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The effect of air-fuel ratio on tailpipe exhaust emission of motorcycles

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A R T I C L E I N F O

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A B S T R A C T

This article presents the actual AFR of the vehicular emission from the tailpipe data of motorcycles with petrol engine in Southwest Nigeria. It also presents the ratio between the actual air-fuel ratio (AFR_{actual}) and the ideal/stoichiometric air-fuel ratio (AFR_{ideal}) known as the equivalence air-fuel ratio or lambda (λ). This was compared with the expected value for lambda by the catalytic technology for exhaust gases emission, which is 1 (± 5%). In this study, over 95% of the sampled motorcycles have higher lambda values than expected, thereby emitting very high concentrations of carbon monoxide (CO), hydrocarbon (HC), and carbon dioxide (CO_2). The Portable, Hand-Held, battery-operated Kane automotive 4-gas analyser with detector tube (Model Auto 4-1) was used to measure the automobile emissions. The air-fuel ratio is a significant indicator and very important measure for gasoline engine performance controlling and tuning, and anti vehicles exhaust emissions pollution reasons [1]. Internal combustion (IC) gasoline fuelled engines exhaust gases emission depend heavily and mainly on the air-fuel ratio. For a gasoline fuelled engine, carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NOx) exhaust gases emission are significantly influenced by air-fuel ratio. CO and HC are majorly generated or produced with rich air–fuel mixture, while NOx with lean air-fuel mixtures which mean that there is no fixed air-fuel mixture for which it can obtain the minimum for all exhaust gases emission [2]. This study can help in reducing fuel consumption, improving the quality of fuel combustion and reducing vehicle exhaust emissions in Nigeria.

Introduction

In developing countries, motorcycles are the most essential and effective means of transport in daily life and overall livelihood due to the large population and high concentration of low-income groups [3]. Motorcycle transport is one of the most dangerous forms of motorised transportation. Motorcycle riders represent a vulnerable group of road users due to the small size of their vehicles [4]. Motorcyclists are about three times more likely than car occupants to be injured in an accident and 16 times more likely to die. Contrary to a car accident, motorcycle riders often absorb all kinetic and compressive energy resulting from the accident [5,6].

Motorcycles are popular in both metropolitan and suburban areas of southwestern Nigeria for all residents due to shuttle mobility and reasonable price when compared to passenger cars. The use of the motorcycle as a means of public transportation is a well known phenomenon across nations of the world, most especially in developing countries [4]. There are several reasons for their emergence as an acceptable means of both public and private transportation within Nigeria’s urban and city landscape. Some of which include the small physical size of motorcycles which allows residents to navigate heavily congested areas in a reasonably efficient manner [6], substantially lower purchase and maintenance costs than the corresponding costs for even small automobiles, and finally, most importantly, it provides easy employment opportunity for a number of unemployed youths as well as retirees and other quasi operators desirous of augmenting their regular source of income [7].

Motorcycles are almost permanent primary means of transport in developing countries, reflecting the economy’s poverty level. Presently, our environment is experiencing a general deterioration in air quality due to increase in the number of vehicles, overcrowding, and traffic congestion resulting from industrialisation. Automobiles which include motorcycles emit pollutants like carbon monoxide (CO), hydrocarbon (HC), carbon dioxide (CO_2) and oxides of nitrogen (NOx) into the air

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Table 1
Motorcycles pollutants and Lambda (λ) values.

Fuel	Use	CO (%)	CO_2 (%)	O_2 (%)	HC (ppm)	Lambda (λ)
Petrol	Commercial	1.480	3.500	15.500	559.000	2.881
Petrol	Commercial	0.640	3.500	16.450	571.000	3.487
Petrol	Commercial	0.140	2.100	18.490	589.000	5.997
Petrol	Commercial	1.780	2.400	16.800	603.000	3.658
Petrol	Private	1.110	4.000	15.140	607.000	2.854
Petrol	Commercial	3.320	4.300	13.170	621.000	1.924
Petrol	Commercial	0.350	1.800	18.950	642.000	6.222
Petrol	Commercial	0.980	1.200	18.850	645.000	5.911
Petrol	Commercial	0.310	0.900	19.420	647.000	7.341
Petrol	Commercial	2.470	5.000	12.480	649.000	1.933
Petrol	Commercial	1.360	1.700	17.230	674.000	4.214
Petrol	Commercial	3.380	3.100	14.270	674.000	2.178
Petrol	Commercial	0.320	3.200	16.280	677.000	2.834
Petrol	Commercial	1.670	2.800	16.300	678.000	3.044
Petrol	Commercial	1.400	4.200	14.580	686.000	2.544
Petrol	Commercial	0.940	2.600	17.260	689.000	3.871
Petrol	Private	2.910	3.400	12.200	694.000	1.312
Petrol	Commercial	0.420	1.600	18.450	697.000	6.191
Petrol	Commercial	1.600	3.800	15.460	700.000	2.693
Petrol	Commercial	0.880	3.400	15.760	705.000	2.710
Petrol	Commercial	0.860	0.900	19.120	706.000	0.783
Petrol	Commercial	0.220	3.900	16.330	712.000	3.445
Petrol	Private	0.340	4.300	15.250	745.000	3.005
Petrol	Commercial	2.390	5.000	12.430	749.000	1.924
Petrol	Commercial	0.690	4.500	15.160	750.000	2.868
Petrol	Commercial	1.640	3.800	15.040	772.000	2.614
Petrol	Commercial	0.880	1.300	18.410	773.000	5.651
Petrol	Commercial	0.590	2.700	17.820	783.000	4.173
Petrol	Commercial	1.770	2.000	16.340	785.000	4.002
Petrol	Commercial	2.710	4.200	13.440	786.000	2.045
Petrol	Commercial	0.070	1.300	19.590	790.000	8.265
Petrol	Commercial	2.660	4.100	13.080	806.000	2.03
Petrol	Commercial	0.690	2.700	17.420	806.000	3.961
Petrol	Commercial	2.690	3.900	13.930	808.000	2.149
Petrol	Commercial	2.600	3.800	13.860	815.000	2.164
Petrol	Commercial	2.510	4.400	13.350	832.000	2.047
Petrol	Commercial	0.880	0.600	19.470	837.000	7.478

Table 2
Motorcycles Pollutants and Lambda (λ) Values.

Fuel	Use	CO (%)	CO_2 (%)	O_2 (%)	HC (ppm)	Lambda (λ)
Petrol	Commercial	1.560	1.500	17.890	837.000	4.230
Petrol	Commercial	1.460	3.200	15.900	839.000	2.953
Petrol	Commercial	1.810	2.500	16.590	840.000	3.160
Petrol	Commercial	1.810	3.800	14.600	847.000	2.486
Petrol	Commercial	0.240	5.600	14.280	867.000	2.492
Petrol	Commercial	0.410	1.200	19.100	884.000	7.06
Petrol	Commercial	1.450	3.000	15.910	898.000	1.285
Petrol	Commercial	1.470	1.600	17.080	899.000	4.147
Petrol	Commercial	1.340	3.400	15.390	912.000	2.833
Petrol	Commercial	0.590	3.000	17.000	924.000	3.744
Petrol	Commercial	1.330	1.100	18.810	932.000	5.076
Petrol	Commercial	1.310	2.000	17.600	936.000	3.840
Petrol	Commercial	1.700	3.100	15.620	941.000	2.803
Petrol	Commercial	0.910	1.000	19.080	945.000	6.745
Petrol	Commercial	1.300	1.300	18.410	954.000	3.711
Petrol	Commercial	0.590	3.300	16.380	962.000	3.417
Petrol	Commercial	0.720	2.500	12.100	968.000	1.832
Petrol	Commercial	4.110	9.500	4.120	969.000	1.033
Petrol	Commercial	0.810	3.300	16.430	974.000	3.307
Petrol	Commercial	2.860	2.500	12.380	977.000	2.258
Petrol	Commercial	0.250	9.300	8.320	984.000	1.510
Petrol	Commercial	0.890	5.200	10.050	985.000	1.897
Petrol	Commercial	1.530	3.000	15.900	987.000	2.961
Petrol	Commercial	3.200	2.900	15.500	987.000	3.211
Petrol	Commercial	3.420	2.800	14.390	988.000	2.168
Petrol	Commercial	2.290	3.500	14.810	1002.000	2.388
Petrol	Commercial	0.980	3.000	16.500	1004.000	3.310
Petrol	Commercial	1.180	4.200	14.740	1015.000	2.543
Petrol	Commercial	2.820	5.100	12.360	1015.000	1.796
Petrol	Commercial	0.630	2.300	18.020	1017.000	4.354
Petrol	Commercial	1.130	1.000	18.610	1032.000	5.484
Petrol	Commercial	0.560	4.800	15.090	1054.000	2.630
Petrol	Commercial	3.050	3.300	13.740	1069.000	2.002
Petrol	Commercial	0.510	3.800	15.810	1085.000	3.087
Petrol	Commercial	1.430	1.000	18.550	1093.000	4.874
Petrol	Commercial	2.570	4.400	13.370	1097.000	1.996
Petrol	Commercial	1.580	3.300	15.520	1103.000	2.746

resulting in smog, acid rains, eye irritation, cardiac and respiratory disorders and other diseases, [8–10].

The huge number of motorcycles in developing countries makes challenges, such as safety, increasing fuel price and air pollution. Motorcycle engines usually operate at incomplete combustion status, and they have poorer emission control after-treatment technologies, motorcycles emit more pollutants per mileage travel relative to cars. In recent years, there has been an improvement in motorcycle engines, especially for the fuel injection system [11]. But it is still far away from satisfactory. To reduce the emission from motorcycles, optimisation of the combustion process and the exhaust after-treatment systems are assumed to be the key issues [12]. Lean burn is considered an effective means to improve the combustion process and reduce emissions of engines [13,14]. However, it is limited due to the narrow range of operating conditions and slower flame speed of gasoline, which results in combustion instability. CO emissions drop sharply when air/fuel mixture changes from rich to lean [15]. There is, therefore, a need to assess motorcycle emissions in southwestern Nigeria by measuring the tailpipe pollutants from motorcycles to determine the level of emissions released into the ambient air and to know the effect of air-fuel-ratio on exhaust emission from motorcycle.

Air-fuel ratio lambda (λ)

A motorcycle engine is an engine that powers a motorcycle. Motorcycle engines are usually two-stroke or four-stroke internal combustion engines. Exhaust emissions from internal combustion (IC) gasoline-fuelled engines contribute majorly to air pollution and global warming. An engine uses air, fuel, and spark to make power. To optimise the performance of the engine, there is a need for the right mixture of air and fuel. Fuel does not burn on its own, it has to be mixed with air. AFR tells how many parts of air is mixed with each part of fuel. For example, a 14.7:1 AFR (or just 14.7) means the mixture is 14.7 parts air to one part fuel. This is the stoichiometric ratio (Stoich) or ideal ratio for motorcycle with gasoline engine. When the AFR is ideal, the mixture burns completely during combustion. AFR is the air mass to fuel mass ratio present in gasoline fuel combustion process, such as in the internal combustion engine. The AFR is a significant measure for controlling the performance of the engine. The ratio between the actual air-fuel ratio (AFRactual) and the ideal/stoichiometric air-fuel ratio (AFRideal) is called equivalence air-fuel ratio or lambda (λ). AFR numbers lower than stoichiometric are considered rich mixtures. AFR numbers higher than stoichiometric are called lean mixtures. A Lambda value lower than 1 is known as a rich mixture [16]. A lambda value higher than 1 is a lean mixture. When more air (oxygen) is present than necessary to combust the fuel, it results into leftover oxygen, and it is called a lean mixture. When more fuel is present than necessary for combustion resulting in unburned fuel, it is called a rich mixture. In the rich mixture, an amount of fuel will be left over after the combustion which increases the power of the vehicle, reduces the fuel economy, increases the emissions of carbon monoxide and hydrocarbon in the air, and leads to overheating of the catalytic converter. An overheated catalytic converter is often the result of excess hydrocarbon in the exhaust stream. Unburnt fuel enters the catalytic converter burning, creating intense heat, this melts the honeycomb substrate, restricting exhaust flow. The most likely cause for the damage of catalytic converter substrate is excess unburnt fuel in the exhaust. In the lean mixture, redundant oxygen is left, causing an increase in the fuel efficiency and nitrogen oxide emissions. Also, the

Table 3
Motorcycles Pollutants and Lambda (λ) Values.

Fuel	Use	CO (%)	CO_2 (%)	O_2 (%)	HC (ppm)	Lambda (λ)
Petrol	Commercial	2.170	2.600	16.190	1105.000	2.789
Petrol	Commercial	1.310	4.200	14.550	1107.000	2.472
Petrol	Commercial	3.200	2.500	15.150	1131.000	2.332
Petrol	Commercial	3.750	3.200	13.560	1135.000	1.126
Petrol	Commercial	2.310	3.500	15.010	1138.000	2.359
Petrol	Commercial	1.380	5.000	14.410	1150.000	2.259
Petrol	Commercial	2.160	2.700	16.050	1153.000	2.755
Petrol	Commercial	2.190	4.500	14.030	1160.000	2.124
Petrol	Commercial	2.770	3.500	13.160	1176.000	2.039
Petrol	Commercial	1.420	2.300	17.740	1181.000	3.561
Petrol	Commercial	1.970	2.300	13.960	1187.000	2.954
Petrol	Commercial	2.960	2.900	11.910	1188.000	1.955
Petrol	Commercial	2.260	0.700	14.840	1194.000	3.326
Petrol	Commercial	2.520	3.800	13.840	1218.000	2.113
Petrol	Commercial	3.910	12.220	3.900	1232.000	1.726
Petrol	Commercial	2.060	3.400	16.890	1236.000	2.331
Petrol	Commercial	2.070	3.100	15.510	1248.000	2.555
Petrol	Commercial	1.570	4.100	15.140	1251.000	2.436
Petrol	Commercial	1.530	1.900	16.990	1292.000	3.528
Petrol	Commercial	1.540	1.000	18.240	1315.000	4.412
Petrol	Commercial	1.940	3.400	13.220	1321.000	1.231
Petrol	Commercial	3.280	3.600	15.580	1348.000	2.120
Petrol	Commercial	1.800	3.600	14.920	1379.000	2.431
Petrol	Commercial	2.780	3.200	14.910	1382.000	2.240
Petrol	Commercial	1.210	2.600	16.910	1385.000	3.260
Petrol	Commercial	3.230	3.300	14.010	1402.000	2.025
Petrol	Commercial	1.540	3.400	15.650	1410.000	2.698
Petrol	Commercial	1.050	1.050	19.020	1414.000	5.170
Petrol	Commercial	0.080	3.200	14.370	1419.000	1.396
Petrol	Commercial	2.310	3.700	14.230	1420.000	2.187
Petrol	Commercial	1.940	1.900	16.620	1423.000	3.140
Petrol	Commercial	1.470	2.200	16.940	1427.000	3.386
Petrol	Commercial	1.510	2.100	17.410	1431.000	3.415
Petrol	Commercial	1.140	4.000	15.670	1436.000	6.216
Petrol	Commercial	0.660	1.000	19.190	1450.000	6.028
Petrol	Commercial	1.850	3.500	14.690	1453.000	2.393

engine is damaged and its performance is reduced.

Methodology

The exhaust emission tests were carried out in Abeokuta. The Portable, Hand-Held, battery-operated Kane automotive 4-gas analyser with detector tube (Model Auto 4-1) was used to measure the automobile emissions. The machine was capable of measuring CO (a resolution of 0.01% with accuracy of ± 0.5% volume), HC (a range of 1.0 ppm), CO_2 (a resolution of 0.1% with accuracy of ± 0.5% volume) and O_2 (a resolution of 0.1% with accuracy of ± 0.5% volume). The Kane Automotive 4-Gas analyser Auto 4-1 model was designed for petrol, LPG, and CNG powered engines. All measured and calculated parameters can be printed on the optional infrared printer or saved to the analyser's memory. The analyser was switched on to initialise to display zero setting fully, then the main menu was accessed and fuel type selected (diesel, petrol, CNG, and LPG). Then the analyser was set within the allowable range (especially oxygen, which should be between 20.9% and 21%). The exhaust was observed for a while to ensure that the smoke was steady, then the analyser's probe was completely inserted into the exhaust pipe and clamped. During the analysis, CO was recorded at the maximum level. Emissions concentrations were reported in parts per million (ppm) or percent (%) where 1% = 10,000 ppm). Raw exhaust samples were taken from each motorcycle.

Results

Pollutants from motorcycles (CO, CO_2 O_2, and HC) using petrol engine, use, air-fuel ratios and lambda values (AFR_{actual}/AFR_{ideal}) is shown in Tables 1–4.

Table 4
Motorcycles Pollutants and Lambda (λ) Values.

Fuel	Use	CO (%)	CO_2 (%)	O_2 (%)	HC (ppm)	Lambda (λ)
Petrol	Commercial	1.680	2.400	16.560	1456.000	3.031
Petrol	Commercial	3.100	3.000	14.310	1460.000	2.104
Petrol	Commercial	2.630	3.500	14.000	1469.000	2.114
Petrol	Commercial	2.880	2.800	14.670	1475.000	2.231
Petrol	Commercial	3.980	3.900	12.650	1481.000	1.701
Petrol	Commercial	2.920	2.700	15.270	1527.000	2.306
Petrol	Commercial	1.770	1.300	17.540	1554.000	3.685
Petrol	Commercial	2.610	3.400	14.970	1584.000	2.195
Petrol	Commercial	0.940	1.200	18.700	1609.000	4.785
Petrol	Commercial	1.790	1.600	17.370	1621.000	3.375
Petrol	Commercial	2.110	2.900	15.250	1740.000	2.434
Petrol	Commercial	2.760	3.100	14.210	1742.000	2.107
Petrol	Commercial	3.560	2.900	13.540	1773.000	1.907
Petrol	Commercial	3.260	2.600	14.480	1808.000	2.092
Petrol	Commercial	2.950	2.500	14.820	1834.000	2.203
Petrol	Commercial	2.590	2.900	15.200	1837.000	2.282
Petrol	Commercial	2.050	2.400	16.210	1891.000	2.717
Petrol	Commercial	1.950	1.300	17.580	1920.000	3.354
Petrol	Commercial	1.600	1.800	16.800	1932.000	3.321
Petrol	Commercial	2.270	3.400	13.910	1993.000	2.107
Petrol	Commercial	4.630	3.700	12.650	1994.000	1.571
Petrol	Commercial	2.790	2.800	14.800	2055.000	2.145
Petrol	Commercial	4.030	3.600	13.340	2063.000	1.696
Petrol	Commercial	4.310	2.600	13.690	2082.000	1.773
Petrol	Commercial	4.030	0.600	13.580	2088.000	2.026
Petrol	Commercial	2.220	2.600	15.610	2134.000	2.436
Petrol	Commercial	2.130	3.300	13.520	2207.000	1.706
Petrol	Commercial	3.970	2.700	14.200	2289.000	1.842
Petrol	Commercial	3.110	2.800	14.610	2306.000	2.023
Petrol	Commercial	1.850	1.500	17.750	2344.000	3.164
Petrol	Commercial	1.140	1.000	19.560	2378.000	4.360
Petrol	Commercial	3.480	2.500	14.780	2492.000	1.962
Petrol	Commercial	2.440	2.300	15.870	2514.000	2.376
Petrol	Commercial	2.370	2.700	15.490	2532.000	2.266
Petrol	Commercial	2.260	2.200	15.630	2545.000	2.401

Table 5
Nomenclature.

Symbol	Meaning
AFR	Air-fuel ratio
AFR_{actual}	Actual air-fuel ratio
AFR_{ideal}	Ideal/stoichiometric air-fuel ratio
Λ	Lambda
CO	Carbon monoxide
CO_2	Carbon dioxide
VOC	Volatile organic compound
HC	Hydrocarbon
O_2	Oxygen
IC	Internal combustion
NOx	Nitrogen oxides
LPG	Liquified petroleum gas
CNG	Compressed Natural Gas
Ppm	Parts per million

Discussion of results

It was observed from the result that over 95% of the equivalence air-fuel ratio or lambda (λ) of the sampled motorcycles was more than the expected value when compared with the standard value for lambda by the catalytic technology for exhaust gas emission, which is 1 (± 5%). This has resulted into the emission of very high concentrations of carbon monoxide (CO), hydrocarbon (HC), and carbon dioxide (CO_2), much more than the concentration of these pollutants in motorcars. This can be attributed to the absence of major emission control devices present in motor cars due to the small sizes of motorcycles and their two stroke engines. They are generally louder, less efficient, and far more polluting than their four-stroke counterparts, they are a major source of air pollution. It was also observed from the result that most of the sampled motorcycles were used for commercial purposes. The regular maintenance of a motorcycle is needed to reduce exhaust emission. Poorly maintained motorcycles consume more fuel and emit higher levels of CO and VOC than those that are regularly serviced. Routine services of motorcycles is a luxury to many commercial riders. Most of the commercial riders use road-side and substandard engine oils to lubricate their engines in addition to postponing vehicle maintenance in order to maximise profits as it is usually observed in vehicular breakdown and accidents on the roads in developing countries.

Conclusion

The actual air-fuel ratio was higher than the ideal air to fuel ratio in most of the data obtained from the motorcycle emission analysis, therefore lambda (λ) values were greater than 1. This indicates that most of these motorcycles were operating with rich mixtures, because the fuel used in the combustion process was more than the required and it altered the expected air-fuel ratio. This study therefore concludes that an alteration in the air-fuel ratio in the combustion process of motorcycles will lead to high concentrations emission of environmental pollutants like CO, CO_2, HC, and VOC which have negative effects on human health, plants and animals.

For future work, there is a need for the introduction of engine management systems that can deliver a very accurate engine fuelling to further control the emission from both 2-stroke and 4-stroke motorcycle engines [17,18].

Declaration of Competing Interest

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