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ADOPTION OF COMPRESSED NATURAL GAS AS ALTERNATIVE AUTOMOTIVE FUEL IN NIGERIA: A REVIEW OF ITS MERIT, DEMERITS AND SUSTAINABILITY

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ABSTRACT

The use of natural gas in transport as an alternative automotive fuel is becoming attractive in Nigeria, which has significant gas reserves. The benefits of this source of energy are both pocket-friendly and climate-friendly. In view of the considerable potential natural gas offers to reduce emissions challenges associated with petrol-fuelled vehicles, this article discusses the emissions from compressed natural gas-fuelled vehicles and how they differ from petrol-fuelled vehicles; comparisons are made with petrol-fuelled engines, where significant experience has been accumulated over several decades. It further highlights the significant merits and demerits of using compressed natural gas as automotive fuel and summarizes the recent adoption of compressed natural gas in some parts of the country.

Keyword: *Alternative Fuel, Natural Gas, Compressed Natural Gas, Emission*

INTRODUCTION

The current emission control standards place a high demand on the need for alternative fuel for vehicles to achieve a greener environment [1]. The burning of fossil fuels contributes significantly to global warming as it releases about 35 million metric tons of carbon dioxide annually [2]. This huge amount of carbon dioxide, together with other harmful gases such as nitrogen oxides and sulphur released into the atmosphere on a constant basis, affects our environment adversely [1, 2]. This energy from fossil fuels is used to generate electricity to power major industrial activities, while petrol, diesel, and compressed natural gas (CNG) are widely used as fuels for running vehicles that help transportation [3]. The introduction and use of clean fuels such as methanol, ethanol, natural gas, propane, reformulated gasoline, and clean diesel as alternative vehicular fuels are thereby encouraged [1]. In a country with abundant natural gas and a

concomitant inability to own and manage a refinery, it will benefit tremendously from adopting the use of natural gas to power vehicles. Similarly, moving to CNG would reduce reliance on imported oil and improve the country's internal reserves [4]. Natural gas is more widely distributed than oil and derives from fossil fuels; it consists mostly of methane, which is one of the cleanest burning fuels. Methane is the chief component of compressed natural gas (CNG), which is produced by compressing the natural gas to less than one percent of the volume it occupies at standard atmospheric pressure [4, 5].

The combustion of methane produces few carbon deposits compared to other forms of fuel sources, and hence it is a preferable substitute for petrol, diesel fuel, and liquefied petroleum gas for both transportation and power generation. [4, 5]. Natural gas in compressed form (CNG) can be used for passengers' cars or city buses and can also be used as fuel for heavy-duty truck in the form of liquefied natural gas (LNG). [6]. CNG is usually stored under high pressure in either a cylindrical or spherical container for transportation or storage for later use as a vehicular fuel [4, 5, 6]. In 2010, Nigeria joined its other counterpart countries to launch its first compressed natural gas (CNG) for vehicular and other applications. [7]. Table 1 represents the comparison between the physiochemical properties of CNG and those of diesel and gasoline.

Table 1: Physiochemical properties of CNG versus Petrol and Diesel

Properties	CNG	Petrol	Diesel
Octane/cetane number	120–130	85–95	45-55
Molar mass (kg/mol)	17.3	109	204
Stoichemetric (A/F)s mass	17.2	14.7	14.6
Stoichemetric mixture density (kg/m3)	1.25	1.42	1.46
L.H.V. (MJ/kg)	47.5	43.5	42.7
L.H.V. of stoichemetric mixture (MJ/kg)	2.62	2.85	2.75
Combustion Energy (MJ/m3	24.6	42.7	36
Flammability limit in air (vol% in air)	4.3–15.2	1.4–7.6	1–6
Flame propagation speed (m/s	0.41	0.5	–
Adiabatic Flame Temp. (1C)	1890	2150	2054
Auto-ignition Temp. (1C)	540	258	316
Wobbe Index (MJ/m3)	51–58	—	–

Source: (Khan et al., 2015)

The conversion mechanism of petrol engine to CNG engine

Compressed natural gas can be used in most light, medium, or heavy-duty applications. Natural gas vehicles function very similarly to gasoline-powered vehicles with spark-ignited engines [4, 8]. CNG-powered engines occur in three main forms: dedicated natural gas vehicles, bi-fuel vehicles, and dual-fuel vehicles. Dedicated natural gas vehicles run exclusively on natural gas, while bi-fuel vehicles can run on either natural gas or a conventional fuel such as petrol or diesel; this dual fuel function is enabled by having two separate fueling systems [4, 9]. In contrast, dual-fuel vehicles can either run on a mixture of natural gas and diesel (maximum of 90% natural gas) with diesel injected near the top of the compression stoke as an ignition source or can solely operate on 100% diesel [4, 10]. An existing petrol vehicle can be readily converted to a dual-fuel petrol/CNG vehicle through installation of CNG cylinder, plumbing, a CNG injection system and electronics into the petrol-powered vehicle by certified CNG installation technicians [11, 12]. The CNG fuel system transfers high-pressure gas from the fuel tank through the fuel lines, where a pressure regulator reduces the pressure to a level compatible with the engine fuel injection system [4, 13]. The use of CNG as a vehicle fuel costs about 50% less than petrol, and emits fewer emissions in comparison with petrol [14]. In general, dedicated CNG vehicles demonstrate better efficiency, enhanced performance and lower emission rate than bi-fuel vehicles because the engines are better adapted for CNG fuel; hence, developing vehicles that run on it would be more efficient than converting existing model [4, 11, 14].

Performance and Emission Characteristics of CNG

Dedicated CNG engines have a high-octane value, which allows them to use a higher compression ratio to enhance their thermal efficiency, which is about 10 times that of petrol engines [15]. Its light weight characteristic gave CNG the capacity to produce a much more homogenous air-fuel mixture [16]. Conversely, liquid fuel takes a longer time for complete atomization and vaporization to form a homogeneous air-fuel mixture [17]. CNG also demonstrates its inherent advantage of a high level of miscibility and diffusion with gaseous air because of its gaseous property at normal atmospheric conditions, which promotes good combustion [18]. Additionally, the useful life of lubricant is enhanced by CNG, as it does not contaminate or dilute engine oil [4]. Apart from this, the lead fouling of the plugs is eliminated due to absence of lead or benzene content in CNG, resulting in lower operation and maintenance costs

compared to petrol-fuelled vehicles [4, 19]. Coupled with its ease of use, flexibility, and sealed fuel system, the basic engine characteristics of the vehicle are retained; spillage and evaporation of the fuel are minimized while running on CNG [20].

However, there has been a growing concern about the negative impact of carbon dioxide (CO2), carbon monoxide (CO), nitrogen oxide (NO), and particulate matter generated by the transportation system on global climate change [4]. The amount of C02 and CO emitted during combustion largely depends on the hydrogen-to-carbon ratio; the higher the hydrogen-to-carbon ratio (H/C) of a fuel, the lower the amount of carbon released into the atmosphere. CNG exhibits the highest hydrogen-to-carbon ratio (H/C) of almost 4:1 compared to either petrol (2.3:1) or diesel fuel (1.95:1) [4, 21], hence emitting less carbon dioxide (CO2) and carbon monoxide (CO) into the atmosphere. Moreover, there is reduced dissociation of CO2 to CO resulting from the low heating value and low flame propagation speed of CNG compared to other fuels; hence, the CO emission of the CNG engine is significantly lower than that of the petrol and diesel vehicles at various load conditions [17]. CNG, though a fossil fuel, is the cleanest burning fuel in terms of NO and soot (PM) emissions [22], hence CNG-powered vehicles emit fewer pollutants into the air when combusted (e.g., unburned hydrocarbons (UHC), carbon monoxide (CO), nitrogen oxides (NO), sulphur oxides (SO) and particulate matter) (Table 2). For every unit of energy consumed, CNG-powered vehicles emit about 5–10% less carbon dioxide when compared to petrol, thereby reducing greenhouse gas emissions.

Table 2: Emission of CO, NO, and PM10 by passenger cars

Fuel	CO_2 [g/km]	NO [g/km]	PM_{10} [g/km]
Gasoline	165	0.076	0
Diesel	139	0.237	0.003
CNG	144	0.009	0

(Source: TNO, 2009, cited in https://www.ctc-n.org)

[24] CNG demonstrates some physical properties that make it environmentally friendly to use as an alternative vehicle fuel. The inherent physical properties that offer it this uniqueness include, but are

not limited to, a low flammability range, a high auto ignition temperature, and ease of dispersion. It has a high auto ignition property of 540 1C compared to 258 1C of petrol and 316 1C of diesel [4] which makes it less inflammable. The auto-ignition temperature is the lowest temperature at which a fuel will ignite due to the heat only, without any external spark or flame [4]. It is light weight afford it the ease of dispersion in case of accidental leakage. CNG density is less than air at atmospheric pressure with the density of CNG [0.68 kg/ m3] compared to air, [1.202 kg/m3]. This reduces the probability of fire outbreak if the tank is breached [4]. The cylinder for storage is well fabricated with safety mechanism in mind to resist the high pressure, with a safety factor which is usually greater than two [25]. CNG is equitably well distributed and an affordable source of energy subject to less fluctuation in price [26]. The price advantage of natural gas over diesel and petrol has made it to be favourably disposed to attract consumer to switch their vehicle from conventional fuel to CNG [27, 28].

Conversely, there are barriers to adaptation of CNG; CNG powered vehicles have a drive-range of about 50% shorter than petrol- or diesel-powered vehicles due to its low energy density [4, 29] limiting its use to passenger cars and city buses. Low energy density couple with its low volumetric efficiency results in low engine performance. CNG takes up more space for each petrol gallon equivalent and hence required a greater amount of space for fuel storage [4, 22 29]. Besides, methane is the primary component of CNG, paradoxically, the leakage of unburned methane posed a significant threat towards climatic change; it is 100 times more potent at trapping energy than carbon dioxide, a principal contributor to greenhouse effect [30].

When diesel powered passenger cars are replaced by natural gas-powered passenger cars, the reduction in NO emission is substantial, about 96%, in contrast, no tailpipe CO2 emission reduction can be expected when a diesel-powered car is replaced by a natural gas-powered car [22]. Heavy duty engine vehicles emit large amount of NO and considerable amount of soot resulting in significant environmental pollution of public health importance, especially when not equipped with particulate matter filters. Similarly, not all technologies employed in CNG buses contribute to local air quality. Lean burn CNG busses, which have CO2 emissions similar to diesel busses, also have similar NO emissions. However, CNG busses employing stoichiometric combustion (one to one oxygen/fuel ratio) have

a 60% lower NO emission than diesel busses, but stoichiometric CNG buses have about 22% higher tailpipe CO2 emissions (Table 3) [22, 31].

Table 3: Emission of CO_2, NO and PM10 by busses

Technology	CO_2 [g/km]	NO [g/km]	PM_{10} [g/km]
Diesel bus	864 - 1076	3.4 – 4.6	~0.3 (< 0.03*)
Lean burn CNG bus		4.1 – 4.5	< 0.03
Stoichiometric CNG bus	1040 – 1440	1.2 – 2.2	< 0.03

Source: (Kadijk, 2008)

While the energy efficiency of a diesel-powered car is about 15% higher than that of gasoline and natural gas-powered cars, the overall well-to-wheel CO2 emission reduction of natural gas compared to diesel is still about 12% [32].

Adoption of CNG and its Sustainability

CNG-powered vehicles cost more than petrol- or diesel-powered vehicles, whether factory-made or converted [4, 22]. This is largely due to the greater expense of high-pressure fuel tanks, which are necessary to store CNG onboard the vehicle [4]. However, CNG fuel is significantly less expensive than petrol in Nigeria. Meanwhile, maintenance requirements for CNG vehicles are different from those for gas and diesel, costing less for some things and more for others; the differences in cost of routine maintenance are similar [4 22] . With respect to fuel and infrastructure availability, the Nigerian independent petroleum company [NIPCO] launched its first compressed natural gas [CNG] in Benin City in 2010. Since then, the operation base has expanded to include 15 CNG running stations in Benin to provide an alternative for gasoline-run automobiles [20] More than 5,600 vehicles were reported to have been converted to CNG for motorists in and around Benin City through the initiative of the Federal Government with the aim of converting automobiles to CNG as well as to supply nearby industries [20].

However, in most countries in the world where CNG is being used, its introduction is hampered by a lack of refuelling infrastructure and inadequate national coverage. Similarly, the Nigeria scenario may not be any different, as most of the refuelling stations for petrol are owned by

private firms. Publicly owned CNG dispensers will reduce costs as fleet companies do not need to install and maintain their own dispensing equipment. The initial investment costs for a CNG refuelling station are significantly higher than those for petrol and vary based on the amount of fuel to be dispensed, the type of dispensing mechanism to be adopted, the amount of compression required, storage needs, and other factors [33]. Hence, there is a likelihood of a low rate of penetration of CNG refuelling stations [22, 34].

Furthermore, CNG as an alternative fuel poses its own negative environmental impact. While it is a fact that CNG is a clean gas with reduced carbon emissions compared to petrol, there is also the fear of damage to the ecosystem during land clearing for drilling and extraction of natural gas [4, 22], as drilling and extraction of natural gas (frecking) leads to large leakages of methane, thereby contributing to greenhouse effect [30, 35].

CONCLUSION

In conclusion, while adopting this as an interim measure to stabilize the economy and reduce the pain and agony of the populace, it must be kept in mind that natural gas is a non-renewable source of energy [22], hence it is not sustainable in the long term. There is therefore a need to work towards a more sustainable form of energy as an alternative automotive fuel.

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