ABUAD Journal of Engineering Research and Development (AJERD)
ISSN (online): 2645-2685; ISSN (print): 2756-6811

Volume 6, Issue 2, 39-49

Emission Characterization of Petrol, Ethanol and Spent Engine Oil Blends for Two-Stroke Spark Ignition Engine

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Date Submitted: 07/07/2023
Date Accepted: 07/08/2023
Date Published: 14/08/2023

Abstract: *Exhaust emission has remained a big global concern in atmospheric change, and has thus, lead to stiffer polices on emission. To achieve the set emission targets different fuel mix and combustion process are continuously been investigated. This work is used to practically model the condition of a two-stroke engine that has run over time whose used lubricating oil finds its way from the sump to the combustion chamber and thus resulting to greater rate of incomplete combustion and higher emission. An exhaust analyser with a deep probe was deployed to access the out-going burnt gasses from a two-stroke spark ignition engine that is fed with multi blends of petrol, ethanol and spent engine oil. The characteristics of the emission constituents were investigated and compared to the global limits set by different organizations such as California Air Resources Board, Environmental Protection Agency in USA, International Council on Clean Transportation, Road Transport Bureau- in Japan, and European Emission Standard Agency, among others. The result shows an increase in* $\boldsymbol{CO}$, $\boldsymbol{HC}$ *and* $\boldsymbol{NO_x}$ *emissions with samples that contain spent oil as against those with new engine oil which is also more effective. It was also found that samples with higher quantity of ethanol show lower emission of* $\boldsymbol{CO}$, $\boldsymbol{HC}$ *and* $\boldsymbol{NO_x}$ *gases. This is likely due to interstation of ethanol molecules with that of the spent oil, thus making it more potent for further combustion. This was also supported with the fact that* $\boldsymbol{CO_2}$ *emission was higher in blends with higher quantity of ethanol. Thus, the presence of ethanol in fuel blend used in two-stroke spark ignition engine may be considered to be a source of improvement in combustion and hence a means of reducing emission in two-stroke port operated spark ignition engines.*

Keywords: *Two-stroke SIE, multiple fuel-blends, ethanol, spent engine oil, charge potency, emission.*

1. INTRODUCTION

Internal Combustions Engines (ICEs), use fuels that have negative impact on human lives and, on the environment [1]. The global impact of the consequences of emission from ICEs had led to stringent polices in the search for alternative sources and better technology to reduce emission to the nearest minimum [2, 3]. In reciprocating two stroke engines, the piston-cylinder arrangement leads to a working cycle that allows some free loss off in-cylinder charges. To get most of the charge burnt is part of the current design concern across board.

Two-stroke engines are largely needed for different mini operations like hand operations in Agriculture, building services, aeronautic, among others, due to their higher power to weight ratio [4]. ICEs are believed to stay long enough that necessitate the need for alternative environmentally friendly fuels and re-engineering of the engine systems for better performance and lower emission.

This work focuses on the magnitude of such impact where petrol, ethanol and spent fuel are blended and used in single cylinder two stroke spark ignition engine, like the Suziiou engine model T1987 T1400.

Lubricating oil is a vital component of an engine working fluid [5] used in two-stroke SI engine by "mist lubrication" process [6]. Based on manufactures recommendation vehicles and engine equipment are usually serviced after some specified hours of operation as a result of contamination from dirt, water, salt, and metal wears. Oil in this condition has lost its lubrication potency and it is described by Lawal and Nurudeen [7] as spent engine oil. Engine oil has a carbon molecule of between $C_{15} - C_{50}$. Its chemical constituent at any time in its life span depends on the refining process, the crude oil source, engine operation, fuel additives and its interactive resident time in the engine [8, 9]. Oil used in lubricating engine mostly finds its way into the combustion chamber as the oil rings get weakened. This situation is more pronounced at high temperatures. However, the presence of engine oil in the engine causes some fundamental issues, namely: lower combustion as the potency of the charge is reduced and high emission of CO and HC into the atmosphere. This situation is greatly enhanced when the oils is a used one. The common means of disposing spent oil in Africa is by removing and throwing it off into a gutter or even running stream. Improper disposal or handling of spent engine oil can result to soil and water pollution, and it is reported by Hamad [10] to slow down thermal degradation processes. However, spent engine oil still contains a large proportion of valuable base oil that may be used to formulate a new lubricant after the undesirable contaminants are removed through recycling process [10]. According to Lawal et al., [7] spent oils can be improved through the use of additives.

Ethanol is commonly produced from feedstock with high starch or sugar content. According to [7], the first process of producing ethanol from organic substance - cassava for example, involves the milling and liquefaction of cassava to break down its starch molecules into building blocks of glucose molecules using enzymes. This is followed by fermentation process to convert glucose into ethanol using yeast. Then, the content is passed through distillation process to separate the ethanol from other reaction product and inert materials. Finally, the product may be blended with petrol to serve as useful fuels in automotive engines. The quantity of starch for ethanol production is dependent on storage temperature. It also degrades with resident time in the storage losing about 5% starch yield during a resident time of 8 months in storage [11]. Availability is a big factor that promotes the tendency of using ethanol because cassava can be grown and harvested throughout the year, thus providing steady supply for ethanol production [11].

In the future, cellulosic biomass such as trees and grasses, particularly from agricultural by-products can provide alternative fuel source with near zero emission as they exhaust the carbon dioxide (CO_2) present in their production [2]. The chemical formula for Ethanol is CH_3CH_2OH. It contains molecules with a hydroxyl group OH bonded to a carbon atom. The oxygen content of this group is said to favour further combustion of gasoline [2, 12].

The emission characterization performance parameters are essential in the design and development of ICE's. They are indications of the degree of success of the engine to effectively convert its fuel chemical energy into useful mechanical work. Despite the discovery of other new sources of conventional energies, fossil fuel remains the major energy source for the automotive systems, providing much of the energy that drives the economy in both industrialized and developing countries. In Africa, huge oil reserves also exist in the Niger Delta, as well as in the Gulf of Guinea, where Nigeria, Cameroon and Angola are major producers [4, 7].

The two-stroke spark ignition engine exhaust gas consist of more emissions of CO, HC and Particle matter [1] and because they are designed for low loads they tend to emit more with increase in load [1]. Air pollution which is higher with two-stroke engines due to their various range of application increases outdoor pollution (as described by the Environ Health Perspective, 2004), WHO ranked urban outdoor pollution as the thirteenth greatest contribution to disease burden and death worldwide [1]. Mainly because they are equipped with no exhaust gas treatment devices which results in huge emission of gases [13], also due to the fact that two-stroke engine intake charge and exhaust gases discharge occurs simultaneously yielding more unburnt fuel and incomplete combustion, Lawal and Nurudeen [7]. This has led to introduction of different fuel feed systems used and their arrangements: such as fuel tank, fuel high- and low-pressure lines (hoses), fuel pumps, carburettor, filters, air filter, inlet manifold. Notably are the gravity feed systems, air pressure systems, vacuum feed system, fuel pump fed system and fuel injector feed system [14].

2. MATERIALS AND METHODS

This study shows details fuel blend of petrol, ethanol and spent engine oil. Engine emission, efficiency and susceptibility to self-ignition are largely dependent on the fuel blend mixture strength as reported by Stone [15]. As such, the fuel blend ratio of petrol: Ethanol: Spent engine oil are designated as O for control sample and A, B and C for various mix ratios as presented in Table 1.

Table 1: Fuel blend percentage composition

S/No.	Sample	% Petrol	% Ethanol	% Spent Oil
1	O	98	0	2
2	A	89	9	2
3	B	91	7	2
4	C	93	5	2

2.1 Stoichiometric Combustion Scenarios

The control is based on stoichiometric combustion; the quantity of the air to fuel ratio was taken as 14.7 and the stoichiometric relation determined from Sara et al., [16] as:

$$C_\alpha H_\beta O_\gamma + \alpha + \frac{\beta}{4} - \frac{\gamma}{2}(O_2 + 3.76N_2) \rightarrow \alpha CO_2 + \frac{\beta}{2}H_2O + 3.76\left(\alpha + \frac{\beta}{4} - \frac{\gamma}{2}\right)N_2 \quad (1)$$

where α, β and γ are the stoichiometric coefficients of carbon, hydrogen and oxygen respectively.

For the blended mixture, the constituent's formation is obtained using their volume fractions and molar mass to determine the energy content and equivalent ratio of the mixture. The individual constituents of Petrol and Ethanol before blending are assumed to have stable formula C_8H_{18} and C_2H_6O respectively [16]. Lubricating oils for automobiles and machines are estimated in several literatures, to have carbon atoms-chain in the range of C_{17} to C_{24}, while regular paraffin starts with a carbon chain of C_{20} to C_{34} [17]. In this work, the analysis of new engine oil 5W-20 and filtered spent engine oil were based on the lower limit of the carbon-chain values as $C_{17}H_{34}$ and $C_{20}H_{42}$ respectively [17].

The air fuel ratio which is used to establish the equivalent ratio of the blended mixture and air is defined here using the expression provided by [16] as;

$$\text{Fuel air ratio } f_s = \frac{m_f}{m_a}/_{sto} = \frac{m_f}{\left(\alpha+\frac{\beta}{4}-\frac{\gamma}{2}\right)4.76m_a} \quad (2)$$

where m_f the mass of is the blended mixture, and m_a is the mass of air that will give a stoichiometric combustion.

2.2 Non-Stoichiometric Combustion Scenarios

In this scenario, the combustion is not complete. Relative to greater weight, viscosity as well as variation in energy content and volatility of the mixture compared to gasoline alone, stoichiometric condition can hardly be reached. Thus, the equivalent ratio is either greater than one (rich combustion) or less than one (lean combustion). Taken the equivalent ratio of gasoline as ϕ_p, and that of other fuel mixture - like engine oil, as ϕ_e. The resultant equivalent ratio, ϕ_{mix} for Y_p% of gasoline and Y_e% of other fuels, in the new mixture is given as:

$$\phi_{mix} = \frac{\phi_p * \phi_e}{Y_p\phi_e + Y_e\phi_p} \quad (3)$$

In non-stoichiometric combustion, either excess or insufficient air is used. With excess air, the combustion is lean and the equivalent ratio $\phi \le 1$. In rich combustion, air is insufficient and $\phi > 1$. It is important to note that air in this context does not mean the supplied air, instead it implies the quantity of air that eventually participate in the reaction or the air that is not inhibited (or resisted) by the mixture [16]. Thus, enough air may be supplied but the state of the blended mixture may resist its adequate participation in the combustion reaction. As a result of this, when the participating air is in excess, some of it will be left out (that is oxygen will be present in the product) and the general equation employed to investigate resulting constituent is that of Sara et al., [16] given as:

$$C_\alpha H_\beta O_\gamma + \frac{1}{\phi}\left(\alpha + \frac{\beta}{4} - \frac{\gamma}{2}\right)(O_2 + 3.76N_2) \rightarrow \alpha CO_2 + \frac{\beta}{2}H_2O + \frac{3.76}{\phi}\left(\alpha + \frac{\beta}{4} - \frac{\gamma}{2}\right)N_2 + + \left(\frac{1}{\phi} - 1\right)\left(\alpha + \frac{\beta}{4} - \frac{\gamma}{2}\right)O_2 \quad (4)$$

The percentage excess air is estimated from exhaust gases constituents with their mole fractions for CO_2 and O_2 as:

$$\frac{\%EA}{100} = \left(1 + \frac{\beta}{4\alpha} - \frac{\gamma}{2\alpha}\right)\frac{x_{CO_2}}{x_{O_2}} \quad (5)$$

For rich combustion ($\phi > 1$), air is inadequate and the products of combustion may contain unburnt blended mixture, CO, and some fractional particle species made by the devaluation of the constituent fuels. With little or zero CO, Sara et al., [16] suggested Equation 6.

$$C_\alpha H_\beta O_\gamma + \frac{1}{\phi}\left(\alpha + \frac{\beta}{4} - \frac{\gamma}{2}\right)(O_2 + 3.76N_2) \rightarrow \frac{\alpha}{\phi}CO_2 + \frac{\beta}{2}H_2O + \frac{3.76}{\phi}\left(\alpha + \frac{\beta}{4} - \frac{\gamma}{2}\right)N_2 + \left(1 - \frac{1}{\phi}\right)C_\alpha H_\beta O_\gamma \quad (6)$$

With significant CO present, Equation 7 is used in conjunction with the equilibrium reaction equation to complement the chemical reaction as in Equation (6)

$$CO_2 + H_2 \leftrightarrow CO + H_2O \quad (7)$$

2.3 Residual Gas from Previous Cycles:

The presence of residual gas reduces the potency of the fresh gas, thus, lowering the power produced. Thus, more fuel is consumed and more CO is emitted. It however lowers the formation of Nitrogen oxides which are temperature dependent. For a normalized chemical equation of combustion based on moles of carbon of fuels presented by Butts worth [18] is employed as given in Equation 8.

$$CH_{\frac{\beta}{\alpha}}O_{\frac{\gamma}{\alpha}} + \frac{n}{\alpha}(O_2 + 3.76N_2) \rightarrow \frac{a}{\alpha}CO_2 + \frac{b}{\alpha}H_2O + \frac{c}{\alpha}C_\alpha H_\beta O_\gamma + \frac{d}{\alpha}NOn_4 + \frac{e}{\alpha}H_2 + \frac{g}{\alpha}CO + \frac{h}{\alpha}N_2 + \frac{f}{\alpha}O_2 \quad (8)$$

2.4 Exhaust Gas Emission Determination:

Equations 1 through 8 are used to estimate the number of moles and hence constituent masses of the products theoretically. For the experimental investigation, an SV-5Q automobile exhaust gas analyser was set up as shown in Figure 1, as provided in the operation manual [19]. The suitability of the SV-Q5 analyser is dependent on its ability to remain accurate in a wide range of atmospheric condition such as temperature range of $5\ to\ 400°C$, humidity of $\leq$ 95% and atmospheric pressure in the range of 60 to 106 kPa. It simultaneously measures five major combustion product constituents with a relative error of + 5%. The range of individual constituents and their corresponding volume specifications with allowable errors are given in Table 2.

Table 2: SV-5Q Automobile exhaust gas analyser specifications

S/No.	Description	Specification	Allowed Error
1	$HC\ 0{\sim}10000$	$10^{-6}\%\ (ppm/vol)$	$\pm 12\ ppm\ vol$
2	$CO\ 0{\sim}10.0$	$10^{-2}\%\ vol$	$\pm 0.06\%\ vol$
3	$CO_2 0{\sim}20.0$	$10^{-2}\%\ vol$	$\pm 0.5\%\ vol$
4	$O_2 0{\sim}25.0$	$10^{-2}\%\ (vol.)$	$\pm 0.01\%\ vol.$
5	$NO\ 0{\sim}5000$	$10^{-6}\%\ (ppm/vol.)$	$\pm 25\ ppm/vol.$

2.5 Experimental Set-up

1) Description of Apparatus: Figure 1 shows the experimental set-up. The two-stroke SI engine - 1, a Suziiou engine model T1987 T1400 generator, is fed with a blended fuel from a calibrated burette - 2, and run with the specified range of speed by the manufacturer using the air throttle as the controller. At a set throttle value, seven set of electrical loads from $100\ W\ to\ 700\ W$ are gradually put-on via sets of manual switches. The probe - 3 is inserted in the generator exhaust which is modified to accommodate during sample collection. The downstream of probe pipe is fixed to the sample intake tube of the analyser - 4. Other units that are provided include; a fronted filter connection, steam vent, an optical thermometer and a meter soft-hose for each of O_2 and N_2 vents. There is also a mini printer that provides immediate data values in order to minimize variation of measured values over time. At the front is a crystal display unit - 5, which gives the results of each constituents of the exhaust gas as well as the reading of temperatures from the optical thermometer. A power load bank circuit was designed with switches and bulb assembly - 6, to select individual and combination of loads for emission tests.

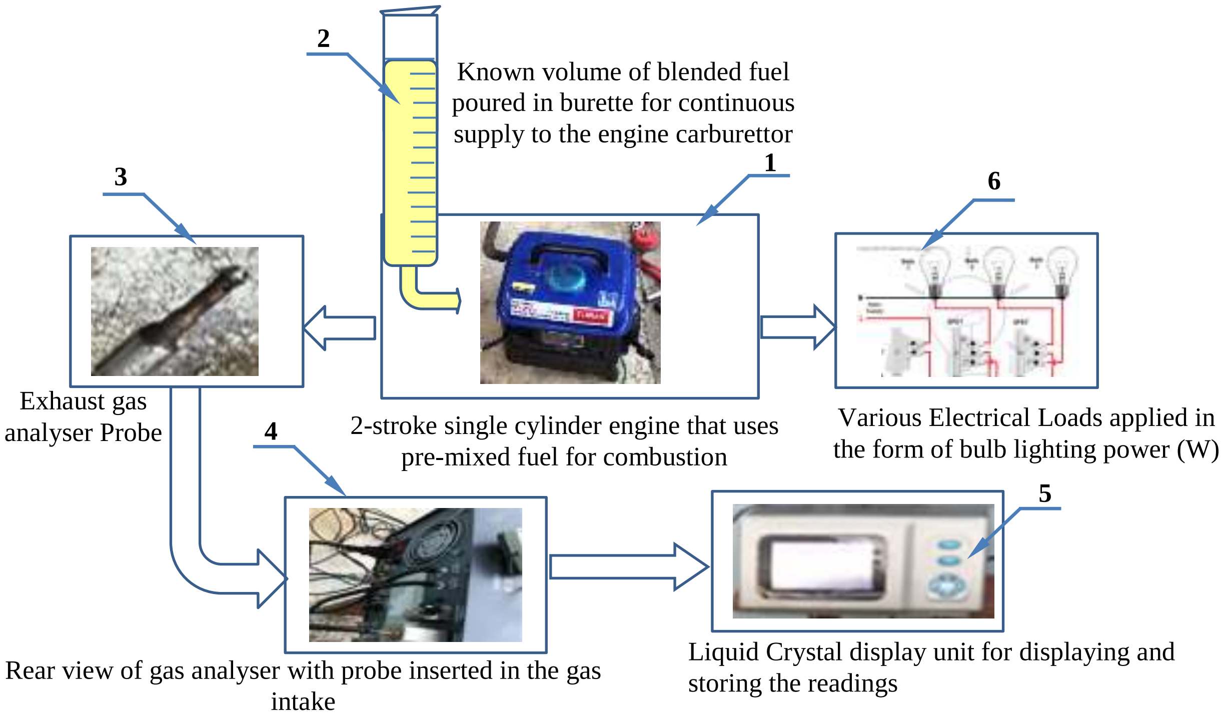

Figure 1: Schematic diagram of system units in the experimental set-up

2) Test Procedure: The test procedure starts by filling a 120 mm^3 burette connected to the engine supply flexible pipe. The supply is controlled using a fuel valve with five distinct positions – $0°, 22.5°, 45.0°, 67.5°, and$ $90°$ marks on a protractor; representing different supply modes. After the necessary starting precautions, the ignition is started and throttle is gradually turned from zero to $90°$ over about 5 $minutes$ for the engine to run at full speed. The condition was allowed to stabilize for a further 5 $minutes$ and then, readings of engine speed for various loads of $100 \sim 700\ W$ at increment of $100\ W$, were taken at intervals of 10 $seconds$ using a stop watch and tachometer.

In each case, a pre-determined blend mixture of petrol, ethanol and spent engine oil samples, O, A, B and C (shown in Table 1), of 100 $millilitre$ each were administered into the burette for supply through the flexible tube to the engine carburetting system.

The exhaust probe of the analyser was placed in the exhaust pipe and the other end connected to the fronted filter and sample gas vent of the analyser. The analyser is preheated for 10 $minutes$ warm-up which is shown as countdown on the analyser liquid crystal display. This is followed with a self-calibration by: (i) testing for leakages and (ii) zeroing the volume state of all the exhaust gas constituents except hydrocarbon (HC) whose remains in the system is expected to be less than 20 ppm, a limit considered having insignificant effect on the results. Next is the selection of two-stroke single cylinder mode as the intended test system. The exhaust analyser probe was then inserted into the modified engine exhaust pipe with the analyser set up for 30 $seconds$ intervals for each load $(100 - 700\ W)$. Printout of the readings and analyser results were collated for emission analyses. In all cases, engine emission values for CO_2, CO, NO_x, O_2 and HC were estimated and plotted in graphs using MatLab software platform due to its simplicity and excellent visual display.

3. RESULTS AND DISCUSSIONS

3.1 Chemical Composition formula for Multiple Blended Fuel of Petrol, Ethanol and Spent Engine Oil

Exhaust Gas sampling Method was used to determine the emission from a fuel blend of petrol, ethanol and spent oil having different samples mix ratio: O (98%: 0%: 2%) as control, and A (93%: 5%: 2%), B (91%: 7%: 2%) and C (89%: 09%: 2%) on a Suziiou engine model Ti987 two-stroke single cylinder SIE. The objective is to investigate the characteristics of the emission produced for running the engine on different loads, engine speeds and stoichiometric conditions. Sample O is taken as control with two types of engine oils – New engine oil and spent engine oil.

Fuel Stoichiometric Chemical Composition: the chemical composition based on stoichiometric combustion for various fuel blend samples A, B and C and that of the control mix (sample O) for new and spent engine oil are presented in Table 3, using Equations 1 to 8.

Table 3: Fuel blend samples stoichiometric composition

Fuel Blend Samples	Chemical composition formula
$Sample\ O$	$8.18CO_2 + 9.16H_2O\ +\ 47N_2$
$Sample\ A$	$7.94CO_2 + 8.72H_2O\ +\ 46.53N_2$
$Sample\ B$	$7.82CO_2 + 8.79H_2O\ +\ 45.82N_2$
$Sample\ C$	$7.7CO_2 + 8.68H_2O\ +\ 45.1N_2$
$New\ engine\ oil\ C_{17}H_{34}$	$C_{17}H_{34} + 25.5(O_2 + 3.76N_2) \rightarrow 17CO_2 + 17H_2O + 95.88N_2$
$Spent\ engine\ oil\ \ C_{20}H_{40}$	$C_{20}H_{40} + 30(O_2 + 3.76N_2) \rightarrow 20CO_2 + 20H_2O\ + 112.8N_2$

The composition formula shows that new engine oil emits less N_2 (95.88), CO_2 (17) and H_2O (17) content compared to spent engine oil with higher N_2 (112.8), CO_2 (20) and H_2O (20).

Further simplification of equation 1 gives details composition of each fuel mix and the rate at wish the blends saturates our environment with exhaust fumes (emission) of CO_2, H_2O and N_2, which are less with ethanol blended fuel samples A, B and C, when compared to the control fuel sample O of 100% Petrol and new or spent engine oil.

3.2 Emission Characterization based on Experimental Analysis

Results from the SV-5Q automobile exhaust gas analyser showing emission content for various fuel mix samples, which were mainly; hydrocarbon (HC), Carbon dioxide (CO_2) and Carbon monoxide(CO), Nitrogen oxides (NO_x) and Oxygen (O_2), are presented in Figures 2 to 7.

Figure 2 presents the quantity of emission by volume from the exhaust of the tested engine. The sample is a controlled one with 98% petrol and 2% new engine oil (5W 20) and 0% ethanol. Three compositions – CO_2, CO and O_2 are shown in percentage volume on the primary axis with blue colour indication while the remaining two – HC and NO_x are on the secondary axis with red colour indication.

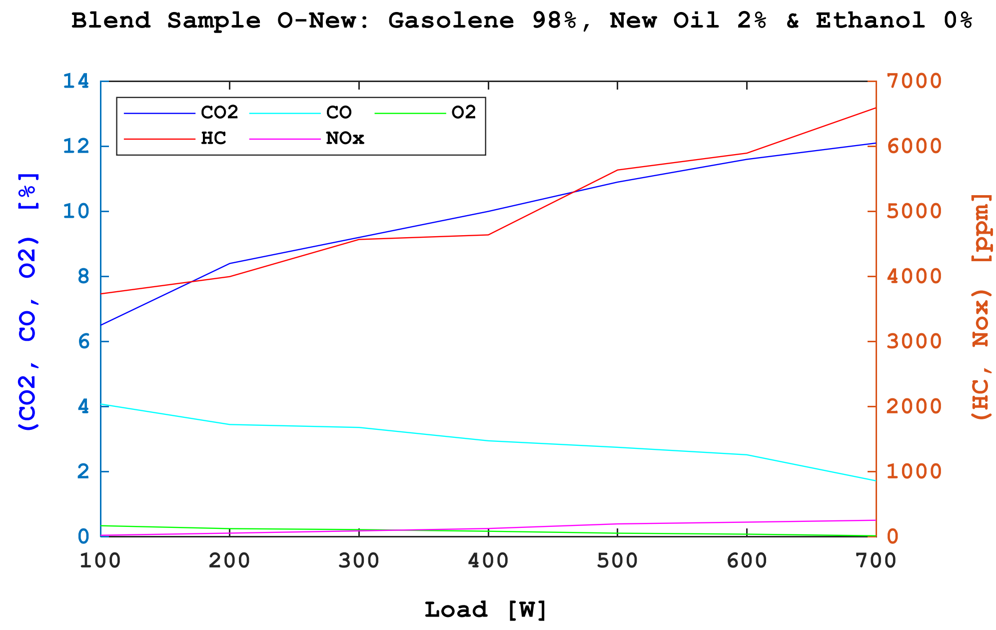

Figure 2: Exhaust gas emission at different loads from Sample O with New Engine Oil

From the primary axis in Figure 2, CO_2 increases with electrical load (load $100\ to\ 700\ W$) from about $6.4\ to$ 12.2% almost linearly, while CO reduces from $4.05\ to$ 1.8% almost linearly with O_2 though very small in volume, but reduces linearly from $0.4\ to$ 0.05%. On the secondary axis, HC increases from $3{,}600\ ppm\ to\ 6{,}650\ ppm$ representing $2050\ ppm$ across the load range. NO_x also increases from almost $23\ to\ about\ 250\ ppm$. This result compares with that of Jen-Hsiung et al., [13] and Maher et al., [22] which shows similar trend of emission from two-stroke spark ignition engines.

The graphs of Figure 3 are obtained from a blend of 98% petrol and 2% spent oil and 0% ethanol. Similar to the trend in the blend with new engine oil, the HC, CO_2 and NO_x all increases with increase in electrical load while CO and O_2 reduces with applied load. However, there is a shrink in CO_2 emission as it varies with load from 3.2% to about 9.5%, thus, there is lower rate of increase per unit load as compared to that from new engine oil. CO on the other hand, reduces from about 4.8% to 3.4%. These trends show that new engine oil is better than spent oil when mixed with petrol as more fuel blend will be combusted and produced more CO_2 and less CO and O_2. Since combustion is more complete with new engine oil, lesser HC is produced as shown in the graph increasing from $6{,}050\ ppm\ to\ 9800\ ppm$ representing $3{,}850\ ppm$ across the load range and approximately twice the emission from new engine oil blend.

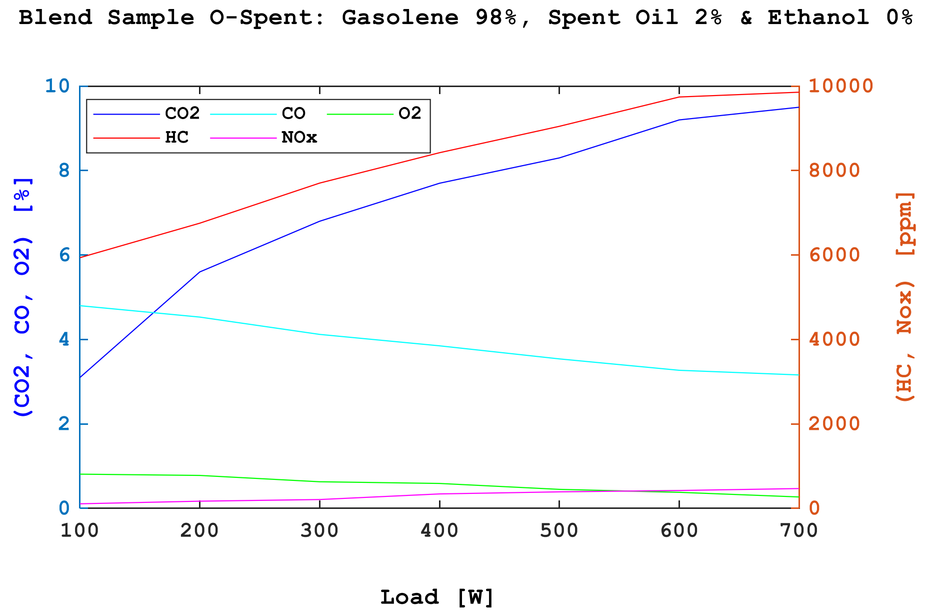

Figure 3: Exhaust gas emission at different loads from Sample O with Spent Engine Oil

The graphs of Figures 4 to 6 show the variation of emission constituents with electrical loads for fuel blends containing $5, 7\ and$ 9% ethanol respectively. The influence of ethanol in a mixture containing spent oil is being investigated in this case.

In this sample C, 5% ethanol is added to the mixture of 93% petrol and 2% spent oil. In the graph, CO_2, HC and NO_x increase with electrical loads while CO and O_2 reduces with the loads. However, the increase in CO_2 is from 6.8 to 12.2% while that of HC is from 2,400 to 4,800 ppm given an emission of 2,400 ppm across the load range. Thus, there is indication that the presence of ethanol makes the spent oil to become a bit potent than without ethanol. However, there is increase in the rate of NO_x emission most likely due to increase in temperature resulting from higher combustion rate.

Sample B has a blend containing petrol 91%, ethanol 7% and spent oil 2%, while Sample A has a blend containing petrol 89%, ethanol 9% and spent oil 2% as shown in Figures 5 and 6 respectively.

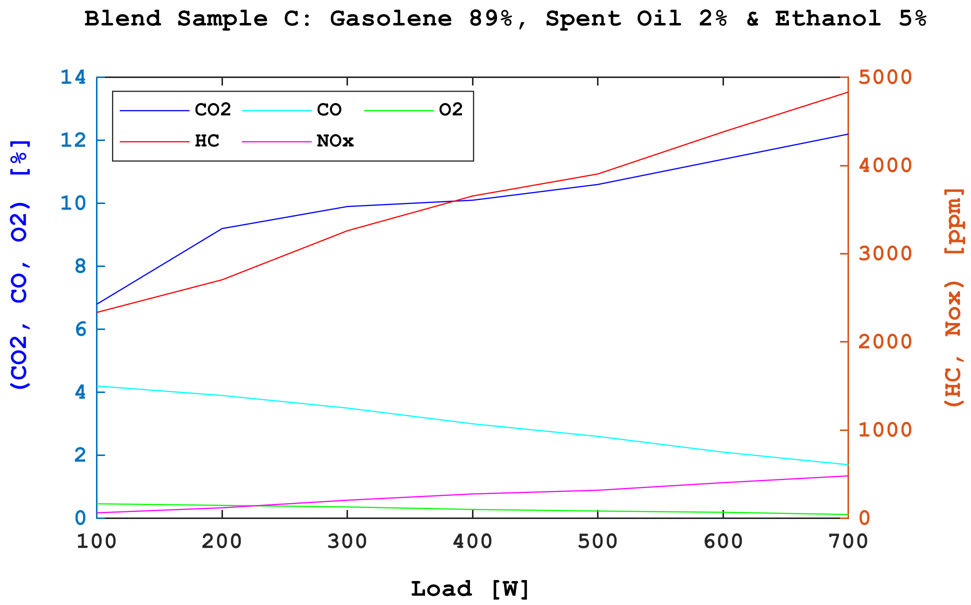

Figure 4: Exhaust gas emission at different loads from Sample C

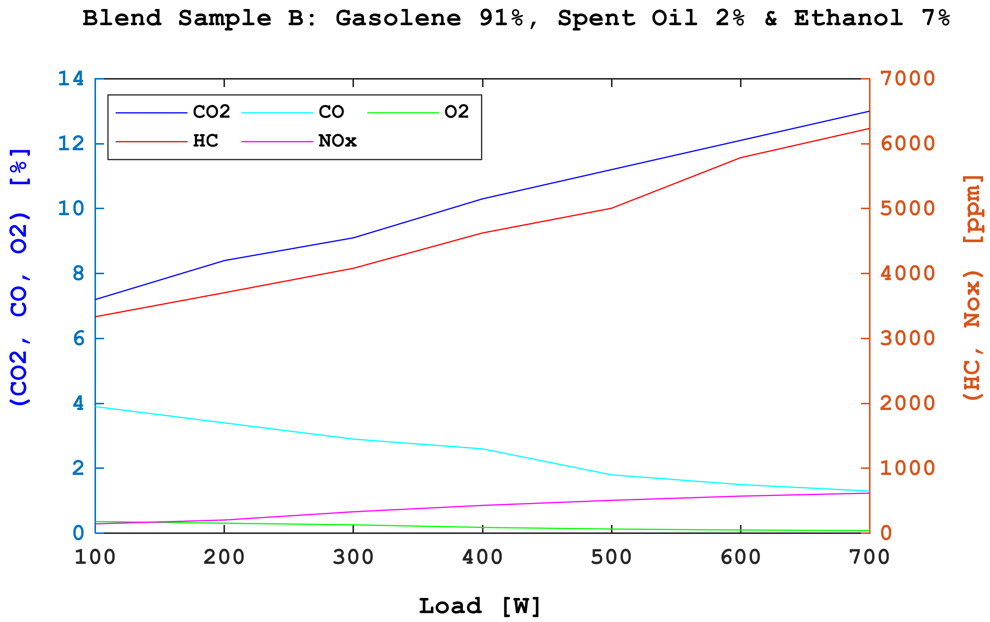

Figure 5: Exhaust gas emission at different loads from Sample B

The trend of emission of the constituent gases from 7% and 9% addition of ethanol follows the same profile as that of 5% addition. But, the production of NO_x increases enormously with increase in the quantity of ethanol while HC reduces with increase in ethanol.

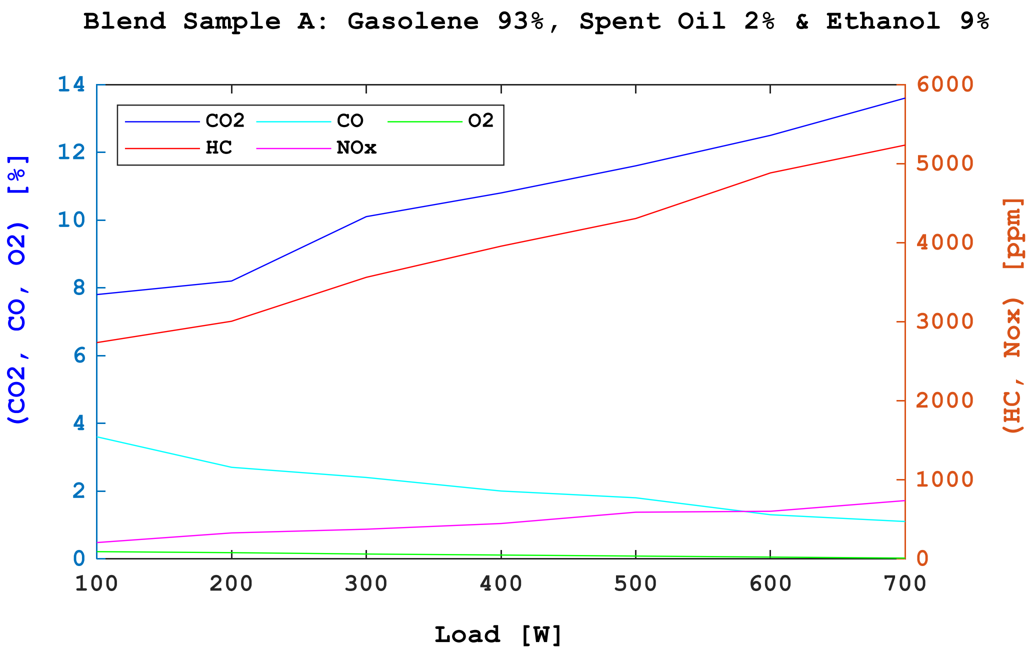

Figure 6: Exhaust gas emission at different loads from Sample A

3.3 Emissions of Immediate Concern

Figures 7 to 9 give the emission trends of CO, NO_x and HC which are of great concerns to human health and immediate environment. Emission for Sample O for new engine oil (98% petrol and 2% new engine oil), Sample O for Spent engine oil (98% petrol and 2% spent engine oil), Samples, A, B and C with 2% spent engine oil and $5, 7$ *and* 9% ethanol respectively.

1) Carbon monoxide (CO): CO is a harmful gas to the human body as it clogs haemoglobins blood cells, thus, reducing oxygen carrying capacity and resulting to inadequate delivery of oxygen to the body organs. It also increases the amount of green-house gases and thus, causes climate change and global warming. The greatest sources of CO are reported to be transport systems that utilize fusil fuels as source of energy.

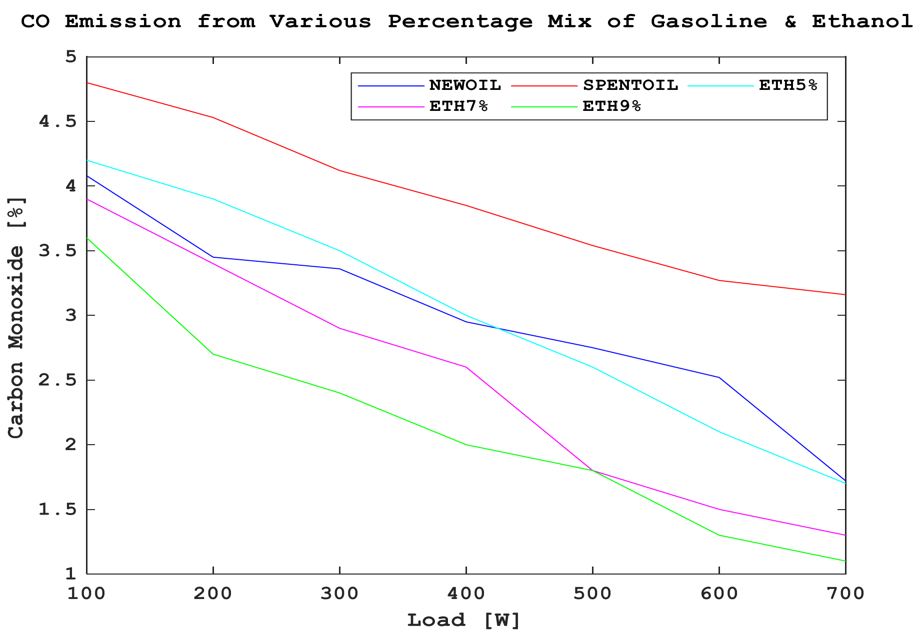

Figure 7: Carbon monoxide emission at different loads from all samples

From the results of Figure 7, the quantity of CO emitted from all the samples reduces as the load increases. This shows that with increase in load, more carbon dioxide is formed in the presence of large quantity of oxygen (air) and thus CO formed is lower. Thus, one way of reduces quantity of CO formed in the 2-stroke engine is to run the engine within a speed or load band that inhibits its formation. The mixture with the highest emission of CO is the spent oil blend followed by the blend with new engine oil, next is the one with 5% ethanol followed by 7% ethanol and finally the 9% ethanol blend. In all, the higher the quantity of ethanol in the blend, the less the amount of CO emitted. Conversely decrease in CO leads to a gradual increase in Carbon dioxide CO_2 as the engine load increases which indicates a lean air-fuel ratio of fuel burning slowly at lower maximum temperature than rich mixture based on the report of [15, 16]. This trend was evident in all fuel blend samples, with fuel sample O (with New oil) having the least CO_2 emission and fuel sample A having the highest values as engine load increases from $100 - 700$ W.

2) Oxides of Nitrogen ($\mathbf{NO_x}$): NO_x are commonly produced from natural sources, combustion of fuels in motor vehicles, gas stoves and wood heaters, at a very high temperature as a mixture of nitric oxide (NO) and nitrogen dioxide (NO_2). They are major constituents of photochemical smog that produces the yellowish-brown colour of the smog [20]. High level of nitrogen dioxides causes damage to human respiratory tracks increases severity of respiratory infection and asthma. It is also harmful to vegetation through foliage damage and thus resulting to stunted growth and power yield.

In Figure 8, the quantity of Nitrogen oxides in all the blend samples increases with increase in load with the highest quantity in the blend with 9% ethanol and the least quantity in the mixture with new engine oil. Since NO_x are produced at high temperature, the presence of new engine oil that lubricates the cylinder-piston contact helps to lower temperature generation and hence the reason for the blend with new engine oil producing the least quantity of NO_x. On the other hand, spent engine oil has lost its effective lubrication property due to high reduction in viscosity and hence produces higher temperature resulting to more production of NO_x, as shown in red in Figure 8. When ethanol are now being added to increase the combustion potency of the oil, extra increase in temperature of combustion takes the production of NO_x to a very high level as shown in 9 % Ethanol blend in green colour which varies from about 200 ppm to as high as 710 ppm. Air quality guidelines by EPP – 2019 placed a limit of 0.12 ppm on human exposure to NO_x in a confined environment for one-hour period and 0.03 ppm for an annual exposure period to protect sensitive individuals such as children and asthmatic patients. Typical outdoor exposure to NO_x is well above the 1-hour guide line [21].

The quantity of NO_x from two-stroke engines is thus, very high when spent engine oil is used to bled gasoline and the addition of ethanol is not an immediate solution as it tends to raise the rate of production of NO_x due to increase in temperature.

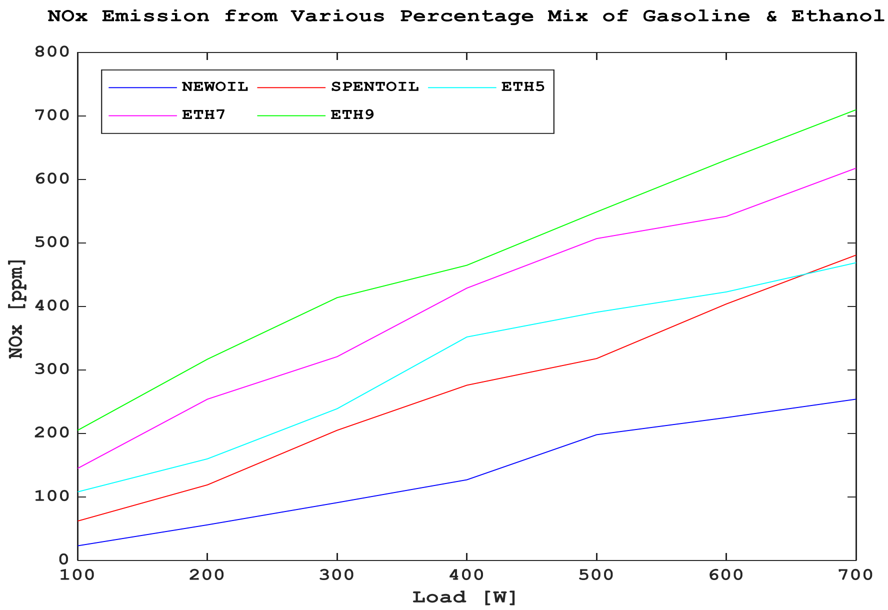

Figure 8: Nitrogen Oxides emission at different loads from all samples

3) Hydrocarbons (HC): HC are unburned oil released through the exhaust path in the form of hydrocarbons and particulate contamination (soot). It is reported by [21] that 17% of the total oil consumption is lost to evaporation through liner surface at around the temperature of 80 – 300℃ and 7% is lost during intake and compression stroke especially with spent oil. Fresh new lubricants have more volatile light-end molecules and are more prone to carbon emission. The service life of the oil has no significant on CO and NO_2 oxide emissions, but it does in the case of HC and particulate matter emission.

The hydrocarbon HC emission rate was lower with fuel blend with new oil (shown in blue) than the spent oil (shown in red) as seen in Figure 9. When Ethanol is added to the blend, lesser HC is produced and the emission reduces with increase in the quantity of ethanol. Since high HC emission indicates rich fuel-air ratio of an incomplete combustion due to insufficient air or excessive fuel supply. Though Jen-Hsiung [13], and Michel at el., [23] show that less engine power and increase in pollution of the atmosphere is associated with higher production of HC, but addition of ethanol indicates an opposite trend as higher external electrical power causes more HC to be produced at higher speeds. Sample A with reduced loads are more eco-friendly, and with increase in engine load more HC emission noted with fuel blend samples A, B and C which is likely due to the high carbon content in the spent engine oil.

The increase in HC emission is likely due to the presence of carbon in the spent engine oil, thus implies that properly process and treated spent engine oil will have less HC emission when mixed with ethanol.

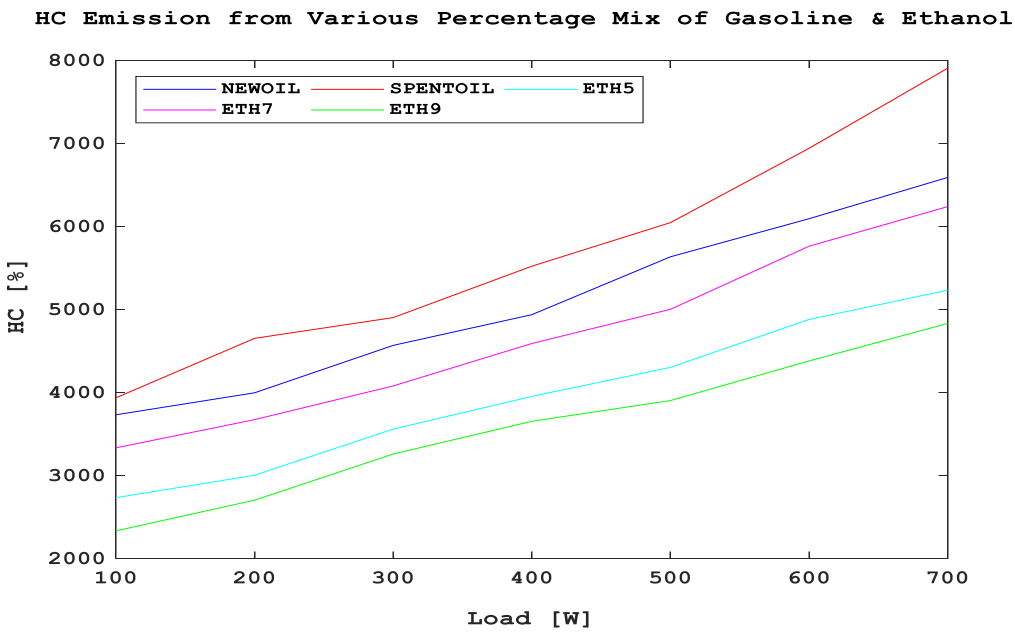

Figure 9: Hydrocarbon (HC) emission at different loads from all samples

4. CONCLUSION

Emission characterization from a Suziiou Ti987 two-stroke single cylinder spark ignition engine powered by fuel blend samples of petrol, new and spent engine oil shows that emission of CO and HC are more eco-friendly when blended with cassava-ethanol, however, due to higher temperature of combustion as the potency of the spent oil is increased, more NO_x are likely to be formed. When the quantity of air supplied and thus, oxygen is completely utilized that is, combustion is stoichiometric, the use of spent oil is advisable for high speed two-stroke engines with fines and other heat dissipation systems modified to handle high temperature, otherwise, operation control systems should be incorporated to restrict the limit of loss of viscosity for the oil to be changed. The presence of lower CO with fuel blend spent oil and ethanol as well as increase in the amount of CO_2 emitted with increase in engine load shows the presence of high carbons in the mixture. Hence the use of spent oil and ethanol as blends is on average beneficent to human and vegetation as reported in [11, 22]. However, two immediate limitations are required to be investigated. First the future emission characteristics as new engines with good emission can metamorphous to high exhaust discharge after long mileage hours of operations. Secondly, the introduction of ethanol increases the combustion rate; thus, the current heat dissipation mechanism has to be investigated to ensure there is no cumulative thermal stress that could weaken the engine systems.

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