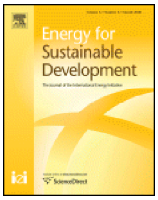
Energy for Sustainable Development 31 (2016) 91–96

Contents lists available at ScienceDirect

Energy for Sustainable Development



A comparative performance analysis of carbonized briquettes and charcoal fuels in Kampala-urban, Uganda

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ARTICLE INFO

Article history:
Received 30 April 2015
Revised 6 January 2016
Accepted 11 January 2016
Available online xxxx

Keywords:
Performance analysis
Carbonized briquette
Charcoal
Nested design
Household waste
Monitoring policies

ABSTRACT

As a result of the rising energy needs and environmental concerns, carbonized briquettes have been looked at as a possible substitute source of energy for charcoal in most of the developing regions. However their use and adoption in Uganda cannot be rated amidst continued increase in charcoal demand from the ever growing urbanization. This study therefore investigated burning performance and cost in affecting briquette use. A comparative performance analysis was carried out for locally purchased carbonized briquettes made from matooke peels plus other household wastes and charcoal fuel denoted as A, B, C, and D, using a nested design. Calorific value, ash content, moisture content, burning time, and time of boil as well as cost per kilogram and per energy output, were the parameters compared. Results showed that gross calorific values were comparable for the two fuel types in the range of 4663–6517 kcal/kg. However, the average cost per energy output of briquettes as received was more than twice that of charcoal. This implies that briquettes are not worth their price since their calorific values are comparable to those of charcoal. The least expected was that shape and size of briquettes did not have influence on burning time and time of boil, an indication of briquette adulteration. Therefore further research needs to look at how the cost per energy output of briquettes can be reduced to be comparable to that of charcoal without compromising the quality. This work will contribute to monitoring policies and promote efficient briquette production methods to reduce the cost of briquettes in order to create a competitive edge against charcoal. But at the moment, charcoal users may not be attracted to briquettes due to their high cost per energy output, calling for an alternative path of household waste utilization to provide sustainable energy.

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1. Introduction

As the subject of universal access to clean energy and sustainable environment continues to dominate international debates, the use of charcoal in urban households remains dominant in Sub-Saharan African countries. Karekezi's (Karekezi, 2002) submission on electricity being largely confined to high-income urban households may not hold as far as the use of electricity is concerned. This is because about 48% of the so called high-income urban households use electricity for lighting and only 1.6% use it for cooking, a Uganda case according Ministry of Energy and Mineral Development (MEMD) (MEMD, 2006) and Uganda Bureau of Statistics (UBOS) (UBOS, 2010). An indication that even those with access to electricity, the capacity to use it and pay for it is limited. With the ever growing urbanization, the demand for charcoal is projected to be about 75% in the tropical countries (May-Tobin, 2011). In Kampala, 76% of the population depends on charcoal as their main source of fuel for cooking (Ferguson et al., 2012). More so, this growing urbanization goes along with challenges of waste disposal management with over 60% of the organic waste coming from households (Ogwueleka, 2013).

In Uganda, the composition of urban waste is dominated by banana (matooke peels) at about 34% according to MEMD, (MEMD, 2012) which are said to be utilized in carbonized briquette making according to a number of sources (Anhwange et al., 2009; Natukunda, 2007; Mallimbo & Rudmec, 2009), in some literature called charcoal briquettes (Akowuah et al., 2012). Since even those with access to electricity have no capacity to pay for it, one would have hoped that these carbonized briquettes would be the possible alternative source of energy to the traditional charcoal which impacts negatively on the environment and in addition serves as a waste control strategy. But this seems not to be the trend as their adoption and use cannot be given any possible rating on top of the continued common sight of the matooke peels in the urban (Achidria, 2015). This is not to mention the 10 million tonnes of fuelwood deficit projected by 2016 (MEMD, 2005) amidst the large quantities of organic waste posing disposal challenges.

Although charcoal's contribution to Uganda's Gross Domestic Product (GDP) is around US$ 48 million, the current level of demand, coupled

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http://dx.doi.org/10.1016/j.esd.2016.01.001
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with unsustainable harvesting causes Uganda to be approaching an energy deficiency (UNDP, 2011). This calls for an alternative source of energy. Therefore, the purpose of this study was to find out why carbonized briquettes have not simulated interest among the end-users as part of the work in trying to forge a way in which the relatively abundant organic household waste can be put to use to provide a sustainable alternative source of energy to charcoal without joining the waste stream to cause pollution.

The process of making carbonized briquettes starts with biomass collection like matooke peels, drying, carbonization to produce charcoal powder, mixing charcoal powder with a binder such as starch and others use soil either as a binder or as a filler for density purposes, compressing the mixture of charcoal powder and binder in molds to produced the briquettes, drying of the briquettes and packing for sale. This is according to briquetting fact sheet of Practical Action Technology Challenging Poverty.

2. Materials and methods

2.1. Study scope

The study was focused on the briquettes in Kampala markets and charcoal from various selling points around Kampala, the capital city of Uganda. A comparative study was based on the following parameters:

i) quality analysis of the briquettes and charcoal on the market and
ii) burning time and time of boil for the briquettes and charcoal using a local ceramic stove
iii) cost-quantity analysis of the briquettes and charcoal on the market.

2.2. Experimental design

A nested design given by the model in Eq. 1 was used in this study. It is able to analyze variability between the two fuel types (briquettes and charcoal) and within. Sample categories designated as A, B, C and D each in three replications for both briquettes and charcoal which were used in experimentation were collected from different markets in Kampala. Three replicates were used as the recommended minimum number of replicates needed in experiments involving stove testing, (Bailis et al., 2007; Wang et al., 2014). All the briquette samples were carbonized but of different shapes, sizes and probably different raw materials due to differences in color as demonstrated in Fig. 1. Charcoal samples for comparison were also obtained from four different vendors from four markets to minimize the likelihood of getting samples of one supplier if bought at one location.

$$Y_{ijk} = u + p_i + \tau_{(i)j} + \varepsilon_{(ij)k} \tag{1}$$

Where Y_{ijk} is the total variation, μ is a constant, ρ_i is variation between factors and in this case briquettes and charcoal, $\tau_{(i)j}$ is variation within the factors and $\varepsilon_{(ij)k}$ is variation due to error. Eq. 1 can further be translated to Eqs. 2 and 3 for computation of the respective variations when μ is zero.

$$\mathrm{TSS} = \mathrm{SSB} + \mathrm{SSW} + \mathrm{SS}_{\mathrm{error}} \tag{2}$$

where TSS is the total sum of square, SSB is the sum of squares between the factors, SSW is the sum of squares within the factors and $\mathrm{SS}_{\mathrm{error}}$ is due to error.

$$\Sigma\Sigma\Sigma\left(Y_{ijk} - \overline{Y}.\right)^2 = m.n\sum_{i\text{-}1}^{M}\left(\overline{Y_i} - \overline{Y}..\right)^2 + n\sum_{i-1}^{M}\sum_{j-1}^{m}\left(\overline{Y_{ij}} - \overline{Y_i}\right)^2 + \sum_{i-1}^{M}\sum_{j-1}^{m}\sum_{k\text{-}1}^{n}\left(\overline{Y_{ijk}} - \overline{Y_{ij}}\right)^2 \tag{3}$$

for i = 1, 2,..,M, where M = number of factors, j = 1, 2,..,m, where m = number of locations representing the categories of samples which is equal to four for this work and k = 1, 2,..,n, where n = replication.

2.3. Cost and quality analysis

Weight of the samples whose cost was already known from the market vendors was measured using an electrical digital weighing scale of ±0.01 g sensitivity. The cost per unit weight of the samples was then calculated from the ratio of the cost of bulk to the weight of the bulk. In quality analysis burning time, moisture content (dry basis), calorific value and ash content were the parameters determined as received. Three grams of the fuel sample were weighed in crucibles and put in Gallenkamp hot box oven set at a temperature of 105 °C for16 h until there was no change in the weight of the sample. Moisture content on dry basis was calculated using the Eq. 4 according to ASTM E 871-82, (ASTM, 2013).

$$\mathrm{MC}_{\mathrm{dry}} = \frac{\text{Weight of the sample-Weight of oven dry sample}}{\text{Weight of oven dry sample}} \times 100\% \tag{4}$$

The weighed dry fuel samples from the moisture content tests were then put in the Carbolite muffle furnace set at a temperature of 550 °C and heated for 24 h. The crucibles with the ashed samples were then cooled in a desiccator for 2 h. The incombustible residues of the samples were weighed. The percentage ash content was calculated using the Eq. 5.

$$\text{Percentage Ash content} = \frac{\text{Weight of ash}}{\text{Original weight of the sample}} \times 100\% \tag{5}$$

Calorific values of the fuel samples were determined as per the ASTM D 2016-93 standard procedures using the oxygen bomb calorimeter. The

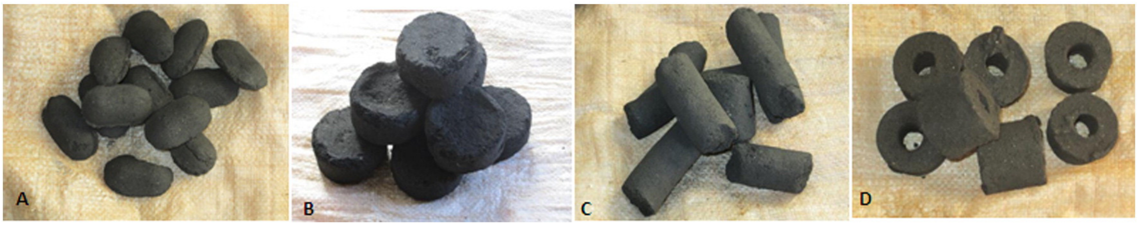

Fig. 1. Carbonized briquettes on the market. A — Pillow Carbonized charcoal dust briquettes; B — Cylindrical char dust briquettes; C — Pelleted char dust briquettes; D — Hollow carbonized saw dust briquettes. It is important to note that differences due to briquette composition or materials used and tree's species from which charcoal was made were not analyzed for as the vendors could not be in position to tell what materials the briquette supplier used or what tree species the charcoal supplier used. It was not also possible to get briquettes of the same size and shape from different manufacturers and this informed the choice of the nested design used. However, the researcher was able to establish that majority of briquette manufacturers use matooke peels as one of the main materials from those who supply the peels to them after gathering them from garbage sites to earn a living shown in Fig. 2.

Table 1
Nested ANOVA for gross energy value versus fuel types and their categories.

Source of variation	df	SS	MS	F	P-value
Fuel type	1	1,286,220	1,286,220	2.01756	0.1937
Categories	6	3,825,076	637,512.7	2.812123	0.089
Error	8	1,813,612	226,701.5		
Total	15				

price per energy output was determined from the ratio of cost per unit weight to the calorific value of samples, an indication of amount of energy transported or stored for the same mass or volume.

2.4. Water boiling test protocol

Water boiling tests were carried out using a precision scale of ± 1 g accuracy, a K-Type thermocouple digital unit, a small shovel/spatula to remove charcoal from stove, tongs for handling charcoal, timer, and a metal tray to hold charcoal for weighing, at least 15 l of clean water, and a charcoal Ceramic stove from Ugastove. A cooking pan of 2.5 l was heated and brought to a rolling boil. The boiling temperature of the water was measured using the K-Type thermocouple digital unit. The temperature over a five minute period was recorded at full boil and the maximum and minimum temperatures observed during this period were noted. The average value of the maximum and minimum temperatures was calculated and it was the local boiling point.

To determine time of boil and burning time of fuel, a pot with 2 l of water was put on the stove and the stopwatch started. The K-Type thermocouple digital unit was installed for recording of the water temperatures until the boiling point was reached. The boiling point was considered to be reached when the temperature remained constant for 10 consecutive seconds. The Time to Boil (TTB) which is the time from the start of the stopwatch until the end of the 10 s was recorded for different samples in batches of 2 l for four to five repeated times, a total to 8 or 10 l depending on the fuel type category. When the fuel samples were fully lit, the stopwatch was started and the burning time which is the total time taken for the fuel to completely burn to ashes was determined.

3. Results and discussion

3.1. Quality parameters

Figs. 3 (a) and (b), show gross calorific values and moisture content respectively of briquettes and charcoal. Gross calorific values of the two fuel types were comparable, with charcoal categories in the range of 5364–6517 kcal/kg and briquettes in the range of 4663–6168 kcal/kg. However, the calorific values of charcoal were below the expected average value of 7500 kcal/kg (Grover & Mishra, 1996). This indicates that the disappearance of the good hard wood tree species and charcoal producers are now turning to what used to remain behind (MEMD, 2011). Statistical analysis showed that there was no significant difference between calorific values of the two fuel types and within their categories with approximate P-values of 0.2 and 0.1 respectively at 5% significance level as shown in Anova Table 1. This implies that the energy content of carbonized briquettes is comparable to that of charcoal.

Moisture content was also found to be not significantly different for the two fuel types at 5% significant value. All the results for the different fuel categories were in the same range of less than 8% as shown in Fig. 2 (b). Akowuah et al. (Akowuah et al., 2012) obtained moisture content of 5.7% db when dealing with sawdust carbonized briquettes which is comparable to the results of this study.

Fig. 4 shows the ash content values which on the other hand were highly significant for the two fuel types with a P-value of 0.00009 at 5% significance level. This may be explained by the loose material used in briquette making compared to woody materials for charcoal. However,

Fig. 2. Matooke peels gathered from a garbage site for sale either for briquette making or animal feeding.

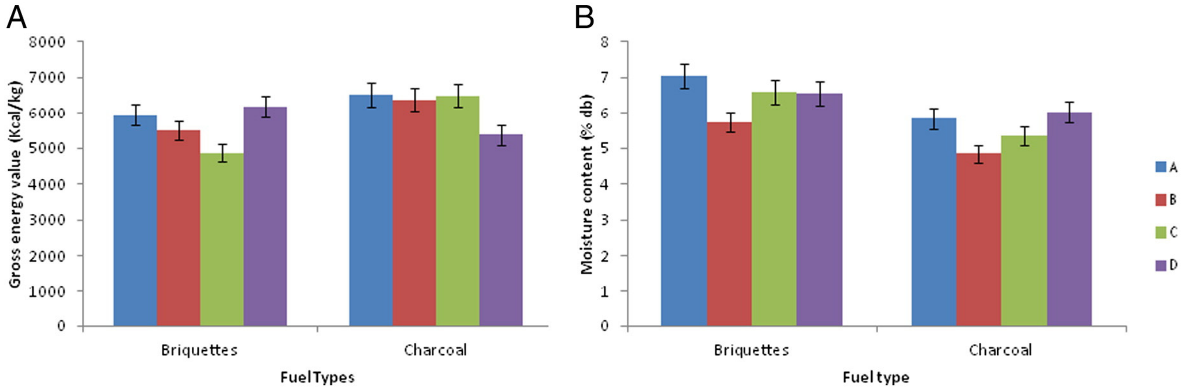

Fig. 3. Gross energy calorific values for briquettes and charcoal of different categories as received Legend: error bars showing 5% positive and negative potential error amounts.

ash content approximating to 30% for briquette is extremely high compared to 2.6% reported by Akowuah et al., (Akowuah et al., 2012) for sawdust briquettes. It is surprising that the calorific value reported by Akowuah et al., (Akowuah et al., 2012) is comparable to what was recorded in this study given that the higher the ash content, the lower the calorific value (Chaney, 2010). As calorific is also dependent on composition (Jayanti et al., 2007), briquette calorific values recorded in this study can be attributed to composition given that categories A, C and D were seen to have a brownish color in them, an indication of red or brown soil addition, compared to category B that was showing a pure black charcoal color. It should be noted that some briquette producers use clay soil and anthill soil as binders and for weight increase as well, which would contribute a great percentage of ash (Onchieku et al., 2012; Katimbo et al., 2014). This is not to mention that the main materials used like matooke peels or wood would affect calorific values and ash content differently.

3.2. Average burning time and time of boil

Table 2 shows the average burning time it took 0.5 kg of each of the different categories of briquettes and charcoal to completely burn and the time it took each category to boil the given volume of water (8–10 l) in batches of 2 l at a time. Statistical analysis showed no significant difference with a P-value of 0.556 in burning time between the two fuel types (briquettes and charcoal). The Anova table was left out due to the P-value not being significant. This implies that the equal quantities of briquettes and charcoal take almost the same time producing energy. This nullifies claims by different reports that briquettes take longer time burning compared to the traditional charcoal. In fact some briquette producers use this 'longer time of burning' as the promotion parameter, which to some extent has discouraged those who bought them and found nothing different from charcoal. This has created negative impact on the adoption and use of briquettes to some degree. However, looking at the individual categories of briquettes, it can be seen that category B took relatively a shorter time of 114.9 min to burn out compared to the rest. This can be attributed again to composition. Categories A, C and D were seen to have a brownish color in them, an indication of red or brown soil addition, compared to category B that was showing a pure black charcoal color. Given that shape and size may also contribute to differences in burning time and time to boil, one would have expected category D with a hole in the middle to take a shorter time of burning and a shorter time of boil than the rest as it offers a larger surface area and increased air circulation releasing more energy per unit time, which was not the case. This again could be due to the soil added revealed by the brown color.

On the other hand, time of boil showed significant difference between briquettes and charcoal with a P-Value of 0.00005. But within the individual categories, there was no significant difference as shown in Anova Table 3. The difference in time of boil between briquettes and charcoal can be explained by the significant ash content in briquettes which blocks radiation heat transfer. Again category B of briquettes took 22 min comparable to charcoal categories unlike the other briquette categories. This implies that carbonized briquettes have the potential to cook or boil the same quantity of food or water in the same time interval as charcoal. However, if the brown color in categories A, C and D indicated an addition of soil, it carries no meaning since only it increases time of burning, ash content and time of boil, yet, do the same or less work (amount of water boiled) as one where soil was not added, a case of category B.

3.3. Cost-quantity analysis

Figs. 5 (a) and (b) show the average cost per unit weight and cost per unit energy output of the different categories (A, B, C, D) of briquettes and charcoal used in this study. Results showed a significant difference in the cost per unit weight of the two fuel types with a P-value of 0.006 at 5% significance level as in Table 4. This significant difference affirms to what can be seen in Fig. 5(a) that the cost for any category of briquettes was much higher than that of charcoal. The average cost per unit weight of briquettes ranged between UGShs 775–1775 equivalent to USD/kg 0.31–0.71 as received while that of charcoal ranged between USD/kg 0.21–0.25. This shows that the most expensive charcoal was cheaper than the cheapest category of briquettes. According to Kaijuka (Kaijuka, 2007), however an innovation might be, scarce resources do not leave room for any unaffordable options, although necessity is the mother of invention. Thus, having considered the quality parameters of briquettes being comparable to those of charcoal, it can

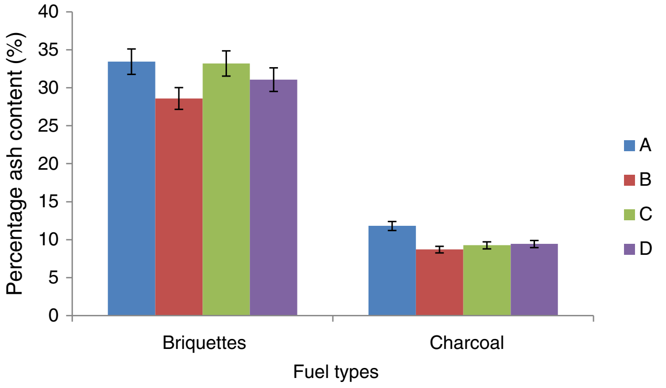

Fig. 4. Percentage ash content for briquettes and charcoal of different categories Legend: Error bars show 5% positive and negative potential error amounts in the results.

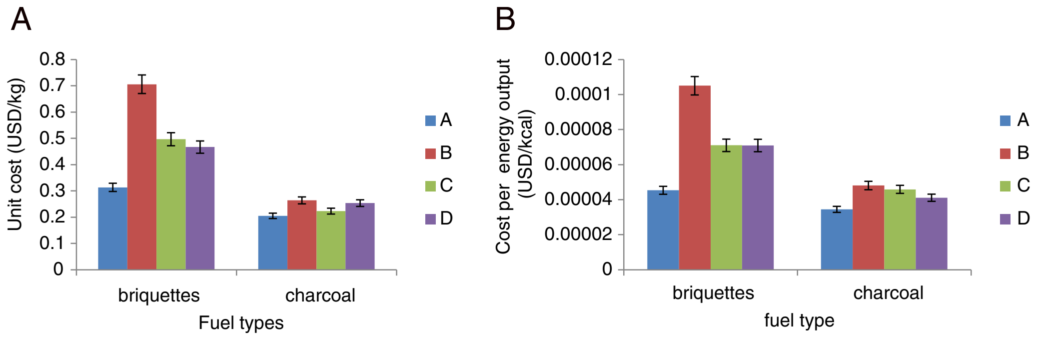

Fig 5. Cost per unit weight and per energy output for briquettes and charcoal of different categories Legend: Error bars show 5% positive and negative potential error amounts in the results.

Table 2
Mean values of burning time, time of boil and amount of water boiled for the tested fuel types.

Briquettes				Charcoal		
Category	Average			Average		
	Burning Time (min)	Time of boil (min)	Amount of water boiled (L)	Burning Time (min)	Time of boil (min)	Amount of water boiled (L)
A	124.5	41.5	8	101.8	20.5	10
B	114.9	22.6	10	127.8	19.1	8
C	159.1	31.5	10	158.1	24.5	10
D	157.2	52.5	10	100.6	24.4	8

be said that however much good briquettes may be superior to charcoal, their adoption and use may not go far if their cost remains high compared to that of charcoal. This is the same reason why about 70% of urban households in Uganda still depend on charcoal for cooking yet they are connected to the national grid which they only use for lighting according to Uganda Bureau of Statistics (UBOS), (UBOS, 2010). More so, there was a high significant difference in cost per unit weight within the different categories with a negligible P-value as shown in Table 4. This was particularly true for briquette categories. To some extent, this difference in cost per unit weight within briquette categories can be explained basing on manufacturing practices. However, this can only be justified if there is a significance difference in their quality parameters. Otherwise, this too will not promote briquettes when they are of the same quality but with high significant difference in cost. Similarly on average, the cost per unit energy output of briquettes was about two times higher than that of charcoal as seen in Fig. 5(b).

Therefore, combining quality parameters with the cost per unit weight of the individual fuel types, it becomes clear that users of briquettes would be paying more for less or equal energy output compared to charcoal users. Thus, briquettes are not worth the premium in price. Given that the dynamics of using briquettes are similar to those of using charcoal, a lot of work is still needed in the briquetting area if adoption and use is to be realized. That is to say, as environmental concerns continue to press hard and charcoal remains relatively cheaper and better than briquettes, more work remains in lowering the cost of briquettes. Otherwise, a more sustainable path is needed through which the materials being used in briquette making like matooke peels and other household wastes can be utilized to provide a cheaper source of energy alternative to charcoal.

4. Conclusions

The gross calorific values and moisture content were comparable for the two fuel types. However, the cost per energy output of briquettes as received was twice and above that of charcoal. This implies that briquettes are not worth their price since their calorific values are comparable to those of charcoal. The least expected was that shape and size of briquettes did not have influence on burning time and time of boil, an indication of briquette adulteration with soil. Therefore further research needs to look at briquette manufacturing practices that produce briquettes whose unit cost per energy output is lower or comparable to that of charcoal without compromising the quality parameters. It is the hope of the authors that this work will contribute to monitoring policies and promoting efficient briquette production methods to ensure that the quality of both charcoal and briquettes is in the acceptable range and lower the cost of briquettes in order to create a competitive edge against charcoal. But at the moment, charcoal users may not be attracted to briquettes due to their high cost per energy output, calling for an alternative path of household waste utilization to provide sustainable energy.

Acknowledgment

This is to acknowledge academic staff members of the department of Agricultural and Biosystems Engineering for their constructive critics during data collection. The Special Faculty Allowance extended to students in the final year for projects at Makerere University funded this work. METEGA (Mobility to Enhance Training of Engineering Graduates in Africa) Project is acknowledged for the scholarship.

Table 3
Nested ANOVA for time of boil.

Source of variation	df	SS	MS	F	P-value
Fuel Type	1	540.6453	540.6453	45.40396	0.000005***
Categories	6	71.44469	11.90745	1.325907	0.30205
Error	16	143.6897	8.980604		
Total	23				

Table 4
Nested ANOVA for cost-quantity analysis versus energy sources (briquettes and charcoal) and their categories.

Source of variation	df	SS	MS	F	P-value
Fuel type	1	2,518,547	2,518,547	10.01308	0.006011***
Categories	6	1,509,154	251,525.7	214.7663	≫ .0000001***
Error	16	18,738.56	1171.16		
Total	23	4,046,439			

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