Sustainable valorisation of date waste for bioethanol production in Algeria: combustion, engine performance and emissions analyses in a CI diesel engine

Ahmed Boulal[a*], Karim Khiari[b], Wahiba Tadmourt[b], Khaled Loubar[c], Mohammed Derradji[b], Irfan Anjum Badruddin [d], A.E. Atabani[e]

[a] Laboratory of Saharan Natural Ressources. Faculty of Science and Technology. University of Adrar 01000, Algeria

[b] Ecole Militaire Polytechnique, BP17 - 16046 Bordj-El-Bahri, Algiers, Algeria

[c] GEPEA, UMR 6144, DSEE, IMT Atlantique, Nantes, 44307, France

[d] Mechanical Engineering Department, College of Engineering, King Khalid University,

Abha 61421, Saudi Arabia

[e] Alternative Fuels Research Laboratory (AFRL), Energy Division, Department of Mechanical Engineering, Erciyes University, Kayseri, Turkey

*Corresponding authors: boulal19@yahoo.fr ; ahm.boulal@univ-adrar.edu.dz (A. Boulal)

Received: 11/08/2023; Accepted: 04/10/2023 Published: 11/10/2023

Abstract

The appalling environmental problems caused by harmful emissions from the transportation sector besides the anticipated depletion of fossil fuels has prompted the scientific community to search for renewable, clean and sustainable fuels. The aim of this study is to evaluate the lower quality common dates for bioethanol production using the yeast Saccharomyces cerevisiae. During the fermentation reaction, the evolution of the sugar level, pH and density was monitored. The produced bioethanol was then used as an additive and blended with the conventional diesel fuel at different volumes 5, 10 and 15% with the use of Span 80 as a surfactant. The tests were performed under stationary conditions in a four-stroke single-cylinder CI diesel engine at different loads 25, 50, 75 and 100% respectively. The main findings of this study indicated that using bioethanol as an additive in the CI diesel engine has led to changes in the combustion characteristics, as well as in the performance and pollutant emissions. Ethanol-blended fuels revealed higher engine efficiencies than pure diesel fuel along with low exhaust gas temperatures. However, high specific fuel consumption was recorded due to the lower calorific value of bioethanol. In regards to the pollutant emissions, bioethanol reduced the NOx, PM and

CO emissions, but slightly influenced CO_2 emissions and favored the formation of UHCs emissions.

Keywords: Valorisation of date waste; Bioethanol; Fermentation; Diesel engine; Pollutant emissions.

Tob Regul Sci. ™ 2023;9(2): 415-434

DOI: doi.org/10.18001/TRS.9.2.27

Nomenclature

BSFC	Brake specific fuel consumption	EGT	Exhaust gas temperature (°C)
CH_4	Methane	FAO	Food and Agriculture Organization
CI	Compression ignition	GHGs	Greenhouse gases
CO	Carbon monoxide (ppm)	NO	nitric oxide (NO)
CO_2	Carbon dioxide (ppm)	NO_2	nitrogen dioxide (NO2)
Diesel	100% Diesel	NOx	Nitrogen oxide (ppm)
D85 E25	85%Diesel and 25% Bioethanol	PM	Particulate matter (g/h)
D90 E10	90% Diesel and 10% Bioethanol	UHCs	Unburnt hydrocarbons (ppm)
D95 E5	95% Diesel and 5% Bioethanol		

1.0 Introduction

The rapid growth in the world's population (~3 billion by 2050) leads to increase the demand for energy consumption. Indeed, fossil fuels contribute about 80% of total energy needs [1]. The transportation sector accounts for 60% of the consumption of non-renewable fuels, generating massive pollution in the environment, 19% of carbon dioxide (CO_2) and more than 70% of carbon monoxide (CO) [2,3]. Harmful emissions such as nitrogen oxides (NOx), CO, unburnt hydrocarbons (UHCs), particulate matter (PM) as well as greenhouse gases (GHGs) such as CO_2 and methane (CH_4) have detrimental effects on humans and environment, especially the depletion of the ozone layer (global warming) [4]. The increase in fossil fuel consumption and the gradual increase in the GHGs emissions have sparked the interest of researchers in alternative fuels that are renewable, sustainable and environmentally friendly. In fact, biofuels such as biodiesel and bioethanol are the most appropriate alternatives to fossil fuels [5].

Bioethanol has been considered as one of the valuable substitutes to conventional fossil fuels in the near future. It is a liquid fuel with many similar physical and chemical properties to petroleum fuel. In addition, it has many advantages over biodiesel such as that bioethanol blend provides a higher oxygen concentration than biodiesel blends, and consequently a higher potential to reduce particulate emissions with the same volume fraction of blended renewable fuel [6,7].

Bioethanol has attracted the attention of researchers because it is derived from renewable and natural resources such as sugar beet, wheat, corn and wood [8]. It has been well-established since the 1980s that ethanol/diesel blends were technically acceptable for conventional unmodified compression ignition (CI) diesel engines [9]. The addition of ethanol results in lower density and lower surface tension of the blended fuel, which improves the spraying of the ethanol-diesel by bursting the fuel droplets as soon as they enter the combustion chamber, and consequently improved macroscopic spray behavior and atomization performance [10].

Some of the challenges that faces the application of bioethanol as an additive to diesel fuel in the CI diesel engines are:

(a) Bioethanol and diesel are immiscible due to their different chemical structures. Bioethanol also has high wax contents, a different hydrocarbon composition and increased water contents [6]. Therefore, an emulsifier must be added in order to make the blended fuel stable.

(b) Bioethanol has a lower calorific value than fossil diesel. Thus, an additional amount of the fuel is required compared to pure diesel fuel in mass and volume [11].

(c) Bioethanol has a low cetane index compared to the fossil diesel, while the CI engine prefers a high cetane index fuel that autonomously ignites and reduces the auto-ignition time [12].

(d) Diesel fuel functions as a lubricant in diesel engines, while bioethanol does not have the same lubricating function [4].

Agricultural and agro-industrial activities generate huge amounts of waste that are undeniably harmful to the environment but very useful organic waste. Many studies have indicated that these wastes, rich in organic matter, are valuable inputs for many industries. In addition, their valorization by the biotechnological processes contributes to the elimination of environmental pollution, enables the production of high value-added products and thus contributes to the industrial and agricultural development of the country. According to the statistics of the Direction of Agricultural Services-Adrar (Algeria) in 2020, the Algerian agricultural sector has achieved significant progress in date palm cultivars, which reaches 18 million palm trees where 11 million trees are productive and produce about 492 thousand tons of dates. The rest of the dates' production, common dates, reaches 250 thousand tons. These dates are not well appreciated by the customers and are difficult to sell at local markets.

Therefore, this study aims to valorize the date waste for the production of bioethanol by alcoholic fermentation using the yeast Saccharomyces cerevisiae. This is followed by testing the produced bioethanol in a CI diesel engine. In this work, bioethanol was used as an additive to the fossil diesel fuel in different compositions 5, 10 and 15% (by volume) in order to evaluate the combustion characteristics and engine emissions under stationary conditions (1500 rpm) and different loads (25, 50, 75 and 100%).

2.0 Material and Methods

2.1 Raw material

The statistics of FAO (Food, and Agriculture Organization of the United Nations) stated that the number of date palms trees in Algeria exceeds 18 million with more than 1,000 varieties and a production that reaches up to 700 thousand tons of dates [13]. Indeed, date waste or poor quality dates represent 30% of the annual national production. These sugar-rich substrates shown in Figure 1 can be converted into bioethanol by fermentation [14]. The biotechnological valorization of these dates allows the production of biomass and various metabolites. This biomass forms the basis of many industrial activities: production of wines, dietary yeasts and especially single-cell proteins [15].

Figure 1. Waste dates used in bioethanol production

2.2 Bioethanol production

The process of producing bioethanol from a sugar material has been known for decades. Treatment, dilution, fermentation and distillation are essential steps regardless of the substrate considered in this type of production [16]. The process of producing bioethanol from date waste consists of washing the material to remove impurities (sand, pebbles, insects, etc.) and then soaking it in hot water (90-95 °C) in order to extract the sweet juice. This juice is then diluted by adding water (800 mL water/200g dates) and fermented into bioethanol using the yeast Saccharomyces cerevisiae, after adjusting the pH to 4.5 [17]. The fermentation reaction occurs in anaerobic conditions at 30±2 °C for 72 h [18]. The evolutions of total sugars, pH and density during the fermentation reaction have been studied according to the methods mentioned in Table 1.

Table 1. Apparatus and methods used

Parameter	Apparatus	References
pH	Mettler Toledo Digital pH Meter	ISO11289, 1993 and AOAC, 98, 1.12
Total sugars	Phenol-sulphuric acid method	[18] (Dubois et al. 1956)
Density at 15 °C	DMA 4500 density meter	ASTM D 4052
Viscosity at 40 °C	SVM 3000 G2 viscometer	ASTM D 88
Calorific value	Adiabatic calorimeter type Parr, model 6200	ASTM D 240
Alcoholic degree	Alcoholometer (0-100°)	
Elemental composition	CHNS-O Flash 1112 E Series Analyzer	

2.3 Engine test

The produced bioethanol is used as an additive to fossil diesel fuel at different compositions 5, 10 and 15% (on volume basis). The engine tests started with operating the engine conventional fossil diesel mode are carried out at a constant speed (1500 rpm) and for different load conditions (25, 50, 75 and 100%). Thereafter, these operating points are maintained for all ethanol-blended fuels (E05D95, E10D90, E15D85). The surfactant (Span 80) was used to facilitate the emulsion of the blends, with a volume of 1% [19].

A1 Diesel engine	A6 Thermocouple	C1 Exhaust gas analyzer
A2 Fuel filter	B1 Dynamometer	C2 Particle analyzer
A3 Air tank	B2 Force transducer	D1 Rapid acquisition system
A4 Encoder	B3 Exhaust gas manifold	D2 Slow acquisition system
A5 Fuel tank	B4 Coupling	

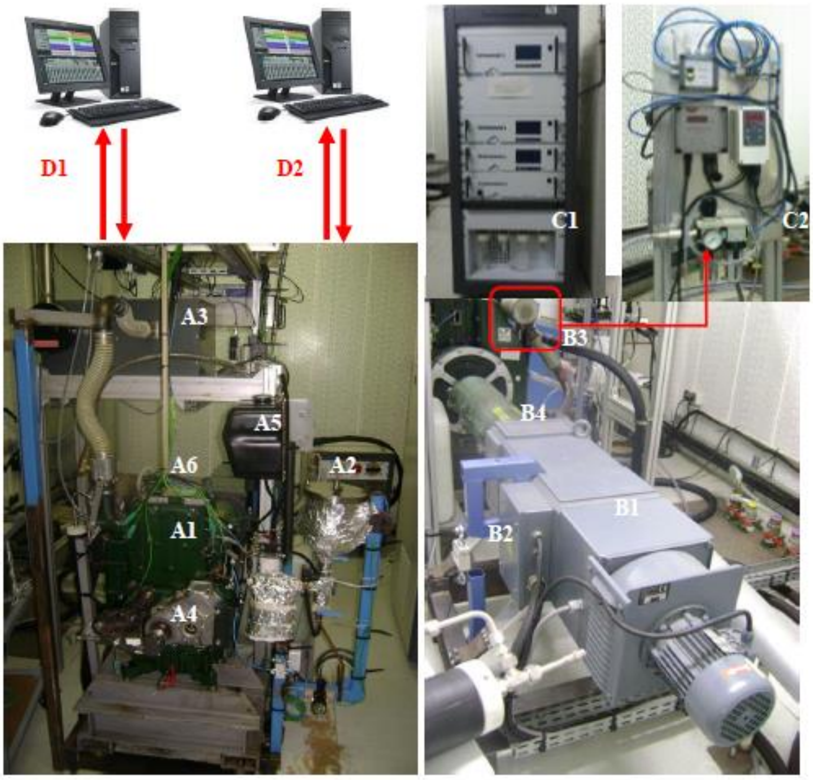

Figure 2. Diesel engine test bench (Lister-Petter TS1)

The experiments were carried out on a test bench, shown in Figure 2 consisting of a diesel engine (LISTER PETTER TS1 single cylinder, four-stroke natural suction and direct injection) and a dynamometer brake (eddy current Eurotherm PARVEX/132 M-G model with a maximum power of 42 kW). It is also equipped with a data acquisition system (two acquisition modes corresponding to data recording are available during testing, a slow scan at 0.5Hz and a fast scan at 90 kHz). An exhaust gas analyser (type Environment S.A placed at the exhaust outlet in order to quantify the engine's pollutant emissions: NOx, CO, CO_2 and UHCs) and a particle analyzer (PPS PEGASOR dedicated to the measurement of fine particles in real time) were also used in this study. The full details of the test bench used in this study can be found in our previous works [20, 21].

3.0 Results and Discussion

3.1 Fermentation

During the fermentation process, the yeast Saccharomyces cerevisiae consumes sugar to produce the energy needed for the production of bioethanol and CO_2 in the medium. As it can be seen from Figure 3, a slight decrease in sugars (17.2 to 15.03% for 20 hours) occurs during the first hours of the fermentation. This is attributed to the adaptation mechanisms of the yeast to its environment in order to maintain its homeostasis [22]. Afterwards, a significant degradation of sugars is revealed up to 50 h. After that, the consumption of sugars by the yeast becomes very slow, which indicates the end of the fermentation. However, sugars were not fully consumed due to the inactivity of the yeast Saccharomyces cerevisiae caused by the accumulation of toxic substances (fatty acids) and the inhibitory effect of bioethanol in the medium [23].

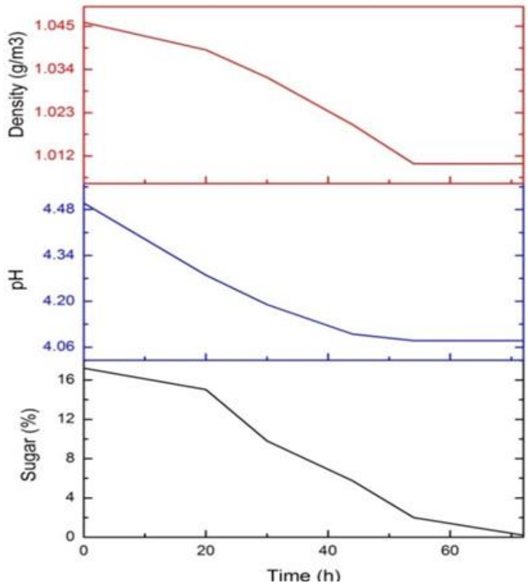

Figure 3. Evolution of total sugars, pH and density during the fermentation reaction

As it can be seen from Figure 3, a slight decrease in the pH and density of the fermentation medium is observed during the process. The evolution of the pH of the medium indicates the metabolic activity of yeast during the fermentation process [24]. It has decreased from 4.5 to 4.08, but this variation remains within the pH range required for the growth of the yeast Saccharomyces cerevisiae (3.5-5) [25]. The decrease in the pH value is due to the accumulation of acids in dates and acids and alcohols metabolized by yeast, such as fatty acids, especially octanoic acid and decanoic acid [24]. In addition, part of the CO_2 produced during the process is dissolved in the fermentation medium, thus contributing to lowering the pH. As for the density of the medium, it decreased from 1.046 to 1.01 g/cm^3; this can be explained by the transformation of sugars into alcohol and the mass loss in the form of CO_2.

3.2 Characteristics of the fuels tested

The ExD(1-x) designation means a mixture containing x% (v/v) of bioethanol, (1-x)% (v/v) of fossil diesel and small amounts of surfactant (Span 80) for the purpose of facilitating the emulsion of both fuels. The **characteristics of the fuels tested are grouped in Table 2.**

Table 2. Characteristics of the tested fuels in the CI diesel engine

Characteristic	Unit	Limit		Fossil diesel	Bioethanol-Diesel blends		
		Min	Max	D100	E05D95	E10D90	E15D85
Density at 15 °C	kg/m3	820	845	837.30	834.30	831.70	829.40

Viscosity at 40 °C	mm²/s	2	4.5	2.78	2.53	2.31	2.19
Calorific value	MJ/kg	-	-	42.91	42.03	41.22	40.42
Elementary analysis	%			86.13 C 13.87 H 0 O	84.55 C 13.84 H 1.61 O	82.94 C 13.80 H 3.26 O	81.31 C 13.76 H 4.93 O

The density and kinematic viscosity of these fuels are consistent with the standards. However, the oxygen content of the developed fuels is further improved by increasing the percentage of bioethanol in the blend; it is improved by ~5% with the addition of 15% bioethanol. As a matter of fact, the higher oxygen content allows the improvement in the combustion reaction, and therefore the energy and environmental performance of the engine.

3.3 Combustion characteristics

3.3.1 Cylinder pressure

The evolution of the cylinder pressure as a function of the crankshaft angle at 25 and 100% load for the developed fuel blends is illustrated in Figure 4.

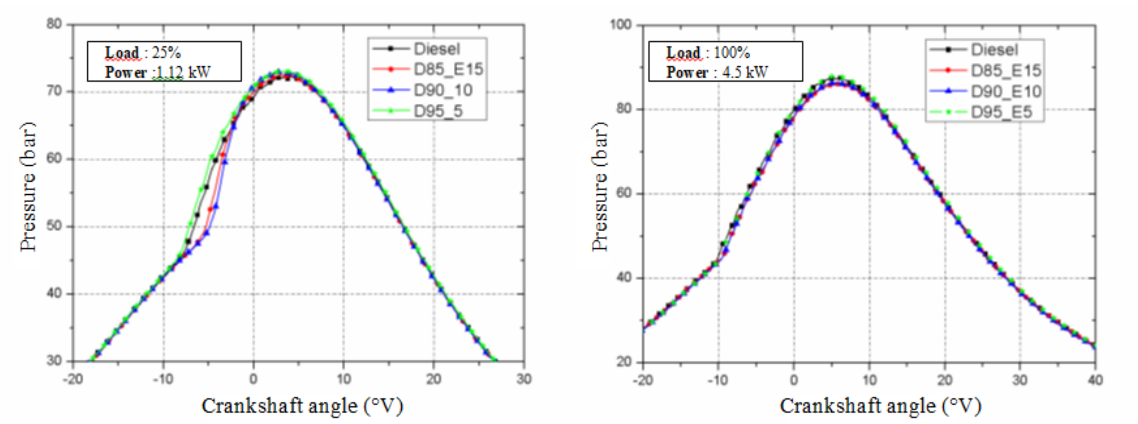

Figure 4. Variation of cylinder pressure as a function of crankshaft angle for fuels D100, E05D95, E10D90 and E15D85 at 25 and 100% load

According to Barik (2017)[26], in the early stages of combustion, the rate of combustion regulates cylinder pressure. The results indicate that at low loads, it has been observed that the cylinder pressure curves are the same for the tested fuels. However, these fuels have different auto-ignition times, due to the differences in the oxygen content and its amount injected into the combustion chamber. E05D95 has the shortest auto-ignition time due to the presence of oxygen which further promotes the combustion reaction and therefore increases the cylinder pressure. Nevertheless, this feature does not have a significant effect on the two bioethanol-blended fuels (E10D90 and E15D85), both of which have a higher auto-ignition time than fossil diesel. This is attributed to the increasing percentage of the oxygen content in the developed fuel blends, which reduces its calorific value, resulting in an increase in the amount of fuel injected into the cylinder and therefore a longer auto-ignition delay. This corresponds to the extinction effect of a longer injection of liquid fuel. Indeed, if the amount of fuel injected is increased, the local temperature decreases as the evaporation of diesel fuel is significant and would cause a sharp drop in the pressure [27, 28].

At high loads, bioethanol-blended fuels are characterized by cylinder pressure variations identical to those of fossil diesel. This characteristic ranged from 73 to 84 bar when increasing the load from 25 to 100%. This increase depends on the amount of the fuel injected to maintain the engine load at the desired conditions. On the other hand, the high cylinder pressure causes a decrease in the auto-ignition time of the tested fuels. This short duration makes the effect of fuel composition negligible, resulting in the same auto-ignition time for all the tested fuels. What may explain according to Nagpure and Rathod (2022) [29] the high viscosity of fossil diesel compared to the prepared mixtures.

3.3.2 Heat release rate

The heat release rate is generally used for the analysis of the combustion process in the heat engine. Based on the pressure traces in the cylinder were determined mined heat release rate [30].

Figure 5 shows the variation in the rate of heat release as a function of the crankshaft angle for the fuels tested, at 25 and 100% load.

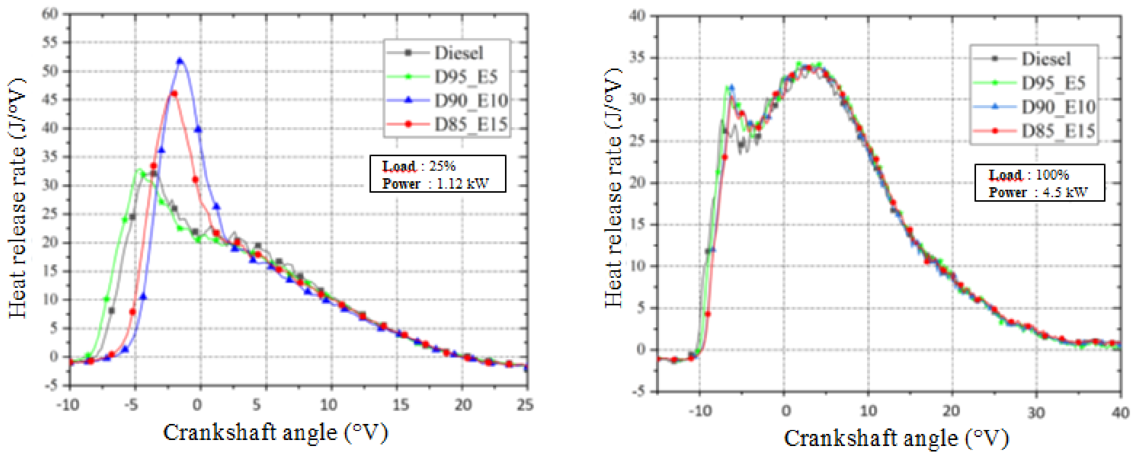

Figure 5. Variation of heat release rate as a function of crankshaft angle for fuels D100, E05D95, E10D90 and E15D85 at 25 and 100% load

Negative heat release rates were obtained at low and high loads, for all fuels tested during the auto-ignition delay, due to the cumulative fuel vaporization during this period. After the combustion reaction is triggered, these rates become positive and follow a typical trend of direct injection and natural suction Diesel engines.

At low loads, ethanol-blended fuels have high heat release rates compared to pure Diesel, because of their high vapor latent heat. Furthermore, the highest heat release rates of approximately 52 and 46 J/°V are attributed to E10D90 and E1585, respectively. These two fuels have lower cetane index due to the presence of ethanol in the blended fuel, which lengthens the auto-ignition time [9]. During this period, a significant amount of less viscous fuel (ethanol) transforms into steam, allowing a greater rate of heat release. However, at high loads the curves of the heat release rate of the tested fuels follow the same trend, due to the high temperature in the cylinder and which makes the influence of the cetane index negligible.

Combustion is more important in the premixed phase for low loads, while it is important in the diffusive phase for high loads. This phenomenon is explained by the long auto-ignition times of low-load fuels: sufficient time for combustion, releasing a significant amount of heat. Thus, in the diffuse phase, combustion is progressive for high-load fuels.

3.4 Engine performance

3.4.1 Brake specific fuel consumption (BSFC)

The evolution of the brake specific fuel consumption (BSFC) as a function of the effective engine power for the developed fuel blend is shown in Figure 6. This characteristic represents the amount of fuel, of a given calorific value, which must be spent on the production of a unit of energy.

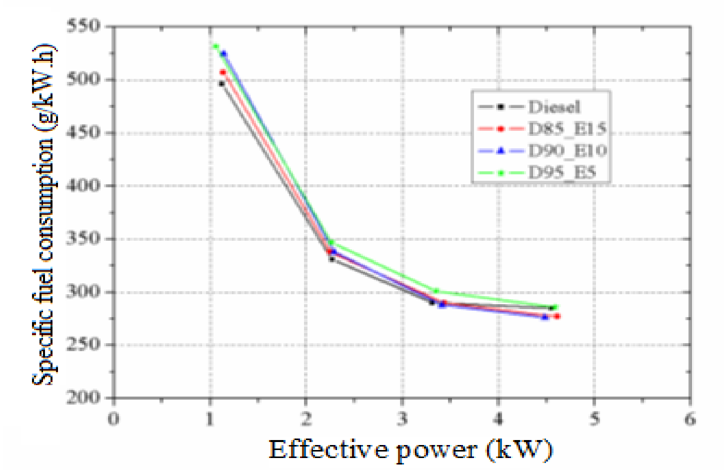

Figure 1. BSFC as a function of effective engine power for D100, E05D95, E10D90 and E15D85 fuels

The BSFC is inversely proportional to the effective power for all the fuels tested. This is attributed to the increase in temperature and air pressure in the combustion chamber before the injection. On the other hand, bioethanol-blended fuels are generally characterized by their higher BSFC compared to fossil diesel.

Bioethanol has a lower calorific value than fossil diesel and therefore the developed fuel blends have a lower calorific value than fossil diesel. Hence, there is a need to increase the flow of the fuel blends in order to maintain the same operating conditions [4]. Nevertheless, at full load condition, the two bioethanol-blended fuels (E10D90 and E15D85) have lower BSFC than fossil diesel. In fact, this consumption depends on the shape of the characteristic thermodynamic cycle of the engine and on the extreme values of temperature and pressure reached by the gas. At high engine load, temperature and pressure are high and the presence of oxygen in the blends leads to improved combustion compared to fossil diesel, resulting in lower BSFC.

3.4.2 Engine brake thermal efficiency

The evolution of engine brake thermal efficiency according to its effective power, in the case of the tested fuels, is illustrated in Figure 7.

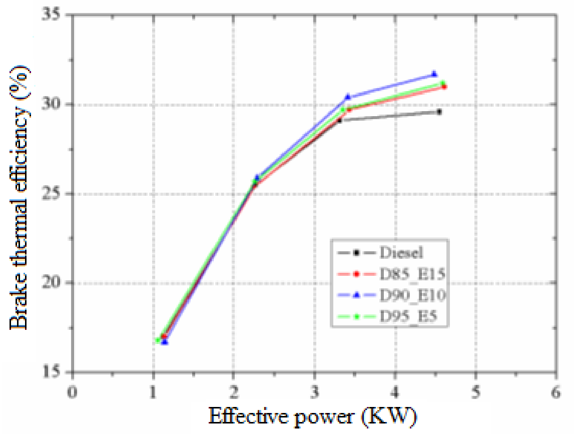

Figure 7. Engine brake thermal efficiency according to its effective power for fuels D100, E05D95, E10D90 and E15D85

The engine brake thermal efficiency is proportional to its effective power. At low engine load, the engine performance is similar for all the tested fuels. The increase in the BSFC for bioethanol/diesel blends is attributed to the decrease in calorific value. Due to the presence of the oxygen molecule in the alcohol, the calorific value corresponding to each formulated fuel blend is reduced compared to that of fossil diesel, which leads to a lower energy content per unit volume. Therefore, the brake thermal efficiency of the engine powered by these fuels will be less than the efficiency obtained when the engine runs on Diesel.

As the engine load increases, the effect of adding bioethanol to fossil diesel fuel becomes positive to the point where the improvement can reach 10% at full load. This is mainly due to the increase in the temperature of the gases where the effect of the latent heat of alcohol evaporation becomes increasingly neglected, where the conversion of injected fuel into mechanical energy is improved. In addition, the presence of oxygen in bioethanol also contributes to improved engine performance for bioethanol-blended fuels.

3.4.3 Exhaust gas temperature (EGT)

The exhaust gas temperature (EGT) is proportional to the load, mainly due to the increase in the amount of the injected fuel. EGT is an important indicator of the combustion inside the cylinder. Figure 8 shows the evolution of the EGT as a function of the effective power for the tested fuels.

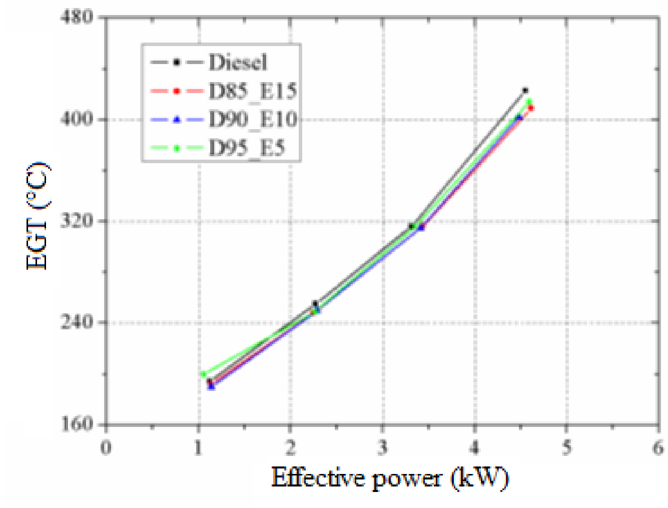

Figure 2. EGT as a function of effective engine power for D100, E05D95, E10D90 and E15D85 fuels

Previous studies have shown that the addition of ethanol lowers the EGT and it continuously decreases with the increase in the ethanol content in the mixture [4]. These conclusions were also confirmed by our results, by obtaining a high latent heat of ethanol vaporization and a short auto-ignition delay. Eventually, most of the heat produced is converted into mechanical work, which would reduce the EGT. These findings are in agreement with [31, 32].

3.5 Engine emissions

3.5.1 NOx emissions

NOx emissions include nitrogen dioxide (NO_2) and nitric oxide (NO) and sometimes other compounds such as N_2O in much lower proportions. NO being predominant. NOx is formed when combustion reaches very high temperatures. These conditions are realized during the combustion of a mixture close to stoichiometry in an environment of high pressure and temperature [33, 34].

Figure 3. EGT as a function of effective engine power for D100, E05D95, E10D90 and E15D85 fuels

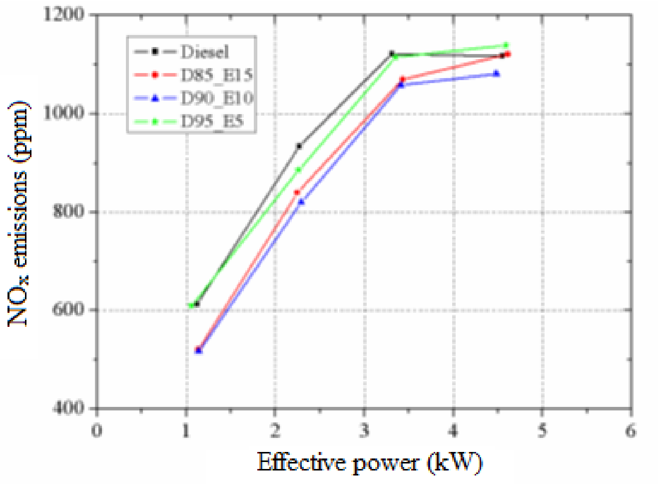

Figure 9 shows the evolution of NOx emissions as a function of effective power, for the fuels tested.

NOx emissions rapidly increase with the increasing load up to 75% load. The increase in these emissions is due to the high temperature inside the cylinder, which promotes the formation of pollutants [4].

Compared to fossil diesel, NOx emissions from bioethanol-blended fuels are lower due to the effect of latent heat of ethanol vaporization and its lower calorific value [4].

The addition of more than 10% bioethanol to fossil diesel results in a slight increase in these emissions, due to the high oxygen content, making the environment conducive to NOx formation. At loads above 75%, NOx emissions tend to stabilize in the case of tested fuels. According to Heywood [33], the interval of the maximum temperatures of the cycle is the most contributing factor in the formation of NOx, that is to say after the start of combustion and in the vicinity of the maximum pressure of the cycle. In this interval, the NOx forms until reaching a maximum, then the temperature begins to decrease and the NOx decomposes for a certain time before stabilizing until the exhaust.

3.5.2 UHCs emissions

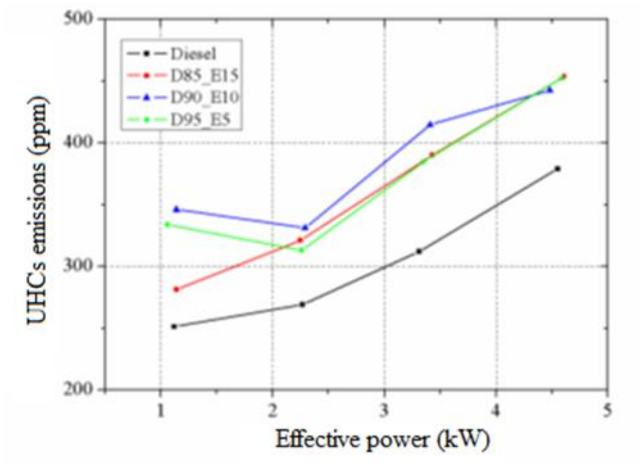

Figure 10 shows the evolution of UHCs emissions as a function of effective power, for all the tested fuels.

The addition of bioethanol to fossil diesel fuel significantly increases the UHCs emissions, likely due to the low temperature in the combustion chamber and also due to the higher latent heat of ethanol vaporization. Thus, there is more unburnt fuel remaining compared to pure fossil diesel. Meanwhile, the evolution of UHCs emissions, depending on the effective power delivered by the engine, tends towards a gradual rise, due to the increase in the amount of fuel injected. This leads to the formation of a rich air/fuel mixture and therefore the formation of UHCs. It is worth noting that incomplete combustion is the basis UHCs cause the generation of pollutants [35].

3.5.3 PM emissions

The evolution of PM as a function of the effective power in the case of the fuels tested is illustrated in Figure 11.

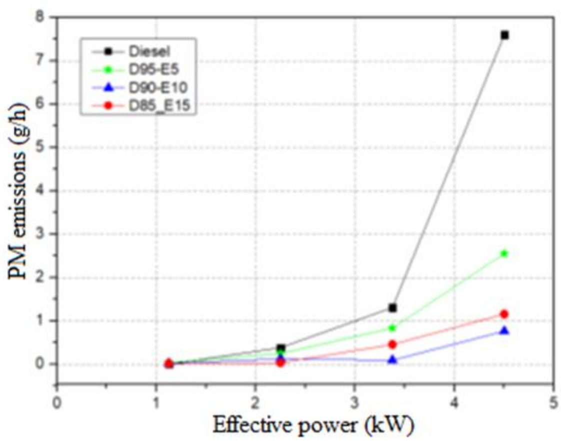

Figure 11. PM emissions as a function of engine power for fuels D100, E05D95, E10D90 and E15D85

A notable decrease in PM emissions is observed for bioethanol-blended fuels and compared to fossil diesel. This is mainly attributed to the increase in the oxygen content of the blends, which leads to the efficient oxidation of hydrocarbons in the rich areas of the combustion chamber, thus preventing the formation of particles. The high volatility of the fuel blended with bioethanol favors a better homogenization of the mixture, where few very rich areas are conducive to the formation of soot. Nevertheless, bioethanol content of more than 10% incorporated into fossil diesel slightly increases the PM emissions due to the high heat of vaporization of the fuel, after a heterogeneous mixture.

PM emissions are proportional to the load for all fuels tested, due to the increased amount of fuel injected. According to Kezrane et al, 2016 [36], the presence of oxygen in the fuel in addition to that contained in the intake air improves the mixing process which leads to more fuel being prepared for premix combustion.

3.5.4 CO emissions

The the fuel-air equivalence ratio is an important factor in determining the level CO emissions. The higher the ratio, the richer the fuel-air mixture becomes [37]. Carbon monoxide (CO) is an intermediate combustion product that will be oxidized to CO_2 later. Its formation is mostly related to the richness of the mixture and gains in a manner similar to the formation of PM [36].

CO emissions as a function of the effective power in the case of the tested fuels are shown in Figure 12.

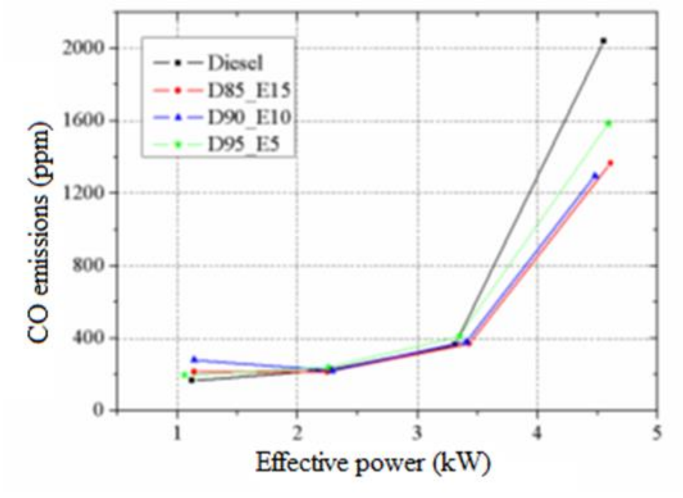

Figure 4. CO emissions as a function of engine power for D100, E05D95, E10D90 and E15D85 fuels

At high engine loads, bioethanol-blended fuels are characterized by low CO emissions compared to pure fossil diesel. Emissions are inversely proportional to the bioethanol content. This is attributed to the high temperature of the high-load cylinder and the sufficient presence of oxygen that makes the combustion complete, This corresponds to [38]. In addition, these emissions are very important for high-load tested fuels, due to the increase in the amount of fuel injected, which is why the blends becomes richer.

At low engine load, a slight increase in CO emissions is observed for bioethanol-blended fuels compared to fossil diesel. This is reflected by a low temperature in the cylinder and a high latent heat of vaporization of the fuel mixed with bioethanol, hence the impossibility to oxidize efficiently the CO gas. can explain that the oxygen content at higher temperature, which promotes the oxidation of CO to CO_2.

3.5.5 CO_2 emissions

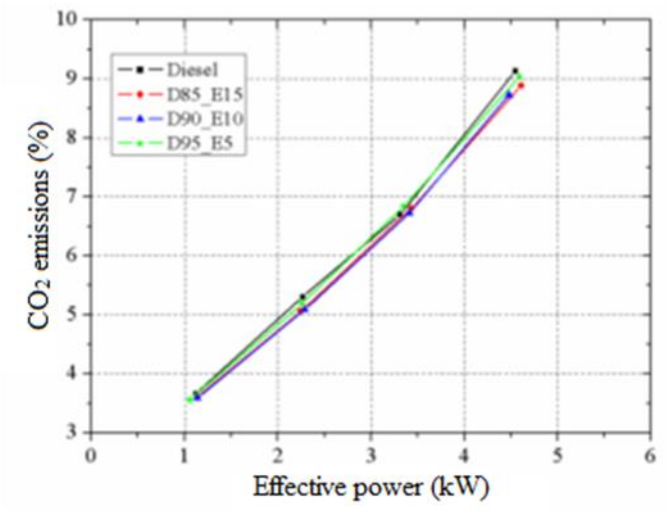

Figure 13. shows the variation in carbon CO_2 as a function of engine power for the tested fuels.

The evolution of CO_2 emissions is practically the same for all the fuels studied. The addition of bioethanol has a negligible effect on CO_2 emissions. Indeed, CO_2 emissions are proportional to the effective power of the engine, because of the increase in the amount of fuel injected into the cylinder. According to the results, the combustion of fossil diesel with bioethanol was shown to be more environmentally friendly than conventional diesel fuel and in agreement with [39, 31].

4.0 Conclusion

This work investigated the recovery of date waste for the production of a major form of energy, which is bioethanol.

The use of bioethanol as an additive to fossil diesel has led to changes in the combustion characteristics, as well as in the performance and pollutant emissions of the engine under study.

Bioethanol-blended fuels have a remarkable property of longer auto-ignition times than fossil diesel, due to low cetane index. However, high BSFC is recorded due to the lower calorific value of bioethanol. Indeed, higher engine efficiencies (compared to fossil diesel) and low EGTs characterize these fuels.

The addition of bioethanol to fossil diesel has reduced emissions of NOx, PM and CO, but has led to increased emissions of UHCs. Finally, the addition of bioethanol does not have a significant effect on CO_2 emissions.

Acknowledgement

The authors would like to thank all members of the GEPEA, UMR 6144, DSEE, IMT Atlantique, Nantes, 44307, France and DGRSDT.

References

1. Khan, O., Yadav, A.K., Emran Khan, M., Parvez, M. Characterization of bioethanol obtained from Eichhornia Crassipes plant; its emission and performance analysis on CI engine. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 2019, 1-11.
2. Aditiya, H.B., Mahlia, T.M.I., Chong, W.T., Nur, H., Sebayang, A.H. Second generation bioethanol production: A critical review. Renewable and sustainable energy reviews, 2016, 66, 631-653.
3. Goldemberg, J. Environmental and ecological dimensions of biofuels. in Proceedings of the conference on the ecological dimensions of biofuels, Washington, DC. 2008.
4. Kumar, R., Chaurasia, O.P. A Review on Performance and Emissions of Compression Ignition Engine Fueled with Ethanol-diesel Blend. Journal Européen des Systèmes Automatisés, 2019, 52(2), 205-214.
5. Lif, A., Holmberg K. Water-in-diesel emulsions and related systems. Advances in colloid and interface science, 2006, 123, 231-239.
6. Sebayang, A.H., Masjuki, H.H., Ong, H.G., Dharma, S., Silitonga, A.S. Prediction of engine performance and emissions with Manihot glaziovii bioethanol– Gasoline blended using extreme learning machine. Fuel, 2017, 210, 914-921.
7. Yadav, A.K., Dewangan A., Mallick, A. Effect of n-butanol and diethyl ether on performance and emission characteristics of a diesel engine fueled with diesel–Pongamia biodiesel blend. Journal of Energy Engineering, 2018,144(6), p. 04018062.
8. Boulal, A., Kihal, M., Khelifi, C. Fermentative Strength of Yeasts Strain, Naturally Isolated Using Common Date in South-West of Algeria. International Journal of ChemTech Research, 2017a,10(01), 180-188.
9. Yahuza, I. & Dandakouta, H., A. Performance review of ethanol-diesel blended fuel samples in compression-ignition engine. Journal of Chemical Engineering & Process Technology, 2015, 6(5), 1-6.

10. Li, DG., Zhen, H., Xingcai, L., Wu-Gao, Z., Jian-Guang, Y. Physico-chemical properties of ethanol–diesel blend fuel and its effect on performance and emissions of diesel engines. Renewable Energy, 1982, 30(6), 967-976.
11. DOANN, H. 1986. Alcohol fuels. Boulder, CO: Westview Press, 860308.
12. Rodica, A.B. Fumigation of Alcohols in a Multicylinder diesel engine-Evaluation of potential. SAE paper. 1986.860308
13. FAO Statistics 2015. Food, and Agriculture Organization of the United Nations.
14. Boulal, A., Kihal, M., Khelifi, CH., Benali, B. Generation of bioethanol from common date byproducts,"Teggaza and Lebghel" in Southern Algeria. African Journal of Biotechnology, 2017b,16(1), 41-50.
15. Boulal, A., Kihal, M., Meknassi, A. Etude du Pouvoir Fermentaire de Levures Isolées Naturellement à Partir des Dattes au Sud d'Algérie (Application à la Fermentation de Deux Variétés de Dattes Communes de Faible Valeur Marchande). Le 4ème Séminaire International sur les Energies Nouvelles et RenouvelablesThe 4thInternational Seminar on New and Renewable Energies. 2016a.
16. Yakoubi, M., Boulal, A., Bakache, Y., Gaffour, H., Benali, B. Valorisation énergétique de la betterave sucrière. Journal of Bioresources Valorization, 2016, 1(1), 52.
17. Boulal, A., Kihal, M., Khelifi, C., Benali, B. . Bioethanol production from date palm fruit waste fermentation using solar energy. African Journal of Biotechnology 2016b, 15(30), 1621-1627.
18. Tadmourt, W., Khiari, K., Boulal, A., Tarabet L. Waste paper valorization for bioethanol production: Pretreatment and acid hydrolysis optimization. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 2020, 1-20.
19. Singh N.K.. Experimental investigations of diesel emulsions as fuel in small direct injection compression ignition engines. MIT International journal of mechanical engineering, 2012, 2(1), 39-44,
20. Khiari, K., Awad, S., Loubar, K., Tazerout, M. Experimental investigation of pistacia lentiscus biodiesel as a fuel for direct injection diesel engine. Energy Conversion and Management, 2016, 108, 392-399.
21. Tarabet, L., Loubar, K., Lounici M.S., Hanchi, S., Tazerout M. Eucalyptus biodiesel as an alternative to diesel fuel: preparation and tests on DI diesel engine. Journal of Biomedicine and Biotechnology, 2012, 1-8.
22. Hohmann, S. Osmotic stress signaling and osmoadaptation in yeasts. Microbiology and Molcular Biology Revews, 2002, 66(2), 300-372.
23. Boulal, A., Kihal, M., Khelifi, CH., Benali, B. Bioethanol production from date palm fruit waste fermentation using solar energy. African Journal of Biotechnology, 2016c,15(30), 1621-1627.

24. Mehani, I., Boulal, A., Bouchekima, B. Biofuel production from waste of starting dates in south Algeria. International Journal of Environmental and Ecological Engineering, 2013, 7(8), 572-574.
25. Acourene, S., Tama, M. Caractérisation physico-chimique des principaux cultivars de dattes de la région des Zibans. Recherche Agronomique Algerie, 1997, 1(1), 59-66.
26. Barik, D.; Satapathy, AK.; Murugan, S. Combustion analysis of the diesel–biogas dual fuel direct injection diesel engine – the gas diesel engine, Int. J. Ambient Energy. 2017, 38 (3), 259–266, https://doi.org/10.1080/01430750.2015.1086681.
27. Aligrot, C. Etude expérimentale et théorique du délai d'auto-inflammation de différents carburants dans une chambre de combustion à volume constant. ECOLE CENTRALE DE LYON. 1994.
28. Liu, J.; Ma, H.; Sun, P.; Wang, P.; Wang, T.; Liu, Y.; Wei, M.; Fang, J. Simulation study on in-cylinder combustion and pollutant generation characteristics of PODE/methanol blends. Fuel Processing Technology 228 (2022) 107165
29. Nagpure, AG., Rathod WS. 2022. Comparative analysis of combustion and heat release characteristics of Alexandrian Laurel methyl ester fueled VCR DI diesel engine. Materials Today: Proceedings 57 (2022) 2417–2422
30. Chen, H.; Cheng, Y.; He, Q.; Wang, X. Experimental study on combustion and unregulated emission characteristics of a diesel engine fueled with light hydrocarbon/diesel blends. Fuel, 2022, 315, 123075. journal homepage: www.elsevier.com/locate/fuel
31. Yilmaz, N.; Atmanli, A.; Vigil, F.M. Quaternary Blends of Diesel, Biodiesel, Higher Alcohols and Vegetable Oil in a Compression Ignition Engine. Fuel, 2018, 212, 462–469.
32. Alahmer, A.; Alahmer, H.; Handam, A.; Rezk, H. Environmental Assessment of a Diesel Engine Fueled with Various Biodiesel Blends: Polynomial Regression and Grey Wolf Optimization. Sustainability, 2022, 14, 1367. https://doi.org/10.3390/su14031367
33. Heywood, J. B. 1988. Internal combustion engines fundamentals, Mc Graw Hill.
34. Niculae, AL.; Chiriac, R.; Racovitza, A. Effects of Injection Rate Shape on Performance and Emissions of a Diesel Engine Fuelled by Diesel and Biodiesel B20. Appl. Sci., 2022, 12, 1333. https://doi.org/10.3390/app12031333
35. Hoseini, SS.; Najafi, G.; Ghobadian, B.; Ebadi, MT.; Mamat, R.; Yusaf, T. 2020. Biodiesels effect of graphene oxide (GO) nanoparticles diesel engine parameters fuelled with biodiesel. Renewable Energy Volume 145, January 2020, Pages 190-201
36. Kezrane, C., Bendriss, A., Loubar, K., Sary, A., LIAZID, A, Tazerout, M. 2016. Comparaison des émissions polluantes d'un moteur diesel alimenté avec quatre carburants. Third International Conference on Energy, Materials, Applied Energetics and Pollution ICEMAEP,2016, October 30-31, 2016, Constantine, Algeria. 146-151
37. Vinayagam, NK.; Hoang, AT.; Solomon, JM.; Subramaniam, M.; Balasubramanian, D.; El-Seesy, AI. 2021. Smart control strategy for effective Hydrocarbon and Carbon monoxide

emission reduction on a conventional diesel engine using the pooled impact of pre-and post-combustion techniques. J Clean Prod 2021:127310

38. Turnera, D.; Xu, H. The effect of bio-ethanol on direct injection spark ignition (DISI) engine performance. Fuel 2011;90:1999–2006.
39. Sharon, H.; Jai Shiva Ram, P.; Jenis Fernando, K.; Murali, S.; Muthusamy, R. Fueling a Stationary Direct Injection Diesel Engine with Diesel-Used Palm Oil-Butanol Blends—An Experimental Study. Energy Convers. Manag. 2013, 73, 95–105