WEENTECH Proceedings in Energy

ICEEE 2016

16th -18th August 2016
Heriot-Watt University, Edinburgh
United Kingdom

Volume 3: International Conference on Energy, Environment and Economics, September 2016

ISSN: 2059-2353
ISBN: 978-9932795-2-2
www.weentech.co.uk

Edited by:
Dr. Renu Singh, IARI, New Delhi, India
Dr. Anil Kumar, PSU, Thailand
Published by World Energy and Environment Technology Ltd.

Evaluation of the effects on performance and fuel consumption of spark ignition engines using ethanol (E85)

L. Serrano* [a,b], Nuno Pires [a], Nuno Mendes [a]

[a] *School of Technology and Management – Polytechnic Institute of Leiria,*

Morro do Lena, Alto do Vieiro, ap.4163, 2411-901 Leiria,Portugal

Tel: +351244820300;

[b]*ADAI, LAETA Department of Mechanical Engineering, University of Coimbra,*

Rua Pedro Hispano 12, ap.10131, 3030-289 Coimbra, Portugal

**Corresponding author's mail: luis.serrano@ipleiria.pt*

Abstract

The use of ethanol as a fuel in vehicles has existed for many years, and today the incorporation of small amounts in gasoline is a reality. Ethanol presents interesting properties as a fuel, especially the higher octane rating, higher latent heat of vaporization and higher laminar flame speed.

Based on these characteristics there are some important competitions worldwide using ethanol or mixtures of ethanol as fuel. Thus the main objective of this research is to study the necessary changes to convert a gasoline engine so that it can run on a fuel containing 85% ethanol and evaluate their effects in terms of performance and fuel consumption.

Tryingto predict the future optimizations to be implemented in the engine to get out the best of the ethanol, a computer model was created using the software Lotus Engine Simulation (LES). Using this software a basic model in a Suzuki GSXR600 K5 engine was created, in order to obtain power curves as closely as possible of the real. After considering the base model as valid, using the petrol fuel and comparing the results with the factory performance curves, simulations were performed using E85 fuel. The properties of the fuel were changed and also the combustion model. Since ethanol behavior during combustion is not the same as that of gasoline, it was necessary to change the adjustable parameters of the Wiebe model "A" and "M", reaching the conclusion that the coefficients that best characterize the combustion of the ethanol were A=5 and M=3.

Using ethanol in the simulation the results reveal a possible increase of almost 8% in engine torque and an increase of fuel consumption by 37.5%, in all the operating conditions.

In order to validate and verify the computational model engine behavior with the use of E85, experimental tests were conducted using the CBR600 F4i Honda engine. This engine is not the same used in simulation but it presents very similar characteristics with that one. The tests result for ethanol (E85) reveal a torque curve very similar to the curve obtained considering the use of gasoline. The reason for this is due to the fact that no optimization changes were made in the engine ignition map. However there was an increase in fuel consumption in the range of 40% very close to the value obtained in computer simulations. This reveal that, with some optimization process, it should be possible to increase the engine torque and power but knowing that it will be obtained with a considerable increase in fuel consumption. Also the possibility to introduce a turbocharger, considering ethanol characteristics, revealing a higher octane index, should be explored.

Keywords: Natural gas; Concentration field;

1. Introduction

The use of ethanol as a fuel in vehicles has existed for many years but the actual problems associated with fossil fuel scarcity resources and atmospheric pollution, namely the Green House Gases effects increases the need to replace those traditional fossil fuels by renewable solutions. Nowadays, the incorporation of some amounts of ethanol in gasoline is a reality in a lot of countries around the earth since ethanol presents some similarity with gasoline and also reveals interesting properties as a fuel, especially the higher octane rating, higher latent heat of vaporization and higher laminar flame speed.

Considering the characteristics of this fuel, there are some important competitions worldwide using ethanol as source of energy to the engine of the vehicles. Following this line of thought, the main objective of this research is to study the necessary changes to convert a gasoline engine optimizing it to run on a fuel containing 85% ethanol (E85) and evaluate the consequent effects in terms of performance and fuel consumption.

To establish and predict the future optimizations to be implemented in the engine to get out the best of the ethanol, a computer model was created using the software Lotus Engine Simulation (LES). Assumed the capabilities of this tool, a basic model in a Suzuki GSXR600 K5 engine was created, in order to obtain power curves as closely as possible of the real. After considering the base model as valid, using the petrol fuel and comparing the results with the factory performance curves, simulations were performed using E85 fuel. The properties of the fuel were changed and also the combustion model was adapted, since ethanol behaviour during combustion is not the same as that of gasoline. Changes necessarily gone through the modification of the wiebe model coefficients reaching the conclusion that the values that best characterize the reaction of the ethanol were A=5 and M=3.

Using ethanol in the simulation the results reveal a possible increase of almost 8% in engine torque and an increase of fuel consumption by 37.5%, in all operating conditions that were analysed.

In order to validate and verify the computational model to simulate engine behaviour with the use of E85, experimental tests were conducted using the CBR600 F4i Honda engine. This engine is not the same used in simulation but it presents very similar characteristics with that one.

The defined methodology considered the development of an acquisition system to obtain the values of the engine operation and correlate those with the chassis dynamometer results. The main objective was to find how the engine performs when 85% of ethanol was mixed in gasoline and used as fuel replacing the 100% of fossil fuel normally used and for which the engine has been developed and calibrated.

2. Problem identification and basic principle

The transport depend around 90% shares of liquid fuels made from crude oil. This important sector represent a significant level of energy consumption, around 20% of total energy consumed globally, and with an expected increase to 40% by 2040 [1]. In the short run, biofuels will play an important role due to their complementarity to the fossil fuels, confirming their position as a key element in a path to achieve the main energy policy goals in the transport sector [2]. Ethanol and Methanol can be used with conventional fuels, in pure form or as a blend, to act as a valid alternative solution for reducing the demand for conventional fuels.[3]. In fact, the interest in the renewable fuel aroused with the development of the internal combustion engines. However, particularly in case of ethanol, it became established as an alternative fuel in 1970 due to the oil crises [3]. Today, it has impact on a regional level, based on markets that provide bigger incentives or production capacity but with overall growing tendency. Several detaching characteristics contribute for the selection of ethanol as energy supply on vehicles.

Besides the excellent source renewability and the energetic density of the liquid form (that has advantage over the gaseous alternatives such as hydrogen), the fuel supply systems of common vehicles is basically prepared for alcohol usage. In fact, these vehicles can be effectively propelled by moderate alcoholic mixtures. Additionally, transport and storage security are improved due to a higher auto-inflammation point [4-7]. Ethanol or other short chain alcohols can also be used in racing applications, where the conditions are more demanding [8]. In fact, the blend of ethanol with gasoline allow the broadening of the lean burn limit and improve the combustion process. This leads to increase cylinder pressure and temperature and lower combustion duration period. This better combustion condition reveals the potential to increase brake power and thermal efficiency of the engines which effect is more pronounced with the increase of the percentage of ethanol in the blend with gasoline[9]

Ethanol may contain about 35% oxygen on weight basis and is therefore considered a partially oxygenated fuel [10,11]. This fact induces a cleaner combustion with lower particle emissions and nitrogen oxides from combustion, low calorific value and low air / fuel ratio when compared to gasoline [11,12].

Even considering that the physical and chemical properties of ethanol and gasoline are similar, it is evident some considerable differences, namely concerning the lower heating value (rounding 65% of the value of gasoline in a volumetric basis) leading to an expected increase in fuel consumption and the oxygen content, which conducts to significant differences of stoichiometric air/fuel ratios, where ethanol is 9.0:1 and gasoline 14.5:1 [13]. There are other important differences between fuels properties, like the higher octane number presented by ethanol and higher laminar flame speed. Both could lead to improved combustion and thermal efficiency of the engine, if that could be used by making the proper adjustments in engine. In fact, even considering that the addition of ethanol to gasoline reduces the heating value of the fuel, it is possible to observe an increase in torque and power in engines running with this blend. It was observed that the presence of oxygen, the higher density and the higher latent heat of vaporization allows increase the amount of energy provided to the cylinder for each stroke, delivering more energy to the wheels.[14]

On a performance point of view, there are indications that lower ethanol-gasoline blends could present a slight increase of the fuel consumption with a correspondent increase in torque output [15,16]. It was observed by Thangavelu et al [17] that a significant improvement was possible to achieve in engine torque, brake power and brake mean effective pressure with the use of bioethanol. However the costs for these achievements were a variation in brake specific fuel consumption more pronounced in higher blends.

Phuangwongtrakul et al reveal that, the use of multi-blend rates of ethanol combined with real time adaptive to obtain the optimum brake thermal efficiency at a certain engine speed and position of intake throttle opening can enhance the performance of engine torque, especially at lower engine speed [18].

These published results allow to have hope that those improvements in engine performance could be achieved in the engine that is going to be tested which is the one that will be used in Fomula student IPleiria team.

3. Methodology

3.1 – Simulation

The engine to be simulated is the one equipping the Suzuki GSX-R 600 K5 motorbike. It is a 4 stroke, multipoint injection engine, with a cylinder capacity of 599 cc, 63 Nm at 10800 rpm and 76 kW at 12800 rpm. It has been selected to be installed in the future Formula Student car of the team of the School of Technology and Management of Leiria. Some more data about the engine are shown in table 1.

Table 1 – Engines characteristics.

Vehicle	Suzuki GSX-R 600 k5	Honda CBR 600 F4i
Number of cylinders	4	4
Bore [mm]	67	67
Stroke [mm]	42,5	42,5
Displacement [cm^3]	599	599
Compression ratio	12,5	12
Valve actuation	DOHC	DOHC
Number of valves / cylinder	4	4
Torque [N.m @ RPM]	63 @ 10800	65 @10500
Power [kW @ RPM]	76,8 @ 12800	81 @ 12500

To simulate this engine, the Lotus Engine Simulation (LES) software was used. LES allows to predict the overall performance of an engine with reasonable accuracy like it was been proven by previous works [19]. With this tool, it is possible to know the engine performance in stationary or transient conditions, changing parameters like displacement, intake and exhaust systems and thus estimate the effects of different solutions.

A model of the gasoline engine was created in LES using as basic model (figure 1), featuring admission systems (plenum chamber, cylinder head pipes) and exhaust (manifold and exhaust muffler), distribution diagram, and so on. This characterization resulted in power and torque curves very similar to the original engine data, providing 69 kW at 13000 rpm and 55 Nm at 10000 rpm, resultant into an average difference rounding 10%.

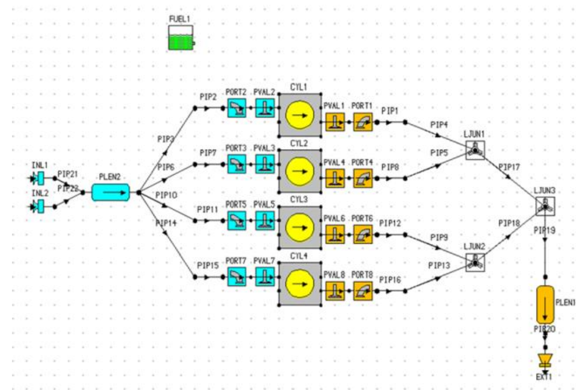


Figure 1 – Suzuki's engine model created in LES.

Having admitted this as a base model, some changes were made in fuel properties in accordance with the introduction of E85 that were possible in the software. Such readjusted properties were density, calorific value, hydrogen/carbon ratio, oxygen/carbon ratio and the molecular weight.

The way how fuel is mixed with air and the consequent developed combustion and how it occurs is not the same between gasoline and ethanol. Thus it was necessary to readjust the value of the parameters that influence the combustion model. LES uses Wiebe function to define the rate of heat release in combustion engines. There are two parameters "A" and "M" that determine the shape of the curve of the mass fraction burnt. The "A" coefficient is responsible for the maximum value of the burnt mass that can reach the curve and may be associated with the number of spark plugs or their location [20,21]. The "M" coefficient represents the behavior of the flame front and is associated with the form factor of the combustion chamber [20,21].

The "A" and "M" coefficients typically used in Otto engines running on gasoline are 5 and 2 [22]. For E85 fuel these parameters will have to be necessarily different, once the mixture contains a greater percentage of ethanol than gasoline. Thus, four possible pairs of coefficients were tested to characterize approximately the mass fraction burned and verified its effect on the power and torque curves.

It was possible to confirm the effects of the coefficients in the combustion process. "A" coefficient was defined as 5 which is similar to the value used in the gasoline engine due to the number of spark plugs per cylinder. It was also tested the value of 7.5 to further increase the time wherein the combustion approaches 100% of the burning fuel. By varying the "M" coefficient it changes the combustion duration. Once ethanol promotes higher flame velocity propagation than in gasoline, it is expected that “M” value will be higher since the duration will be shorter. Thus, the increase of "M" to 5 corresponds to a short burn time of the fuel, implying that the combustion becomes quicker.

3.2 – Experimental Tests

Due to some problems in Suzuki engine that was simulated in LES software, the experimental tests were performed using a very similar engine from another manufacturer but with equivalent characteristics, the Honda CBR F4i, as can be confirmed by Table 1. It was expected that the variations observed in the simulation were confirmed by the tests made with the engine in a chassis dynamometer. This assumption is based on the similarity of the engines and also in the fact that the results are made in a comparative bases, having the petrol fuel as a reference.

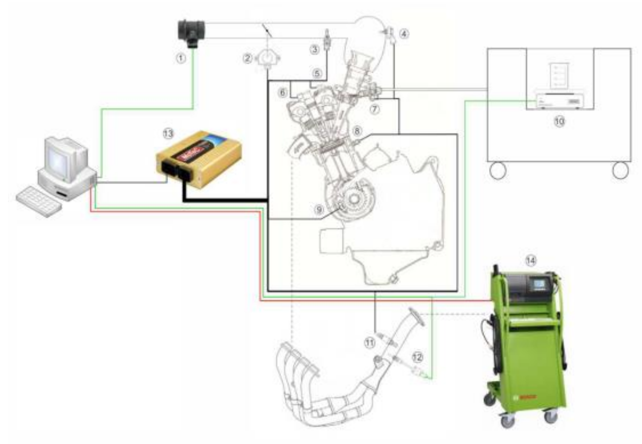
The experimental structure arranged to allow accomplishment of the tests is presented in figure 2.

It involves the chassis dynamometer, which supports the vehicle mounted with the Honda engine. This allows to get the engine torque and speed (imposing engine rotation at a given gearbox relation). It was used the output available in the ECU, which is not the original control unit from the manufacturer of the engine but instead, an open ECU manufactured by MoTeC. Also some other parameters were monitored using some extra equipment or sensors, like exhaust gases analyzer, a gravimetric fuel consumption system, air flow measurement (MAF) sensor, a wide-band lambda sensor, and a temperature exhaust gases sensor, besides all the data available in the ECU. From all the data obtained through the control unit, some particular attention was given to the fuel injector operation information, namely the advance of injection and the duration of the opening period, once this were crucial aspects regarding the different engine operation with the fuels (petrol and E85).

The tests reflect the evaluation of the engine performance counting with power, torque and fuel consumption, considering the use of the two different fuels.

The first task was to perform several tests with petrol fuel in order to get a higher reliability in the engine, in the experimental structure and in the acquisition system avoiding problems during the experiments. After assuring the repeatability of the tests with petrol IO98, two other tests were performed with E85, which result in the data represented in the next chapter. For these performance tests, 8 different engine rotations were defined since 5000rpm at 12000rpm with increments of 1000rpm regarding a 6^{th} gearbox relation and full open throttle. The mixture was defined as rich (λ=0,9) and the ignition timing was set the same for all the tests and for all the fuels. This was assured by a closed loop control program with the lambda sensor values.

For all the valid tests, the environment conditions was very close (T_{amb}=9 ± 3ºC; p_{atm}=1023 ± 4mbar; $T_{intake\ air}$ = 19 ± 1ºC; T_{Fuel}= 29 ± 1ºC).



1	Mass of air flow	8	Engine temperature
2	Admission throtle	9	Cranckshaft position
3	Intake air temperature	10	Fuel temperature and mass fuel consumption
4	Intake air pressure	11	Wide band lambda sensor
5	Came shaft position sensor	12	Exhaust gases temperature
6	Ignition coil	13	ECU – Eletronic Control Unit
7	Fuel injector	14	Exhaust Gases Analizer

Figure 2 – Experimental structure for the tests.

4. Results and discussions

The results obtained in the simulation, represented in figure 3 presents an evident similarity, even considering the fact that the engine of the simulation and the engine used in experimental tests was not the same,. The differences are visible mainly between 8000 rpm and 10000 rpm but the curve profile is highly comparable. The profile of the engine torque curves with gasoline is very similar to the original curve provided by the manufacturer and is also similar between the several simulations with E85, which gives a good confidence on software results.

The tests made with ethanol in simulation allow having same gains in power, with variations in all the engine rotation between 7 and 10%. The obtained differences revealed the expected possibility to increase the engine performance with the use of ethanol since this fuel allows better combustion efficiency. In the simulations it was not yet altered the compression ratio or altering the ignition timing, which will allow to raise the differences on torque for E85, given the higher octane number of ethanol.

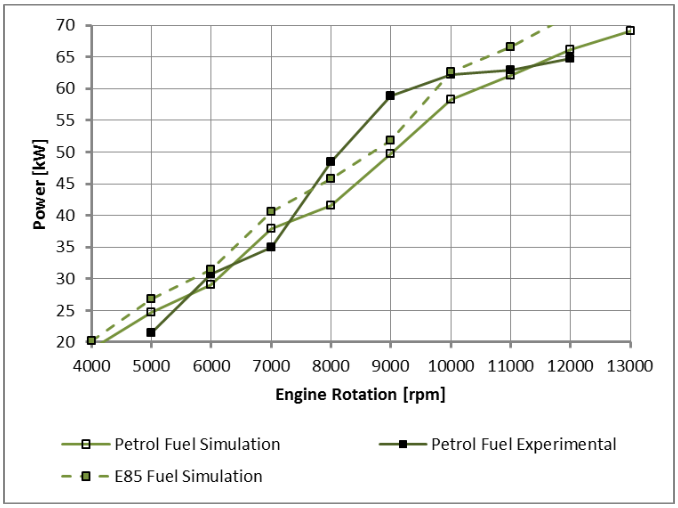


Figure 3 – Comparison engine power curves with petrol fuel obtained in simulation software and experimental tests.

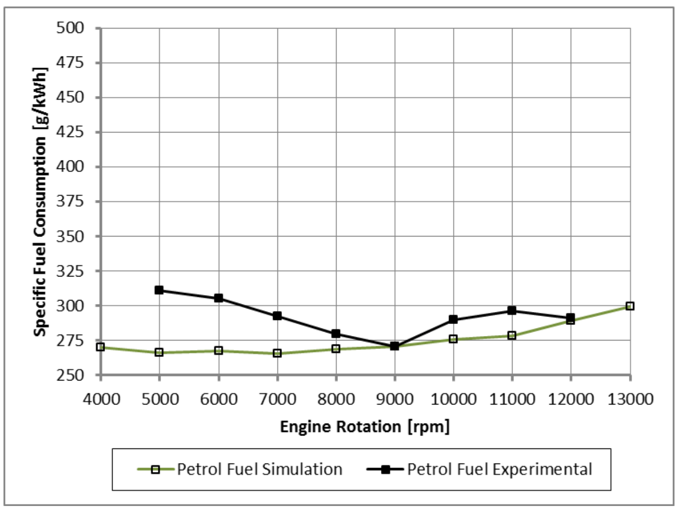


Figure 4 - Comparison between specific fuel consumption with petrol fuel obtained in simulation software and experimental tests.

Also in specific fuel consumption results, the obtained data reveal an interesting similarity, even considering that in almost all the engine rotation ranges there is a small divergences. Analyzing the simulations results between petrol and E85 it is revealed that there was an increase in consumption with the use of E85, for any of the coefficients used in relation to the use of gasoline. This increase is approximately 38%, which is in accordance with the literature review [10,11,23]. The increase on fuel consumption is justifiable with the lower heating value of ethanol compared to gasoline, which is associated to the oxygen content in the fuel. The presence of oxygen atoms in the fuel molecule decreases the energy availability of ethanol but also allows a better and quicker combustion which has a strong influence in the obtained increase in torque. Regarding the main objective of the work, where the engine performance is the main goal, ethanol represents a very promising solution.

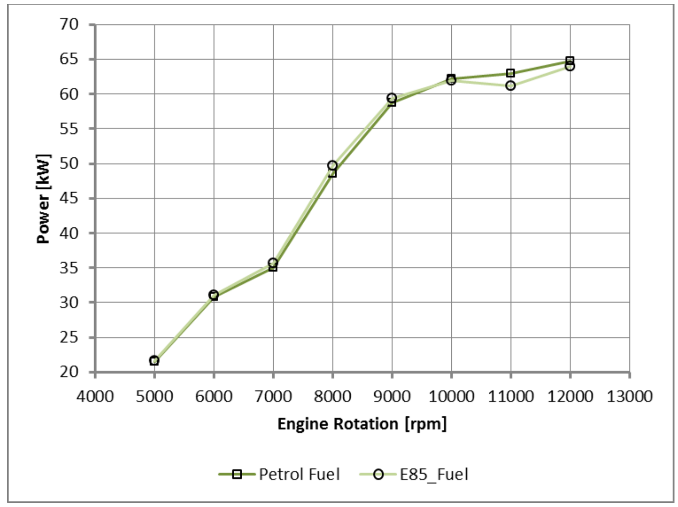


Figure 5 – Comparison engine power curves with petrol fuel and E85 obtained in experimental tests.

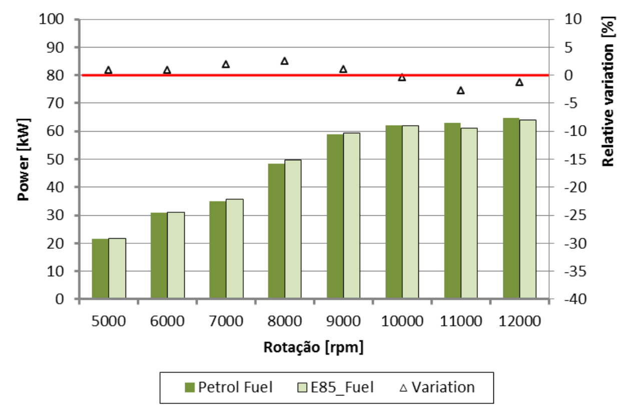
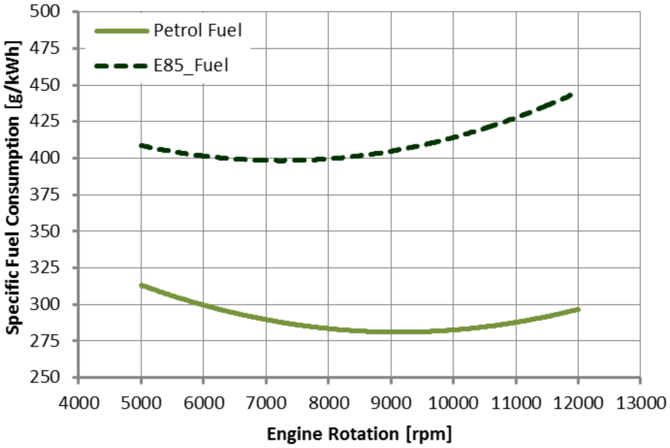


Figure 6 – Variations between engine power results considering petrol fuel and E85 in experimental tests.

Considering the experimental results, obtained with petrol and E85 and with WOT (Wide Open Throttle) it is possible to disclose that the power curve for E85 is very similar to the one obtained for petrol with a small increase for some points of the engine rotation range as it is represented in figure 5.

The power gains obtained does not confirm the 7-10% raise in engine performance revealed in simulation, but represents the real possibility of maintain the power of the engine or provide some small gains without any engine modifications besides the autonomous adjustment of the air/fuel ratio by the lambda sensor. The relative variations between power values are always below 5% difference as it is visible in figure 6.

The evaluation about the specific fuel consumption exposes the expected increase for E85, once the lower energetic content of ethanol is clearly revealed. For a better perception about the results the representation of the absolute values of specific fuel consumption is made by the tendency curve that better fits to the experimental results.



Confirming the simulation results, the increase in the specific fuel consumption relays between 30 and 45% for the tested range (5000rpm to 12000rpm), presenting higher differences for higher regimes.

Once more this is somewhat expected, given the need to supply the necessary amount of energy to the engine to allow to reach the power values that the engine could give. However, this does not represent what could be obtained with ethanol, once the adjustment of the injection timing and the possibility to increase the volumetric efficiency of the engine provides some founded expectations to have better performance and better efficiency which could represent higher gains in power and a reduction in specific fuel consumption.

5. Conclusions

The main purpose of the present work was achieved by the obtained results of a simulation and experimental evaluation of the potentialities of using ethanol to improve performance of an engine.

In fact, besides the constraints of using two different engines, even so it is possible to conclude that those engines are very similar and the results was promising about the ethanol potential to get higher power of the engine used in Formula Student vehicle.

The tests result for ethanol (E85) reveal a torque curve very similar to the curve obtained considering the use of gasoline. The reason for this is due to the fact that no optimization changes were made in the engine ignition map. However there was an increase in fuel consumption in the range of 40% very close to the value obtained in computer simulations.

The results of the simulation with ethanol point to gains on power between 7 and 10%. However this increase in power was not proven in experimental data. The tests results reveal that the best improvements in power were lower than 5% and were not obtained if the full engine speed range. In fact, for higher regimes a decrease in power was observed. This is possible explained with the non-optimization of the engine parameters like ignition timing and distribution diagram which could represent a better adjustment for the E85 fuel properties. With the more pronounced increase in engine power also the specific fuel consumption will experience a small decrease.

A further work is to be done, changing parameters of the engine, trying to experience some optimization process for E85 forwarding to improve engine performance.

Abbreviations

E85 – fuel with Ethanol (85%)+Gasoline (15%)
LES – Lotus Engine Simulator
ECU – Electronic Control Unit
MoTeC - Copyright © MoTeC Pty Ltd 2008.
MAF – Mass Air Flow
IO98 – Octane index 98
WOT – Wide Open Throttle

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Commonwealth Energy and Sustainable Development Network (CESD-Net)

CESD-Net is a major global initiative in energy and sustainable development. The objective of network is to promote energy and sustainable development in commonwealth countries.
Focussing on Multidisciplinary Research, Promoting Future Low Carbon Innovations, Transferring Knowledge and Stimulating Networking among Stakeholders to Ensure the UK Achieves World Leading Status in Energy and Sustainable Development. https://www.weentech.co.uk/cesd-net/

The 1st International Conference on Energy, Environment and Economics (ICEEE 2016) was held at Heriot-Watt University, Edinburgh, EH14 4AS, UK, 16-18 August 2016. ICEEE2016 focused on energy, environment and economics of energy systems and their applications. More than fifty eight delegates from 31 countries with diverse expertise ranging from energy economics, solar thermal, water engineering, automotive, energy, economics and policy, sustainable development, bio fuels, Nano technologies, climate change, life cycle analysis etc. made conference true to its name and completely international. During conference total 51 oral presentations and six posters were shared between delegates. The presentations showed the depth and breadth of research across different research areas ranging from diverse background. ICEEE2016 aimed:

- To identify and share experiences, challenges and technical expertise on how to tackle growing energy use and greenhouse gas emissions and how to promote sustainability and economical, cost effective energy efficiency measures.

In total 11 technical sessions and two invited talks both from academia and industry provided insight into the recent development on the proposed theme of the conference. Preparation, organisation and delivery of the conference started from July 2015 and further co-ordinated by vibrant team of Conference Centre, Heriot Watt University. Conference organisers would like to acknowledge support from the sponsors particularly World Scientific Publication ltd and its team members for the delivery of the conference. Organisers are also thankful to all reviewers who contributed during peer review process and their contributions are well appreciated. At the end and during vote of thanks following awards have been announced and we would like to congratulate all well deserving delegates.

- Best Paper –Academia: Amela Ajanovic, EEG, TU Vienna, Austria
- Best Paper – Student : Christian Jenne,University of Duisburg-Essen, Germany
- Best Poster – Student: Yoann Guinard, University of New South Wales, Sydney, Australia
- Best Poster – Academia: E. Salleh, Universiti Kebangsaan Malaysia, Malaysia
- Active Participation Award - Yoann Guinard, University of New South Wales, Sydney, Australia

At the end we would like to extend our gratitude to all of you for your participation and hopefully welcome you again during ICEEE2017.

Editors:
Dr. Singh is Senior Scientist at Indian Agricultural Research Institute, New Delhi, India. Her area of expertise are bio energy and bio fuels, environmental engineering, carbon accounting and renewable energy integration for rural development.
Dr. Kumar is visiting faculty at Prince of Songkla University, Thailand. He have 16 years of research and teaching experience in the field of solar energy, drying and energy efficiency.

WEENTECH Proceedings in Energy- International Conference on Energy, Environment and Economics, September 2016
Edited by:
Dr. Renu Singh, IARI, New Delhi, India
Dr. Anil Kumar, PSU, Thailand
Publisher: World Energy and Environment Technology Ltd., Coventry, United Kingdom
Publication date: 12 September 2016
ISSN: 2059-2353
ISBN: 978-9932795-2-2
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