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On the possibility to run an internal combustion engine on acetylene and alcohol

S. Brusca[a]*, R. Lanzafame[b], A. Marino Cugno Garrano[b], M. Messina[b]

[a]*University of Messina, ctr. Di Dio, S. Agata, Messina, 98166, Italy*
[b]*University of Catania, viale A. Doria, 6, Catania, 95125, Italy*

Abstract

It is well known that acetylene is a high flammable and explosive compound. In comparison with commercial liquid fuels, very wide flammability limits and a low Octane Number have relegated the acetylene into the "iperdetonat" fuels category. Thus, it is impossible to run an internal combustion engine on acetylene without a detonation phenomena control system.
The current paper deals with a theoretical and experimental analysis of an internal combustion engine running on acetylene and alcohol.
A standard 8 kW spark ignition engine with carburettor was modified with electronic injection control system (ECU) and two standard commercial injectors: one for the acetylene and one for the alcohol. The two injectors were installed using a modified engine intake system. The ECU is able to manage two fuels: acetylene and alcohol. Moreover, an optimization method base on Genetic Algorithms and Neural Networks was used to cerate engine parameters map. Thus, Running an ICE on acetylene and alcohol it is possible to achieve acceptable engine performance and very low pollutant emissions.

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Keywords: Alternative fuels; Internal Combustion Engines; Pollutant Emissions; Detonation Control;

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1. Introduction

The actual worldwide energy scenario and the stringent regulations about pollutant emissions in the industrialized countries impose to put into effect new strategies about energy sources and power generation [1]. The power generation industry and the transport systems use a large amount of the primary energy demand in the industrial

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* Corresponding author. Tel.: +39-090-397-7564; fax: +39-090-397-7464.
E-mail address: sbrusca@unime.it

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countries. However, there is a continuing need for improved energy efficiency, coupled with a pressing need to reduce toxic and noxious emissions. In view of the uncertainties related to global warming, there is also a definite requirement to monitor and reduce, where possible, CO_2 emissions. In long term, the potential exists for a significant impact on both energy efficiency and environmental protection.

Moreover, power production and mobility systems strongly depend on conventional fuel such as crude oil derivate and/or natural gas. New technologies for the use of non–conventional power sources are also an important way for fuel supplying variation and the use of local energy sources in an environmentally acceptable manner. Furthermore, the growing attention of the public opinion about environment has induced industrial country governments to reduce power stations and transports pollutants emissions to very low limits. At the early stage of the Internal Combustion Engines (ICE) development, many fuels were used to feed the engines [2]. Nowadays, two main fuels are normally used for transport systems, gasoline and Diesel, while natural gas is the main fuel in firing power plants. Several research activities were developed in order to study the possibility to feed Internal Combustion Engines with alternative fuels. Acetylene is one of the tested fuels. This fuel has a wide flammability limits and a lower Octane Number in comparison with commercial liquid fuels. Thus, it is necessary to control detonation phenomenon using water to rise its ON and reduce pollutant emissions as reported in [4, 5, and 6] for both types of ICE [7, 8]. It is also possible to use alcohol to reduce detonation and control the combustion of these types of fuels as acetylene.

The present research activity deals with an experimental study on Internal Combustion Engines (ICEs) running on acetylene and alcohol. The latter is actually used to control detonation phenomena. At the same time, alcohol takes part in combustion as fuel. In particular, in the present paper ethanol was used as secondary fuel. The main goal of the present research activity is the reduction of the pollutant emissions at very low levels maintaining at the same time acceptable engine performance, as well as the engine efficiency. Also, it has been obtained the chance of running an ICE on acetylene that is a non crude oil derivate fuel.

Nomenclature

ICE	Internal Combustion Engine
ON	Octane Number
GA	Genetic Algorithm
NN	Neural Network
SSE	Sum Squared Error
FM	Fuel Main
FS	Fuel Secondary
SA	Spark Advance
BSFC	Break Specific Fuel Consumption
MAP	Manifold Absolute Pressure
ECU	Electronic Control Unit
WOT	Wide Open Throttle
HC	Hydrocarbon

2. Experimental set-up

In the present work the following test rigs were used to perform test on both gasoline and acetylene–alcohol engine configurations:

1. Hydraulic test bench;
2. Flow meters (for air, gasoline, acetylene and alcohol);
3. Engine and exhaust gas temperature measurement systems;
4. Pollutant emissions concentration measurement systems.

A Stuska XS19A hydraulic brake was used in the test bench. It is designed especially for small sized and high-performance engines, and it is able to operate in either rotational direction. The main hydraulic test bench characteristics are reported in Table 1.

Table 1 Main test bench characteristics and dimensions.

Description	Value
Mark	STUSKA
Model	XS19
Straight keyed input shaft diameter	23.8 mm
Piston rod length	160 mm
Torque range	0-24 N m

The dynamometer uses water as a load mechanism during engine testing. Water flow proportional to desired applied load is used to create resistance to the engine. A controlled flow of water is directed at the absorber center, and via centrifugal force, is expelled towards the outside of the dynamometer and into the stator. As the water hits the stator, it decelerates, causing an applied load to the input device. Through the water's continual acceleration and deceleration, load can be controlled and measured. This is a very effective and safe way to measure the performance of an engine running under a controlled load.

A specific hydraulic system was built in order to allow the correct dynamometer run. The water was taken from a tank with constant water level due to an external water source. Thus, using a water pump the correct water flow was supplied to the brake at a constant pressure (413.7 kPa). After the water was discharged to the tank. Manometers and thermometers were installed in the circuit to monitor water pressure and temperature before and after the brake. A schematic diagram of the system is shown in Fig. 1.

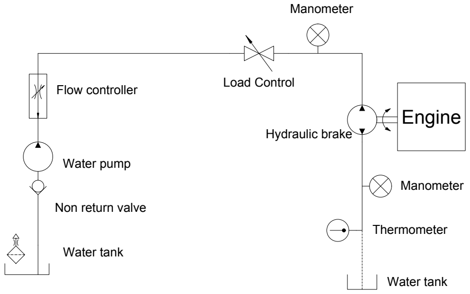


Fig. 1. Hydraulic scheme of break water supply system.

Table 2. Main airflow indicator characteristics.

Description	Value
Scale	m/s
Range	0 – 44
Resolution	0.1
Threshold	0.5
Accuracy	± 1

An electronic airflow velocity indicator was used to determine air mass flow rate at the engine intake. In order to reduce pressure waves effects a chamber before air filtering system was introduced. The volume of the chamber was set to ten times the intake manifold volume to be sure about complete pressure waves extinction. In Table 2 main instruments characteristic are reported. Gasoline, acetylene and alcohol consumption was measured with a gravimetric method, measuring fuel mass at different time step using a precision scale.

In order to measure the pollutants concentrations in the exhaust gas two different measurement systems were used: TIF5GA Automotive exhaust gas analyser and TSI CA-CALC™ Combustion Test Kit. Main instrument characteristics are reported in Table 3 and Table 4, respectively.

Table 3. TIF5GA automotive exhaust gas analyzer main specifications.

Parameter	Measurement range	Resolution
Carbone monoxide	0.00 to 9.99 %	0.01 %
Hydrocarbons	0.00 to 9999 ppm	1 ppm
Carbon dioxide	0.00 to 19.99 %	0.01 %
Oxygen	0.00 to 25.50 %	0.01 %
Oxides of nitrogen	0.00 to 4999 ppm	1 ppm
AFR	0.00 to 99.9	0.1

Table 4. TSI CA-CALC combustion test main specifications.

Parameter	Measurement range	Accuracy
Carbone monoxide	0.00 to 5000 ppm	0 to 400 ppm: ± 20 ppm >400 to 2000 ppm: ±5% of reading >2000 to 5000 ppm: ±10% of reading
Oxygen	0.00 to 25 %	± 0.3 %
Oxides of nitrogen (NO)	0.00 to 4000 ppm	0 to 100 ppm: ±5 ppm >100 to 1000 ppm: ±5% of reading >1000 to 4000 ppm: ±10% of reading
Sulfur dioxide	0.00 to 4000 ppm	0 to 200 ppm: ±10 ppm >200 to 1000 ppm: ±5% of reading >1000 to 4000 ppm: ±10% of reading
Fuel type	Natural gas Coke-gas Town gas Propane	
Operating temperature	0 to 1273 K	0 to 472 K: ±1 K > 472 K: ±0.5 % of reading
Calculation range	Combustion efficiency	0 to 125 %
	Excess air (%EA)	0 to 1000 %
	CO_2	Calculated from O_2 and fuel type

3. The original engine

In this section a brief description of the manufacturer engine used in this paper is given. The engine is a Briggs & Stratton mono cylinder four strokes spark ignition engine. Main engine characteristics are reported in Table 5.

4. The Modified engine

In this section a brief description of the modified engine used in this project is given.

In order to run the engine on acetylene and alcohol, some modifications to the original engine structure were required. The structural main modifications consist in:

1. Gasoline fuel tank substitution with a alcohol suitable tank;
2. Acetylene suitable tank introduction with secure systems;
3. Intake pipe modification in order to install fuels injectors;
4. ECU introduction in order to control injections and ignition;
5. Exhaust gas pipe modification to allow lambda sensor installation.

Standard alcohol tank and acetylene storage system with secure valves were used to store fuels (see Fig. 2(a)). A modified intake manifold was built to install acetylene and alcohol injectors (see Fig. 2(b)). Taking into account the high instability of the acetylene, it was necessary to inject the acetylene in gas phase at low pressure (103.425 kPa), while the alcohol was injected at 206.850·kPa. A methane-designed injector was used to inject acetylene, while a standard designed gasoline injector to inject alcohol. A MOTEC-M400 Electronic Control Unit (ECU) was adopted in the present work. It consists of control unit and management software, through which it is possible to interact in real time with different control parameters. Moreover, a throttle position sensor, an intake manifold absolute pressure (MAP) sensor, an intake manifold air temperature sensor, an engine temperature sensor, a trigger sensor and a lambda sensor were installed and connected to the ECU. The ECU is able to control timing and duration of both injections, as well as spark advance timing.

Table 5. Main engine characteristics from the manufacturer.

Description	Value
Engine type	4 stroke spark ignition
Cylinder number	1
Bore	79.2 mm
Stroke	62 mm
Displacement	305.44 cm^3
Max power @ speed	8 kW @ 3600 r/min
Max torque @ speed	18.5 Nm @ 2400 r/min
Refrigeration type	Air cooled
Fuel type	Gasoline
Fuel meting system	Carburetor

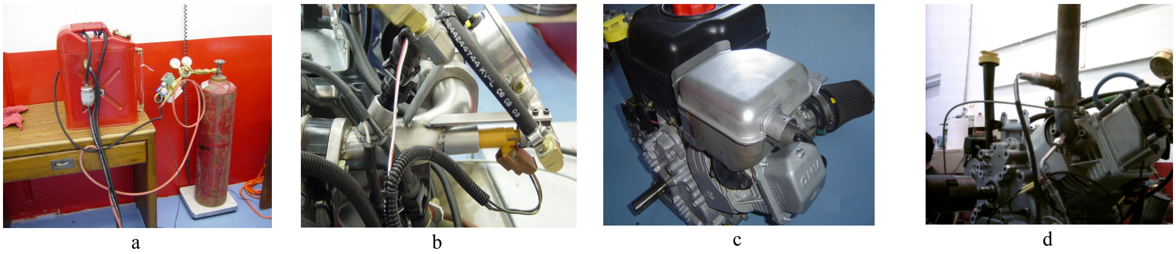


Fig. 2. (a) Alcohol and acetylene fuel tanks; (b) Intake manifold with alcohol and acetylene injectors; (c) Original exhaust pipe; (d) modified exhaust pipe.

5. Engine mapping and optimization

In order to obtain a correct engine run an innovative engine mapping procedure was carried out. First of all, a trial and errors procedure was used to obtain a correct engine run using acetylene and alcohol. Secondly, a genetic approach, coupled to Neural Networks, was used to optimize the first attempt engine map in order to get best performance and low pollutant emissions.

5.1. Genetic Algorithms Background

Genetic Algorithms (GAs) are search algorithms based on the mechanics of natural selection and natural genetics. GAs are successfully applied to a number of optimization problems in different sectors, where more traditional methods are often found to fail [10, 11]. These algorithms are computationally simple yet powerful in their search for improvements. Furthermore, they are not fundamentally limited by restrictive assumptions about the search space as continuity, existence of derivatives, unimodality, etc. Simplicity of operation and power of effect are two of the main attractions of GAs. They are different from the traditional optimization and search procedure in several ways. First of all, they search from a population of points and not from a single point. Secondly, they use payoff information based upon an objective function, rather than derivatives or other auxiliary knowledge. Thirdly, they use probabilistic transition rules, not deterministic rules, to guide the search. However, the use of probability does not suggest that the methods are some simple random search. GAs use randomized operators as a tool to guide a search towards regions of the solution space with likely improvement. Lastly, they are able to depart from local optima, maintaining at the same time a high rate of convergence towards the global optimum. Taken together, these differences contribute to a GAs' robustness and resulting advantage over other more commonly used optimization techniques.

5.2. Neural network background

Neural Networks represent a powerful tool for the description of physical systems and they are successfully applied to solve a number of problems in different sectors. NN are able to represent the physical knowledge of complex systems that are highly non linear and to extract such knowledge from the data presented to them and reproduce it with very low errors. The main NN skills are related to its massively distributed structures and its ability to learn from examples [12, 13]. In fact, NN may learn complex relationships between inputs and outputs of physical systems from available data. Moreover, due to the high distribution of the knowledge throughout the network, these systems are fault tolerant. If processing elements are damaged or lost the response of the entire system is only slightly affected. If more artificial neurons are destroyed, the performance of the neural network as a whole will be a bit further altered. Traditional computing systems will become useless by the same or even smaller degree of memory damage [14, 15]. A neural network consists of a combination of single artificial neurons. Then, various network architectures are possible. The most suitable neural network for the topic is the "Elman Neural Network" with a "Back Propagation Algorithm" according to literature [12 – 15] and authors' experiences [16, 19]. The Elman network [15] commonly is a two-layer network with feedback from the first-layer output to the first layer input. This recurrent connection allows the Elman network to both detect and generate time-varying patterns. This type of neural network normally has "tansig" neurons in its hidden layer, and "purelin" neurons in its output layer. Using this combination, Elman network, that is an extension of the two–layer sigmoid/linear architecture, is able to approximate any function with a finite number of discontinuities and with an arbitrary accuracy. The only requirement is that the hidden layer must have enough neurons. More hidden neurons are needed as the function being fit increases in complexity. Because the network can store information for future reference, it is able to learn temporal patterns as well as spatial patterns. The Elman network can be trained to respond to, and to generate, both kinds of patterns [15].

5.3. The Implemented Genetic Algorithm

In the current work constrains a real coded gene Genetic Algorithm was used. The initial population was chosen randomly with genes in the ranges reported in Tab. 6. During the evaluation phase, a Neural Network fitness function was used. The fitness function is shown in Eq. 1.

$$F_{CW} = C_1\,[CO + HC] + C_2\,[NO_x] \tag{1}$$

where [CO+HC] and [NO_x] are the concentrations levels for carbon monoxide, unburned hydrocarbon, as well as nitrogen oxides.

Table 6. Gene ranges.

Gene	Real variable	Lower limit	Upper limit
1	FM	55	60
2	FS	56	66
3	SA	15	30

Specific neural networks give these values. C_1 and C_2 are the weights. In order to obtain the same weight for each criteria, all the weights in the fitness function were set to one. In the genetic algorithm constrains about the performance were introduced, in order to reduce the emissions level maintaining at the same time performance level. As in the case of the emissions levels, the engine performance was given by a suitable neural network. Crossover and mutation operators modified the population obtained by reproduction. The single point crossover, that is the exchange of chromosomes between parents in the natural generation process, was implemented in the algorithm. A couple of individuals was selected from the population in a random manner and their genomes were crossed over a randomly chosen point with a probability set to 0.5. When the crossover process was performed, it produced two offspring that replaced the parent genes. The mutation operator randomly mutated the individual's genome with an imposed probability (0.02). The choice of a high crossover probability and a low mutation probability was made according, also, to De Jong [10]. In the implemented genetic algorithm a generation gap (proportion of created children at each generation) of 30% of the stipulated number of the individuals for each generation was imposed in the procedure. The new generation was used as starting generation and all phases were repeated. When the maximum number of generations was reached the genetic algorithm stopped.

5.4. The Implemented Neural Networks

The neural network type used in the current work is an Elman two–layer back propagation network. The networks have "tansig" neurons in its hidden and output layers and present 3 inputs (Spark Advance SA, Fuel Main FM and Fuel Secondary FS), and 1 output for the emission networks (CO+HC and NO_x concentrations) 2 outputs for the performance network (Torque and Power). In order to identify the best number of the hidden layer neurons, a trial and errors procedure was used on the basis of the experimental training data (sse less than 10^{-5} in all NN with 16 hidden neurons). At the end of the Neural Networks optimization phase, a test phase was carried out. Fig. 3 shows test phase results for two examples (Power and NO_x concentration). It is well observed the good agreement between NN outputs and experimental data. This result was obtained for all implemented and trained NN. Therefore, it is possible to state that the implemented Neural Networks are able to simulate the engine behavior in all explored range. Using the GA and NNs the optimal values of the mass ratio between acetylene (FM) and alcohol (FS), as well as spark timing (SA) was obtained in all studied engine speed and load. The optimization technique results are shown in Fig. 4. In Fig. 4 CO+HC and NO_x concentrations variation, as well as torque and power variations are shown. Results analysis shows very well that there is a strong reduction in pollutant emissions, especially for NO_x emission, maintaining at the same time engine performance.

a

b

Fig. 3. (a) Power NN output versus experimental data; (b) NOx concentration versus experimental data.

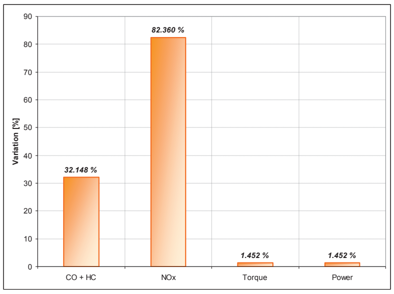
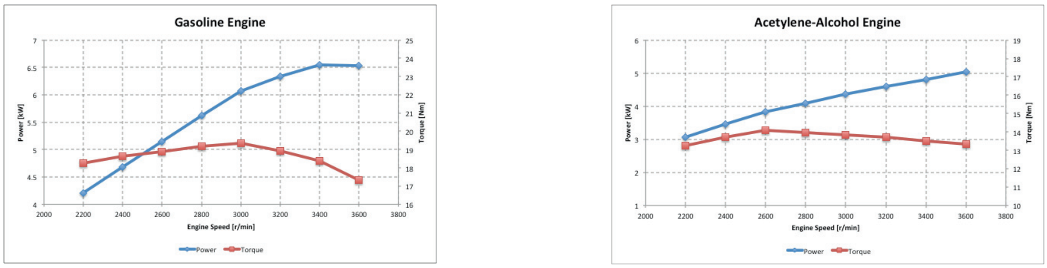


Fig. 4. CO+HC and NOx concentrations, as well as power and torque variations.

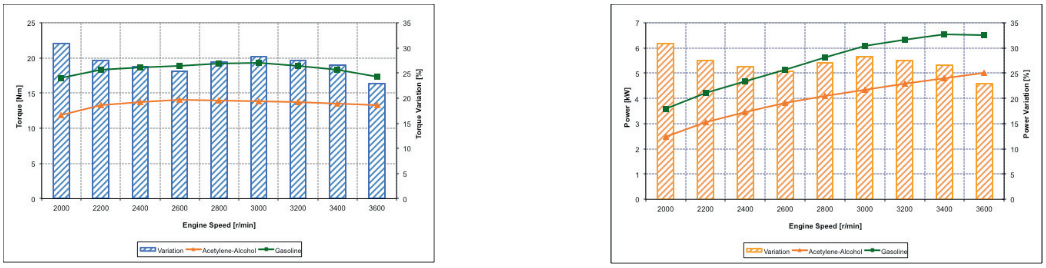
6. Results and discussion

In order to compare the two analysed engine configurations, several tests WOT were carried out in both engine-running configurations: gasoline (original) and acetylene-alcohol (new) modes. In Fig. 5 engine performance (torque and power) are shown as function of engine speed for both running modes – gasoline (Fig. 5(a)) and acetylene-alcohol (Fig. 5(b)) – while Fig. 5 shows the comparisons in terms of torque (see Fig. 5(a)) and power (see Fig. 5(b)), respectively. In the graphs reported in Fig. 6 performance variations are shown. Results analysis highlights that engine running on acetylene and alcohol has about 25 % reduction in engine performance because of the reduced global low heating value and likely because of the use of a combustion chamber optimized for gasoline combustion.



a b

Fig. 5. (a) Engine performance running on gasoline; (b) Engine performance running on acetylene-alcohol.



a b

Fig. 6. (a) Gasoline and acetylene-alcohol torque comparison; (b) Gasoline and acetylene-alcohol power comparison.

Break Specific Fuel Consumption is reported in Fig. 7 as function of engine speed. In the same graph BSFC variations are reported as well. It is evident, observing Fig. 7, that "acetylene-alcohol BSFC" is lower than "gasoline

BSFC" in almost all engine speed range analysed. The slightly increase in "acetylene-alcohol BSFC" at maximum engine speed is probably due to the different lower heating value of the acetylene-alcohol mixture.

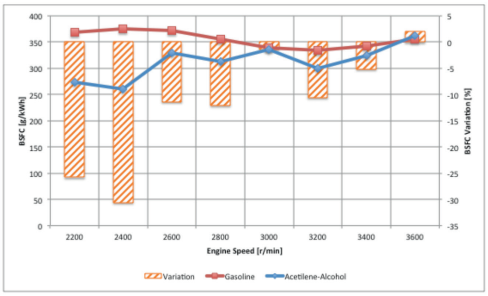
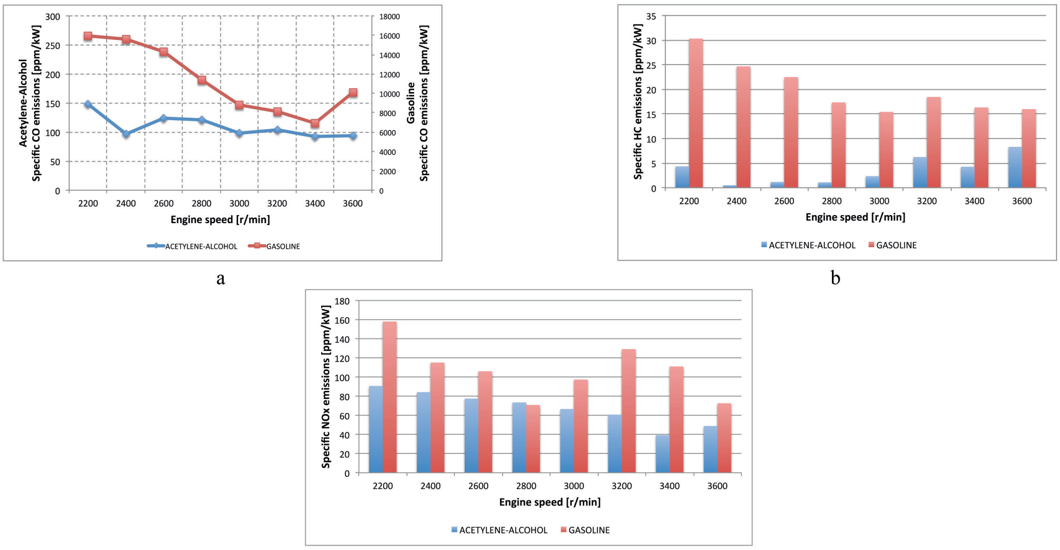


Fig. 7. Specific Fuel Consumption in both running modes



a

b

c

Fig. 8. (a) Acetylene-alcohol CO emissions respect to gasoline CO emissions; (b) Acetylene-alcohol HC emissions respect to gasoline HC emissions; (c) Acetylene-alcohol NOx emissions respect to gasoline NOx emissions.

As far as the pollutant emissions it is concerned, Fig. 8 shows engine running on acetylene-alcohol CO (Fig. 8(a)), HC (Fig. 8(b)) and NO_x (Fig. 8(c)) specific emissions compared to the specific emissions from the engine running on gasoline. The results analysis highlights that all considered pollutants reduce at all engine speed.

As it is possible to observe in Fig. 8(a), a strong reduction in CO emissions occurs running on acetylene-alcohol at all engine speed respect to run on gasoline. At the same time HC and NO_x emissions (Fig. 8(a) and (b)) decrease using acetylene-alcohol instead of gasoline. These effects are probably related to lower combustion temperature due to a fuel lower heating value and the refrigerant effect of the alcohol during combustion tail.

Thus, on the basis of the results, acetylene-alcohol fuel mixture allows to run the engine with low pollutant emissions.

7. Conclusions

On the basis of the presented results it is possible to state that it is possible to run a conventional internal combustion engine on acetylene controlling detonation phenomena using alcohol. Moreover, a complete characterization of the engine in two configurations, gasoline (original) and acetylene-alcohol (new) was carried out obtaining acceptable performance in terms of torque and power in all analyzed engine speed range. An optimization technique based on genetic algorithms and neural networks was implemented to optimize the engine map. This technique permitted to obtain furthers reductions of pollutant emissions by searching optima controlling parameters combinations in all speed range. Therefore, It is possible to obtain lower pollutant emissions rather than the original configuration. In conclusion, the new engine configuration based on acetylene-alcohol represents a good alternative to gasoline and diesel engines in terms of pollutant emissions, as well as engine performance.

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