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Research article

# Evaluation of emission indices and air quality implications of liquefied petroleum gas burners

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ABSTRACT

Major cities in Nigeria has adopted the use of liquefied petroleum gas (LPG) as their main source for domestic cooking, however, this adoption led to different designs of LPG burners in Nigeria market. The emission indices of these burners and their air quality implications are yet to be ascertain. To solve these problems and fill the data gap, laboratory analysis were carried out on 16 conventional LPG burner heads identified in Nigeria market. The emission factors for Carbon monoxide (CO), Oxide of Nitrogen (NOx), Carbon dioxide ($CO_2$), Hydrocarbons (HC) and sulphur dioxide ($SO_2$) on the basis of useful energy delivered were 0.123–21.784 $g/MJ_d$, 1.973–32.943 $g/MJ_d$, 73.819–147.639 $g/MJ_d$, 4.069–171.643 $g/MJ_d$ and 0–0.1644 $g/MJ_d$ while the emission rates were 0.000238–0.1125 g/s, 0.0071–0.2 g/s, 0.1083–0.7 g/s, 0.0117–1.2583 g/s and 0–0.000194 g/s respectively. It was observed that results from the study were within the International Organization for Standardization, International Workshop Agreement 11 and World Health Organization indoor air quality guidelines for human protection.

## 1. Introduction

Liquefied Petroleum Gas (LPG) plays an important role in permitting those households currently exposed to high concentrations of household air pollution to benefit from reliable and efficient clean household energy benefits that about 60% of the world's populations are already enjoying on a daily basis (Isihak et al., 2012).

Quantifying and characterization of gaseous emissions from combustion sources is very vital for many reasons which includes; compliance of source emission with regulations and available set standards, generation of inventories of emissions at various level of government, developing appropriate emission management and abatement strategies as regards its air quality, ambient air quality prediction in the affected source areas and also assesses the effect of exposure on human and the environment (Mitra et al., 2002).

Emission factor has variety of units. Emission factors based on useful cooking energy ($MJ_d$) enabled comparisons among all cook stove and fuel combinations (Mutlu et al., 2016). There are two main important metrics for evaluating fuel and stove combinations from an air pollution standpoint. The unit $g/MJ_d$ gives useful information on heat transfer characteristics during development of stove in the laboratory testing and seeks to normalize emissions by energy delivered. While from an atmospheric standpoint the unit g/kg gives useful information that can be combined with surveys on fuel usage in other to evaluate the overall mass of pollutants entering the atmosphere from household fuel combustion (WHO, 2014). The emission factor is useful in predictions of indoor concentration of air pollutants and source modification for mitigating indoor air pollution (Chen et al., 2007). The hood-method is best for determination of emission factors under laboratory conditions while the mass-balance method is found to be convenient under field conditions (Shen et al., 2013).

Emission rate is an important part of emission indices that assesses the quality of air in a given circumstances. It gives adequate information on potential health risks and emission rate target (Shen et al., 2018). Emission rate is the amount of air pollutant emitted per unit time and thus should have a unit such as g/s or g/min. Emission rate is also regarded as source strength (Zhang and Morawska, 2002).

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Air quality is an indicator of environmental sustainability, healthy living and social well-being. Health implications due to poor quality of air are complex which involves both short and long term effect based on the level of exposure to the air pollutants (Bruce et al., 2015). The effects of $SO_2$ are well evidenced on environment and human health (Chen et al., 2007). Health effects of $SO_2$ exposure are responsible for respiratory illness and exacerbation of existing cardiovascular and pulmonary diseases in children and adults. Low levels of nitrogen oxides in ambient air produce irritation of the eyes, nose, throat, and lungs. It also causes shortness of breath, tiredness, and nausea (USEPA, 2015).

International and national efforts are directed to usage of clean fuels for cooking to reduce indoor air pollution, improve air quality and protect human health. Increase in adoption of liquefied petroleum gas for cooking in Nigeria has resulted in importation of different design of burner heads used in LPG cook stoves in the country. However, the emission indices and indoor air quality implications of these burners are not available. In this study, work is restricted to identification of single and double burners available in Nigerian market and the development of air emission factors for Nigerian domestic cooking liquefied petroleum gas burner. The gaseous air pollutants from the combustion of LPG were captured using the Hood method with E8500 plus combustion analyzer. The results obtained were compared with International Organization for Standardization guidelines, World Health Organization indoor air quality guidelines and previous studies. These were done to establish a margin of safety for human health and indoor air quality. Hence, the aim of this study is to evaluate emission factors and establish the air quality implications of common burners of LPG stoves found in Nigeria's market.

## 2. Methodology

### 2.1. Collection and selection of burner

Singles and double face burners tested in this work were assembled at the Environmental Engineering Research Laboratory, Department of Chemical Engineering, Obafemi Awolowo University, Ile-Ife, Nigeria. The burners were selected based on construction material (Stainless Steel, Cast Iron and Brass), diameter of port after market survey was done. Old burners were also collected from household; this helps the study to ascertain the effect of burner's age on it gaseous emissions during LPG combustion.

### 2.2. Experimental procedure

The direct flue-gas measurement technique (Hood method) was employed, the LPG combustion gas effluents were sampled with E8500 plus combustion analyser (Portable tool for EPA compliance level for monitoring emissions of boilers, engines and combustion equipment). The combustion analyser measures Hydrocarbons (HC), Carbon-monoxide (CO), carbon-dioxide ($CO_2$), Oxides of Nitrogen (NO, $NO_2$, $NO_X$), Sulphur-dioxide ($SO_2$) and Hydrogen Sulphide ($H_2S$). The burner control valve was opened and LPG fuel was passed to maintain uniform inlet pressure of the gas to the burner head, the stove is switched on and the combustion analyser gas sampling probe is inserted into the combustion zone, with the probe close to the burner head. The concentration of each of the gaseous air pollutants are stored in the combustion analyser from the beginning of the combustion process. The experimental procedure was repeated thrice and average values were reported. LPG combustion was carried out at constant mass for all the burners assembled; the amount of LPG consumed during this period was recorded for each of tested burner.

The emission rates of the characterised and quantified gases were determined using Eq. (1) while the emission factors were calculated using Eqs. (2) and (3), and Eq. (4).

Emission rate were calculated on the basis of time;

$$\mathrm{ER} = \frac{n}{t} \tag{1}$$

Emission factors on basis of mass (g/kg) were calculated using;

$$\mathrm{EF} = \frac{n}{M} \tag{2}$$

Emission factors on basis of energy content (heating value) of LPG were calculated;

$$\mathrm{EF} = \frac{n}{E} \tag{3}$$

Emission factors on basis of useful energy delivered by the LPG;

$$\mathrm{EF} = \frac{n}{ED} \tag{4}$$

Where; n is the mass of pollutants emitted in g, M is the mass of LPG combusted in kg, E is the energy content of LPG in MJ/kg, ED is the useful energy delivered in $MJ_d$, t is the time taken for combustion of LPG in sec, ER is the emission rate.

#### 2.2.1. Evaluation of air quality implication

The evaluation of air quality implication of the burner heads, the emission factors and emission rates determined in this study were compared with WHO Indoor Air Quality guidelines and International Organization for Standardization guidelines (Table 1).

## 3. Results and discussion

### 3.1. Single burners identified in the Nigerian market

Sixteen (16) burners are identified and collected, however these burners were imported into Nigeria market with 57 %, 31 %, 6% and 6 % from Italy, China, India and Nigeria respectively. The distribution of material of construction are shown in Figure 1 with burners A,B,C,J and K made of Stainless Steel, D, F,G, H, L and O from Brass while E, I, M, N and P are made of Cast Iron. The port diameter and number of ports were ranged 0.1–0.12 cm and 192–297 ports respectively for all tested burners. Burners A – M are single, N and O are of double burner stove while P is a high pressure burner.

### 3.2. Emission factors for air pollutants from LPG combustion

Emission rates (ER) for this study are calculated on the basis of mass of pollutants released and time taken during the combustion of LPG. The time taken for each burner to completely combust the LPG was recorded in Table 6. Using Eq. (1), the estimated emission rate for this study were in the range of 0.0071–0.2 g/s for NOx, 0.000238–0.1125 g/s for CO, 0–0.000194 g/s for $SO_2$, 0.0117–1.2583 g/s for HC and 0.1083–0.7 g/s for $CO_2$.

Using Eqs. (2), (3), and (4), the Emission Factors (EF) of the gaseous emissions from the burners were calculated based on the mass of fuel consumed (kg), Energy content of the fuel (MJ) and useful energy delivered ($MJ_d$) are presented in Tables 2, 3, 4, and 5. The emission factors for CO were 5–960 g/kg, 0.003–0.436 g/MJ and 0.123–21.784 g/$MJ_d$, respectively, NOx were found to be in the range of 100–1450 g/kg, 0.039–0.659 g/MJ and 1.973–32.943 g/$MJ_d$, respectively, For $CO_2$ the emissions were 3250–6450 g/kg, 1.473–2.953 g/MJ, 73.819–147.639 g/$MJ_d$, respectively, HC were 200–7550 g/kg, 0.082–3.432 g/MJ and 4.069–171.643 g/$MJ_d$ while for $SO_2$ the emission factors were 0–7.5 g/kg, 0–0.0033 g/MJ and 0–0.1644 g/$MJ_d$. Presented in Table 6 is the EF for $SO_2$, EF was in the range of 0–7.5 g/kg, 0–0.033 g/MJ and 0–0.1644 g/$MJ_d$. however, only burners A and L were observed to emit $SO_2$. The implication is that the LPG combusted contain little amount of sulphur content (see Table 7).

**Table 1.** Standard for Indoor emission rate and Emission factor Tiers for CO.

| Tier | Indoor Emissions CO (g/min) (emission rate) | Indoor Emission CO (g/s) (emission rate) | High power CO ($g/MJ_d$) (emission factor) |
|---|---|---|---|
| Tier 0 | >0.97 | >0.0161 | >16 |
| Tier 1 | ≤0.97 | ≤0.0161 | ≤16 |
| Tier 2 | ≤0.62 | ≤0.010 | ≤11 |
| Tier 3 | ≤0.49 | ≤0.008 | ≤9 |
| Tier 4 | ≤0.42 | ≤0.007 | ≤8 |

Source: IWA, 2012.

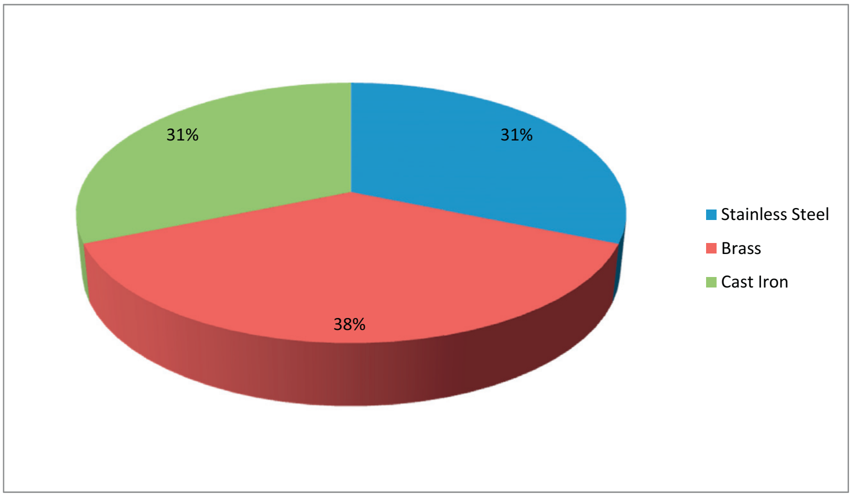

**Figure 1.** Distribution of burner's material of construction.

**Table 2.** Emission Factors (EFs) for CO during the experiment.

| BURNER | Concentrations of CO (mg/m3) | Mass of CO (mg) | EF based on mass combusted (g/kg) | EF based on fuel energy (g/MJ) | EF based on useful energy delivered ($g/MJ_d$) |
|---|---|---|---|---|---|
| **A** | 191.5 | 0.0069 | 345 | 0.157 | 7.871 |
| **B** | 103.5 | 0.0037 | 185 | 0.085 | 4.254 |
| **C** | 530 | 0.0192 | 960 | 0.436 | 21.784 |
| **D** | 319.5 | 0.0116 | 580 | 0.263 | 13.132 |
| **E** | 48.5 | 0.0018 | 90 | 0.040 | 1.993 |
| **F** | 421 | 0.0152 | 760 | 0.346 | 17.304 |
| **G** | 275.5 | 0.0099 | 495 | 0.227 | 11.323 |
| **H** | 309 | 0.0112 | 560 | 0.254 | 12.701 |
| **I** | 7 | 0.0003 | 15 | 0.006 | 0.288 |
| **J** | 257.5 | 0.0093 | 465 | 0.213 | 10.584 |
| **K** | 513.3 | 0.0186 | 930 | 0.4212 | 21.098 |
| **L** | 50 | 0.0018 | 90 | 0.041 | 2.055 |
| **M** | 5 | 0.0002 | 10 | 0.004 | 0.206 |
| **N** | 4.5 | 0.0002 | 10 | 0.004 | 0.185 |
| **O** | 3 | 0.0001 | 5 | 0.003 | 0.123 |
| **P** | 373.5 | 0.0135 | 675 | 0.307 | 15.352 |

### *3.3. Discussion of results*

The emission factors obtained in this study are compared with the ISO (2012) standards as presented in Table 1. The comparisons of CO were based on useful energy delivered by the cooking stoves. It was observed that burners A, B, E, I, L, M, N and O were in the category of tier 4, burner J in tier 2, burners D,H and P were in tier 1 category while burners C, F, and K were in tier 0 category. 50 % of the tested burners were in the best tier category (Tier 4) while 19 % were in the worst category (Tier 0) using the ISO (2012) emission factor for CO. Using the standard for emission rate, 44 % of the burners were within the best tier while 56 % of the emission rate showed worst tier.

Results obtained in this study are also compared with previous studies of LPG cookstoves in literature (MacCarty et al., 2010; Shen et al., 2018; Smith et al., 2000; Zhang et al., 2000). However, it is noted that different experimental methodologies were used in these studies which may be responsible for various differences in results obtained; also different designs of cooking stoves were tested. In this study, the CO emission factor were in the range of 0.206–21.784 $g/MJ_d$. CO emission in this study showed larger differences between different stove and the

**Table 3.** Emission Factors for NOx during the experiment.

| BURNER | Concentrations of NOx (mg/m3) | Mass of NOx (mg) | EF based on mass combusted (g/kg) | EF based on fuel energy (g/MJ) | EF based on useful energy delivered (g/$MJ_d$) |
|---|---|---|---|---|---|
| **A** | 411 | 0.015 | 750 | 0.338 | 16.893 |
| **B** | 801.5 | 0.029 | 1450 | 0.659 | 32.943 |
| **C** | 258.5 | 0.01 | 500 | 0.215 | 10.625 |
| **D** | 48 | 0.002 | 100 | 0.039 | 1.973 |
| **E** | 152.5 | 0.006 | 300 | 0.125 | 6.268 |
| **F** | 266.5 | 0.009 | 450 | 0.219 | 10.954 |
| **G** | 662.5 | 0.024 | 1200 | 0.545 | 27.23 |
| **H** | 464.5 | 0.017 | 850 | 0.382 | 19.092 |
| **I** | 192.5 | 0.007 | 350 | 0.158 | 7.912 |
| **J** | 391 | 0.014 | 700 | 0.321 | 16.071 |
| **K** | 452.5 | 0.016 | 800 | 0.372 | 18.598 |
| **L** | 177 | 0.006 | 300 | 0.146 | 7.275 |
| **M** | 100 | 0.004 | 200 | 0.082 | 4.11 |
| **N** | 49.5 | 0.002 | 100 | 0.041 | 2.035 |
| **O** | 87.5 | 0.003 | 150 | 0.072 | 3.596 |
| **P** | 675.5 | 0.024 | 1200 | 0.555 | 27.765 |

**Table 4.** Emission Factors for $CO_2$ during the experiments.

| BURNER | Concentrations of $CO_2$ (mg/m3) | Mass of $CO_2$ (mg) | EF based on mass combusted (g/kg) | EF based on fuel energy (g/MJ) | EF based on useful energy delivered (g/$MJ_d$) |
|---|---|---|---|---|---|
| **A** | 3592 | 0.129 | 6450 | 2.953 | 147.639 |
| **B** | 1796 | 0.065 | 3250 | 1.476 | 73.819 |
| **C** | 1796 | 0.065 | 3250 | 1.476 | 73.819 |
| **D** | 1796 | 0.065 | 3250 | 1.476 | 73.819 |
| **E** | 1796 | 0.065 | 3250 | 1.476 | 73.819 |
| **F** | 3592 | 0.129 | 6450 | 2.953 | 147.639 |
| **G** | 1792 | 0.065 | 3250 | 1.473 | 73.655 |
| **H** | 1792 | 0.065 | 3250 | 1.473 | 73.655 |
| **I** | 1792 | 0.065 | 3250 | 1.473 | 73.655 |
| **J** | 1792 | 0.065 | 3250 | 1.473 | 73.655 |
| **K** | 3592 | 0.129 | 6450 | 2.953 | 147.639 |
| **L** | 1792 | 0.065 | 3250 | 1.473 | 73.655 |
| **M** | 1792 | 0.065 | 3250 | 1.473 | 73.655 |
| **N** | 1792 | 0.065 | 3250 | 1.473 | 73.655 |
| **O** | 1792 | 0.065 | 3250 | 1.473 | 73.655 |
| **P** | 2325 | 0.084 | 4200 | 1.911 | 95.563 |

**Table 5.** Emission Factors for HC during the experiment.

| BURNER | Concentrations of HC (mg/$m^3$) | Mass of HC (mg) | EF based on mass combusted (g/kg) | EF based on fuel energy (g/MJ) | EF based on useful energy delivered (g/$MJ_d$) |
|---|---|---|---|---|---|
| **A** | 1033 | 0.037 | 1850 | 0.849 | 42.458 |
| **B** | 216 | 0.008 | 400 | 0.178 | 8.878 |
| **C** | 1311 | 0.047 | 2350 | 1.078 | 53.885 |
| **D** | 422 | 0.015 | 750 | 0.347 | 17.345 |
| **E** | 206 | 0.007 | 350 | 0.169 | 8.467 |
| **F** | 189 | 0.007 | 350 | 0.155 | 7.768 |
| **G** | 1545 | 0.056 | 2800 | 1.27 | 63.503 |
| **H** | 916 | 0.033 | 1650 | 0.753 | 37.649 |
| **I** | 251 | 0.009 | 450 | 0.206 | 10.317 |
| **J** | 377 | 0.014 | 700 | 0.309 | 15.496 |
| **K** | 386 | 0.014 | 700 | 0.317 | 15.866 |
| **L** | 143 | 0.005 | 250 | 0.118 | 5.878 |
| **M** | 99 | 0.004 | 200 | 0.082 | 4.069 |
| **N** | 153 | 0.006 | 300 | 0.126 | 6.289 |
| **O** | 144 | 0.005 | 250 | 0.119 | 5.919 |
| **P** | 4176 | 0.151 | 7550 | 3.432 | 171.643 |

**Table 6.** Emission Factors for $SO_2$ during the experiment.

| BURNER | Time taken for Combustion (min) | Concentrations of $SO_2$ (mg/m3) | Mass of $SO_2$ (mg) | Per mass burnt (g/kg) | Per fuel energy (g/MJ) | Per useful energy (g/$MJ_d$) |
|---|---|---|---|---|---|---|
| **A** | 17 | 4 | 0.00015 | 7.5 | 0.0033 | 0.1644 |
| **B** | 7 | 0 | 0 | 0 | 0 | 0 |
| **C** | 6 | 0 | 0 | 0 | 0 | 0 |
| **D** | 6 | 0 | 0 | 0 | 0 | 0 |
| **E** | 10 | 0 | 0 | 0 | 0 | 0 |
| **F** | 4 | 0 | 0 | 0 | 0 | 0 |
| **G** | 5 | 0 | 0 | 0 | 0 | 0 |
| **H** | 6 | 0 | 0 | 0 | 0 | 0 |
| **I** | 9 | 0 | 0 | 0 | 0 | 0 |
| **J** | 9 | 0 | 0 | 0 | 0 | 0 |
| **K** | 5 | 0 | 0 | 0 | 0 | 0 |
| **L** | 6 | 2 | 0.00007 | 3.5 | 0.0016 | 0.0822 |
| **M** | 4 | 0 | 0 | 0 | 0 | 0 |
| **N** | 4 | 0 | 0 | 0 | 0 | 0 |
| **O** | 7 | 0 | 0 | 0 | 0 | 0 |
| **P** | 2 | 0 | 0 | 0 | 0 | 0 |

**Table 7.** Emission rates of the gaseous pollutants.

| BURNER | Time taken for Combustion (min) | Emission rate of NO (g/s) | Emission rate $SO_2$ (g/s) | Emission rate of CO (g/s) | Emission rate of $CO_2$ (g/s) | Emission rate of HC (g/s) |
|---|---|---|---|---|---|---|
| **A** | 17 | 0.0147 | 0.000147 | 0.0068 | 0.1265 | 0.0363 |
| **B** | 7 | 0.0691 | 0 | 0.0088 | 0.1548 | 0.0191 |
| **C** | 6 | 0.0278 | 0 | 0.0533 | 0.1806 | 0.1305 |
| **D** | 6 | 0.0056 | 0 | 0.0322 | 0.1806 | 0.0417 |
| **E** | 10 | 0.01 | 0 | 0.003 | 0.1083 | 0.0117 |
| **F** | 4 | 0.0375 | 0 | 0.0633 | 0.5375 | 0.0292 |
| **G** | 5 | 0.08 | 0 | 0.033 | 0.2167 | 0.1867 |
| **H** | 6 | 0.0472 | 0 | 0.0311 | 0.1806 | 0.0917 |
| **I** | 9 | 0.0129 | 0 | 0.0006 | 0.1204 | 0.0167 |
| **J** | 9 | 0.0259 | 0 | 0.0172 | 0.1204 | 0.0259 |
| **K** | 5 | 0.0533 | 0 | 0.062 | 0.43 | 0.0467 |
| **L** | 6 | 0.0167 | 0.000194 | 0.005 | 0.1806 | 0.0139 |
| **M** | 4 | 0.0167 | 0 | 0.0008 | 0.2708 | 0.0167 |
| **N** | 4 | 0.0083 | 0 | 0.0008 | 0.2708 | 0.025 |
| **O** | 7 | 0.0071 | 0 | 0.000238 | 0.1547 | 0.0119 |
| **P** | 2 | 0.2 | 0 | 0.1125 | 0.7 | 1.2583 |

generally CO emission factor ranged from 100 – 1700 mg/$MJ_d$ (Shen et al., 2018). Comparison based on useful energy delivered with (WHO, 2014) reported a value of 0.118–3.064 g/$MJ_d$. Few of the burners tested in this study were in that range while some breached the value reported by WHO.

For emission factor based on mass of fuel used (g/kg), WHO recommended a value in the range of 2.31–62.1 g/kg, however in this study the range of emission factor based on mass used were 5–960 g/kg for CO. It was observed that burners I, M, N and O were within the WHO value while burners A, B, C, D, E, F, G, H, K, L and P were above the WHO recommended emission factor for CO. The release of $CO_2$ during the experiment shows that there is complete combustion. However, burners A, F and K gave higher value of 6450 g/kg, 2.953 g/MJ and 147.639 g/$MJ_d$ while remaining tested burners have similar as presented in Table 4. Good combustion is a function of excess air around the combustion zone, hence it is necessary that users of LPG stove should have good ventilated kitchen system. This will help to mitigate the formation of carbon monoxide. Emission factor for $CO_2$ in this study as presented in Table 4, were in the range of 73.655–147.639 g/$MJ_d$. Shen et al. (2018) reported a value of 108–157 g/$MJ_d$, a range of value of emission factor for $CO_2$ as 126–153 g/$MJ_d$ were reported by (MacCarty et al., 2010; Smith et al., 2000; Zhang et al., 2000). Comparing with WHO guidelines in terms of mass of fuel used a value of 2943–3714 g/kg were reported. For burners tested in this study, burners B, C, D, E, G, H, I, J, L, M, N and O were in the range of the WHO limit while burners A, F, K and P breach the WHO guidelines.

The emission factor for NOx in this study were in the range of 1.973–32.943 g/$MJ_d$, 100–1450 g/kg and 0.039–0.659 g/MJ. A value of 148 ± 18 for a conventional stove and 27–53 mg/$MJ_d$ were reported respectively by (Shen et al., 2018; Zhang et al., 2000).

For HC, its emission factors for were in the range of 200–7550 g/kg, 0.082–3.432 g/MJ and 4.069–171.643 g/$MJ_d$, this shows great deviation from 0.086 – 36 g/kg, 1.7–766 mg/MJ and 4.1–1144 mg/$MJ_d$ as reported by Shen et al. (2018), this may be due to differences in the composition of the LPG combusted, different burners used and the protocols used in obtaining the results.

Emission rate of CO for vented and unvented stoves are recommended by world health organization (WHO) guidelines on household air pollution (WHO, 2014). In this study, the range of emission rate for CO were 0.000238–0.1125 g/s. The CO emission rates for burners E, I, M, N and O were within the WHO emission rate target of 0.16 g/min (0.008 g/s). Comparing the CO emission rate in this study with the ISO (2012) standard for cooking stoves as presented in Table 1, it was observed that burner A, E, I, L, M, N and O were within the tier 4 while burner B, C, D, F, G, H, J, K and P were in tier 0. Tier 4 representing the best level while tier 0 shows the worst level of emission rate of CO.

## 4. Conclusions and recommendations

Several Experiments were carried in the laboratory with industrial combustion analyser E8500 to evaluate the emission factors and emission rates of conventional burners used in LPG domestic cooking in Nigeria. The study concluded that choosing the right material of construction for burner is essential for mitigating air pollutants from combustion of LPG during domestic cookstoves and improves indoor air quality greatly.

The study data will be useful in developing emission inventories for LPG cookstoves in the country and the data could be used to evaluate the impacts of LPG cookstoves on air quality in the indoor environment. From this study, burners made of cast iron and brass have emission indices that are within the acceptable standard limit by International Organization for Standardization, International Workshop Agreement 11 and WHO air quality guidelines.

The estimated emission factor and emission rates obtained in this study shows that LPG cookstove in Nigeria could be used as a major source of cooking energy that can improve indoor air quality and health conditions of the users.

The study therefore encourages user of LPG cookstove in the country to have a well-ventilated kitchen, both government and private sector are encourage to inform people of the country the need for cleaner fuels for cooking through media campaign and organization of seminar in other to creating awareness in the country.

### *4.1. Implications, limitations and future work*

In this study, 48 laboratory tests were performed to evaluate the emission indices and establish the air quality implications of identified gas burners. The influence of parameters such as port diameter, number of ports and material of construction of burners were investigated. The study confirmed low emission of gaseous air pollutant. Limitations of this study and the need for field investigation and further laboratory experiments are acknowledged.

## Declarations

### *Author contribution statement*

Daniel Olawale Oke: Performed the experiments; Wrote the paper.

Bamidele Sunday Fakinle: Analyzed and interpreted the data.

Jacob Ademola Sonibare: Conceived and designed the experiments.

Funso Alaba Akeredolu: Contributed reagents, materials, analysis tools or data.

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### *Competing interest statement*

The authors declare no conflict of interest.

### *Additional information*

No additional information is available for this paper.

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