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CHARACTERIZATION AND SI ENGINE TESTING OF GASOLINE AND BLENDS OF GASOLINE AND BIOETHANOL PRODUCED FROM CO-FERMENTED WATERMELON AND PINEAPPLE WASTES

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Abstract

Industrial development and population growth are two key factors that have led to increased energy consumption. Conventional energy sources are fast becoming insufficient in matching the increased demands. Over the last two decades, a great interest in exploring alternative energy sources has been developed. Amongst the highly sought for alternatives to fossil fuel, biofuel has gained high recognition. In this research, bioethanol produced from co-fermentation of watermelon and pineapple waste using Saccharomyces cerevisiae was successfully studied and compared to standard values. Performance evaluation of the spark ignition (S.I) single cylinder, four stroke and air-cooled engine running on gasoline and bioethanol blends was analysed. The engine brake power, torque, exhaust gas temperature performance with E14 (blending 14% bioethanol with 86% gasoline) was found to be better than pure petrol at various load ranging between 500g to 3000g. The brake specific fuel consumption was however better with gasoline than the blends at various loads. The overall performance results showed that a blend containing 14% bioethanol, and 86% gasoline can be successfully used as petrol substitute without any modification in the available engine design.

Keywords: *Bioethanol, Co-fermentation, Saccharomyces cerevisiae, spark ignition (S.I) engine, engine performance, watermelon, pineapple waste.*

1.0 Introduction

The looming energy crisis in the world due to limited energy as against ever-increasing energy demand, oscillation of oil prices, problems of global warming and environmental pollution relating to fossil fuels, has over the years being responsible for alternative fuels search for the future [1]. It is proposed that renewable biofuels such as bioethanol and biodiesel replace the use of oil. The major problem faced in producing these fuels from crops at such scale, are, availability of feedstock's that can match the large production scales required and food versus fuel controversies. In order to avoid these stated challenges, fruit, root crops and vegetables wastes have been receiving huge attention over the past years for bioethanol production. This is because fruit and vegetable wastes, agro residues, forestry waste, and other lignocellulosic raw materials are good source of bioethanol due to abundance of natural sugars in them. In 2020, world fruit production was estimated at 887 million metric tonnes [2]. Out of this stated figure, 23.37 % was produced from China, with India and Brazil following with 11.94 % and 4.48 % respectively [2]. According to FAO, 40-50% of the global food waste comes from root crops, fruits and vegetables [3]. In Asia alone, 37% of the total agricultural waste is from fruits and vegetable wastes. According to Bancal, V. and Ray, R. C [4], about 35 - 40% of fruits and vegetables are lost every year as wastes. In addition to problem caused by fossil fuel, waste dumping in open places especially in Africa resulting to malignant of the natural habitat requires urgent attention. In developed countries, most of the food wastages happens at the consumption stage, however, in under developed countries, huge food wastage occurs at different stages of food supply chain [5]. In the said developing countries, food waste either of vegetables or perishable fruits or both as the case may be happen due to various post-harvest unit operations and poor storage conditions [6]. Fruit wastes are good for bioethanol production due to their low lignin content and rich hemicelluloses and cellulose contents [7]. Lignocellulosic is a renewable energy source with the capacity for CO_2 mitigation. Since fruit wastes are rich natural sugars, its conversion to value-added products in form of energy, conforms with the sustainable development goals three, seven, nine, eleven and thirteen. These goals are meant to ensure healthy lives and promote well-being for all at all ages, ensure access to affordable, reliable, sustainable and modern energy for all, build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation, make cities and human settlements inclusive, safe, resilient and sustainable, take urgent action to combat climate change and its impacts. All of which targeted food security, environmental protection and energy efficiency. Since about 15% of total fruit yield is said to be wasted [8], it becomes reasonable to device a means to ensure that these large quantities of food or fruit waste is used to harvest energy and chemicals needs of the nation since of course the end product is renewable. Presently, the main sources of energy are coal (27%), natural gas (22%) and oil (32%) [9]. Despite the benefits of biofuels as regards reductions in greenhouse gases emissions [10, 11], renewability and global warming [12, 13], when compared with fossil fuels, biofuels still represents less than 1% of the global market for automobile fuels [14, 15]. Among the various biofuels for spark ignition (SI) engine fuels, bioethanol (C_2H_5OH) have been adjudged most suitable owing to its renewability, eco-friendliness and similarities in properties with gasoline in terms of low stoichiometric air-fuel ratio, high octane number, low heating value and high flame speed [16, 17]. Bioethanol can be used with special additives in absence of fossil fuel (e.g in Brazil, where 4% water content and dehydrated bioethanol is used in vehicles); or ethanol-gasoline mixture with up to 85% ethanol content (E85) as seen in adapted gasoline engine cars or Flexible Fuel Vehicles (FFV); and lastly as low content of ethanol (up to E20) in the ethanol-gasoline fuel mixture in non-adapted cars.

An important advantage of crop-based ethanol is its greenhouse gas (GHG) benefits [18]. Bioethanol has a broader flammability limit, higher octane number, higher heats of vaporization and higher flame speeds. All of which allowed for a shorter burn time and higher compression ratio, thereby giving it a better theoretical efficiency over gasoline in engines [19]. Octane number is a measure of the gasoline quality for prevention of early ignition, which leads to cylinder knocking. Fuels with higher octane numbers are preferred in spark ignition (SI) and internal combustion (IC) engines [20] and so oxygenate fuels like bioethanol provides a reasonable antiknock value [20]. According to some authors [21, 22], brake specific fuel consumption (BSFC), carbon dioxide and hydrocarbon emissions will decrease, while the brake thermal efficiency (BTE), volumetric efficiency, NOx emission and brake power increases when engines compression ratio increases. However, other studies tied the reduction in exhaust emissions of spark ignition engines to the high oxygen content of bioethanol [23, 24]. According to some authors [25, 26] the oxygen content increases the volumetric efficiency and thus causes an increase in the thermal efficiency values of bioethanol during combustion in spark ignition engine. Engine performance have been reported to decrease with the use of bioethanol as fuel due to its low calorific value [27]. In the report by Karthikeyan *et al*. [28] citrus peel wastes bioethanol blends on a four strokes spark ignition showed a slightly increased specific fuel consumption (SFC) and a decreased brake thermal efficiency. It was also observed that CO, NOx and HC emission concentrations decreased while that of CO_2 slightly increased. Also, Najafi, Ghobadian [29] investigated the performance and emission behaviour of a four-stroke, four-cylinder spark ignition engine using blends of gasoline-ethanol (E5, E7.5, E10, E12.5 and E15) and observed that; the blends caused an increase in brake torque and brake power, an improvement in the exhaust emissions and a decreased in brake specific fuel consumption. According to the report of F. Yüksel & B. Yüksel [30], gasoline-bioethanol mixture with up to 20% bioethanol can be safely used without causing any damage to SI engine. Alok Kumar et al. [31] studied the possible problems with higher ethanol/gasoline blends on a single cylinder SI engine with 10%, 30% and 70% ethanol and gasoline blends. The experimental results showed that performances decreased by 10-14% with 70% ethanol blend at all operating conditions compared to neat gasoline while at optimized operating conditions the performance was same as neat gasoline and reduced emissions. Finally, bioethanol is renewable, has high energy value and can be produced from local sources. It's usage as alternative fuel in spark plug ignition engines was favoured by its high-octane number. The use of bioethanol as a source of energy would be more than just complementing for solar, wind and other intermittent renewable energy sources in the long run [32]. Due to the similarities in fuel properties between bioethanol and gasoline, bioethanol can be used both directly and mixed with gasoline in spark ignition engines. Despite the many advantages of bioethanol over gasoline fuel as highlighted, there still exist some drawbacks. Low carbon content of Bioethanol has been the reason for low fuel energy content and high fuel consumption. Bioethanol also has high volatility aspect, which is responsible for its high cavitation affecting its use in different weather conditions (i.e. hot or cold). It needs high heat of vaporization to facilitates its combustion difficulty in a cold environment. The lower calorific value of bioethanol than gasoline causes high BSFC consumption of bioethanol to increase in the same injection volume [22]. It also has lower kinematic viscosity, which causes wear problems and a short life of the fuel system [33]. In this study, watermelon and pineapple mixture were fermented and bioethanol produced. The bioethanol was characterized and blended with gasoline. The effects of blends from 2 to 14% gasoline-bioethanol on performance and emission parameters were analysed. The engine torque, Brake Power, Exhaust Gas Temperature and Brake Specific Fuel Consumption values were investigated. The results obtained were compared with gasoline and presented. Hence, the objective of this study was to identify a suitable bioethanol–gasoline blend that yields the best engine performance for spark-ignition engines.

2.0 Materials and Methods

Watermelon and pineapple waste (Figure 1) were collected from local juice peelers and washed with alkaline (2.0% NaOH) to pretreat it. A sterilized knife was used to cut the samples into smaller pieces and 1kilogram each was taken. The watermelon and pineapple samples were poured into a fermenting vessel.

Figure 1: Pretreated samples

Two grams of the yeast species (*Saccharomyces cerevisiae*) was measured and added to the watermelon and pineapple samples in the fermenting vessel and a liter of water was added and stirred with a stirrer for a few minutes for homogeneous mixture. The fermenting vessel was sealed and then left for approximately seven days. After which the fermenting sample (Figure 2) was filtered, and the filtrate poured into a container (Figure 3).

Figure 2: Fermented sample

Figure 3: Filtrate

The fermented samples were then distilled at 78^{0}C for the bioethanol to boil off and Gravimetric method was used to determine the characteristics of the bioethanol. Chemical and physical tests were carried out on the produced bioethanol in order to characterize and compare it to standard. Physico-chemical properties such as density, specific gravity, moisture content, calorific value, octane number, acid number, kinematic viscosity, Sulphur content, flash point, pour point and cloud point where determined. The test was carried out based on percentage blends between the produced bioethanol (E) and gasoline (P). In which seven different tests were done, which are E2 (2% of bioethanol and 98% of gasoline), E4, E6, E8, E10, E12, E14 and P100 (100% of gasoline). The test setup consists of a single cylinder S.I. engine coupled with hydraulic dynamometer for torque measurement. Technical detail of the engine is given in Table 1.

Table 1: Technical Specifications of Engine Test Rig

S/N	Engine Specification
1	Single cylinder, four stroke, air
2	Bore x stroke: 65mm x 70mm
3	Brake power: 2.34kw
4	Rated speed: 1500rpm
5	Starting method: Manual cracking
6	Compression ratio: 20:5:1
7	Net weight: 45kg
8	Manufacturer: TQ Educational
9	Model: TD110-115

The engine was allowed to run for an hour for sufficient warm up before commencing test. The engine was run for all the blend samples at a constant speed of 2500rpm varying load of 500g, 1000g, 1500g, 2000g, 2500g and 3000g. The time taken by the engine to consume 8ml of the fuel sample was recorded. The torque, exhaust gas temperature and barometric pressure were also recorded. The procedure was repeated for the remaining. Engine performance parameters such as brake power, torque, brake specific energy consumption, thermal efficiency was computed from the results obtained.

3.0 Results and Discussion

3.1 Characteristics of Produced Bioethanol

The result of the characterization of the bioethanol produced is shown in Table 2. The liquid was clear, colourless, flammable, and fully miscible in water. It had a sharp alcoholic taste as well as a typical ethanol smell.

Table 2: Fuel Properties

S/N	Properties	E100	ASTM	Gasoline
1	Appearance	Colourless	Colourless	Clear and Bright
2	Flash point °C	19.80	18.60	–45 to –38
3	Cloud point	19.90	23	
4	Sulphur (%)	0.082	-	0.0143
5	Ash content (%)	0.66	-	
6	Density (g/cm^3)	0.87	0.80	0.74
7	Viscosity	1.64	1.20	
8	Specific gravity	0.95	0.80	0.78
9	Acid value	23.69	-	
10	Refractive index	1.36	1.40	
11	Octane number	107	106 - 110	95
12	Moisture content	4.33	0.02	
13	Solubility	Highly Soluble	Highly Soluble	
14	Calorific value (kJ/kg)	27,350	26,380	42,500

The density, specific gravity and viscosity of the sample were determined using Gravimetric method. Viscosity is an indication of the ability of a material to flow and a lower viscosity is indicative of good flow and is dependent upon temperature. Fuel density directly affects fuel performance, as some of the engine properties, such as cetane number, heating value and viscosity are strongly connected to density. The density and specific gravity were 0.87 kg/L and 0.95. Two values obtained were slightly higher as compared to the standard values. The result confirms that the bioethanol produced was a little heavier when compared to standard values. The viscosity of the sample was determined using Gravimetric method. The viscosity was found to be 1.64 $_c$p. This value as compared to standard value (1.20$_c$p) was very close. The differences were owing to the temperature at which the viscosity of the sample was taken which was higher because viscosity decrease as temperature increases. The flash point of a fuel is said to be the minimum temperature at which it will ignite when exposed to an ignition source. In addition, flash point of fuels is useful in the knowledge of precautionary measures to be applied while blending of such fuels [34]. Comparing the standard flash point value of bioethanol (18.60) to that of the bioethanol produced in this study (19.80). It can be inferred that the sample is slightly less flammable than standard ethanol. Ash content is characterized as the quantity of metals which are contained in the samples fuel. Problem such as injector plugging, post combustion residues or deposits and wear of the injection system of any engine. The ash content of ethanol produced is 0.66, while [34] noted ash point of ethanol to be 0.00. In essence, the ash content of the produced bioethanol sample is slightly higher than that produced in the reference paper. Refractive index is an analytical method used to establish the concentration of liquids. It is a significant optical property of any liquid fuel as the case may be, with its importance being attached to fibre optics and film technology especially when it comes to bioethanol. From the ASTM standard values, refractive index of bioethanol is given as 1.40. The refractive index for this was 1.36. The value is quite consistent with standard. Therefore, it can be said that the product is of high quality in terms of concentration and product specification.

Water moisture content of any substance determines the concentration of the substance. The sample shows a very high value of water content as against the standard water content value for bioethanol and other fuels. Water content of bioethanol produced from watermelon rind is recorded after distillation as 4.33% which is slightly higher than the given standard of concentration of bioethanol (0.02). The calorific value of the bioethanol was found lower than that of gasoline, this means that a greater quantity of sample or its blends would be needed to achieve the same volume of energy as that produced by gasoline alone.

3.2 Performance of Bioethanol on a S.I. Engine

3.2.1 Torque Vs Load

In internal combustion engines or electric motors, torque (rotational force) indicates the force to which the drive shaft is subjected. Expressed in in pound-feet (lb-ft) or newton-meters (Nm), interaction of torque and engine speed (rpm) determines the engine power. In automobile, high torque means the shortest possible delay between the driver pressing the gas pedal and the engine responding. A high torque enables efficient and energy-saving driving. From Figure 4, it was observed that the blended fuels and gasoline produce highest torque at 2.5kg of load. Torque increases rapidly as the load increased and have a lower value for gasoline compared to the blends. Although bioethanol have lower calorific value than gasoline [35], the increased bioethanol torque with increment of bioethanol ratio in blends can be linked to the high oxygen content of bioethanol which allows for better combustion. Additionally, the density of bioethanol is higher than that of gasoline, this in turn is believed to facilitate more volume of fuel to be sprayed into the cylinder [36]. The blends also undergo complete combustion which helps in generating more hydroxyl radical which thus enhances advanced flame speed [37] and early heat release. As can be observed from Figure 4, the percentage torque increase for E10, E12, and E14 was about, 1.11%, 1.22% and 1.35%, respectively, as compared to neat gasoline. It worth noting that with an increase in octane number of blends due to addition of bioethanol, the compression ratio also increases [38] which could also be said to be the reason for the increase in torque. As documented by some researchers, a mixture of ethanol and gasoline have up to 20% increase in octane range [39, 40] and as well, the engine torque increases with the rise of octane number [41].

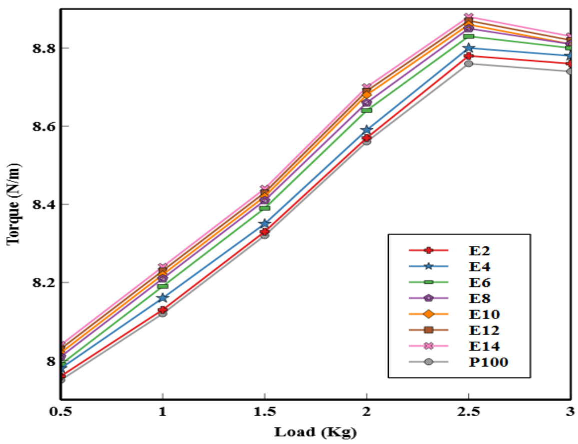

Figure 4: The graph of Torque Vs Load

3.2.2 Brake Power Vs Load

An engine's power is the product of force and the speed with which this force acts. A high engine power enables a car to accelerate quickly and reach a high-top speed. An internal combustion engine achieves its maximum torque at engine speeds lower than the maximum power output. From Figure 5, it was observed that the blends produce higher brake power compared to pure gasoline when driving on the same variation of load. In this study brake power rises as the engine was increasingly loaded for all the samples and gasoline reaching it maximum at 2.5kg load. The variations of brake power for E10, E12 and E14 were higher than that of gasoline by 1.12 %, 1.41 % and 1.64 % higher than that of E0 (P100). The increment in brake power with blends can be attributed the cooling effect of bioethanol as a result of the bioethanol's significantly higher latent heat compared with gasoline [42]. This high latent heat for the blend as compared with gasoline results in cooler and denser charge entering into engine. Moreover, high flame speed of ethanol increases the combustion rate and enhances the power output significantly. Cooling effect of blends means that the blends will have enhanced breathing capacity (volumetric efficiency) when compared to that of engine [42]. According to Adian, Fransiskus, *et al*. [41] engine power increases with the rise in octane number. In essence, with higher blending ratio, average output pressure enhances braking strength at all speeds. So, the blended fuel latent heat exceeds the oil evaporation, causing the air/fuel load to cool down thereby causing reduction in density and an increase in fuel volume and engine braking power. Nasir, K. F. [43] in his study also observed that brake power rises as the volume percentage of ethanol increases in the blends.

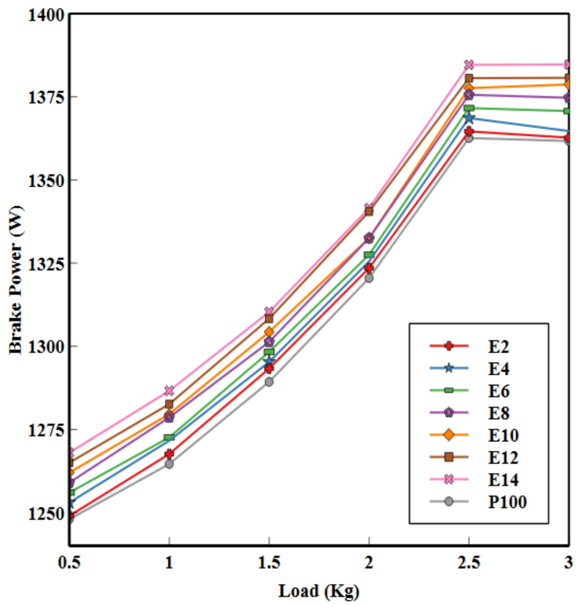

Figure 5: Brake Power Vs Load

3.2.3 Exhaust Gas Temperature (EGT) Vs Load

The EGT is the temperature of the exhaust on an engine at the point it leaves the cylinder (or close there to). It can be said to be a measure of the work an engine is doing, or the effort it is expending. The higher the exhaust temperature, the lower the thermal efficiency of the engine becomes since higher amount of heat energy is wasted through exhaust. Hence to boost engine performance, exhaust temperature should be as low as possible.

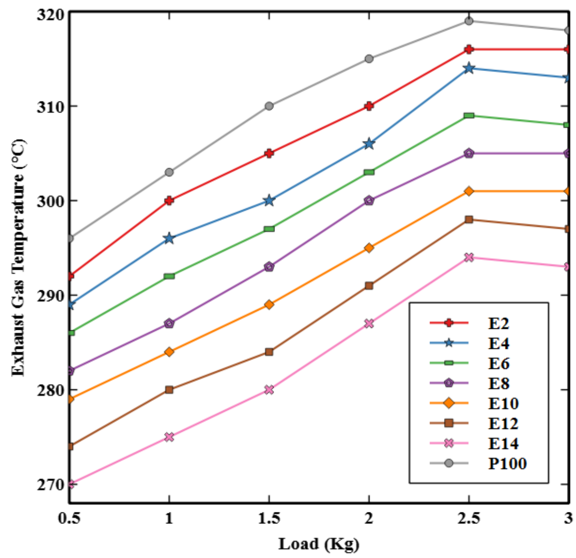

Figure 6: Exhaust Gas Temperature (EGT) Vs Load

In Figure 6, it was observed that the exhaust gas temperature (EGT) increases with increase in engine load for all fuel blends. Exhaust gas temperature for the blends is lower when compared to pure gasoline. E14 blend had the best EGT with 1.62% reduction when compared with gasoline ahead 1.12% and 1.37% from both E10 and E12 respectively. It should be noted that minimum exhaust temperature signifies complete combustion and available maximum power at the crank, which means higher thermal efficiency. The engine with a higher compression ratio also has higher expansion ratio, which means that exhaust temperature should be less than that of an engine with a lesser compression ratio. Other characteristics of alcohol-based fuel such as calorific value, density, cetane number, viscosity, higher latent heat of vaporization and lower heating value of the alcohol-based fuel than gasoline affect the exhaust gas temperature (EGT) [44, 45]. A lower EGT generally means good combustion and less heat loss, indicating the effective usage of thermal energy in the fuel. It worth mentioning that with increase in speed, power output and load, the heat generated in the cylinder also increases, meaning that the EGT will increase [46, 47]. This is depicted in Figure 6 as the graph was seen to increase as the load increased because with increase in engine load, higher quantity of fuel enters to the cylinder at the same speed with not enough time to burn it, this then amounts to incomplete burning of the quantity of fuel supplied and a subsequent decrease in EGT. Authors like [48, 49] also observed an increase in exhaust gas temperature for all fuels as the engine load increases because the heat generated increases due to additional burning of fuel and improved combustion efficiency with increased oxygen content of bioethanol. The peak bulk temperatures during the combustion of ethanol blends are lower than that of gasoline, causing lower NOx emission and higher flow rates of ethanol into the engine [50].

3.2.4 Brake Specific Fuel Consumption Vs Load

Brake Specific Consumption of Fuel (BSFC) characterises a fuel's heating value, time of spark, air to fuel ratio, the load the engine is carrying and the engine speed. The BSFC is the volume rate of fuel required to produce 1 kW of engine power, therefore it is a measure of the power output of fuel consumed implying the ability of the engine to produce useful work. A fuel's calorific value and its oxygen content largely governs its BSFC. Meaning that the higher the heating value of a fuel, then the lower its oxygen content and BSFC. The variation of BSEC with engine load and bioethanol content are shown in Figure 7. It was observed that as the load increases, the brake specific fuel consumption decreases. Maximum consumption of fuel occurs at lower engine load. From records, pure ethanol has an approximately 34% heating value lesser than that of gasoline and since heating value of fuel affects BSFC of an engine, it is reasonable enough to link the higher fuel consumption to the burning of the blends. This is because the reduced energy content of ethanol–gasoline fuel ultimately resulted to an increased mass flow leading to the fuel consumption by the engine. To reduce fuel consumption during bioethanol usage, engine compression ratio needs to be increased.

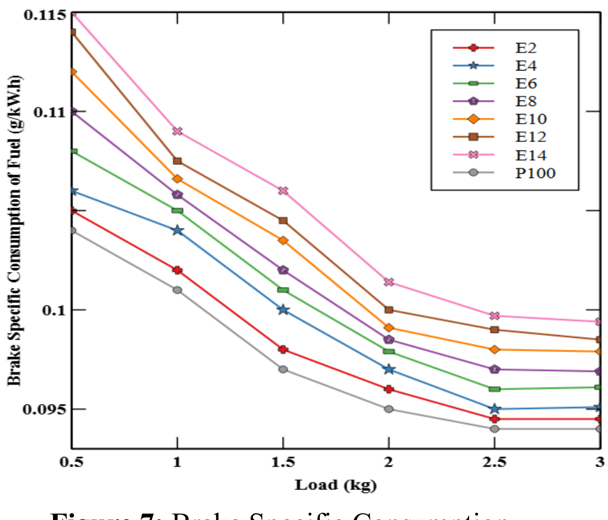

Figure 7: Brake Specific Consumption (BSFC) Vs Load

Considering average engine loads, the approximate respective increase in BSEC for all the blends as compared to gasoline are 0.08 %, 0.20 %, 0.32 %, 0.42 %, 0.54 %, 0.64 % and 0.76 % for E2, E4, E6, E8, E10, E12 and E14 respectively. Low load was also observed to show higher BSFC than higher load due to higher heat loss, choking at the throttle and efficient air suction which is better at low load than at high load. From the experimental result, the lowest BSFC values for all test fuels were obtained at 3 kg engine load. At this point the BSFC of the gasoline ranged from 94 - 104 g/kW.h while that of E14 which was the highest ranged from 99.4 - 115 g/kW.h. According to Zhuang and Hong [51] the low calorific value of bioethanol was responsible for the decrease in the amount of heat energy released in the cylinder and increase in fuel consumption with bioethanol increase. The raising BSFC of the engine when bioethanol was used without altering the engine is caused by the lower heating value of bioethanol-gasoline fuel and this increment largely depends on the percentage of bioethanol [52] other factors that also contributed to the higher BSFC of bioethanol fuel are its low heating value, density and higher viscosity which obstructs atomisation and vaporisation causing a deteriorated combustion, pumping losses and increased brake torque [53, 54]. Decreased BSFC at higher load compared to lower load is as a result of slow motion of air intake in the cylinder due to some of the air sent back to the intake system [55]. The decreasing BSFC with reference to load as observed in this experiment could also be explained in terms of the lesser percentage fuel increase required for the engine operation than the percent increase in brake power due lesser heat loss at higher loads.

3.3 Conclusion

Bioethanol had been successfully generated from watermelon and pineapple waste using Saccharomyces cerevisiae as yeast for the fermentation process. The physicochemical characterized bioethanol was determined and compared with the standard values and gasoline. The properties of bioethanol are very close to the standard values. Engine tests were conducted on an SI engine to evaluate the performance of spark ignition engine using E2, E4, E6, E8, E10, E12 and E14 blends. Based on the experimentation the following outcomes were arrived at:

i. The density and specific gravity were slightly higher as compared to the standard values which confirms that the bioethanol produced was a little heavier when compared to standard values.
ii. Comparing the standard flash point value of bioethanol (18.60) to the bioethanol produced in this study (19.80). It can be inferred that the sample is slightly less flammable than standard ethanol.
iii. The calorific value of the bioethanol was found lower than that of gasoline, this means that a greater quantity of sample or its blends would be needed to achieve the same volume of energy as that produced by gasoline alone. This parameter had an adverse effect on the engine performance.
iv. Performance characteristics showed that the blends performed better than pure gasoline at different loads except for the fuel consumption which was higher with the blends than gasoline.
v. At different engine loads of the tested fuels, the brake power, engine torque and EGT increased with increase in load while the BSFC reduces at higher loads.
vi. Brake power, Torque, EGT are all better with the blends than gasoline with E14 producing the best results among the blends. The peak bulk temperatures produced by the combustion of ethanol blends were lower than those produced by gasoline, which also accounted for

the higher ethanol flow rates into the engine.

vii. Comparing E14 to gasoline, there were improvements of 1.35% on torque, 1.64 % on brake power and 1.62% on EGT while gasoline was better than E14 by 0.76 % ranging from 94 - 104 g/kWh as against 99.4 - 115 g/kWh for E14.

viii. Generally, no significant problem was encountered in the engine during the experiment, meaning that all blends tested are suitable for use in SI engine. However, the low thermal value of bioethanol and higher combustion rate due to oxygen content are largely responsible for its negative effect on performance parameters.

References

[1] Midttun, A. and Piccini, P. B., "Facing the climate and digital challenge: European energy industry from boom to crisis and transformation," Energy Policy, 2017; 108 330-343.

[2] Mishra, K., Rathore, M., Tickoo, J., and Singh, A. K., "Production of bioethanol from fruit waste," Materials Today: Proceedings, 2022; 68 1167-1171.

[3] Food, S., "Global initiative on food loss and waste reduction," Key facts on food loss and waste you should know, 2016;

[4] Bancal, V. and Ray, R. C., "Overview of food loss and waste in fruits and vegetables: From issue to resources," in *Fruits and vegetable wastes: Valorization to bioproducts and platform chemicals*, ed: Springer, 2022: 3-29.

[5] Ong, K. L., Kaur, G., Pensupa, N., Uisan, K., and Lin, C. S. K., "Trends in food waste valorization for the production of chemicals, materials and fuels: Case study South and Southeast Asia," Bioresource technology, 2018; 248 100-112.

[6] Jha, S. N., Vishwakarma, R. K., Ahmad, T., Rai, A., and Dixit, A. K., "Report on assessment of quantitative harvest and post-harvest losses of major crops and commodities in India," All India Coordinated Research Project on Post-Harvest Technology, ICAR-CIPHET, 2015; 130

[7] Jahid, M., Gupta, A., and Sharma, D. K., "Production of bioethanol from fruit wastes (banana, papaya, pineapple and mango peels) under milder conditions," Journal of Bioprocessing & Biotechniques, 2018; 8 (3): 1-11.

[8] Mannepula, S., Bathal, V. K., and Obulam, V. S. R., "A comparative study on utilisation of citrus and mango peels for lactic acid production and optimisation by Rhizopus oryzae in submerged fermentation," Eur. J. Biotechnol. Biosci, 2015; 3 18-26.

[9] Celik, A. N. and Özgür, E., "Review of Turkey's photovoltaic energy status: Legal structure, existing installed power and comparative analysis," Renewable and Sustainable Energy Reviews, 2020; 134 110344.

[10] Elfasakhany, A., "Modeling of secondary reaction of tar (SRT) using a functional group model," International Journal of Mechanical Engineering and Technology, 2012; 3 (3): 123-136.

[11] Elfasakhany, A., "State of art of using biofuels in spark ignition engines," Energies, 2021; 14 (3): 779.

[12] Thangavelu, S. K., Ahmed, A. S., and Ani, F. N., "Review on bioethanol as alternative fuel for spark ignition engines," Renewable and Sustainable Energy Reviews, 2016; 56 820-835.

[13] Moka, S., Pande, M., Rani, M., Gakhar, R., Sharma, M., Rani, J., *et al.*, "Alternative fuels: an overview

of current trends and scope for future," Renewable and Sustainable Energy Reviews, 2014; 32 697-712.

[14] Thompson, W., Whistance, J., and Meyer, S., "Effects of US biofuel policies on US and world petroleum product markets with consequences for greenhouse gas emissions," Energy Policy, 2011; 39 (9): 5509-5518.

[15] Kay, A. and Ackrill, R., "Governing the transition to a biofuels economy in the US and EU: Accommodating value conflicts, implementing uncertainty," Policy and Society, 2012; 31 (4): 295-306.

[16] Abdu Yusuf, A. and L Inambao, F., "Bioethanol production techniques from lignocellulosic biomass as alternative fuel: a review," International Journal of Mechanical Engineering and Technology, 2019; 10 (6):

[17] Zhen, X., "Methanol as an internal combustion on engine fuel," in *Methanol*, ed: Elsevier, 2018: 313-337.

[18] Demirbas, B., "Biofuels for internal combustion engines," Energy Educ Sci Technol Part A, 2009; 22 117-32.

[19] Balat, M., "Global bio-fuel processing and production trends," Energy Exploration & Exploitation, 2007; 25 (3): 195-218.

[20] Balat, M. and Balat, H., "Recent trends in global production and utilization of bio-ethanol fuel," Applied energy, 2009; 86 (11): 2273-2282.

[21] Sakthivel, P., Subramanian, K., and Mathai, R., "Effects of different compression ratios and spark timings on performance and emissions of a two-wheeler with 30% ethanol-gasoline blend (E30)," Fuel, 2020; 277 118113.

[22] Prasad, B. N., Pandey, J. K., and Kumar, G., "Impact of changing compression ratio on engine characteristics of an SI engine fueled with equi-volume blend of methanol and gasoline," Energy, 2020; 191 116605.

[23] Balki, M. K. and Sayin, C., "The effect of compression ratio on the performance, emissions and combustion of an SI (spark ignition) engine fueled with pure ethanol, methanol and unleaded gasoline," Energy, 2014; 71 194-201.

[24] Celik, M. B., "Experimental determination of suitable ethanol–gasoline blend rate at high compression ratio for gasoline engine," Applied Thermal Engineering, 2008; 28 (5-6): 396-404.

[25] Qi, D. and Lee, C.-F., "Combustion and emissions behaviour for ethanol–gasoline-blended fuels in a multipoint electronic fuel injection engine," International Journal of Sustainable Energy, 2016; 35 (4): 323-338.

[26] Schifter, I., Diaz, L., Rodriguez, R., Gómez, J., and Gonzalez, U., "Combustion and emissions behavior for ethanol–gasoline blends in a single cylinder engine," Fuel, 2011; 90 (12): 3586-3592.

[27] Renzi, M., Bietresato, M., and Mazzetto, F., "An experimental evaluation of the performance of a SI internal combustion engine for agricultural purposes fuelled with different bioethanol blends," Energy, 2016; 115 1069-1080.

[28] Karthikeyan, A., Venkatesh, D., and Ramkumar, T., "Experimental investigation on spark ignition engine using blends of bio-ethanol produced from citrus peel wastes," International Journal of Ambient Energy, 2017; 38 (2): 112-115.

[29] Najafi, G., Ghobadian, B., Yusaf, T., Ardebili, S. M. S., and Mamat, R., "Optimization of performance and exhaust emission parameters of a SI (spark ignition) engine with

gasoline–ethanol blended fuels using response surface methodology," Energy, 2015; 90 1815-1829.

[30] Yüksel, F. and Yüksel, B., "The use of ethanol–gasoline blend as a fuel in an SI engine," Renewable energy, 2004; 29 (7): 1181-1191.

[31] Kumar, A., Khatri, D., and Babu, M., "An investigation of potential and challenges with higher ethanol-gasoline blend on a single cylinder spark ignition research engine," SAE Technical Paper 0148-7191, 2009.

[32] Pandey, A., Tiwari, S., Jadhav, S., and Tiwari, K., "Efficient microorganism for bioethanol production from Lignocellulosic Azolla," Research Journal of Environmental Sciences, 2014; 8 (6): 350.

[33] Elfasakhany, A., "Comparative Analysis of the Engine Performance and Emissions Characteristics Powered by Various Ethanol–Butanol–Gasoline Blends," Processes, 2023; 11 (4): 1264.

[34] Ghobadian, B., Rahimi, H., TAVAKOULI, H. T., and KHATAMI, F. M., "Production of bioethanol and sunflower methyl ester and investigation of fuel blend properties," 2008;

[35] Alhassan, A. G., Mshelia, R. B., and Yusuf, R., "Review of the use of bioethanol as alternative fuel for internal combustion engines," Acta Technica Corviniensis-Bulletin of Engineering, 2021; 14 (2): 139-144.

[36] Yusoff, M. N. A. M., Zulkifli, N. W. M., Masjuki, H. H., Harith, M., Syahir, A., Khuong, L., *et al.*, "Comparative assessment of ethanol and isobutanol addition in gasoline on engine performance and exhaust emissions," Journal of Cleaner Production, 2018; 190 483-495.

[37] Godwin, D. J., Geo, V. E., Thiyagarajan, S., Martin, M. L. J., Maiyalagan, T., Saravanan, C., *et al.*, "Effect of hydroxyl (OH) group position in alcohol on performance, emission and combustion characteristics of SI engine," Energy Conversion and Management, 2019; 189 195-201.

[38] Setiyawan, A., "Kajian Eksperimen Pengaruh Etanol pada Gasoline terhadap Kerja Mesin Bensin," Disertasi Fakultas Teknik: Universitas Indonesia, 2012;

[39] Anderson, J., DiCicco, D., Ginder, J., Kramer, U., Leone, T., Raney-Pablo, H., *et al.*, "High octane number ethanol–gasoline blends: Quantifying the potential benefits in the United States," Fuel, 2012; 97 585-594.

[40] Yelbey, S. and Ciniviz, M., "Investigation of the effects of gasoline-bioethanol blends on engine performance and exhaust emissions in a spark ignition engine," European Mechanical Science, 2020; 4 (2): 65-71.

[41] Adian, F., Sugiarto, B., Wibowo, C. S., Zikra, A., and Mulya, T., "The effect of 5% ethanol in 88, 92, and 98 RON gasoline on motorcycle engine performance," in *AIP Conference Proceedings*, 2019.

[42] Devunuri, S. and Porpatham, E., "Investigations on effects of ethanol blending on performance and combustion characteristics of gasoline fuelled lean burn SI engine," in *IOP Conference Series: Earth and Environmental Science*, 2019: 012019.

[43] Nasir, K. F., "Experimental Investigation of Using Ethanol-Gasoline in Spark Ignition Engine," Al-Nahrain Journal for Engineering Sciences, 2018; 21 (3): 368-373.

[44] Rahman, S. A., Masjuki, H., Kalam, M., Abedin, M., Sanjid, A., and Sajjad, H., "Production of palm and

Calophyllum inophyllum based biodiesel and investigation of blend performance and exhaust emission in an unmodified diesel engine at high idling conditions," Energy Conversion and Management, 2013; 76 362-367.

[45] Sanjid, A., Masjuki, H., Kalam, M., Rahman, S. A., Abedin, M., and Palash, S., "Impact of palm, mustard, waste cooking oil and Calophyllum inophyllum biofuels on performance and emission of CI engine," Renewable and sustainable energy reviews, 2013; 27 664-682.

[46] Anwar, M., Rasul, M. G., and Ashwath, N., "A pragmatic and critical analysis of engine emissions for biodiesel blended fuels," Fuel, 2020; 270 117513.

[47] Wu, G., Ge, J. C., and Choi, N. J., "A comprehensive review of the application characteristics of biodiesel blends in diesel engines," Applied Sciences, 2020; 10 (22): 8015.

[48] Singh, M., Gandhi, S. K., Mahla, S. K., and Sandhu, S. S., "Experimental investigations on performance and emission characteristics of variable speed multi-cylinder compression ignition engine using Diesel/Argemone biodiesel blends," Energy Exploration & Exploitation, 2018; 36 (3): 535-555.

[49] Khan, M. Y., Pachauri, P., and Mittal, A., "PERFORMANCE EVALUATION OF SPARK IGNITION ENGINE RUNNING ON PETROL DOPED WITH VARIOUS ADDITIVES," International Journal of Advance Research in Science and Engineering, (5):

[50] Mamat, R., Azri, A., and Sudhakar, K., "Effects of lean combustion on Bioethanol-Gasoline blends using turbocharged spark ignition engine," International Journal of Automotive and Mechanical Engineering, 2021; 18 (3): 9140–9148-9140–9148.

[51] Zhuang, Y. and Hong, G., "Primary investigation to leveraging effect of using ethanol fuel on reducing gasoline fuel consumption," Fuel, 2013; 105 425-431.

[52] Najafi, G., Ghobadian, B., Moosavian, A., Yusaf, T., Mamat, R., Kettner, M., *et al.*, "SVM and ANFIS for prediction of performance and exhaust emissions of a SI engine with gasoline–ethanol blended fuels," Applied Thermal Engineering, 2016; 95 186-203.

[53] Shameer, P. M. and Ramesh, K., "Experimental evaluation on performance, combustion behavior and influence of in-cylinder temperature on NOx emission in a DI diesel engine using thermal imager for various alternate fuel blends," Energy, 2017; 118 1334-1344.

[54] Hasan, A. O., Al-Rawashdeh, H., Ala'a, H., Abu-jrai, A., Ahmad, R., and Zeaiter, J., "Impact of changing combustion chamber geometry on emissions, and combustion characteristics of a single cylinder SI (spark ignition) engine fueled with ethanol/gasoline blends," Fuel, 2018; 231 197-203.

[55] Cairns, A., Zhao, H., Todd, A., and Aleiferis, P., "A study of mechanical variable valve operation with gasoline–alcohol fuels in a spark ignition engine," Fuel, 2013; 106 802-813.