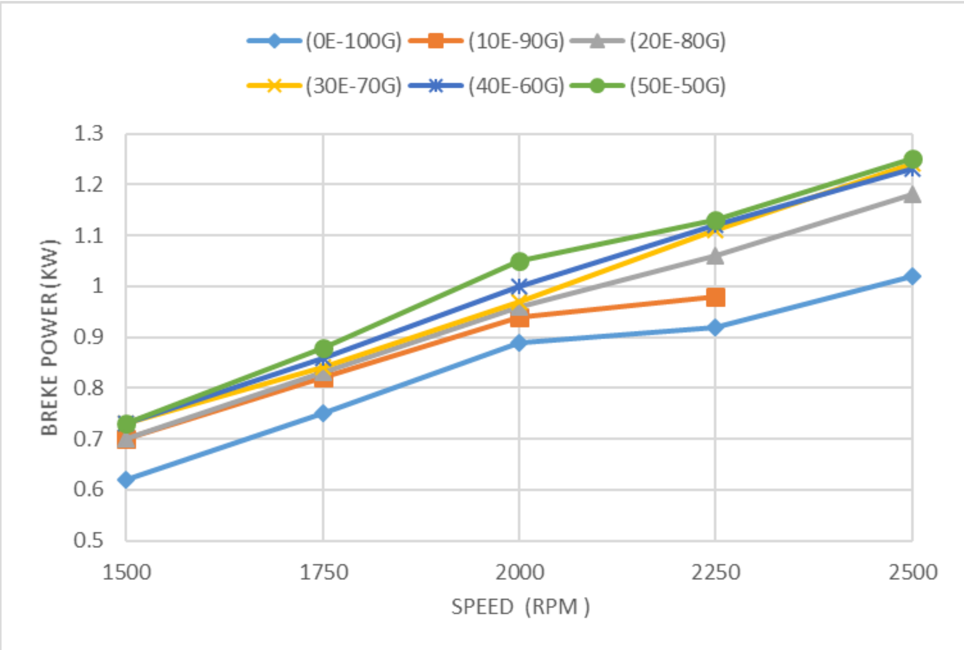

Figure 4.10 Brake power versus engine speed at different blends with load

The brake thermal efficiency versus different engine speeds with load at different blends is shown in Figure (4.11).η_{bth} increases as the volume percentage of ethanol-gasoline 450 increases. It can be viewed that η_{bth} increases as the engine speed increases. It increased by 3.7% for 10% blend 3.6% for 20% blend, 6.1% for 30% blend, and 7.1% for 40% blend and by 12.7% for 50% blends at various engine speeds (1500-2500) rpm. This is due to the heat of evaporation of ethanol is greater than that for gasoline450. Highest η_{bth} was observed at engine speed of 2500 rpm for E50. η_{bth} begins to increase more when ethanol content is 40%.

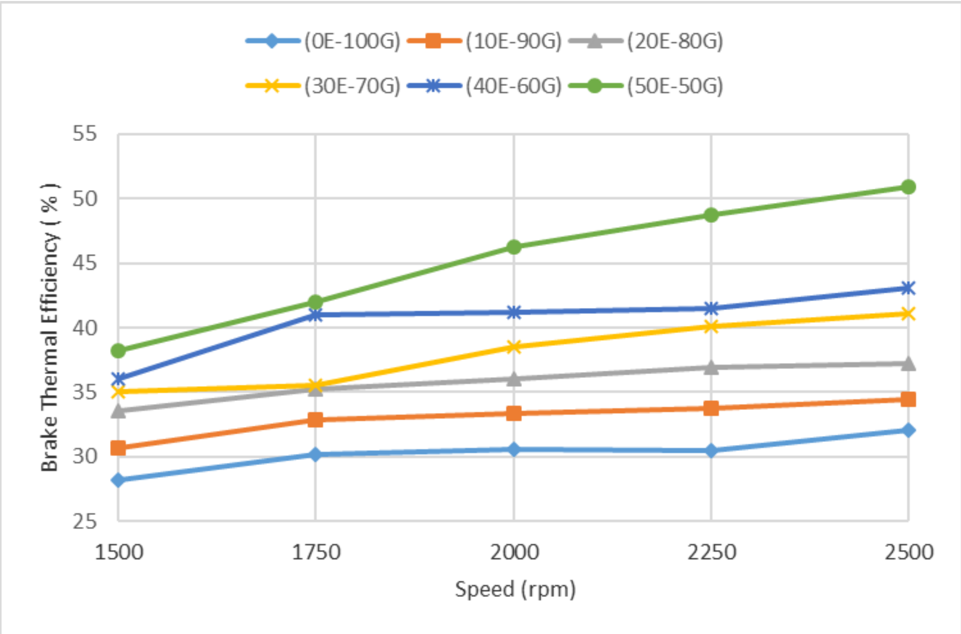

Figure 4.11 Brake thermal efficiency against engine speed at different blends with load

Volumetric efficiency versus various engine speeds with load at different blends is shown in Figure (4.12). It can be seen, that η_V increases as the volume percentage of ethanol increases. It increased by 1.1% for 10% blend, 0.4% for 20% blend, 1% for 30% blend, 1.2% for 40% blend and 1.8% for 50% blend at different engine speeds(1500-2500) rpm. Because of that ethanol has a heat of vaporization 2.75 times higher than that of gasoline450, as shown table (3-3). η_V begins to increase more when ethanol-gasoline450 blends at 30%.

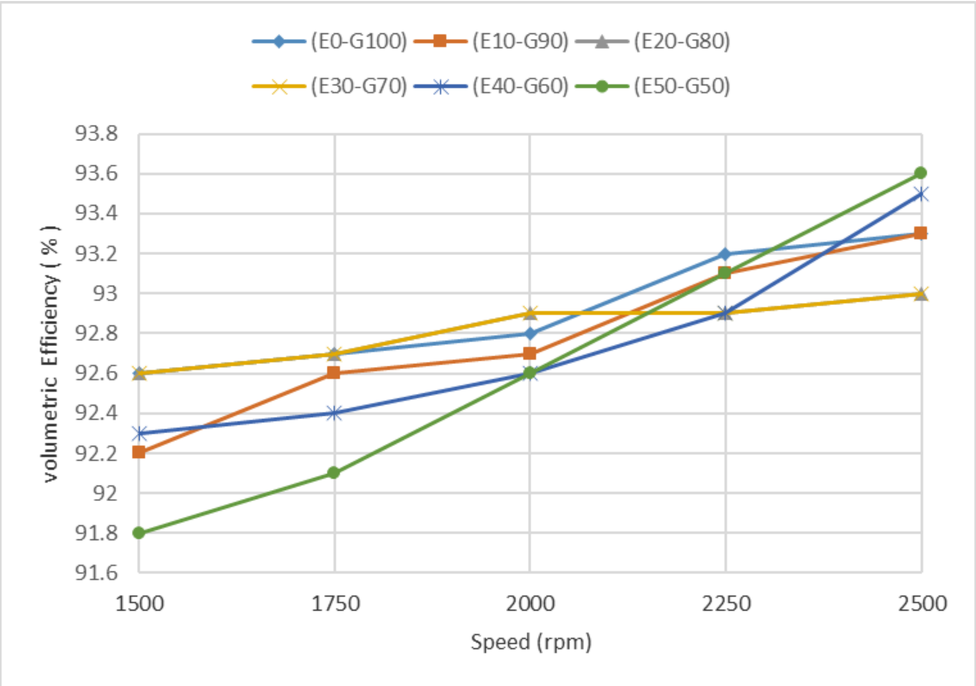

Figure 4.12 Volumetric efficiency versus engine speed at different blends with load

Exhaust gas temperature versus different engine speeds at different blends with load is shown in Figure (4.13). It can be viewed that EGT increases as engine speed increases for all blend fuels (E10-E50). It is observed that EGT increases slowly at the engine speeds of 2000-2500 rpm, when measure up to pure gasoline450 (E0). However, at the engine speeds of (1750-2500 rpm), results show an opposite effect where E30 shows the largest increase in EGT. It may indicate that EGT changes proportionally with the highest cylinder temperature. Because of the fact that ethanol has higher latent of vaporization than that of gasoline450. This interpretation is correct for the speed range 2000-2500 rpm. However, for speed range between 1750-2500 rpm, E30 shows great growth in EGT.

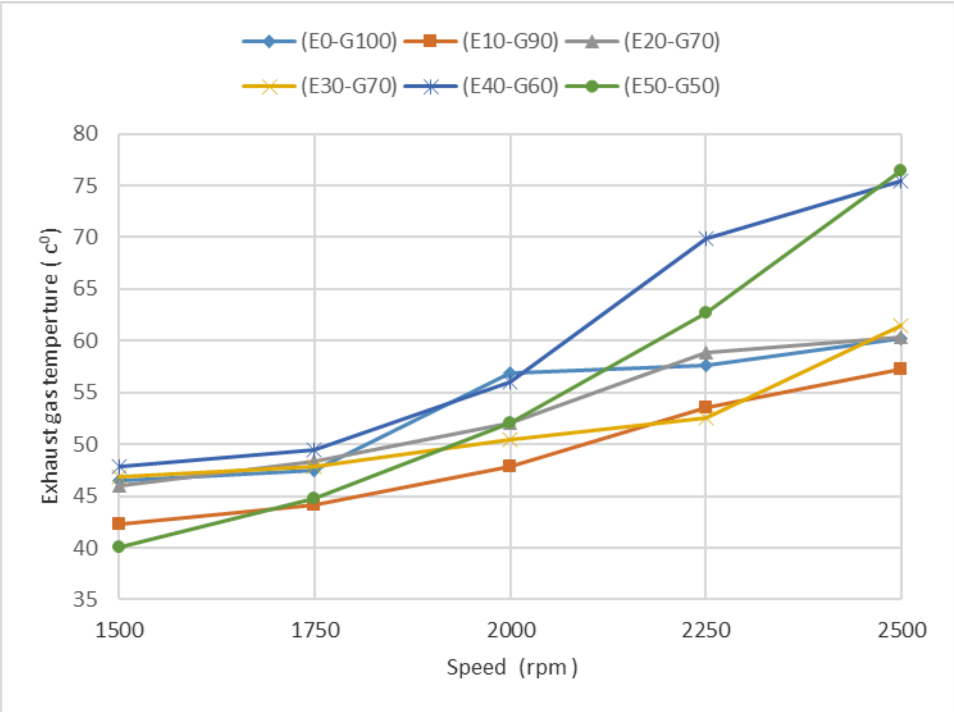

Figure 4.13 Exhaust gas temperature versus engine speed at different blends with load

4.5 Emission characteristics for ethanol-gasoline450 blends with load:

The result of carbon monoxide (%CO), carbon-dioxide (%CO2), and amount of hydrocarbon burns (HC ppm) for ethanol- gasoline450 blends versus various engine speed with load.

Carbon monoxide versus various engine speeds with load for different blends is presented in Figure (4.14). It can be viewed that when ethanol –gasoline450 volume proportion increases the concentrations of CO decreases. Also, it can be noticed that the lowest CO concentration was obtained at the blend E40-G60. It can be explained by enrichment of oxygen in ethanol. Ethanol has a high oxygen content that will enhance oxidation through the engine exhaust process. The CO emission begins to decrease when ethanol- gasoline450 is at 30% blend and when the engine speed is more than 1750 rpm. The concentration of CO emission is 0.08% at 1750rpm for E50, which is much lower than pure gasoline450.

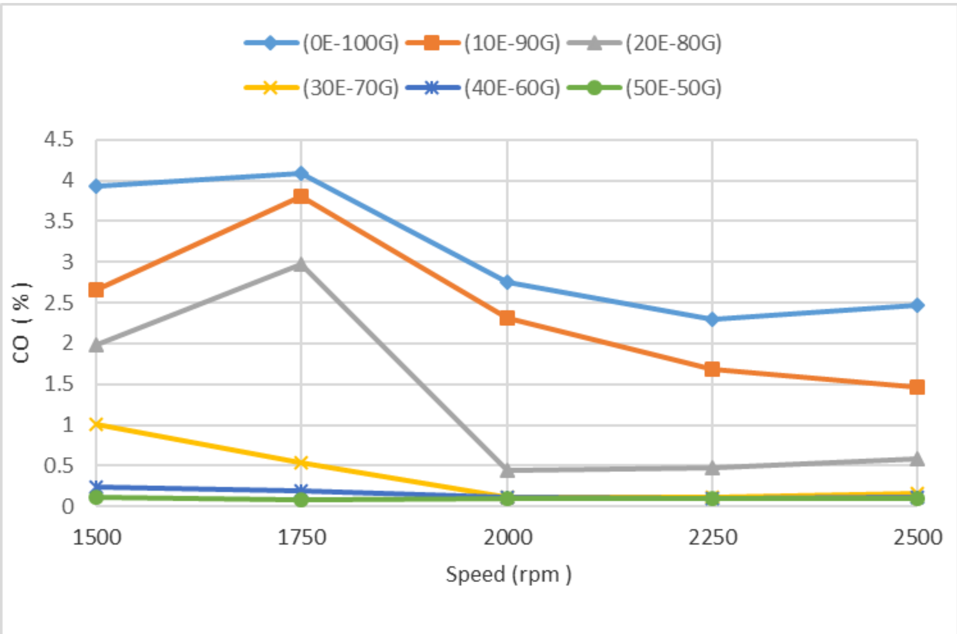

Figure 4.14 Carbon monoxide versus engine speed at different blends with load

Carbon-dioxide versus different engine speeds with load at different blends is shown in Figure (4.15). The lowest CO2 emission value is 8.6% which was obtained at a concentration of 50E at 2000rpm. It can be viewed that there is a great decrease in the concentrations of CO_2 emission when using volume percentage of ethanol- gasoline450 blends in comparison to pure gazoline450. The most noticeable reduction is noticed at E50-G50 blend. Because of the existence of maximum blends of additive in ethanol-gasoline450 blends.

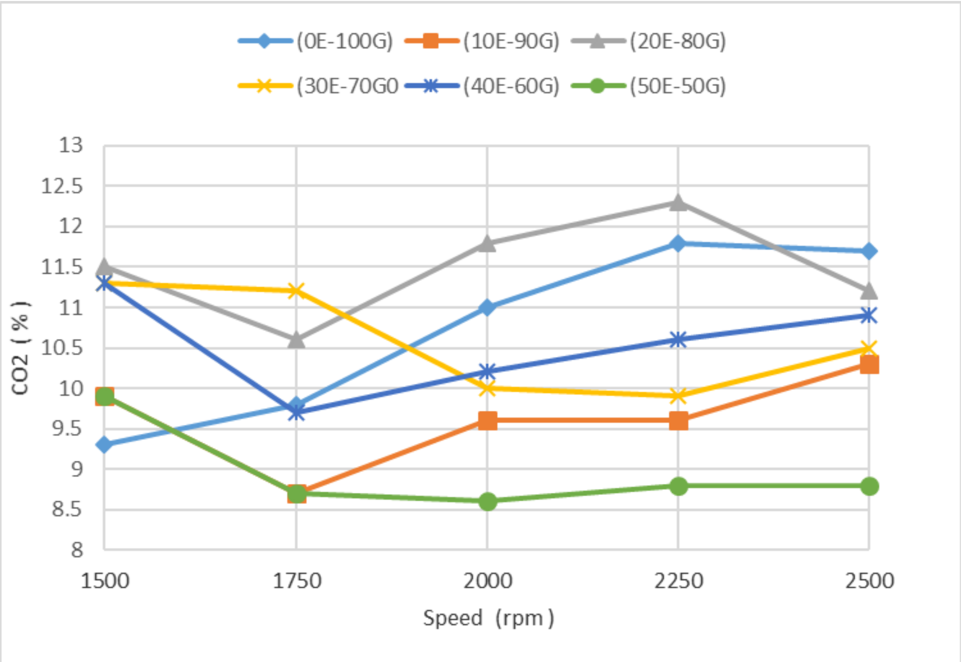

Figure 4.15 Carbon-dioxide versus engine speed at different blends with load

Hydrocarbon burn versus different engine speeds with load at different blends is shown in Figure (4.16). It can be viewed that when ethanol volume proportion increases, the amount of HC decreases as the engine speed increases. The content of HC emission at all blends percentage is less when compared with pure gasoline450 at all engine speeds. Because of the fact that, ethanol has less flame speed compared to pure gasoline450 fuel operation. At E30-70G, the volume of the HC emission is 25ppm at 2500rpm which is lowest obtained value for HC in this experiment.

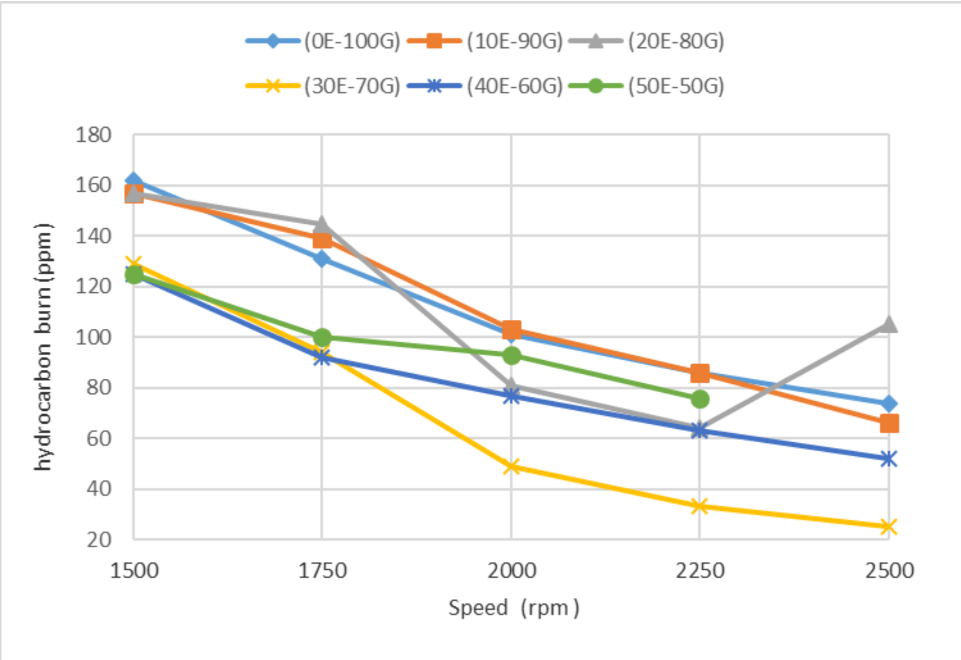

Figure 4.16 Hydrocarbon burn versus engine speed at different blends with load

4.6Engine performance and emission characteristics for ethanol-gasoline750 blends without load:

The results of SFC, carbon-monoxide (%CO) and carbon-dioxide (%CO2) for ethanol–gasoline 750 blends at different engine speeds without load are shown and investigated.

The variation of SFC versus the engine speeds without load at various blends is presented in Figure (4.17). It can be viewed that SFC increases as the engine speed increases. SFC decreases when compared with pure gasoline750 (E0) by adding ethanol. Because of the lower heat value of ethanol compared with gasoline750, as shown in table (3-3). The Minimum SFC value (2.55×10^{-5} kg/sec) was obtained at concentration of E10-G90 at speed of 1500 rpm**.**

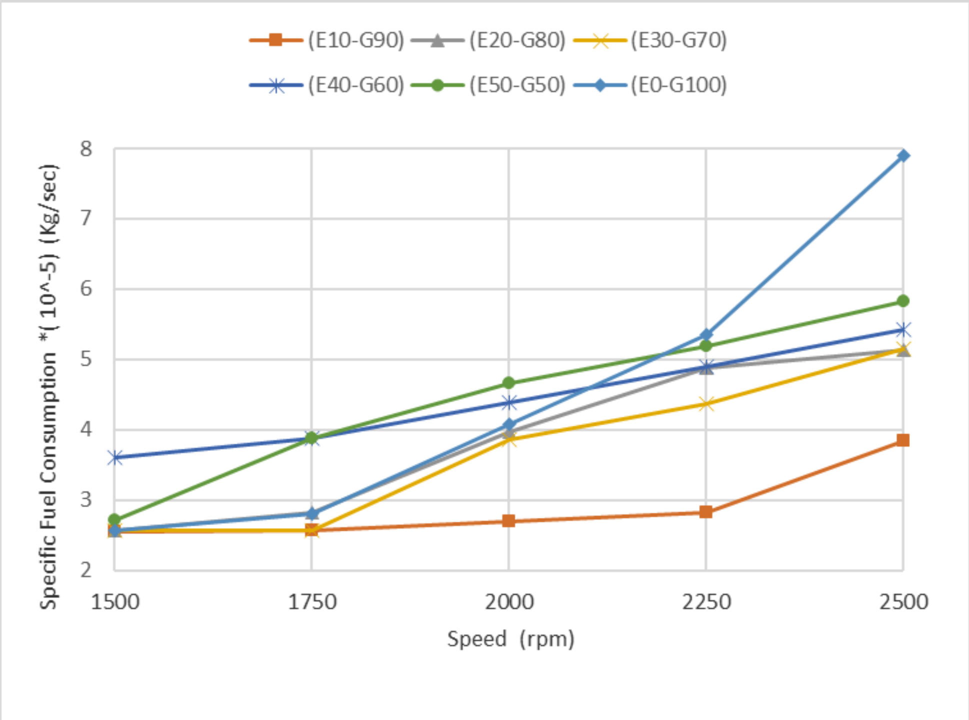

Figure 4.17 The variation of specific fuel consumption in relation to the engine speed at different blends without load

The variation of carbon- monoxide (CO) emissions in relation to the engine speeds without load at different blends is shown in Figure (4.18). It can be seen that when ethanol –gasoline750 volume ratio increases the concentrations of CO decreases when compared with pure gasoline 750(E0). It can be viewed that the fuel E30-G70 at 1500 rpm has the lowest CO emission (0.14%) and the emission is lower when compared with pure gasoline750 (0E) fuel. It can be explained by enrichment of oxygen in ethanol. Ethanol has a high oxygen content that will enhance oxidation through the engine exhaust process.

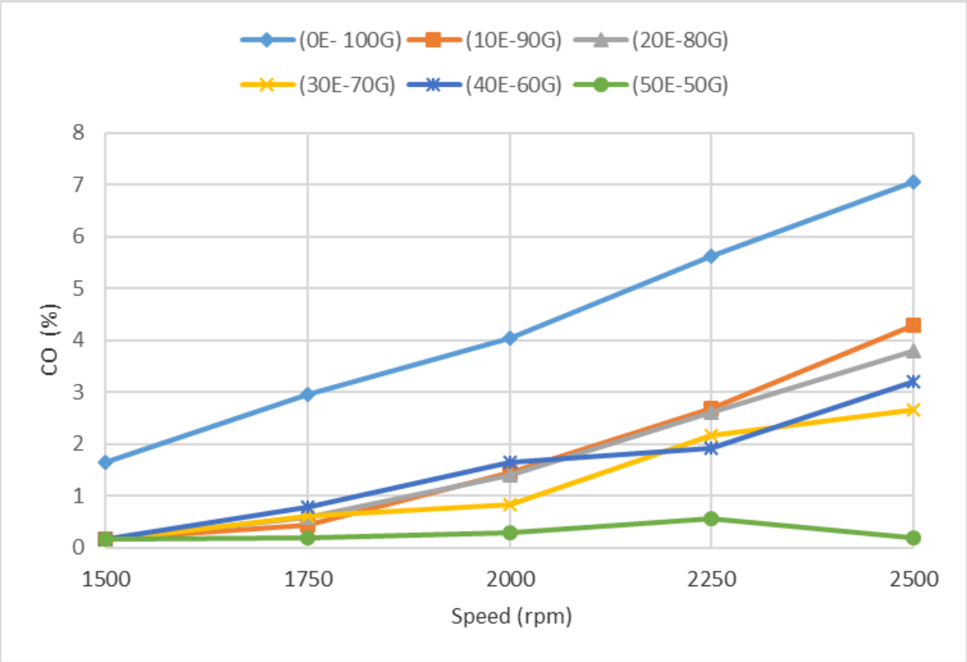

Figure 4.18 The variation of carbon monoxide (CO) emissions in relation to the engine speed at different blends without load

The variation of carbon-dioxide CO_2 emissions versus engine speeds without load at different blends is shown in Figure (4.19). The concentration of CO_2 value of 9.1% is minimum at 1500rpm for E50 and it is lower than pure gasoline750 (0E) fuel. It can be viewed that there is a significant decrease in concentrations of CO_2 emission when using volume ratio of ethanol- gasoline750 blends at speeds lower than 2000 rpm. As the engine speed increases above 2000 rpm, the CO2 concentrations start to increase as the ethanol concentration increases in the blend.

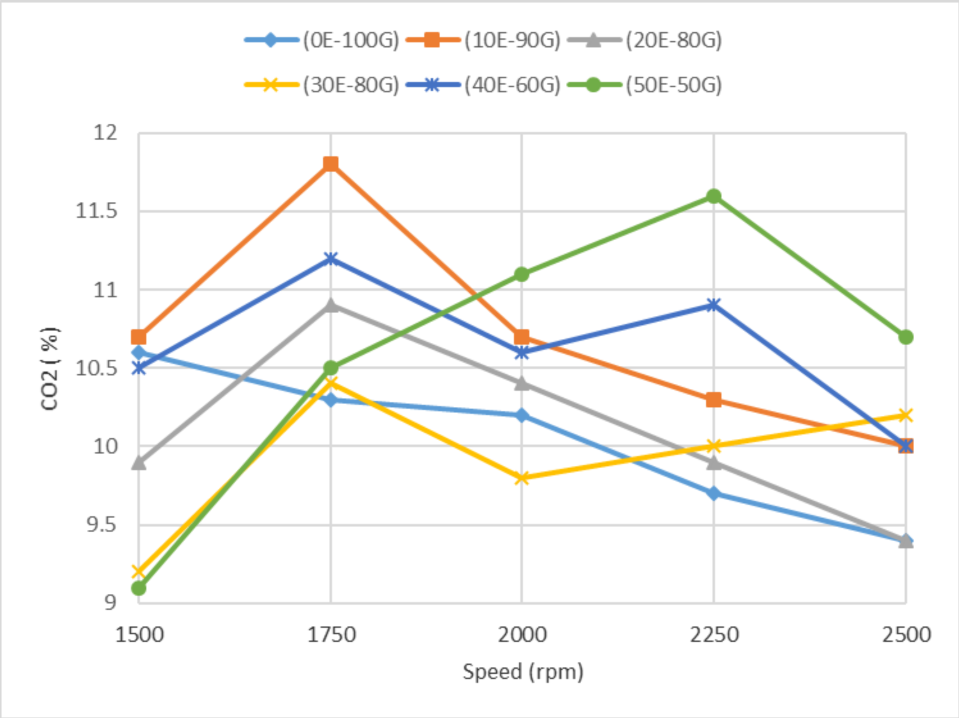

Figure 4.19 The variation of carbon dioxide CO2 emissions in relation to the engine speed at different blends without load

4.7 Engine performance and emission characteristics for ethanol-gasoline450 blends without load:

The results of SFC, carbon-monoxide (%CO) and carbon-dioxide (%CO2) for different ethanol–gasoline450 blends at different engine speeds without load are addressed and analyzed.

The variation of specific fuel consumption in relation to the engine speed without load at different blends is presented in Figure (4.20). It can be perceived that SFC increases as the engine speed increases for each blend. The lowest SFC (2.434×10^{-5} kg/sec) was observed at ethanol concentration of E10-G90 at the different engine speeds. At engine speed of 2250 rpm, SFC of the pure gasoline increases above the other blends.

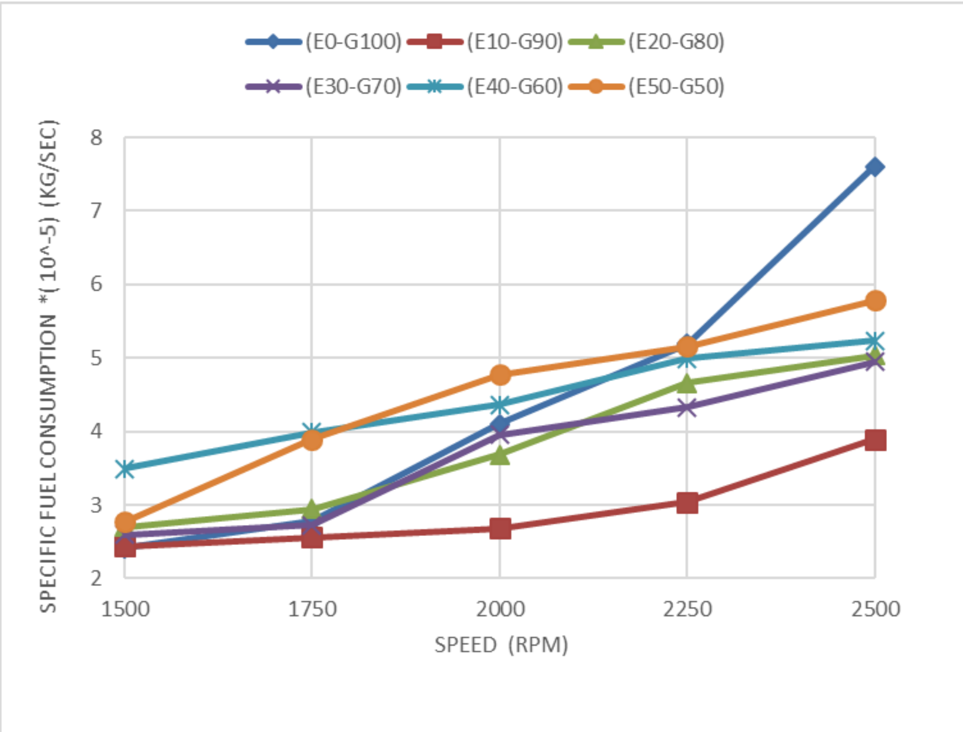

Figure 4.20 The variation of specific fuel consumption in relation to the engine speed at different blends without load

The variation of carbon-monoxide (CO) emissions in relation to the engine speeds without load at different blends is shown in Figure (4.21). It can be noted that when ethanol –gasoline450 volume ratio increases, the concentrations of CO decreases when compared with pure gasoline450. It can be viewed that the fuel E30-G70 at 1500 rpm yields the lowest CO concentration (0.15%) in the experiment and lower than the pure gasoline450 (0E) fuel. It can be explained by enrichment of oxygen in ethanol. Ethanol has a high oxygen content that will enhance oxidation through the engine exhaust process. The concentration of CO emission is 0.15% at 1500 rpm for E30, which is less than pure gasoline450.

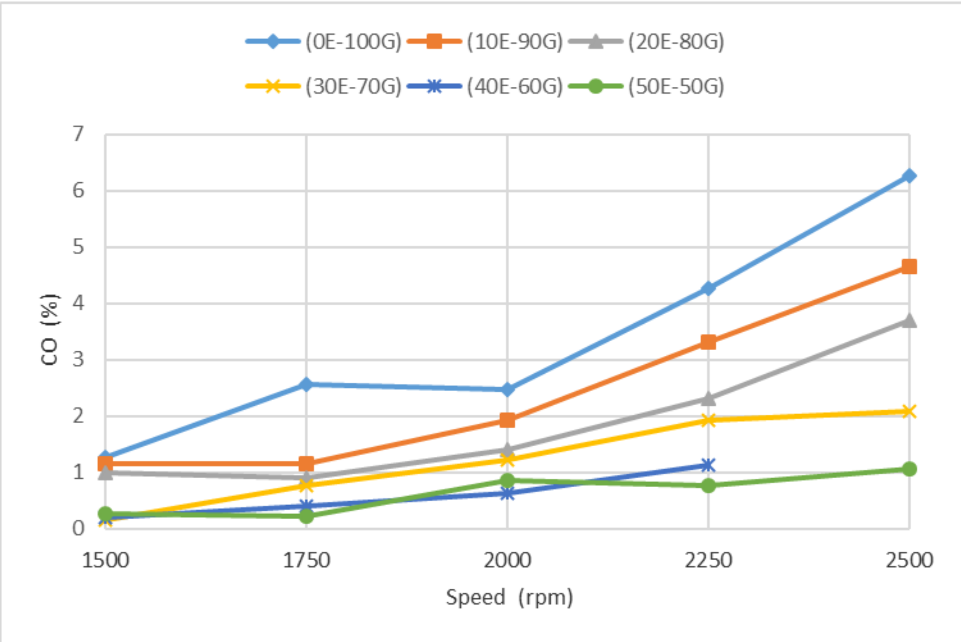

Figure 4.21 The variation of carbon monoxide (CO) emissions in relation to the engine speed at different blends without load

The variation of carbon-dioxide CO_2 emissions in relation to the engine speeds without load at different blends is shown in Figure (4.22). The concentration of CO_2 value is 8.1% at 1500rpm for E40, which is the lowest in this research and lower than pure gasoline450 (0E) fuel. It can be noticed that there is a substantial decrease in concentrations of CO_2 emission when using volume ratio of ethanol- gasoline450 blends, and there is a marked decline at concentration of E10-G90. Due to the existence of combination of blends additive in ethanol-gasoline450 blends.

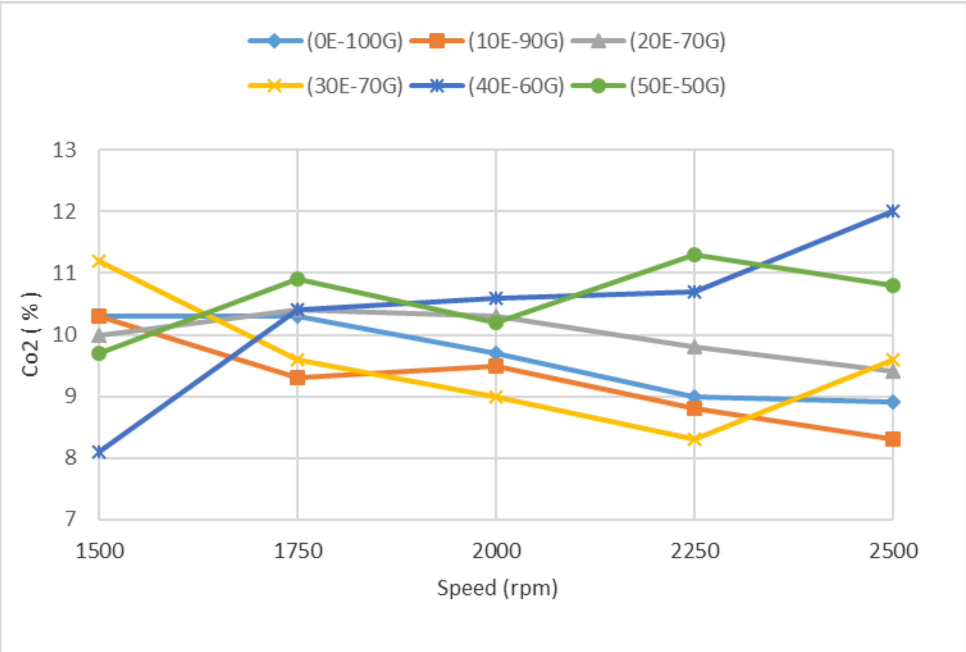

Figure 4.22 The variation of carbon dioxide CO2 emissions in relation to the engine speed at different blends without load

4.8 Comparative engine performance and emission characteristics for ethanol-gasoline 750 and 450 for different blends with load.

The results of η_{bth}, Bsfc, %CO and %CO2 for ethanol–gasoline750 and 450 at different blends and various engine speeds are investigated in this section.

Figure (4.23) shows the comparison results of Bsfc for ethanol-gasoline 750,450 versus engine speeds with load. It can be viewed that the minimum Bsfc value (5.18×10-5 kg/kw.sec) was obtained at engine speed 2500 rpm for ethanol- gasoline750 (E50-G50) blend. This means that Bsfc with ethanol-gasoline750 blend is lower than Bsfc of ethanol- gasoline450 blend. This is because of the heat value of ethanol -gasoline750 blends slightly higher than ethanol-gasoline450 blends as shown in table (3-3)

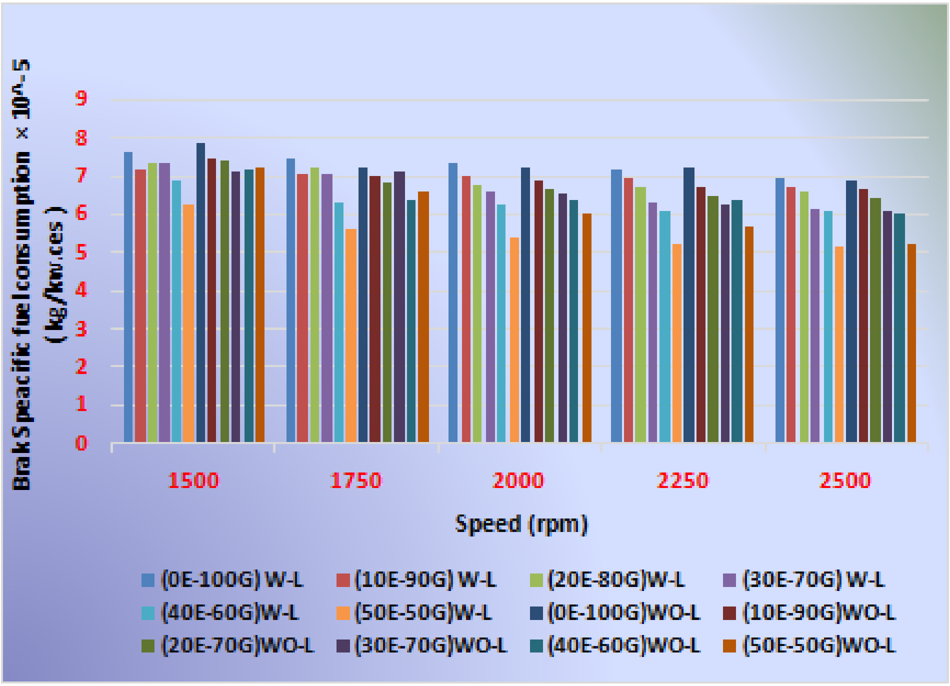

Figure 4.23 Shows the comparison results of brake specific fuel consumption for ethanol- gasoline 750,450 versus engine speeds at different blends with load

Figure (4.24) shows the comparison results of performance η_{bth} for ethanol- gasoline 750,450 blends versus engine speeds with load. It can be viewed that the maximum η_{bth} (54.4%) value was obtained for ethanol-gasoline750 (E50-G50) blend at engine speed 2500 rpm. It means that η_{bth} for ethanol-gasoline750 blends is more that for ethanol- gasoline450. The reason is due to the heat of evaporation of ethanol -gasoline750 blends is higher than ethanol-gasoline 450 blends, as shown in table (3-3).

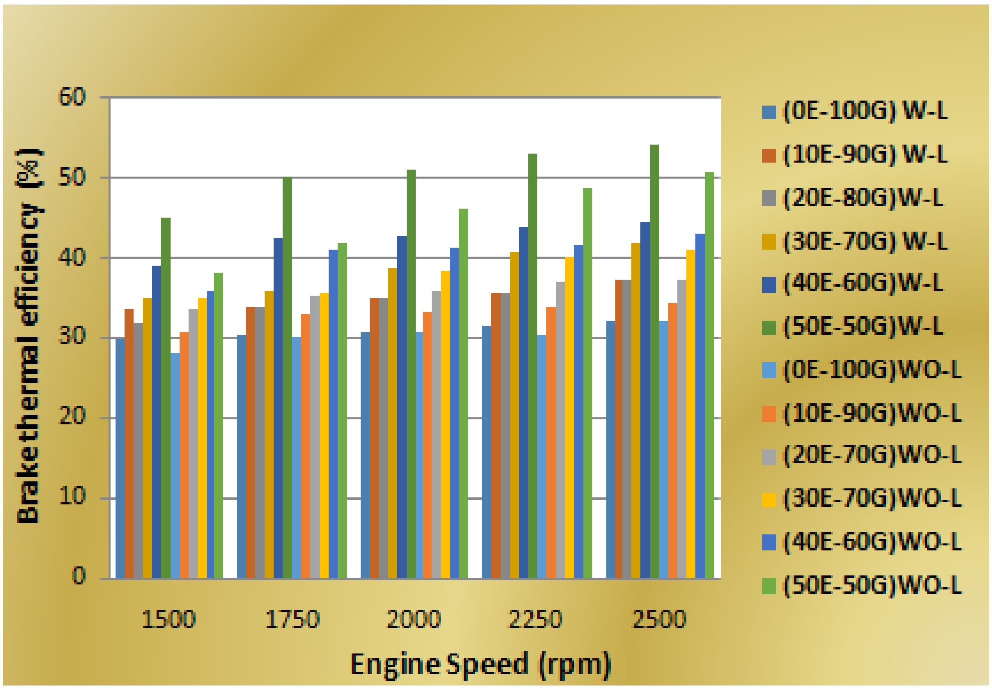

Figure 4.24 The comparison results of performance brake thermal efficiency for ethanol- gasoline 750,450 blends versus engine speed at different blends with load

Figure (4.25) shows the comparison results of carbon-monoxide (CO) emission for ethanol- gasoline 750,450 blends versus engine speeds with load. It can be seen that both ethanol-gasoline750 and 450 blends are decreasing the CO concentration. The minimum CO was obtained for ethanol - gasoline450 at engine speed 1750 rpm for (E50-G50) when comparing with all other blends fuel.

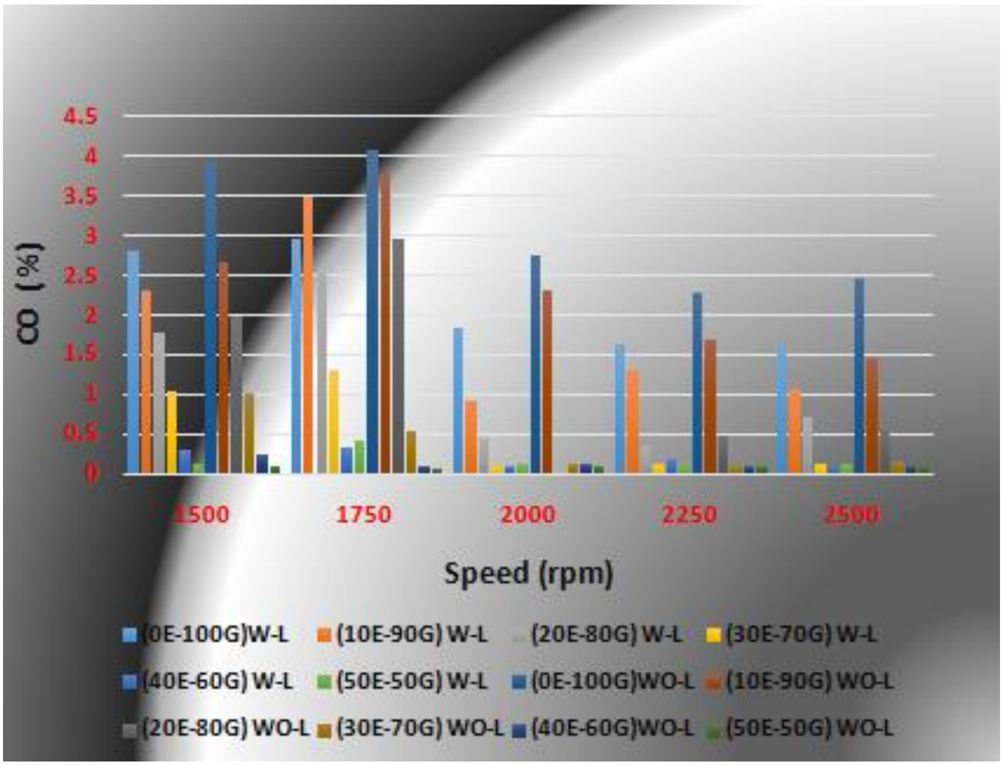

Figure 4.25 The comparison results of carbon monoxide (CO) emission for ethanol- gasoline 750,450 blends versus engine speed at different blends with load

Figure (4.26) shows the comparison results of carbon- dioxide (CO_2) emission for ethanol- gasoline 750,450 blends versus engine speeds with load. It can be viewed that the minimum CO_2 of 8.6% is obtained for ethanol- gasoline450 blends (E50-G50) at engine speed 2000rpm, comparing with ethanol- gasoline750 blend at the same engine speed.

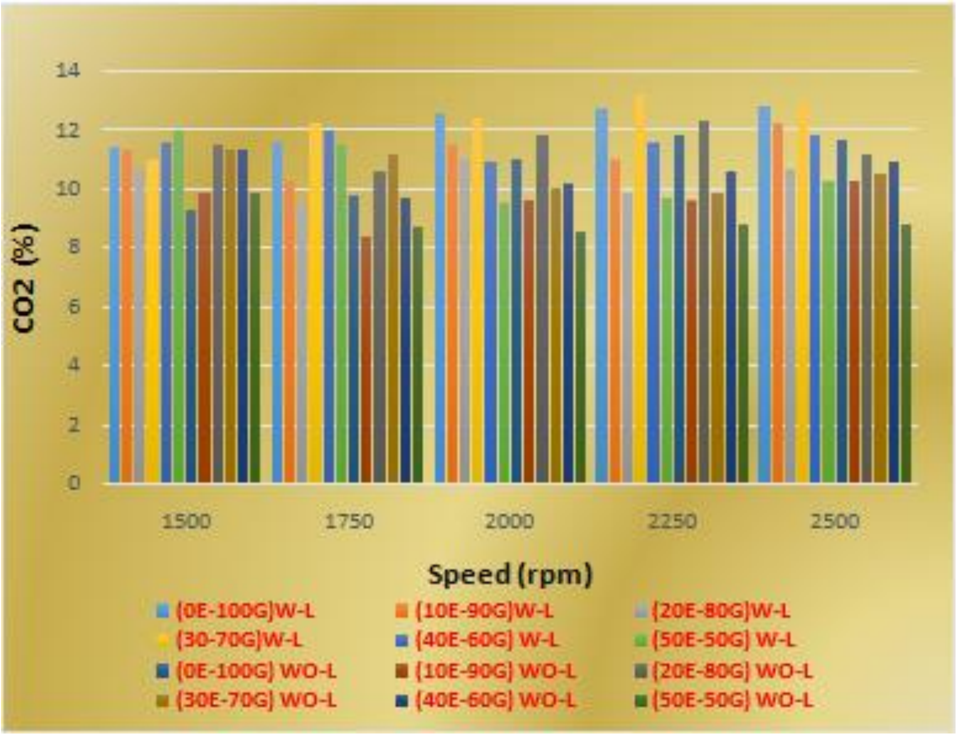

Figure 4.26 The comparison results of carbon dioxide (CO2) emission for ethanol- gasoline 750,450 blends versus engine speed at different blends with load

In 2009, Talal et al. [42] have conducted experimental analysis about the effects of ethanol gasoline blends on SI engine performance. The engine is a 4 cylinder 4 stroke with 8 valves. They have studied the following ethanol-gasoline blends: E0 –G100, E5-G95, E10-G90, E15-G85 and E20-G80. Comparing their results with the ones obtained in this study, the following notes can be drawn:

Engine Performance:

1-η_{bth} in this study has increased by 6.4 % at E20-G80 and at engine speed of 2500 rpm.
2-Bsfc has decreased by approximately 1% in the present study at E20-G80 and speed of 2000 rpm.
3-$\eta_V$in this study had increased by 9.6% E20-G80 and at engine speed of 2500 rpm (at those conditions, their volumetric efficiency is maximum).

Engines exhaust emissions:

1-The CO emission concentration has decreased by 19.5 % in the present case at E20-G80 and speed 2000 rpm.
2-The HC has decreased by 91.3% in the present study at E20-G80 and at engine speed of 2500 rpm.
3-CO2 emission concentration gas reduced by 20.3% in the present case at E20-G80 and speed 2000 rpm.

Chapter Five

Conclusion and Recommendations

5.1. Conclusions

In this work, the influence of using ethanol–gasoline 750and 450 (E0, E10, E20, E30, E40, E50) blends for SI engine on the performance and emission characteristics with two cases load and without load are analyzed. The following can be concluded:

- Ethanol- gasoline750 and 450 blends fuel increase BP, Bsfc and η_V Also, Bsfc slightly decreases.
- Increasing the ethanol- gasoline750 and 450 blends fuel lead to decrease the CO, HC emissions.
- EGT increases as engine speed increase for all fuel types.
- The addition of up to %50 ethanol to gasoline (750 and 450) is investigated in our experiments without any trouble.
- Ethanol may be used as are placement fuel and it could be added to gasoline to improve the engine performance and emission in the engine operation.
- The minimum Bsfc of 5.18×10^{-5} (kg/kw.sec). It was obtained at engine speed 2500 rpm, for ethanol-gasoline750 blends (E50-G50).
- The maximum BP output of 1.30 KW was obtained at engine speed 2500 rpm, for ethanol-gasoline750 blends (E50-G50).
- The maximum η_{bth} and η_V of 54%, 93.9%, respectably, were obtained at engine speed 2500 rpm, for ethanol-gasoline750 blends (E50-G50) with load.
- The minimum CO of 0.08% was obtained for ethanol-gasoline 450 blends at engine speed 1750 rpm for (E50-G50) with load.
- The minimum CO2 of 8.6% was obtained for ethanol-gasoline 450 blends (E50-G50), at engine speed 1750 rpm with load.

- At ethanol- gasoline 750 blends (E30-G70), it is find that the minimum amount of the HC emission is (10ppm), at 2500 rpm with load.
- It is find that the best engine performance for ethanol- gasoline 750 blends and the best exhaust emission of ethanol-gasoline 450 blends.
- The best blend regarding environmental effects was the E30-G70 at 2500 rpm. In this case, the exhaust emissions are minimum.

5.2 Recommendations:

- Heating the inlet air into the engine to assure the vaporization of the whole blend which goes into the engine
- Conducting the experiments at various operational circumstances for the engine (such as changing the equivalent ratio, spark timing, compression ratio) and for various types of fuel and comparing the results with the current ones.
- Conducting the experiments on several types of engines and try to obtain the special carburetor for alcohol.
- Using several kinds of alcohol for example: methanol, propane, and others to produce different blends.

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Appendix A

Without add(E0-G100) 750 and without load

NO	rpm	St-1 C^0	St-2 C^0	St-3 C^0	St-4 C^0	St-5 C^0	Sc-1 m^3/h	Sc-2 m^3/h	Sc-3 Ml/min	Sp-1 mbar	%CO2	%CO	HC ppm	λ	Φ	ρ m^3/kg
1	1500	33.6	37.3	33.2	49.7	50.4	47.91	39.94	2	1041.05	10.6	1.64	91	0.935	1.069	1.183
2	1750	34.0	40.9	34.1	58.8	69.0	47.56	40.46	2.2	1036.30	10.3	2.96	103	0.905	1.104	1.176
3	2000	34.9	45.0	34.3	61.6	80.5	47.02	43.03	3.2	1030.55	10.2	4.05	106	0.861	1.16	1.166
4	2250	35.8	50.5	34.5	62.6	87.5	46.56	46.51	4.2	1026.89	9.7	5.61	122	0.829	1.20	1.158
5	2500	36.5	52.9	34.6	62.7	91.1	46.22	48.84	6.2	1023.37	9.4	7.05	133	0.796	1.25	1.153

Appendix A-1

With add(E10-G90) 750 and without load

NO	rpm	St-1 C^0	St-2 C^0	St-3 C^0	St-4 C^0	St-5 C^0	Sc-1 m^3/h	Sc-2 m^3/h	Sc-3 ml/min	Sp-1 mbar	%CO2	%CO	HC ppm	λ	Φ	ρ m^3/kg
1	1500	36.5	39.4	34.8	60.3	68.3	46.66	43.59	2	10331.44	10.7	0.18	273	0.986	1.01	1.163
2	1750	37.5	42.8	36.7	65.3	79.3	46.11	44.31	2	1027.67	11.8	0.43	126	0.978	1.02	1.153
3	2000	37.8	43.9	37.0	65.0	83.0	45.90	45.63	2.1	1025.40	10.7	1.45	111	0.946	1.05	1.149
4	2250	38.3	46.9	37.3	66.4	89.5	45.62	46.22	2.2	1022.50	10.3	2.68	086	0.909	1.10	1.144
5	2500	39.1	52.4	38.5	66.9	92.6	45.23	50.55	3	1019.30	10.0	4.28	092	0.951	1.05	1.137

With add(E20-G80) 750 and without load

NO	rpm	St-1 C^0	St-2 C^0	St-3 C^0	St-4 C^0	St-5 C^0	Sc-1 m^3/h	Sc-2 m^3/h	Sc-3 ml/min	Sp-1 mbar	%CO2	%CO	HC ppm	λ	Φ	ρ m^3/kg
1	1500	33.8	38.2	32.3	54.7	57.7	47.71	41.45	2	1038.92	9.9	0.17	143	0.984	1.01	1.179
2	1750	34.2	40.1	32.6	57.4	64.7	47.44	44.66	2.2	1035.16	10.9	0.58	195	0.967	1.03	1.174
3	2000	34.5	41.0	32.7	58.0	70.4	47.32	45.88	3.1	1034.80	10.4	1.39	231	0.935	1.06	1.172
4	2250	35.3	43.9	33.3	62.1	81.3	46.87	46.17	3.8	1030.29	9.9	2.60	072	0.918	1.08	1.164
5	2500	36.2	44.3	33.6	63.0	88.2	46.41	51.73	4	1026.67	9.4	3.80	077	0.863	1.15	1.156

Appendix A-3

With add(E30-G70) 750 and without load

NO	rpm	St-1 C^0	St-2 C^0	St-3 C^0	St-4 C^0	St-5 C^0	Sc-1 m^3/h	Sc-2 m^3/h	Sc-3 ml/min	Sp-1 mbar	%CO2	%CO	HC ppm	λ	Φ	ρ m^3/kg
1	1500	36.5	39.8	37.0	60.0	70.4	46.50	43.94	2	1029.94	9.2	0.14	161	0.993	1.00	1.159
2	1750	37.0	41.9	37.5	62.4	75.8	46.30	44.84	2	1028.73	10.4	0.60	354	0.965	1.03	1.156
3	2000	37.9	44.2	38.5	64.8	84.1	46.00	45.60	3	1026.02	9.8	0.83	102	0.959	1.04	1.152
4	2250	39.5	52.4	39.4	67.8	94.2	45.29	47.24	3.4	1022.60	10.0	2.17	104	0.923	1.08	1.140
5	2500	40.0	55.4	39.8	67.9	97.8	44.98	50.93	4	1019.22	10.2	2.67	088	0.909	1.10	1.134

Appendix A-4

With add(E40-G60) 750 and without load

NO	rpm	St-1 C^0	St-2 C^0	St-3 C^0	St-4 C^0	St-5 C^0	Sc-1 m^3/h	Sc-2 m^3/h	Sc-3 Ml/min	Sp-1 mbar	%CO2	%CO	HC ppm	λ	Φ	ρ m^3/kg
1	1500	34.7	40.1	32.7	56.7	60.2	47.08	44.63	2.8	1031.15	10.5	0.16	134	0.985	1.01	1.167
2	1750	35.1	41.3	33.2	58.9	66.3	46.90	45.90	3	1029.36	11.2	0.79	176	0.962	1.03	1.164
3	2000	36.5	43.3	35.5	63.7	80.6	46.22	46.05	3.4	1023.78	10.6	1.65	138	0.932	1.07	1.152
4	2250	36.9	44.7	35.4	62.9	84.8	46.07	47.80	3.8	1022.94	10.9	1.92	077	0.936	1.06	1.150
5	2500	37.3	46.3	35.5	63.3	87.8	45.89	48.14	4.2	1022.28	10.0	3.20	082	0.885	1.12	1.147

Appendix A-5

With add(E50-G50) 750 and without load

NO	rpm	St-1 C^0	St-2 C^0	St-3 C^0	St-4 C^0	St-5 C^0	Sc-1 m^3/h	Sc-2 m^3/h	Sc-3 ml/min	Sp-1 mbar	%CO2	%CO	HC ppm	λ	Φ	ρ m^3/kg
1	1500	36.1	43.4	34.9	56.1	53.7	46.75	48.78	2.8	1032.92	9.1	0.17	493	0.961	1.04	1.164
2	1750	37.9	49.8	38.3	64.2	72.3	45.76	49.67	3	1023.09	10.5	0.19	539	0.971	1.02	1.146
3	2000	39.2	53.5	40.0	66.7	81.9	45.05	50.67	3.6	1015.84	11.1	0.29	423	0.975	1.02	1.133
4	2250	40.4	56.2	40.9	68.5	89.5	44.44	51.29	4	1010.06	11.6	0.56	308	0.972	1.02	1.122
5	2500	40.9	56.2	41.0	69.1	93.1	44.14	53.65	5	1006.15	10.7	0.20	145	0.992	1.00	1.116

Appendix A-6

Appendix B

Without add(E0-G100) 450 and without load

NO	Rpm	St-1 C^0	St-2 C^0	St-3 C^0	St-4 C^0	St-5 C^0	Sc-1 m^3/h	Sc-2 m^3/h	Sc-3 Ml/min	Sp-1 mbar	%CO2	%CO	HC ppm	λ	Φ	ρ m^3/kg
1	1500	34.3	37.1	34.3	49.2	58.1	47.31	38.94	2	1033.27	10.3	1.26	121	0.945	1.05	1.171
2	1750	34.7	38.9	35.1	55.5	62.9	47.04	39.45	2.3	1030.11	10.3	2.56	107	0.904	1.10	1.166
3	2000	35.4	39.4	35.7	56.3	68.6	46.79	42.03	3.4	1028.20	9.7	2.46	199	0.906	1.103	1.162
4	2250	35.7	40.0	36.1	58.9	73.6	46.73	45.50	4.3	1026.97	9.0	4.26	146	0.850	1.17	1.160
5	2500	36.0	43.0	36.8	59.7	78.7	46.45	47.88	6.3	1025.40	8.9	6.26	127	0.788	1.26	1.156

With add(E10-G90) 450 and without load

NO	rpm	St-1 C^0	St-2 C^0	St-3 C^0	St-4 C^0	St-5 C^0	Sc-1 m^3/h	Sc-2 m^3/h	Sc-3 Ml/min	Sp-1 mbar	%CO2	%CO	HC ppm	λ	Φ	ρ m^3/kg
1	1500	33.7	38.4	34.0	43.8	52.2	47.61	30.76	2	1035.43	10.3	1.16	147	0.947	1.05	1.176
2	1750	34.6	39.0	35.1	54.7	58.0	47.23	33.39	2.1	1033.20	9.3	1.16	245	0.945	1.05	1.170
3	2000	35.3	41.8	35.7	59.0	61.1	46.87	34.83	2.2	1030.37	9.5	1.93	080	0.927	1.07	1.164
4	2250	36.0	43.8	36.2	61.6	67.8	46.49	39.59	2.5	1026.33	8.8	3.32	077	0.869	1.15	1.157
5	2500	36.3	44.9	36.4	62.2	70.5	46.28	40.41	3.2	1024.14	8.3	4.65	080	0.834	1.19	1.153

Appendix B-2

With add(E20-G80) 450 and without load

NO	rpm	St-1 C^0	St-2 C^0	St-3 C^0	St-4 C^0	St-5 C^0	Sc-1 m^3/h	Sc-2 m^3/h	Sc-3 Ml/min	Sp-1 mbar	%CO2	%CO	HC ppm	λ	Φ	ρ m^3/kg
1	1500	34.1	40.6	33.7	55.9	58.9	47.55	34.98	2.2	1037.02	10.0	0.99	112	0.953	1.04	1.177
2	1750	34.2	41.1	33.8	56.4	60.3	47.48	36.80	2.4	1036.49	10.4	0.91	103	0.958	1.04	1.173
3	2000	34.5	42.5	34.0	58.2	67.0	47.40	37.65	3	1034.84	10.3	1.41	066	0.942	1.06	1.171
4	2250	35.0	44.7	34.4	60.3	73.7	47.04	38.71	3.8	1032.01	9.8	2.31	073	0.917	1.09	1.166
5	2500	35.6	50.1	34.7	61.6	81.8	46.70	41.59	4.1	1028.57	9.4	3.69	078	0.865	1.15	1.163

Appendix B-3

With add(E30-G70) 450 and without load

NO	rpm	St-1 C^0	St-2 C^0	St-3 C^0	St-4 C^0	St-5 C^0	Sc-1 m^3/h	Sc-2 m^3/h	Sc-3 Ml/min	Sp-1 mbar	%CO2	%CO	HC ppm	λ	Φ	ρ m^3/kg
1	1500	33.8	38.1	33.2	49.9	49.2	47.63	31.30	2.1	1037.12	11.2	0.15	096	0.989	1.10	1.177
2	1750	34.4	41.0	33.5	55.5	58.5	47.37	32.46	2.2	1035.16	9.6	0.76	125	0.960	1.04	1.173
3	2000	34.6	41.9	33.5	57.1	63.0	47.07	35.43	3.2	1033.91	9.0	1.21	117	0.940	1.06	1.171
4	2250	35.1	43.4	33.6	59.2	70.4	46.98	41.12	3.5	1031.58	8.3	1.92	082	0.910	1.09	1.166
5	2500	35.6	46.7	33.7	61.0	77.7	46.78	47.33	4	1030.10	9.6	2.08	063	0.916	1.09	1.163

Appendix B-4

With add(E40-G60) 450 and without load

NO	rpm	St-1 C^0	St-2 C^0	St-3 C^0	St-4 C^0	St-5 C^0	Sc-1 m^3/h	Sc-2 m^3/h	Sc-3 ml/min	Sp-1 mbar	%CO2	%CO	HC ppm	λ	Φ	ρ m^3/kg
1	1500	37.7	40.2	35.1	62.4	83.7	45.55	91.24	2.8	1017.24	8.1	0.20	1403	0.908	1.10	1.140
2	1750	37.9	45.0	35.4	62.8	84.9	45.48	43.46	3.2	1016.43	10.4	0.39	699	0.955	1.04	1.139
3	2000	38.2	48.8	35.8	63.4	87.7	45.32	43.57	3.5	1015.01	10.6	0.63	529	0.957	1.044	1.136
4	2250	38.4	49.6	35.9	63.6	88.9	45.25	45.85	4	1014.48	10.7	1.13	375	0.957	1.04	1.135
5	2500	38.6	53.1	36.2	64.9	92.2	45.11	49.52	4.2	1013.10	12.0	1.88	104	0.942	1.06	1.132

Appendix B-5

With add(E50-G50) 450 and without load

NO	rpm	St-1 C^0	St-2 C^0	St-3 C^0	St-4 C^0	St-5 C^0	Sc-1 m^3/h	Sc-2 m^3/h	Sc-3 Ml/min	Sp-1 mbar	%CO2	%CO	HC ppm	λ	Φ	ρ m^3/kg
1	1500	37.6	48.1	36.7	62.8	89.0	44.81	42.88	2.2	1009.91	9.7	0.27	1479	0.916	1.09	1.127
2	1750	38.9	49.9	36.9	63.2	90.3	44.66	43.94	3.1	1008.79	10.9	0.21	845	0.956	1.04	1.124
3	2000	39.8	50.3	37.0	64.5	91.2	44.55	45.33	3.8	1007.51	10.2	0.85	846	0.932	1.07	1.122
4	2250	40.8	51.6	37.0	64.9	94.1	44.49	47.83	4.1	1007.13	11.3	0.76	253	0.969	1.03	1.121
5	2500	41.4	53.7	37.1	65.4	95.3	44.43	51.38	4.6	1006.94	10.8	1.06	178	0.959	1.04	1.121

Appendix C

Without add(E0-G100) 750 and with load

NO	rpm	St-1 C^0	St-2 C^0	St-3 C^0	St-4 C^0	St-5 C^0	Sc-1 m^3/h	Sc-2 m^3/h	Sc-3 ml/min	Sp-1 mbar	%CO2	%CO	HC ppm	λ	Φ	ρ m^3/kg	η_v %	Bp kw	η_{Bth} %	Sf-1 N	Bspc Kg/kw.s $\times 10^{-5}$
1	1500	37.7	49.0	35.2	67.3	93.3	42.75	46.44	3.7	1020.24	11.4	2.83	128	0.910	1.09	1.151	92.6	0.62	29.8	9.91	7.60
2	1750	38.4	52.7	53.5	68.0	97.1	42.66	53.98	4.4	1018.18	11.6	2.96	117	0909	1.10	1.14	92.5	0.75	30.3	10.23	7.48
3	2000	39.1	57.6	35.9	68.4	101.4	42.32	59.15	5.2	1016.04	12.6	1.83	090	0.945	1.05	1.137	92.8	0.90	30.8	10.74	7.36
4	2250	39.9	64.8	36	69.3	106.4	42.05	64.77	5.4	1013.50	12.7	1.62	074	0.952	1.05	1.131	93	0.96	31.6	10.19	7.17
5	2500	40.7	73.5	37.1	70.5	111.6	41.75	70.39	5.6	1011.52	12.8	1.60	063	0.946	1.05	1.127	93.2	1.03	32.2	9.86	6.93

Appendix C-1

With add(E10-G90) 750 and with load

NO	rpm	St-1 C^0	St-2 C^0	St-3 C^0	St-4 C^0	St-5 C^0	Sc-1 m^3/h	Sc-2 m^3/h	Sc-3 l/min	Sp-1 mbar	%CO2	%CO	HC ppm	λ	Φ	ρ m^3/kg	η_v %	Bp kw	η_{Bth} %	Sf-1 N	Bspc Kg/kw.s $\times10^{-5}$
1	1500	37.5	47.2	39.9	70.4	97.3	43.19	48.95	4.2	1012.13	11.3	2.32	140	0.924	1.08	1.15	91.9	0.75	33.0	12	7.16
2	1750	38.1	56.4	39.8	71.0	101.3	42.74	52.31	4.7	1009.39	10.3	3.48	113	0.888	1.12	1.14	92.5	0.85	33.4	11.61	7.07
3	2000	38.6	59.4	40.2	71.6	102.7	42.56	60.92	5.2	1007.20	11.5	0.94	070	0.970	1.03	1.137	92.6	0.95	33.8	11.39	7.00
4	2250	39.2	70.5	41.2	74.2	111.2	42.25	67.03	5.3	1003.41	11.0	1.30	055	0.957	1.04	1.131	92.9	0.98	34.1	10.43	6.91
5	2500	40.5	73.4	41.7	74.6	114.0	41.99	72.02	5.6	1002.18	12.2	1.08	044	0.968	1.03	1.127	93	1.06	34.9	10.18	6.70

Appendix C-2

With add(E20-G80) 750 and with load

NO	rpm	St-1 C^0	St-2 C^0	St-3 C^0	St-4 C^0	St-5 C^0	Sc-1 m^3/h	Sc-2 m^3/h	Sc-3 ml/min	Sp-1 mbar	%CO2	%CO	HC ppm	λ	Φ	ρ m^3/kg	η_v %	Bp kw	η_{Bth} %	Sf-1 N	Bspc Kg/kw.s $\times 10^{-5}$
1	1500	37.2	46.9	34.7	67.7	93.13	43.09	51.91	4.2	1020.47	10.7	1.77	138	0.929	1.07	1.146	92.3	0.79	32	12.60	7.35
2	1750	37.8	47.9	35.1	69.1	96.3	42.78	52.70	4.8	1019.43	9.5	2.53	096	0.907	1.10	1.142	92.4	0.85	34	11.87	7.24
3	2000	38.1	50.7	35.7	69.9	100.5	42.70	61.82	5	1017.85	11.0	0.45	035	0.989	1.01	1.139	92.6	0.95	35	11.34	6.75
4	2250	38.6	52.4	35.0	70.39	103.12	42.48	64.08	5.8	1015.44	9.9	037	023	0.992	1.00	1.135	92.8	1.11	35.5	11.85	6.70
5	2500	39.4	60.4	36.3	71.0	107.01	42.18	66.34	6.2	1013.91	10.7	0.72	013	0.979	1.02	1.13	92.9	1.21	37.4	11.60	6.57

Appendix C-3

With add (E30-G70) 750 and with load

NO	rpm	St-1 C^0	St-2 C^0	St-3 C^0	St-4 C^0	St-5 C^0	Sc-1 m^3/h	Sc-2 m^3/h	Sc-3 ml/min	Sp-1 mbar	%CO2	%CO	HC ppm	λ	Φ	ρ m^3/kg	η_v %	Bp kw	η_{Bth} %	Sf-1 N	Bspc Kg/kw.s $\times 10^{-5}$
1	1500	37.9	48.7	40.6	73.2	99.5	42.88	50.81	4.5	1015.30	11.0	1.05	162	0.961	1.04	1.143	92.3	0.79	35	12.51	7.33
2	1750	38.3	57.9	40.9	72.6	103.9	42.71	56.23	5	1008.80	12.2	1.30	086	0.960	1.04	1.14	92.4	0.91	36	12.30	7.07
3	2000	38.9	64.6	41.4	73.4	107.8	42.48	58.02	5.2	1005.47	12.4	0.09	0.36	1.003	0.997	1.136	92.7	1.01	38.8	12.10	6.62
4	2250	39.9	71.6	41.8	75.2	111.9	42.09	70.84	5.6	1003.64	13.2	0.14	011	1.002	0.998	1.129	92.9	1.14	40.9	12.11	6.32
5	2500	40.6	77.8	42.8	75.1	114.8	41.80	74.51	6	1002.02	12.9	0.13	010	1.002	0.998	1.124	93.4	1.26	41.9	12.01	6.12

Appendix C-4

With add (E40-G60) 750 and with load

NO	rpm	St-1 C^0	St-2 C^0	St-3 C^0	St-4 C^0	St-5 C^0	Sc-1 m^3/h	Sc-2 m^3/h	Sc-3 ml/min	Sp-1 mbar	%CO2	%CO	HC ppm	λ	Φ	ρ m^3/kg	η_v %	Bp kw	η_{Bth} %	Sf-1 N	Bspc Kg/kw.s $\times10^{-5}$
1	1500	38.1	48.9	35.8	69.3	90.5	42.74	47.99	4.1	1020.14	11.6	0.31	142	0.955	1.04	1.14	92.5	0.77	39.1	11.88	6.86
2	1750	38.8	50.5	35.9	68.8	93.2	42.25	53.62	4.3	1018.92	12.0	0.33	090	0.991	1.00	1.13	93.1	0.88	42.6	12.01	6.30
3	2000	39.7	57.1	36.2	69.8	97.4	42.15	61.32	5	1017.05	10.9	0.09	051	1.002	0.998	1.13	93.1	1.03	42.9	12.30	6.26
4	2250	41.2	71.0	36.7	71.7	104.3	41.57	63.92	5.4	1013.58	11.6	0.19	049	0.998	1.00	1.12	93.2	1.15	44	12.17	6.06
5	2500	41.8	76.5	37.0	71.8	106.7	41.13	71.56	6	1010.87	11.8	0.09	025	1.003	0.997	1.11	93.9	1.28	44.5	12.22	6.05

With add(E50-G50) 750 and with load

NO	rpm	St-1 C^0	St-2 C^0	St-3 C^0	St-4 C^0	St-5 C^0	Sc-1 m^3/h	Sc-2 m^3/h	Sc-3 ml/min	Sp-1 mbar	%CO2	%CO	HC ppm	λ	Φ	ρ m^3/kg	η_v	Bp kw	η_{Bth} %	Sf-1 N	Bspc Kg/kw.s $\times 10^{-5}$
1	1500	38.6	41.0	36.7	58.5	66.4	42.67	46.45	3.8	1026.35	12.0	0.14	130	0.996	1.00	1.14	92.4	0.79	45.2	12.63	6.22
2	1750	39.9	45.9	37.8	68.8	83.3	42.40	55.3	4	1021.36	11.5	0.43	114	0.986	1.01	1.137	92.8	0.92	50.1	12.46	5.63
3	2000	40.8	53.0	38.5	71.5	93.0	41.63	63.40	4.5	1016.88	9.5	0.12	68	1.000	1.00	1.12	93.4	1.08	51.1	12.89	5.39
4	2250	41.8	63.7	39.2	75.4	99.3	41.13	70.3	4.6	1011.08	9.7	0.14	48	1.001	0.999	1.11	93.8	1.17	53	12.42	5.19
5	2500	42.5	77.4	40.1	75.1	107.4	40.10	71.36	5.2	1005.74	10.3	0.13	45	1.001	0.999	1.109	94.5	1.30	54.4	12.43	5.18

Appendix C-6

Appendix D

Without add(E0-G100) 450 and with load

NO	rpm	St-1 C^0	St-2 C^0	St-3 C^0	St-4 C^0	St-5 C^0	Sc-1 m^3/h	Sc-2 m^3/h	Sc-3 ml/min	Sp-1 mbar	%CO2	%CO	HC ppm	λ	Φ	ρ m^3/kg	η_v %	Bp kw	η_{Bth} %	Sf-1 N	Bspc Kg/kw.s $\times 10^{-5}$
1	1500	37.5	46.5	35.4	67.8	88.2	42.79	44.97	4	1017.66	9.3	3.93	162	0.862	1.16	1.14	92.6	0.62	28.2	9.95	7.84
2	1750	37.8	47.5	35.9	67.0	91.2	42.74	51.44	4.5	1016.26	9.8	4.09	131	0.864	1.15	1.139	92.7	0.75	30.2	10.21	7.24
3	2000	38.1	56.9	36.1	67.0	95.3	42.59	57.66	5.3	1014.42	11.0	2.76	101	0.904	1.10	1.136	92.8	0.89	30.6	10.62	7.20
4	2250	38.5	57.6	36.5	67.9	98.9	42.31	64.80	5.5	1010.91	11.8	2.29	0.86	0.859	1.16	1.130	93.2	0.92	30.5	9.77	7.20
5	2500	39.1	60.2	36.7	69.3	104.1	42.07	66.99	5.8	1009.03	11.7	2.47	0.74	0.924	1.08	1.126	93.3	1.02	32.1	9.75	6.90

Appendix D-1

With add(E10-G90) 450 and with load

NO	rpm	St-1 C^0	St-2 C^0	St-3 C^0	St-4 C^0	St-5 C^0	Sc-1 m^3/h	Sc-2 m^3/h	Sc-3 ml/min	Sp-1 mbar	%CO2	%CO	HC ppm	λ	Φ	ρ m^3/kg	η_v %	Bp kw	η_{Bth} %	Sf-1 N	Bspc Kg/kw.s $\times 10^{-5}$
1	1500	37.2	42.3	35.8	65.4	81.3	43.13	45.03	4.3	1021.34	9.9	2.66	157	0.904	1.10	1.147	92.2	0.70	30.7	11.19	7.47
2	1750	37.6	44.2	36.3	66.2	85.8	42.80	47.32	4.7	1019.57	8.4	3.80	139	0.856	1.16	1.14	92.6	0.82	32.9	11.21	6.97
3	2000	38.2	47.9	36.5	67.3	91.6	42.64	55.06	5.3	1016.54	9.6	2.32	103	0.914	1.09	1.138	92.7	0.94	33.4	11.30	6.86
4	2250	38.8	53.5	37.0	69.2	96.8	42.27	62.03	5.4	1013.25	9.6	1.68	086	0.936	1.06	1.13	93.1	0.98	33.8	10.42	6.70
5	2500	39.2	57.3	37.3	69.6	101.3	42.13	65.40	5.8	1011.19	10.3	1.46	066	0.949	1.05	1.128	93.3	1.06	34.4	10.20	6.66

Appendix D-2

With add(E20-G80) 450 and with load

NO	rpm	St-1 C^0	St-2 C^0	St-3 C^0	St-4 C^0	St-5 C^0	Sc-1 m^3/h	Sc-2 m^3/h	Sc-3 ml/min	Sp-1 mbar	%CO2	%CO	HC ppm	λ	Φ	ρ m^3/kg	η_v	Bp kw	η_{Bth} %	Sf-1 N	Bspc Kg/kw.s $\times10^{-5}$
1	1500	37.7	46.0	36.0	66.1	86.0	42.79	48.25	4.2	1017.29	11.5	1.99	197	0.932	1.07	1.140	92.6	0.70	33.6	11.17	7.37
2	1750	38.1	48.4	36.1	66.1	90.2	42.67	51.25	4.6	1016.63	10.6	2.97	145	0.900	1.11	1.138	92.7	0.83	35.2	11.40	6.80
3	2000	38.6	52.0	36.4	66.9	94.2	42.44	58.46	5.2	1015.00	11.8	0.45	081	0.987	1.01	1.134	92.9	0.96	36.0	11.50	6.65
4	2250	39.2	58.8	36.7	68.1	99.0	42.25	60.75	5.6	1013.77	12.3	0.47	064	0.988	1.01	1.131	92.9	1.06	36.9	11.32	6.48
5	2500	39.4	60.4	37.0	71.0	102.02	42.15	63.33	6.2	1012.91	11.2	0.58	105	0.981	1.01	1.129	93	1.18	37.2	11.30	6.44

Appendix D-3

With add(E30-G70) 450 and with load

NO	rpm	St-1 C^0	St-2 C^0	St-3 C^0	St-4 C^0	St-5 C^0	Sc-1 m^3/h	Sc-2 m^3/h	Sc-3 Ml/min	Sp-1 mbar	%CO2	%CO	HC ppm	λ	Φ	ρ m^3/kg	η_v	Bp kw	η_{Bth} %	Sf-1 N	Bspc Kg/kw.s $\times 10^{-5}$
1	1500	38.2	46.9	34.7	67.6	93.13	42.79	50.90	4.2	1020.47	11.3	1.01	129	0.957	1.04	1.142	92.3	0.73	35	11.68	7.12
2	1750	38.8	47.9	35.1	69.0	95.3	42.57	51.69	4.8	1018.44	11.2	0.54	094	0.974	1.02	1.138	92.5	0.84	35.5	11.52	7.08
3	2000	39.1	50.4	35.6	66.8	100.4	42.45	60.80	5.1	1017.88	10.0	0.12	049	1.003	0.997	1.136	92.5	0.97	38.5	11.46	6.51
4	2250	39.6	52.6	35.9	70.40	102.12	42.20	63.08	5.6	1015.34	9.9	0.11	033	1.002	0.998	1.131	92.7	1.11	40.1	11.81	6.25
5	2500	40.4	61.4	36.4	71.01	106.01	41.80	65.34	6.1	1014.90	10.5	0.16	025	1.000	1	1.128	93.3	1.24	41.1	11.88	6.09

With add(E40-G60) 450 and with load

NO	rpm	St-1 C^0	St-2 C^0	St-3 C^0	St-4 C^0	St-5 C^0	Sc-1 m^3/h	Sc-2 m^3/h	Sc-3 ml/min	Sp-1 mbar	%CO2	%CO	HC ppm	λ	Φ	ρ m^3/kg	η_v	Bp kw	η_{Bth} %	Sf-1 N	Bspc Kg/kw.s $\times 10^{-5}$
1	1500	37.1	47.8	34.8	68.2	89.4	43.14	46.98	4.2	1021.14	11.3	0.24	125	0.992	1.008	1.147	92.3	0.73	36	11.66	7.19
2	1750	37.8	49.4	34.9	67.7	92.2	42.89	52.60	4.4	1019.91	9.7	0.09	092	1.000	1.00	1.143	92.4	0.86	41	11.63	6.39
3	2000	38.7	56.0	35.2	68.8	96.3	42.54	60.32	5.1	1018.04	10.2	0.12	077	0.993	1.007	1.137	92.6	1.00	41.2	12.03	6.37
4	2250	40.2	69.9	35.7	70.6	102.4	42.00	62.90	5.7	1014.57	10.6	0.09	063	1.001	0.999	1.128	92.9	1.12	41.5	11.89	6.36
5	2500	40.9	75.4	36.0	71.8	105.7	41.65	70.55	6	1010.77	10.9	0.11	052	1.001	0.999	1.121	93.5	1.23	43.1	11.80	6.04

With add(E50-G50) 450 and with load

NO	rpm	St-1 C^0	St-2 C^0	St-3 C^0	St-4 C^0	St-5 C^0	Sc-1 m^3/h	Sc-2 m^3/h	Sc-3 ml/min	Sp-1 mbar	%CO2	%CO	HC ppm	λ	Φ	ρ m^3/kg	η_v %	Bp kw	η_{Bth} %	Sf-1 N	Bspc Kg/kw.s $\times 10^{-5}$
1	1500	37.6	40.0	35.7	57.5	65.4	43.18	45.45	4.2	1025.35	9.9	0.11	0125	0.997	1.003	1.150	91.8	0.73	38.2	11.58	7.25
2	1750	38.9	44.8	37.7	67.7	82.3	42.71	54.3	4.6	1022.33	8.7	0.08	100	1.000	1	1.142	92.1	0.88	0.42	12.03	6.58
3	2000	39.8	52.0	38.3	70.5	92.0	42.25	62.39	5	1017.87	8.6	0.09	093	1.000	1	1.133	92.6	1.05	46.2	12.54	6.00
4	2250	40.8	62.7	39.1	74.3	98.3	41.74	70.36	5.1	1012.08	8.8	0.09	076	1.000	1	1.123	93.1	1.13	48.7	11.99	5.68
5	2500	41.4	76.4	39.9	75.5	106.4	41.36	71.33	5.4	1006.74	8.8	0.10	064	1.001	0.999	1.115	93.6	1.25	50.9	11.94	5.24

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