Proposition of a new approach for calculating the efficiency of domestic gas cooking appliances

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Abstract: The process of measuring the performance of gas cooking appliances is based on the simple calculation of the arithmetic mean between the results obtained from different burners, without any metrological rigour related to the behavior of the data. This study proposes a new methodology and compares it against the traditional one. The proposed approach evaluates whether data are far apart on the normality, treats outliers and calculates the efficiency from the position measure inversely weighted by the dispersion measure of each burner. For the datasets studied, there may be divergences between the results found for the efficiency calculation when treated by the traditional approach and the proposed approach. However, this study recommends a detailed analysis of the algorithms used, in order to better understand the reason for the divergences found; as well as the implementation of measurement uncertainty calculation, in order to evaluate the partial overlap between specification ranges.

Keywords
Metrology; Stoves; Altitude; Measurement uncertainty; Thermal performance.

1. Introduction
Based on the Energy Efficiency Law, the Interministerial Ordinance MME / MCT / MIDC number 363, of May 26, 2011 [1] establishes the minimum levels of energy efficiency of stoves sold in Brazil, indicating the methodologies established by the Brazilian Labeling Program (PBE) to assess the conformity of these products. The evaluation standards involve a series of tests related to performance and safety aspects, the results of which are passed on to the consumer by means of the National Energy Conservation Label (ENCE), which is mandatory for products.

In the past, divergences were found in interlaboratory comparisons that were coordinated by Brazilian Institute of Metrology, Standardization and Industrial Quality (INMETRO), but despite the negotiations, no conclusion was reached regarding the deviations found.

In order to contribute to the advancement of knowledge on the interpretation of this information in Brazil among consumers, an interlaboratory comparison, focusing tests of efficiency determination in stoves, was conducted with the objective of evaluating a new approach for the calculation of the efficiency.

2. Experimental Method for the Calculation of efficiency
The tests to determine the performance of a domestic cooker were carried out in accordance with the methodology established in the Brazilian Standard ABNT NBR 13723-2 [2]. The tests were conducted in four burners, two of the fast type and two of the semi-fast type, of a four-burner stove.
The calculation of efficiency ($\mu$) is based on Equation (1), where, $M$ is the mass of water, in kg, determined according to the power of the burner; $C$ is the specific heat of water in kJ / kg °C; $T_1$ and $T_2$ are initial and final temperatures, respectively, in °C; $V_c$ is the consumed volume of gas, in m³, corrected for the reference conditions by Equation (2); $PCS$ is the superior calorific value of the reference gas, in MJ / m³, $V$ is the gas volume measured under the test conditions, in m³; $P_a$ is the atmospheric pressure, in kPa and $P$ is the gas feed pressure in the meter, in kPa. In Equation (3), $W$ is the water vapor pressure, in kPa, related to $T_g$ gas temperature, in °C, calculated by Equation (4) [9-11].

$$\mu = \frac{M \times C \times (T_2 - T_1)}{V_c \times PCS} \times 100$$

(1)

$$V_c = V \times \frac{P_a + P - W}{101.33} \times \frac{288.15}{273.15 + T_g}$$

(2)

$$W = \frac{e^x}{10}$$

(3)

$$x = 21.094 - \frac{5262}{273.15 + T_g}$$

(4)

3. Statistical Methods

This study proposes a methodology whose approach evaluates if data are far apart on normality, treats outliers and calculates the efficiency from a weighted position measure (mean or median) of each burner.

3.1. Evaluation of the normality of the data

There are several tests to evaluate if the data are well modeled by a normal distribution. However, the Shapiro-Wilk test has the highest statistical power among these [3-5].

To carry out the Shapiro-Wilk test, the following hypotheses must be formulated:

$H_0$: The sample comes from a normal distribution;

$H_1$: The sample does not come from a normal distribution.

Establish the level of significance of the test ($\alpha$), which in this study is considered as 0.05;

Calculate the test statistic:

Sort the $n$ sample observations: $x_{(1)}, x_{(2)}, x_{(3)},..., x_{(n)}$, and calculate the mean $\bar{x}$;

Calculate $\sum_{i=1}^{n} (x_i - \bar{x})^2$

Calculate $b = \sum_{i=1}^{n} a_{(n-1+1)} \times (x_{(n-i+1)} - x_i)$
Calculate $W_{calculated} = \frac{b^2}{\sum_{i=1}^{n}(x_i - \bar{x})^2}$

Make the decision: Reject $H_0$ at the level of significance of $\alpha$ if $W_{calculated} < W_{\alpha}$ (critical value).

3.2. Treatment of outliers
The existence of values that can be considered dispersed, that is, atypical values that present a distance from the measurements are called outliers.

The choice of method to treat the outliers depends on the understanding if the parameters that define the populations present a normal distribution. If the data point to a normal distribution, one can use parametric tests such as Grubbs’ and Dixon’s test or Chauvenet’s criterion. If they do not indicate a normal distribution, nonparametric tests such as MAD – median absolute deviation or Interquartile Range (IQR) can be used [3,4].

3.2.1. Grubbs’ test. The Grubbs’ test is firstly performed to verify the existence of a scattered value at each extremity of the data set. If in the first analysis, one of the two values is considered to be dispersed, it is rejected, removed from the data set and a new test, verifying the existence of a dispersed value in each extremity of the data set is performed and so on. Otherwise, if in this first analysis, both values are classified as non-dispersed, the test is finished and one uses the remaining data set for analysis. If in the second analysis, the two results from one extremity are considered as scattered, they should be rejected, removed from the data set and new test is performed, checking for the existence of two outliers in each extremity of the data and so on, until both values are classified as non-dispersed.

One outlier
Given a set of data $g_i$ with $i = 1, 2, ..., p$, arranged in ascending order, the determination, by the Grubbs’ test, for the largest observed value to be a discrepant value, uses the following statistical value, Equation (5):

$$G_C = \frac{|g_i - \bar{g}|}{s}$$

where:

- $g_i$ is the suspect value;
- $\bar{g}$ is the arithmetic mean;
- $s$ is the standard deviation, Equation.

The calculated value ($G_{calculated}$) is compared with a critical value at a chosen significance level. An outlier is detected if $G_{critical} > G_{calculated}$.

Two outliers
Alternatively, for the detection of two outliers, Eqs. (6) and (7) are recommended, two largest or two smallest values, respectively:

$$G_{largest} = \frac{S^2}{\sum_{i=1,p} S^2_i}$$

(6)
\[ G_{\text{smallest}} = \frac{S^2_{h,2}}{S^2_o} \]  

(7)

Where:

- \[ S^2_o = \sum_{i=1}^{n} (g_i - \overline{g})^2 \] is the sum of squared deviations from the mean for the original sample;

- \[ S^2_{p-1,p} = \sum_{i=1}^{n-2} (g_i - \overline{g}_{p-1,p})^2 \] and \[ S^2_{1,2} = \sum_{i=3}^{n} (g_i - \overline{g}_{1,2})^2 \] are the sum of squared deviations obtained after removal of the two highest or the lowest values, respectively;

- \( \overline{g}_{p-1,p} \) and \( \overline{g}_{1,2} \) are the means for the original sample, without the two highest or the lowest values, respectively.

Outliers are detected if the test statistic of Eqs. (6) and (7) are smaller than the critical value.

3.2.2 Interquartile range (IQR). This approach takes into account the rules of the quartiles considering as outliers those smaller or larger than 1.5 times the interquartile range (the difference between the third and first quartile) from the first and third quartiles, \( Q_1 \) and \( Q_3 \), respectively, i.e., the values below of the Eq. (8) and above of the Eq. (9):

\[
Q_1 - 1.5 \times (Q_3 - Q_1) \\
Q_3 + 1.5 \times (Q_3 - Q_1)
\]

(8)

(9)

Here, \( Q_1 \) is the median of the data equal or smaller than the median of the entire data set and \( Q_3 \) is the median of the data equal to or greater than the median of the entire data set.

3.3. Measurement of position weighted by dispersion measures

3.3.1. Data with normal distribution. In this study, the estimation of the quantity, from the mean, is weighted inversely proportional to its respective variances, Equation (10).

\[
p_i = \frac{1}{\sigma_i^2}
\]

(10)

Finally, the mean yield of the National Energy Conservation Label is calculated by the weighted mean, Equation (11) [6].

\[
\overline{X} = \frac{\sum_{i=1}^{m} x_i \cdot p_i}{\sum_{i=1}^{m} p_i}
\]

(11)

3.3.2. Data whose behavior distances itself from normality. The estimate of the quantity, from the median (M), is weighted inversely proportional to its respective dispersion measures, Equations (12) and (13).
Finally, the median (M) of the National Energy Conservation Label yield is weighted by the nonparametric dispersion measure, Equation (14) [6].

\[
p_t = \frac{1}{(MAD / 0.6745)_i^2}
\]

\[
MAD = \text{Median}(|x_i - \text{median}(x_i)|)
\]

(13)

4. Results and Discussion

Tables 1 and 2 show the experimental results before treating the outliers.

| Laboratory A | Table 1 – Experimental data at sea level |
|---------------|----------------------------------------|
| Q1 | Q2 | Q3 | Q4 |
| 63.9 | 67.7 | 66.7 | 62.0 |
| 62.5 | 67.9 | 67.1 | 61.2 |
| 65.5 | 68.4 | 67.2 | 62.6 |
| 63.9 | 68.8 | 65.7 | 62.1 |
| 62.0 | 68.6 | 66.8 | 61.9 |
| 64.4 | 68.3 | 66.8 | 61.9 |
| 63.6 | 68.0 | 66.4 | 62.2 |

| Laboratory B | Table 2 – Experimental data at altitude above sea level |
|---------------|---------------------------------------------------------|
| Q1 | Q2 | Q3 | Q4 |
| 62.3 | 64.5 | 64.2 | 60.3 |
| 62.5 | 67.6 | 66.3 | 60.0 |
| 63.3 | 64.9 | 65.6 | 60.4 |
| 63.3 | 65.8 | 66.4 | 60.3 |
| 63.0 | 67.9 | 66.9 | 60.7 |
| 63.1 | 67.2 | 66.2 | 60.8 |
| 63.9 | 67.7 | 66.7 | 60.9 |

Tables 3 and 4 show the results obtained by the Shapiro-Wilk test.

| Laboratory A | Table 3 – Data collected at sea level |
|--------------|--------------------------------------|
| Q1 | W calculated = 0.9537 > W critical = 0.8290 → accept H₀ |
| Q2 | W calculated = 0.9752 < W critical = 0.8290 → accept H₀ |
| Q3 | W calculated = 0.9584 > W critical = 0.8290 → accept H₀ |
| Q4 | W calculated = 0.9498 < W critical = 0.8290 → accept H₀ |

| Laboratory B | Table 4 – Data collected at altitude above sea level |
|--------------|-----------------------------------------------------|
| Q1 | W calculated = 0.8598 > W critical = 0.8290 → accept H₀ |
| Q2 | W calculated = 0.8456 < W critical = 0.8290 → accept H₀ |
| Q3 | W calculated = 0.8161 < W critical = 0.8290 → rejects H₀ |
| Q4 | W calculated = 0.9080 < W critical = 0.8290 → accept H₀ |

Using the Shapiro-Wilk test, it was observed that most of the experimental data collected has a Gaussian distribution, so the Grubbs’ parametric test was used to evaluate the dispersed results with
Normal distribution and the nonparametric IQR test was used to evaluate the presence of scattered results that distance themselves from normality (Laboratory B, Q3).

After the treatment of the outliers, the Shapiro-Wilk test was applied again and all data sets meet the assumption of the normality.

Tables 5 and 6 show the experimental results after treatment of the outliers and the efficiency of domestic gas cooking calculated by weighted mean.

**Table 5 – Experimental data at sea level**

|        | Laboratory A       |        |
|--------|---------------------|--------|
|        | Q1  | Q2  | Q3  | Q4  |
|        | 63.9| 67.7| 66.7| 62.0|
|        | 62.6| 67.0| 66.3| 61.4|
|        | 64.1| 67.4| 66.2| 62.3|
|        | 62.5| 67.9| 67.1| 61.2|
|        | 65.5| 68.4| 67.2| 62.6|
|        | 63.9| 68.8| 65.7| 62.1|
|        | 62.0| 68.6| 66.8| 61.9|
|        | 64.4| 68.3| 66.8| 61.9|
|        | 63.6| 68.0| 66.4| 62.2|
|        |      |      |      |      |
| Arithmetic mean of each burner | 63.6 | 68.0 | 66.6 | 62.0 |
| Arithmetic mean of (ENCE)% | 65.0 |      |      |      |
| Standard deviation of each burner | 1.09 | 0.58 | 0.47 | 0.43 |
| Individual weight | 0.8  | 3.0  | 4.5  | 5.3  |
| Weighted Mean (ENCE)% |      |      |      | 64.9 |

**Table 6 – Experimental data at altitude above sea level**

|        | Laboratory B       |        |
|--------|---------------------|--------|
|        | Q1  | Q2  | Q3  | Q4  |
|        | 62.3| 64.5| 60.3| 60.0|
|        | 63.4| 67.1| 66.2| 60.3|
|        | 62.5| 67.6| 66.3| 60.0|
|        | 63.3| 64.9| 65.6| 60.4|
|        | 62.9| 65.8| 66.4| 60.3|
|        | 63.0| 67.9| 66.9| 60.7|
|        | 63.1| 67.2| 66.2| 60.8|
|        | 63.9| 67.7| 66.7| 60.9|
|        |      |      |      |      |
| Arithmetic mean of each burner | 63.1 | 66.4 | 66.3 | 60.4 |
| Arithmetic mean of (ENCE)% | 64.0 |      |      |      |
| Standard deviation of each burner | 0.51 | 1.41 | 0.42 | 0.33 |
| Individual weight | 3.9  | 0.5  | 5.8  | 9.4  |
| Weighted Mean (ENCE)% |      |      |      | 62.8 |

Considering the specification range, according to ordinance Nº. 400 of August 1, 2012 [7, 8], (61.1 % to 64.9 %), the result of Laboratory A does not meet by the traditional approach, 65.0 %; however, by the proposed approach, it fit into the specification. For Laboratory B, the results of both approaches meet the specification, 64.0 % (traditional) and 62.8 % (proposed), Table 7.

**Table 7 – Comparison of results**

|                 | Laboratory A | Laboratory B |
|-----------------|--------------|--------------|
| Traditional     | 65.0 %       | 64.0 %       |
| Proposed        | 64.9 %       | 62.8 %       |

5. Conclusions
Based on results generated in the development of this study, it was possible to compare statistically two experiments, one at sea level and the other at altitude above sea level. Here, new approach proposes calculating the efficiency of tabletop burners in domestic stoves using weighted position measures after treating outliers. The arithmetic mean currently used considers a principle of equality in
the burners, however as they have different potencies and consequently different efficiencies, one should be weighted them by their dispersion measures.

For future studies, it is proposed to evaluate the algorithms involved, specifically the effect of atmospheric pressure and the implementation of the uncertainty calculation, in order to evaluate its influence on the results reported to the consumer.

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