Journal of Renewable Energies 27 (2024) 297 – 317

DOI: https://doi.org/10.54966/jreen.v27i2.1216

Journal of Renewable Energies

Revue des Energies Renouvelables

journal home page: https://revue.cder.dz/index.php/rer

Research paper

Influences of ternary ethanol methanol gasoline mixtures on the performance of a spark ignition engine

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ARTICLE INFO

Article history:

Received June 21, 2024
Accepted October 20, 2024

Keywords:

Methanol,
Ethanol,
Blends,
Performance,
Exhaust gas temperature.

ABSTRACT

The principal aim of this study is to determine the influence of ternary mixtures of gasoline, ethanol and methanol as fuels, on a spark ignition engine performance. Four samples of fuels were prepared with varying concentrations of each constituent. The different fuels studied are: EM0 (gasoline), EM5 (2.5% ethanol, 2.5% methanol, 95% gasoline), EM10 (5% ethanol, 5% methanol, 90% gasoline) and EM15 (7.5% ethanol, 7.5% methanol, 85% gasoline). A battery of tests (appearance, color, odor, lower heating value, density, research octane number, vapor pressure, total sulfur content and distillation curve) was carried out on these mixtures in order to determine their physicochemical properties and their ability to be used as fuel. Then, the different prepared mixtures were used as fuels to determine the performance of the 4-stroke, carbureted Renault 4 engine. These tests show that these additions give rise to a fuel with a lower sulfur level, a higher RON and a lower low heating value compared to unleaded gasoline and therefore improve, depending on the circumstances, the power of the fuel engine, its specific consumption, its speed and combustion. At the end of this study, it was concluded that the use of fuel mixtures was relevant for high speeds and also more suitable for total loads.

1. INTRODUCTION

The world is in an ecological transition. The energy issue is more relevant than ever. Today, most of the energy used by human being comes from fossil resources and the transport sector represents 61.5% of the total demand for oil even though the latter are exhaustible (Lennartsson, et al., 2014).

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ISSN: 1112-2242 / EISSN: 2716-8247

Furthermore, the excessive use of gasoline in the internal combustion engine destroys the environment through the pollution it causes. Indeed, the combustion of fossil fuels represents 80% of the anthropogenic sources which are at the origin of the effects of degradation of the global environment such as climate change, the greenhouse effect, acid rain, the depletion of the layer ozone, etc. (Roberta & Sierra, 2007). Indeed, in the road sector, gasoline remains the most consumed fuel (51.5%) according to 2022 data provided by the French Institute of Petroleum and New Energies. One possible reason for the environmental degradation caused by gasoline is that it contains compounds that pollute after being released as smoke (flue gas), such as aromatics and methyl tert-butyl ether (MTBE) (R. Paul & Emilie, 2007) (Chi-When, et al., 2005). In addition, molecules (e.g., CO, SO_2, NO_x, VOC_s, O_3, etc.) resulting from the combustion of gasoline itself also contribute to the atmospheric pollution (Rachida, 2019). This justifies the environmental concerns that have increased considerably around the world, especially over the last decade.

Alcohols are among the substitutes for petroleum, especially in the transport sector (Qayyum, et al., 2021). For example, ethanol alone saw its annual global production increase from 17.0 x 10^6 to 86.1 x 10^6 m^3 from 2000 to 2011 (Lennartsson, et al., 2014). Brazil (28%) and USA (56%) are the top major producers of ethanol in the world (Iram, et al., 2022). Although its production sometimes poses problems since it is mainly done following the first generation which means that it enters into competition with human food (Yaser, et al., 2019). Note that second generation ethanol continues to arouse interest due to its ability to reduce greenhouse gas emissions by 86% unlike the first which can only do so by 39-52% (Wong, et al., 2007). At the same time the low cost of the materials necessary for its production is a major factor in this increasingly growing interest (ul, et al., 2021). Studies are currently being carried out to improve the enzymes necessary for its production which until now are very expensive and less suitable for industry (Iram, et al., 2022).

The high-octane number of alcohols and the absence of sulfur in their composition naturally influence alcohol mixtures. That is why the interest in using alcohols is not only aroused by their renewable characteristics but also by their contributions to improving the octane number, the combustion and the reducing of the sulfur level (Hansen, et al., 2005) (Tangka, et al., 2011). Adding alcohols such as ethanol and methanol to gasoline allows the fuel to burn more completely due to the presence of oxygen in their chains, 49.93% and 34.7% respectively (Qayyum, et al., 2021), by increasing the combustion efficiency that contributes to the reduction of the air pollution (Latika, et al., 2012). Emissions (ozone precursors) from the combustion of alcohols have a reactivity, which can significantly promote the formation of ozone (Elfasakhany, 2015).

Methanol (CH_3OH) can be produced from a number of carbon-based raw materials, such as natural gas, coal, biomass and CO_2 . It is mainly (90%) produced from natural gas (Quirina I., et al., 2019) cited by (Dalena, et al., 2018). The production process from natural gas is relatively simple. Depending on the production of syngas, the conversion of syngas into crude methanol and distillation of crude methanol into pure methanol are the essential steps in the production of methanol via this method (Dalena, et al., 2018). Its low cost compared to ethanol encourages researchers to study the possibility of using ternary mixtures (gasoline-ethanol-methanol) (Pearson, et al., 2015). It is also important to point out increased toxicity (neurological, ophthalmic and systemic) of methanol compared to ethanol, the contamination of which is either via ingestion, inhalation, or dermal exposure to methanol or formulations containing methanol in base (Habib, et al., 2019) (Nekoukar , et al., 2021).

Ethanol (C_2H_5OH), can be obtained using two different methods. The first method is by a chemical reaction between ethane and the steam (Bae, et al., 2017) cited by (Qayyum, et al., 2021). The second method is by the fermentation of sugars or biomass containing lignocellulose (Petrou, et al., 2009) cited by (Qayyum, et al., 2021). This method is the most used by manufacturers. From the resources used for its production we therefore have 3 generations of ethanol:

(1) The first generation is that of alcohols derived from essentially conventional agricultural materials. Any plant having starch, starchy plants ($(C_5H_{10}O_5)_n$) (cassava tuber, barley, sweet potato, wheat, rye, potato, corn...) or sucrose (sugar cane , beet, etc.) can be used to produce ethanol (Lennartsson, et al., 2014).

(2) There are mainly two conversion technologies for the production of second-generation ethanol by biochemical and thermochemical or BTL (Biomass To Liquid) (Lennartsson, et al., 2014). The biochemical conversion process is a common and efficient technic for producing ethanol (Sharma, et al., 2020). Biochemical conversion includes pretreatment, hydrolysis and fermentation (Sharma, et al., 2020). For thermochemical method lignocellulosic biomass goes through pretreatment, gasification, gas purification, syngas conditioning and then hydrocarbon synthesis ($CxHyOz$) which can be done with the gas to liquid conversion process GTL (Broust, et al., 2008).

(3) Finally, the third-generation ethanol is produced from algal biomass (Brennan & Owende, 2010). Usually, species such as Chlorella are targeted because of their high lipid content (around 60 to 70%) according to (Liang, et al., 2009) cited by (Lee & Lavoie, 2013) and their high productivity of 7.4 g/L per day for Chlorella prototheorids (Chen, et al., 2022) cited by (Lee & Lavoie, 2013). The biochemical route, by enzymatic hydrolysis of algal cultures can be used to produce sugar from algal oil and the sugar that will be produced from it, will be transformed using the fermentation and distillation technique.

However, Ethanol from the first generation remains the most abundant (99%) due to the mastery of the technique on the part of manufacturers, and the affordable cost of the enzymes used for saccharification (Talia, et al., 2022). Unfortunately, the raw materials used for the first generation compete with human food, pushing manufacturers to move on to the other generations (Iram, et al., 2022).

Ethanol would be produced for the first time around 11th century from the distillation of wine (Rasmussen, 2012). The first prototype of an internal combustion engine using alcohol as fuel (ethanol and turpentine), was providing in the USA from the American inventor Samuel Morey, in 1826 (Hardenberg, 1992). In 1876 the German inventor, Nikolaus Otto, designed an internal combustion engine fueled with ethanol (Cummins, 2000).

Mixing alcohol with gasoline is a source of several concerns. Among which there is the instability of mixtures, the reduction in energy content compared to gasoline and a consequent increase in consumption, due to the large amount of oxygen in ethanol, the increase in vapor pressure (Muanda, et al., 2019) and in fuel volatility (Amine & Barakat, 2019). To mitigate these problems, alcohol can be added to gasoline in low concentrations (Amine & Barakat, 2019). It is noticed that the presence of alcohol in gasoline has a positive impact on the research octane number (Amine & Barakat, 2019).

Many researchers have studied gasoline-alcohol mixtures (gasoline-ethanol and/or methanol) and have all, roughly observed the increase of following parameters: the density of the mixture, the octane number and the kinematic viscosity. They related the reduction of the other parameters such as: the severity of the vapor pressure, the low heating value, and the sulfur content. Some authors noticed that the replacement of gasoline by a slightly quantity of alcohol contributes to the reduction of the engine pollution and has some effects to its performances.

Pearson et al. related that it is not possible to completely abandon fossil energy and switch to the use of the other alternative fuels in a few delay (Pearson, et al., 2015). They noted that the increasing demand of alcohol like fuel must affect the raw materials used in its production. This could be one of the reasons why researchers and manufacturers are looking for a way to use these fuels in an additive manner. So, in this work, we will deal with a ternary mixture of gasoline ethanol and methanol to characterize the engine performances fueled with this mixture in different proportions.

In the ternary domain we can cite Nazzal who carried out a study on 4 different types of fuels (E12, M12, E6M6 and gasoline where E12 indicates 12% of ethanol in the mixture with gasoline while M12 means that there is 12% of methanol in the mixture and finally E6M6 indicates 6% of ethanol and 6% of methanol in the same mixture) by evaluating the power, the thermal efficiency, the exhaust temperature and the fuel consumption at different speeds (Nazzal, 2011). At the end of his experiments, he noticed a significant improvement in performance. Furthermore, it claims that the M12, E6M6 and E12 showed better performance respectively, compared to gasoline. Finally, he specifies that the addition of methanol makes it possible to increase the octane number, thereby allowing the engine to operate at higher compression ratios (Nazzal, 2011).

Sileghem, for his part, studied the hypothesis according to which iso-stoichiometric ternary mixtures can be used as supplemental fuels for flex-fuel spark-ignition engines. In addition to confirming this hypothesis, during his study he also provided similar results to those of Nazzal. The author related that the ternary mixtures compared to gasoline presented the disadvantage in the increasing of the specific consumption. These results agree with the European report on the effects of gasoline vapor pressure and ethanol content on evaporative emissions from modern cars (Martini, et al., 2007). He believes that additional efficiency gains can be achieved by applying significant size reduction with higher compression ratio, direct injection and supercharging which would partly compensate for the low value of LHV of blends containing the alcohols (Sileghem, et al., 2014).

Elfaskhany studied, among other things, the effects of fuels mixed in different non-iso-stoichiometric proportions on a single-cylinder, 4-stroke spark-ignition engine with 7:1 compression ratio, air-cooled, no catalytic converter unit and a carburetor fuel system performance and emissions. He related that methanol and gasoline blends showed the highest volumetric efficiency and torque while ethanol-gasoline blends provided the highest braking power. He observed that ethanol blends with methanol and gasoline showed a moderate level of volumetric efficiency, torque, and braking power between methanol-gasoline and ethanol-gasoline blends. They confirmed that gasoline showed the lowest volumetric efficiency, torque and braking power among all the tested fuels. Specifying that the tests were carried out in the range of 2600 and 3000 rpm (Elfasakhany, 2015).

Finally, Qayyum et al. studied the effect of blending ethanol with a methanol-gasoline fuel on the performance and emissions of a spark-ignition engine. With M10 (10% methanol in the mixture) , E5M10 (5% ethanol and 10% methanol in the mixture) E10M10 (10% ethanol and 10% also methanol in mixture), and E15M10 (15% ethanol and 10% also methanol in mixture) fuels, they concluded that methanol-gasoline and ethanol-methanol-gasoline blends showed an increase in efficiency compared to gasoline. E10M10 had the highest average yield improvement of 9.4%. However, methanol-gasoline and ethanol-methanol-gasoline blends resulted in an increase in consumption compared to gasoline, the E15M10 showed the largest increase in the specific consumption at 17.2% on average (Qayyum, et al., 2021).

Regarding emissions, Sileghem et al. carried out a study on 4 different mixtures of ethanol, methanol and gasoline, two of which were iso-stoichiometric. Having studied only the concentrations of CO and NO_X, they observed that gasoline produced the greatest quantity of NO_X while the lowest quantities were observed with methanol (M57:57% methanol in mixture). The literature suggests that the addition of alcohols improves combustion and therefore reduces CO. This could not be observed in the study by Sileghem et al. Indeed, gasoline and methanol gave similar CO emissions to such an extent that it was impossible to conclude that *CO* emissions are actually lower or higher for the blends (Sileghem, et al., 2014).

Elfasakany, for his part, studied several proportions E3, E7 and E10: 3,7 and 10 vol. % of ethanol in gasoline; M3, M7 and M10: 3,7 and 10% vol. methanol in gasoline; EM3, EM7 and EM10: 3.7 and 10% by volume of ethanol and methanol in gasoline.

It showed that ethanol-methanol-gasoline (EM) blends burned cleaner than ethanol-gasoline (E) and the latter more than gasoline. However, methanol-gasoline (M) blends have the lowest *CO* and *HC* (unburned hydrocarbons) emissions among all fuels tested (Elfasakhany, 2018).

In this study we propose to study the influence of a ternary ethanol-methanol-gasoline mixture according to different proportions of the constituents in the mixture to the spark ignition engine performance.

To achieve this goal, three different formulation fuel are used: EM5 (Ethanol 2.5%, Methanol 2.5% and Gasoline 95%), EM10 (Ethanol 5%, Methanol 5% and Gasoline 90%) and EM15 (Ethanol 7.5%, Methanol 7.5% and Gasoline 85%).

In the current investigation, the low rates of additives (ethanol and methanol) were employed to prevent changing the engine systems and the corrosions that these additives induce, as was previously described.

2. MATERIALS AND METHODS

Following the mixing of alcohols and gasoline, the fuels obtained EM5, EM10 and EM15 were tested on a test bench. The ethanol that was used came from the Kwilu-ngongo sugar refinery with a purity rate of 96.4% vol. and therefore underwent prior treatments bringing it back to 99% vol. with the method of dehydrating calcium lime or quicklime (*CaO*) additives.

The test bench, Figure (1), of the University of Kinshasa "Engine and Fuel Laboratory" used is equipped with a Renault 4 internal combustion engine whose characteristics are presented in Table 1. And this engine is coupled to a hydraulic brake powered by pressurized water and a fuel supply system. In addition to these main constituents, the tachometer, the stopwatch and the thermal camera were used to respectively determine the rotational speed of the engine, the time taken for the flow of fuel with a volume of 25 mL in order to deduce the volume flow fuel flow and temperatures at different locations in the engine, such as exhaust gases.

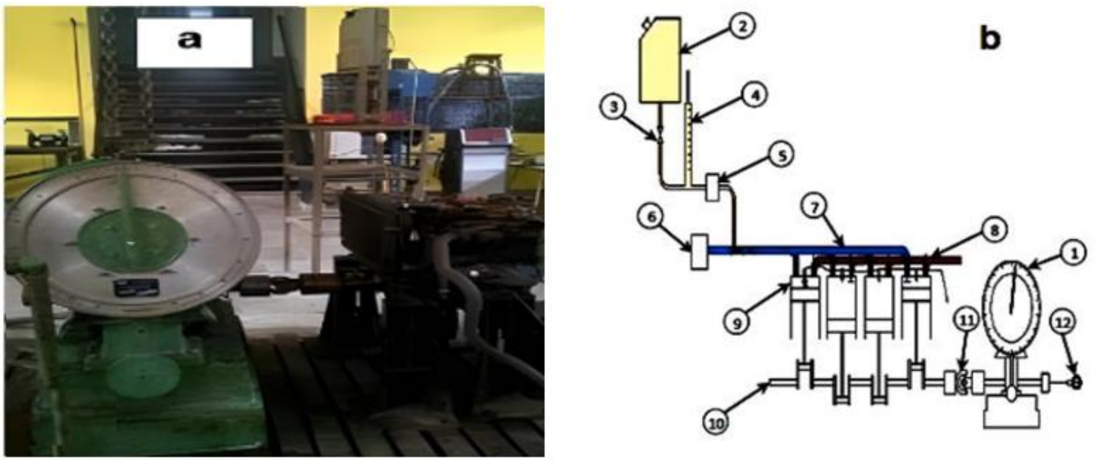

Fig 1. Presentation of the test bench (a) and its principle diagram (b)

1. Hydraulic brake; 2. Fuel tank; 3. Fuel supply valve; 4. Burette; 5. Fuel filter; 6. Air filter; 7. Air supply line; 8. Exhaust pipe; 9. Cylinders; 10. Crankshaft; 11. Cardan joint; 12. Tachometer.

Table 1. Engine specifications

Model–index	**Billancourt-800S61.**
Year of manufacture/Modification	**1983**
Lighting order	**1-3-4-2**
Number of cylinders - Engine type	**4Cylinders- 4stroke**
Displacement	**845cm ^{3}**
Bore X Stroke	**58 x 80mm**
Combustion chamber volume	**27.3 cm ^{3}**
Carburetion	**Single carburetors**
Compression ratio	**8:1**
Cylinder head height	**94.7 or 96.4 mm**
Fiscal power	**5HP**
Power SAE	**32hp at 4800rpm**
Diet	**4700 rpm**
Couple	**5.9kg.m at 2300rpm**
Cooling	**Water with radiator**

The tests were carried out at variable speeds (from 1494 to 3578 rpm) obtained by controlled opening of the carburetor throttle. Thus, we carried out our study at 1/1 total load and ½ partial load. The different operating points were obtained by taking the characteristics of the engine during the variation of the torque by regulating the quantity of water penetrating the hydraulic brake. A rest period and washing of the fuel line with gasoline always separated the transition from one speed to another and from one fuel to another to ensure good results.

3. RESULTS AND DISCUSSION

3.1. Physico-chemical properties

The test results in the chemistry laboratories of the Polytechnic Faculty of the University of Kinshasa and SEP Congo are presented in Table 2. From Table 2, we have presented the comparison between the different mixtures and gasoline (Fig. 2).

As expected, the LHV values of the mixtures decreased as the alcohol content increased, i.e., by 2.42%, 7.26% and 11.08% for EM5, EM10 and EM15 respectively compared to the 'essence. Knowing that methanol and ethanol have a low PCI compared to gasoline, i.e., 20, 26.9, and 44.3 [MJ/kg] respectively; the different mixtures necessarily had to have a PCI lower than that of gasoline, especially since the alcohol content is high in the mixture. This order of magnitude can also be observed in the study by Qayyum et al. who by determining the LHV of M10, E5M10, E10M10, and E15M10 observed a decrease of 8.4%, 10%, 15.6 and 16.9% respectively (Qayyum, et al., 2021).

We also observe, unsurprisingly, the improvement in density. Qayyum, et al. obtained similar results to those of the present study. Similarly, to Tuner et al., we observe that the measured densities are almost linear combinations of the component densities (Turner, et al., 2012).

Indeed, in their study they observed an increase in the density of M10, E5M10, E10M10, and E15M10 respectively of 1.7%, 3.2%, 7.8% and 10.7% and that the mixtures with the higher the alcohol level, the higher the density (854 kg/m^3) (Qayyum, et al., 2021). The EM5, EM10 and EM15 increased by 0.27%, 0.69% and 1.82% respectively. It is evident that EM15 shows the most improvement in density compared to the reference gasoline. In fact, methanol and ethanol have a density greater than that of gasoline. This explains a proportional improvement in density to the level of alcohol present in the mixture.

Table 2. Physico-chemical properties of mixtures

Characteristic		Method	Unit	Limit	EM0	EM5	EM10	EM15
Appearance		Visual	-	Clear	Clear	Temporary trouble, At rest, a liquid precipitate	Clear	Temporary trouble, At rest, a liquid precipitate
Color		Visual	-	Red	Red	Red	Red	Red
Smell		Organoleptic	-	Merchant	Merchant	Merchant	Merchant	Merchant
Lower heating value		ASTM D240-92	MJ kg^{-1}	Min 42	45.85	44,742	42.52	40,769
Density at 15°C		ASTM D4052	kg m^{-3}	715 - 770	754.3	756.3	759.5	768
Research octane number (RON)		ASTM D2699	-	Min 91.0	97.5	99.6	100.2	100.5
Total sulfur content		ASTM D4294	% mass	Max 0.030	0.032	0.03	0.03	0.028
Distillation	0%	ASTM D86	°C		35	37	35	36
	10%		°C	Max 70	57	50	56	53
	20%		°C		67	61	66	57
	30%		°C		76	73	75	61
	40%		°C		86	85	85	65
	50%		°C	Max 115	98	96	95	88
	60%		°C		109	108	108	107
	70%		°C		122	121	120	119
	80%		°C		136	134	134	134
	90%		°C	Max 180	157	154	152	155
	100%		°C	Max 215	193	191	187	182
	Difference (20 – 10) %		°C		10	11	10	4
	Residue		% flight,		1.1	1.2	1.4	1.5
	Losses		% flight,		0.9	0.8	0.6	0.5

The octane number, for its part, increases by 2.15%, 2.77% 3.08% for EM5, EM10 and EM15 respectively and this proportionally with the quantity of alcohols present in the mixture. Indeed, the improvement of this index is an assurance of engine operation far from the knocking zone affirm Amine et al. in their study of ternary and binary mixtures. A similarity emerges between our two studies in the sense that a progressive improvement in the index is observed in proportion to the quantity of alcohol in the mixture. Methanol has the highest-octane rating compared to gasoline and ethanol. Thus, to better adjust this index in a ternary mixture, it is enough to control the quantity of methanol in the mixture (Amine & Barakat, 2019).

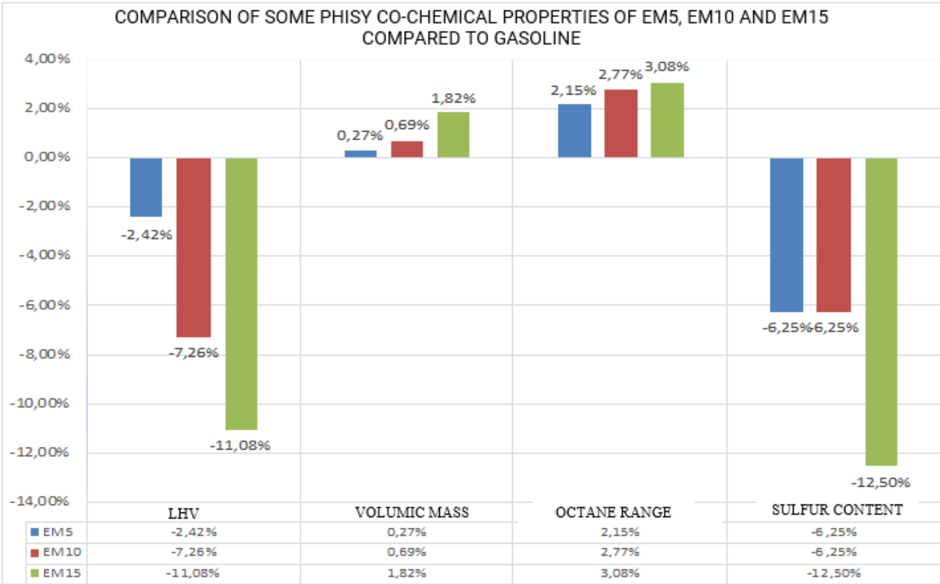

Fig 2. Comparison of some physicochemical parameters of EM5, EM10 and EM15 compared to gasoline

All mixtures present good sulfur content guaranteed by the absence of sulfur in the chemical composition of ethanol and methanol. It decreases with the increase in alcohols in the mixtures and therefore guarantees a reduction in pollution given that sulfur promotes emissions of sulfur dioxide SO_2 and sulfuric SO_3 leading to acid rain (Jiena, et al., 2019).

The red coloring of the different mixtures is due to the presence of gasoline in the mixture which is colored either for reasons of fuel traceability or for reasons of differentiation of fuel types (gasoline, fuel oil, etc.) (Tim, et al., 1985) (Colleen, 2010).

As with coloring, the smell of different mixtures is due to the presence of gasoline in the mixture. It should be noted that certain mixtures presented an appearance of temporary cloudiness, and a rest, a liquid precipitate. We think that this would be due to the instability of the gasoline-alcohol mixture as was also observed by Muanda et al. (Muanda, et al., 2019).

As with the other parameters, the distillation curve reveals that at different temperatures, the fuels obtained comply with ASTM specifications . Based on the distillation fractions given in Table 1, we trace, using Microsoft Excel software, the distillation curves illustrated in Figure (3) using the distillation points, which confirm the principles identified.

In Figure (3), 0% indicates the initial point and 100% the end point of evaporation and the following observations were made:

1. Gasoline (EM0) has a lower volatility compared to all other fuels but quite similar to that of EM10 up to around T50. Beyond T50, the gasoline curve approaches that of EM5 and both coincide with EM15 at the final point;
2. EM15 is best placed for cold start while EM0 and EM10 should be preferred for hot start. With the exception of EM0, EM5 and EM10, EM15 is more susceptible to icing;
3. EM10 is less economical and is likely to form more deposits than all other fuels.

The EM5 curve is in the middle of all the others. This position makes EM5 a fuel which would best adapt under different operating situations, hot weather or cold (in winter for example for temperate climates). We also see a decrease significant in the distillation temperature compared to alcohol-free gasoline. This observation was also made by Amine & Barakat and allows us to affirm that these Additions increase the evaporation of mixtures (Amine & Barakat, 2019).

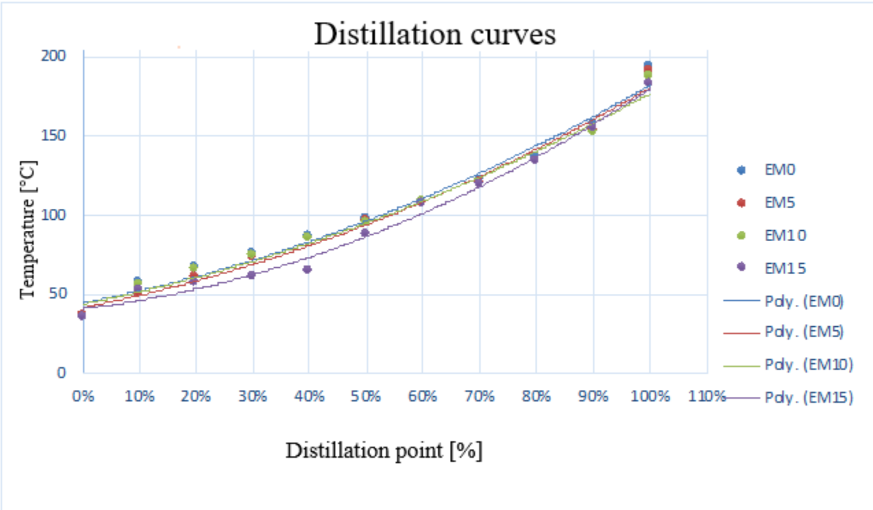

Fig 3. Distillation curve of EM0, EM5, EM10 and EM15

3.2. Engine tests

3.2.1. Partial load tests

Combining the positive effect in terms of combustion of the latent heats of vaporization of ethanol and methanol respectively approximately 2.7 and 3.6 times greater than that of gasoline and the presence of oxygen in their chemical structure; we expected an improvement in torque at all speeds. (Muanda, et al., 2019) believed that this poor performance illustrated in Figure (4) can be justified by the character of homogeneous pseudo-mixtures, gasoline-alcohol for example, whose behavior can vary depending on different temperatures (Muanda, et al., 2019). As for us, in addition to this possibility we believe that this behavior can also be justified by a low vapor pressure of our two alcohols compared to that of gasoline. Indeed, this lower vapor pressure means that alcohols need a higher temperature or a longer time to completely vaporize (Kar, et al., 2008) cited by (Yuqiang, et al., 2016).

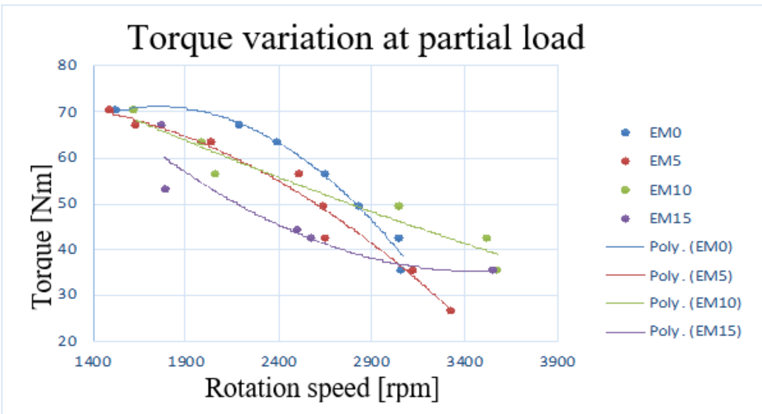

Fig 4. Variation of torque at partial load as a function of rotation speed

Figure (5) allows us to observe the power variations. The engine was operated in speed range of 1494–3578 rpm similar to Muanda et al. (around 1600-3000), with a higher maximum (Muanda, et al., 2019). We could not go below this speed since the test bench is not suitable for operating at these speeds. Having used the same test bench, this difference could be explained by the improvements made to the engine and the presence of methanol in the mixture.

Until 2800 rpm, the EM0 develops better power to the large torque it develops but from 2800 rpm, the EM10 develops better power. A similarity emerges with the study led by Salih Özer where he analyzed the effects of LPG use in a turbocharged stratified injection (TSI) engine using ethanol/gasoline as pilot fuel in a speed range from 500 rpm to 5500 where we observe a demarcation of E10+LPG (liquefied petroleum gas) on E0+LPG, E5+LPG and E20+LPG from around 3000 rpm (ÖZER, et al., 2021). It clearly emerges that under these conditions the use of a ternary mixture only becomes interesting at high speeds

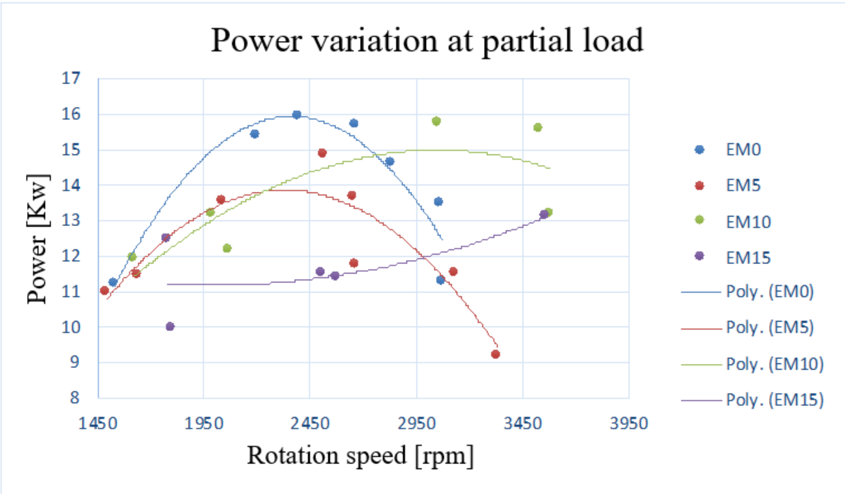

Fig 5. Variation of partial load power as a function of rotation speed

An improvement in specific consumption is observed with the EM10 and EM15 from around 2700 rpm illustrated in Figure (6). This is essentially due to the increase in partial load power associated with the reduction in mass flow. of EM10 and EM15. The first two points of EM15 seem to deviate from the others.

It is observed that the number of alcohols in the mixture has an impact on the low heating value that influences the specific consumption. The results obtained in this study are in agreement with those presented in literature. Muanda, et al. and Raif, et al have made the same observations. Raif et al. Still specify a maximum threshold beyond which no further improvement is observed (Raif, et al., 2017) (Muanda, et al., 2019). Manzenera, while using ternary mixtures as fuels, related a similar result while confirming that this would be due to a greater thermal efficiency by explaining that this thermal efficiency is obtained by the addition of the ethanol, on the one hand (Najafi, et al., 2009) cited by (Manzanera, 2011). On the other hand, he found that consumption increased as the percentage of methanol increased but remained higher than gasoline in other binary mixtures in his study. In both cases the minimum was reached at around 1600 rpm, since the increase in alcohol in the gasoline first caused a drop in consumption before starting an increase (Manzanera, 2011). The aforementioned behaviors may be due to the basis of the fact that before around 2650 rpm gasoline presents lower consumption.

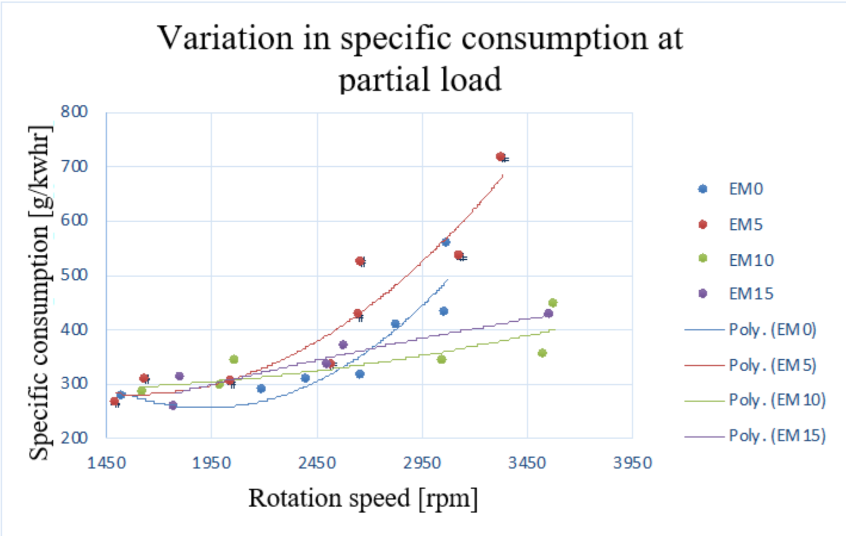

Fig 6. Variation in specific consumption at partial load

We observe, from Figure (7), a clear improvement in efficiency from 2650 rpm. At speeds below 2650, the efficiency curves of EM0, EM10 and EM15 coincide.

We notice an improvement in performance, as also observed by Elfasakhny, when adding alcohols allowing the fuel to burn more completely due to the presence of oxygen, which increases combustion efficiency and reduces air pollution (Elfasakhany, 2015). However, we think that the low power developed by the EM5 means that the associated efficiency is also low. In addition, we see the influence of torque because the EM10 displays better efficiency than the EM15.

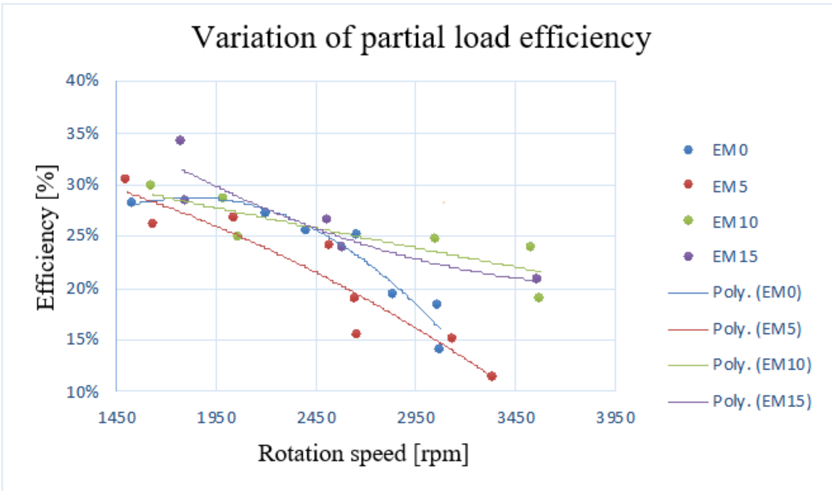

Fig 7. Variation of partial load efficiency as a function of rotation speed

Comparing gasoline to our blends, the curves look as follows in Figure (8):

1. From the point of view of speed, the EM5 offers a small improvement of around 1% while the EM10 and EM15 do not positively influence the mixture since they cause a reduction in said parameter of 4 and 14% respectively;
2. Depending on the fuel flow, the EM5 increases the fuel flow by around 5%, unlike the EM10 and EM15 which decrease by 14 and 30% respectively. These low flow rates are caused by the low speeds developed by the EM10 and EM15 ;

3. The EM5 increases specific consumption by 20% while for the EM10 and EM15 it decreases by 9 and 16% respectively;
4. Only the EM10 provides a gain, of 1%, in torque while the EM5 and EM15 favor a loss of around 13 and 2% respectively;
5. None of the three fuels tested offer an improvement in power. Indeed, a decrease of 12, 4 and 16% are observed for EM5, EM10 and EM15 respectively.
6. The trend is reversed in terms of yield, where EM15 shows a better improvement compared to EM10 which is at 13% and EM5 decreases by 18%.

The literature reviewed did not allow us to make a comparison at this level with the results of other researchers.

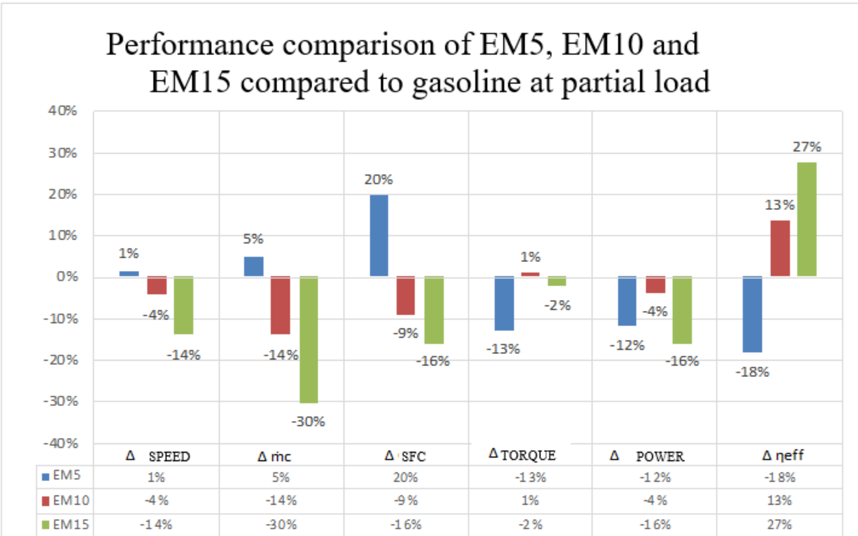

Fig 8. Performance of EM5, EM10 and EM15 at partial load compared to gasoline

3.2.2. Full load tests

It should be noted that it is interesting to carry out this study at partial and full load because this allows us to get closer to the driving conditions of cars where the load varies regularly and therefore to better understand the different influences of the fuels studied.

In overall terms, blends offer a better result compared to gasoline. Although at one level, all values tend to merge. We see from Figure (8) that we had to wait around 2600 rpm for the EM5 to give better values compared to those of EM0.

In addition, the effect of the latent heats of vaporization of our two alcohols combined with the improvement in the octane number also played a more or less important role in the improvement of the torque. This allowed for more advanced timing which results in higher combustion pressure and therefore much greater torque and power than gasoline fuel (Elfasakhany, 2015). This could also explain the difference in speeds between gasoline and mixtures.

Muanda et al. noticed that beyond 2200 rpm the trend of the curves reversed, that is to say, the E10 presented the highest torque values, followed by the E15 (Muanda, et al., 2019). This phenomenon was also observed by Elfasakhany, with the mixture of iso-butane-methanol-gasoline and also those of Gravalos et al. with ethanol-gasoline mixtures. However, the methanol-gasoline results did not present this reversal in the study by Gravalos et al. Let us point out, however, that Gravalos only carried out his study in a speed range of 700 to 2500 (Gravalos, et al., 2011; Elfasakhany, 2015).

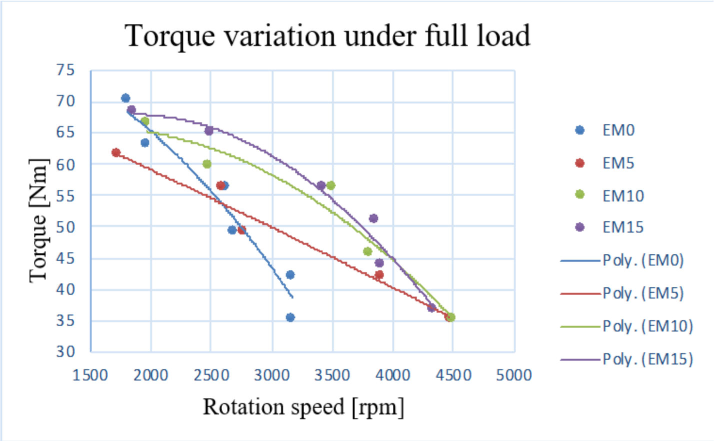

Fig 9. Variation of torque at full load

Referring to the theory on internal combustion engines, power is proportional to torque, so the behavior displayed at the torque level in Figure (9) will also be felt in the power. Thus, we see a clear improvement in power with the EM10 and EM15 mixtures which tend to reverse when we reach the speed of a little more than 4000 rpm due to the proportionality of the power with the torque. The EM5 attempts to join the other two mixtures, therefore exceeding gasoline from around 3000 rpm.

These results indicate, roughly speaking, that, as shown in Figure (9), potency improves more the higher the amount of alcohol in the mixture (within our study range 5 to 15 % alcohol). This is in accordance with the literature since our results are similar to those found by Elfasakhany indicating that the effect of latent heats of vaporization of alcohols and the improvement of the octane number are the main factors underlying this performance (Elfasakhany, 2015).

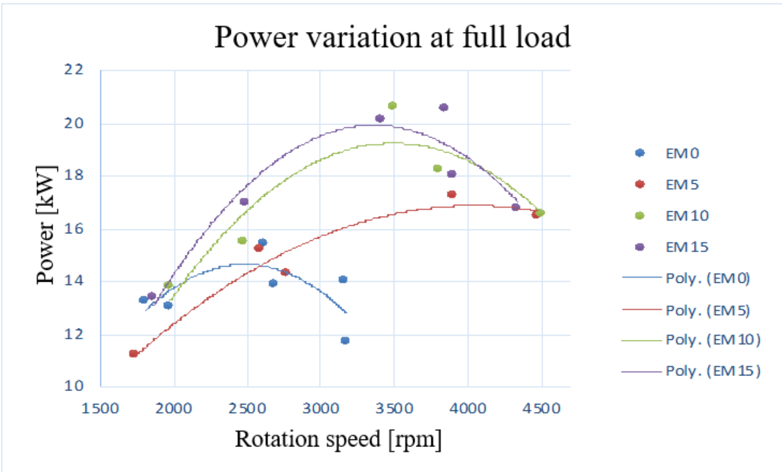

Fig 10. Variation of power at full load as a function of rotation speed

Overall, the EM15 offers a better performance in specific consumption followed by EM10 , then comes the EM5 observed from Figure (10). The latent heats of vaporization of ethanol and methanol, the presence of oxygen in their compositions are the main reasons for this improvement. We believe that the same reasons given for the partial load are responsible in this case, that is to say, the power played a very important role in addition to the fact that the species used was a commercial species.

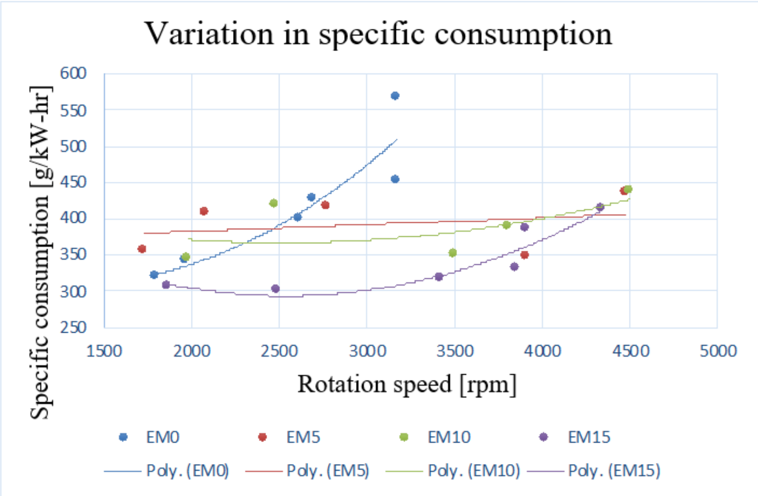

Fig 11. Variation of specific consumption at full load as a function of rotation speed

Figure (12) shows the evolutions of different efficiencies where EM15 offers by far the best efficiency performance compared to all other fuels. Then comes the EM10 whose efficiency values become higher than gasoline after 2400 rpm. Finally, EM5 only joins other fuels at high speeds and becomes superior to gasoline from 2900 rpm.

The influence of the flow rate is clearly more noticeable than that of the lower calorific value. Of course, power is the main cause of these appearances.

The result obtained presents curves similar to those of the study carried out by Sileghem et al. Indeed, the latter presented the evolution of the curves of the different mixtures in a speed range going from 1500 to 3500 rpm (Sileghem, et al., 2014).

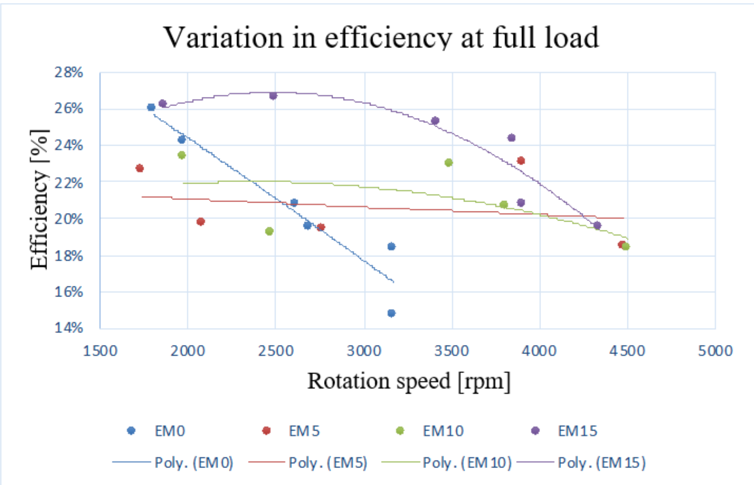

Fig 12. Variation of full load efficiency as a function of rotation speed

By observing Figure (13) , we quickly see the positive influence of adding alcohols to gasoline. In details we observe :

1. An improvement in speed is observed in all the samples tested: 27% for the EM15, 17% for the EM10 and finally 2% for EM5. It therefore improved as the quantity of alcohols increased in the mixture;

2. The flow increases by 11% for the EM10, 8% for the EM15 and decreases by 5% for the EM5.
3. In terms of consumption, a general decrease is observed. We note that this reduction is proportional to the quantity of alcohols contained in the mixture.
4. The torque, for its part, increases by 7% for the EM10, by 2% for the EM15 and decreases by 1% for the EM5; Despite a greater torque for the EM10, the EM15 displays a better influence, i.e. 30% compared to 25% for the EM10. We therefore think like that speed exerts a very significant influence on mechanical characteristics.
5. The power is boosted by the addition of alcohols to the mixture. The EM15 presents the best performance of around 30%, followed by EM10 then EM5 which present improvements of 25 and 1% respectively.
6. The low throughput of EM15 compared to EM10, low PCI and high power meant that the gap between EM15 and EM10 was greater in terms of efficiency than it was in terms of power. The EM15 presents a 17% improvement in efficiency, the EM10 in second place with 9% and the EM5 at 3%.

Except for consumption, all other parameters have undergone significant improvements as shown in the literature (Elfasakhany, 2015) (Sileghem, et al., 2014).

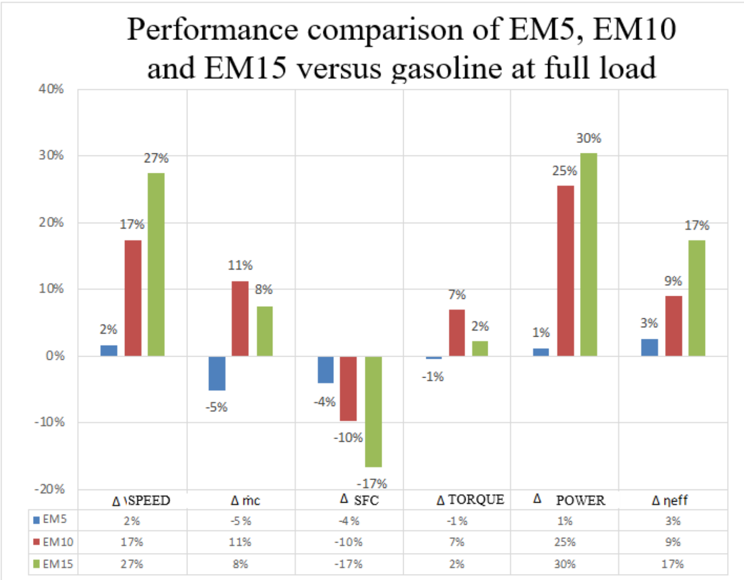

Fig 13. Performance of EM5, EM10 and EM15 at full load compared to gasoline

3.2.3 Exhaust gas temperatures

Figure (14) illustrates the variations of Exhaust gas temperatures (EGT) with different fuels and test conditions. It can be observed that the increase in engine speed led to an increase in EGT for EM0, EM5 and EM10 until reaching the maximum value and then decreasing. This may be related to the increase in cylinder temperature with increasing engine speed, as obtained by Deng et al., in which the authors obtain an increase in cylinder temperature when the engine speed increases from 3000 at 7000 rpm and a reduction beyond this speed (Deng, et al., 2013). They worked on mixtures containing at least 30% butanol and found an increase of around 75% while in the present study we obtained an increase of around 88% between the minimum temperature and that of the peak developed by gasoline. The EM15 shows an opposite trend, that is to say, a decrease in temperature is observed to begin an increase from 2650 rpm. In addition to speed, exhaust temperatures are strongly dependent on horsepower.

In general, an increase in temperature is observed with the addition of alcohols. This can be attributed to better combustion of mixtures facilitated by the presence of oxygen in their chemical composition, on the one hand. On the other hand, the higher laminar flame speed of alcohols than that of gasoline could explain this (Zaharin, et al., 2018).

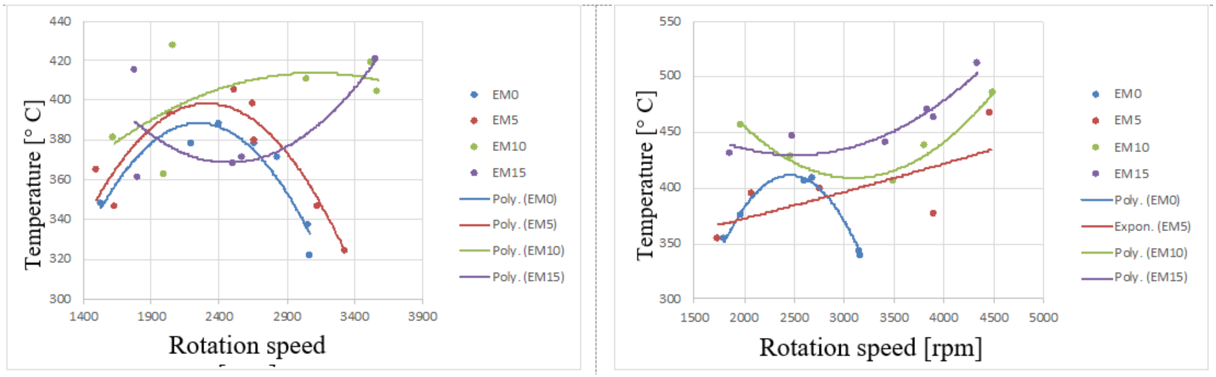

Fig 14. (a) Variation of the exhaust gas temperature as a function of the rotation speed at partial load (b) Variation of the exhaust gas temperature as a function of the rotation speed at full load

From Figure (15) we observed an increasing variation in temperature as the power increases in the range studied. At the same time, we point out that at each power the mixtures produce much more heat compared to unleaded gasoline. This is explained by a rich mixture and the type of fuel (Khayal, 2020). According to the data collected there is no reason to worry about possible engine overheating, since temperatures generally above 900°C can be an indicator of unfavorable conditions likely to lead to catastrophic engine failure while temperatures at the exhaust barely reach 700°C (Khayal, 2020).

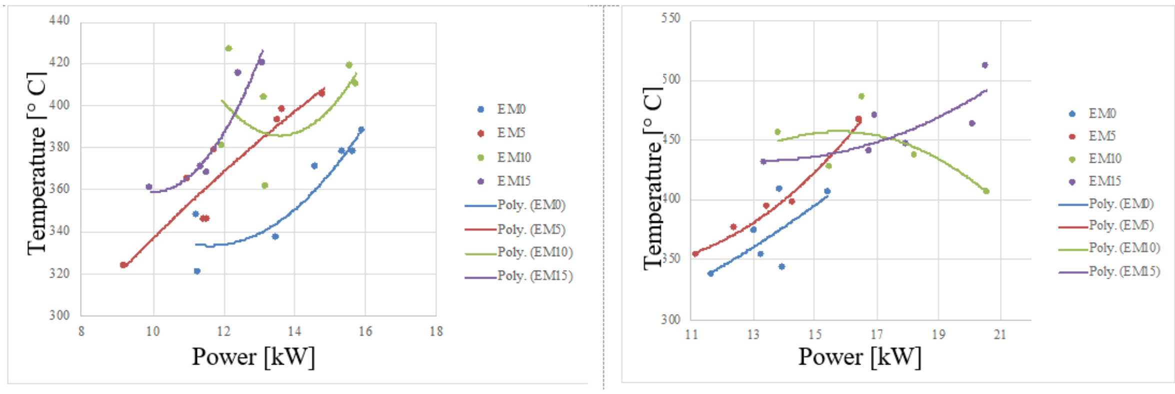

Fig 15. (left) Temperature variation as a function of partial power (right) Temperature variation as a function of total power

By carrying out a comparison from the point of view of exhaust temperatures between the mixtures and gasoline we obtain the following graphs (Figure 16).

The mixture of alcohols and gasoline improved the EGT as EM5, EM10, EM15 showed an improvement of 5, 13 and 9% respectively for reasons already mentioned in the previous points. Logic would dictate that the EM15 would cause a greater increase in temperature in both cases (partial and total load) but this is not the case here. We think this could be caused by the fact that ethanol and methanol are polar molecules, just like the solvent water. So, alcohols are soluble in water. Hydrogen bridges are therefore established between the molecules of water and these alcohols. Gasoline (made up of non-polar alkanes) and water (polar) do not mix (B) while polar substances like alcohols and water (A) do mix.

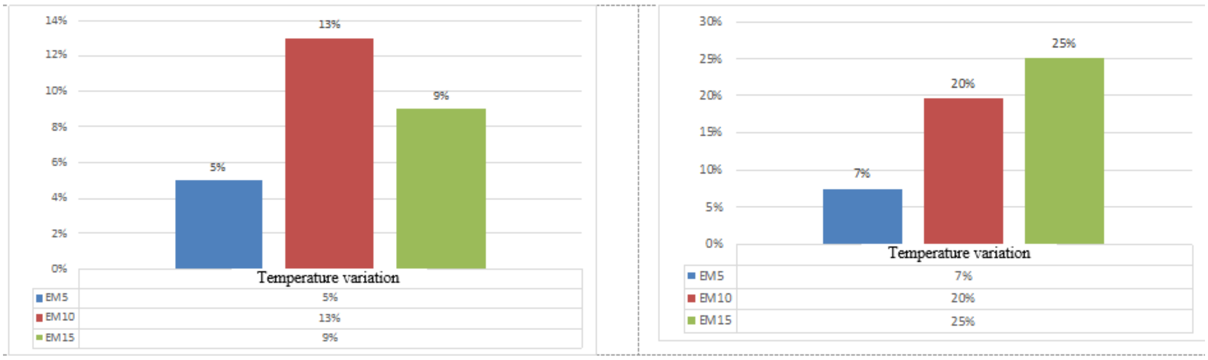

Fig 16. (left) Comparison of EGT of EM5, EM10 and EM15 compared to gasoline at partial load (right) Comparison of EGT of EM5, EM10 and EM15 compared to gasoline at full load

4. CONCLUSION

In the present study, the principal aim was to evaluate the performance of a control ignition combustion engine operating with gasoline, ethanol and methanol mixtures following the given proportions. After evaluating the physicochemical properties and mechanical performance of the test bench engine, we note that:

1. The fuels studied presented the physicochemical properties according to the ASTM standard;
2. The addition of alcohols to gasoline reduces the low heating value and the sulfur content but nevertheless increase the density and the octane number;
3. At partial load, the EM10 and EM15 showed similar behaviors, only showing performance improvements in specific consumption and efficiency.
4. At full load, an improvement was observed in almost all study characteristics.
5. The operating temperature is fairly normal but the mixtures also improve combustion thus causing higher temperatures than those observed when operating the engine with gasoline.

At the end of this research, we therefore conclude that the use of ternary mixtures is relevant but that it is more so at high speeds and/or at total load. We suggest conducting studies on emissions analysis to assess pollution and also doing the same study on engines using injectors.

ACKNOWLEDGMENTS

This study is the result of the collaboration of several people, some from the Polytechnic Faculty of Kongo University (UK) and others from the Polytechnic Faculty of the University of Kinshasa. We would like to thank the deans of these two faculties, respectively Professors SUMUNA TEMO Vertomene and KAZADI MABIKA Hubert, who made this collaboration possible.

The authors thank all the people (physical and moral) who participated in the completion of this work; Gentlemen B. MBOMBOLO LUZOLO, R. MPABA-LIR-O-MEAN, H. KASEYA MUKANYA, M. MUANDA LUTETE, without forgetting the Sep-Congo for his contribution to the fuel analyzed step.

ABBREVIATIONS

LHV: Lower Heating Value	Mxx:Gasoline-Methanol Blend, percentage by volume is xx%
RON:Reseach octane number	EMxx:Gasoline-Ethanol-Methanol Blend, percentage by volume is xx%

ICE : Internal combustion engine	Sep-Congo: Congo Oil Exploitation Company
MTBE:Methyl Tert-butyl Ether	ASTM: American Society for Testing Materials
GTL: Gas to liquid	rpm: Revolution per minute
UniKin: University of Kinshasa	CaO: Calcium Oxide (Quicklime)
UK: Kongo University	EGT: Exhaust gas temperature
Exx:Gasoline-Ethanol Blend, percentage by volume is xx%	DRC: Democratic Republic of Congo

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