Final Report of the Interlaboratory Comparison in Diesel Cycle Motors Emissions Tests

Inmetro
Instituto Nacional de Metrologia, Qualidade e Tecnologia

PEP-Inmetro

Programa de Ensaios de Proficiência do Inmetro

INTERLABORATORY COMPARISON IN DIESEL CYCLE MOTORS EMISSIONS TESTS

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SUMMARY

1 Introduction

Due to requirements of regulatory bodies and accreditation bodies, there is an increasing need to execute better measurement tests. Besides, due to constant emissions limit reductions, measurement methods should fit these new needs. Gases emissions analysis became one of the more sensitive items in a dynamometer bench motor test.

In this sense, the execution of interlaboratory comparisons (CI) in Diesel Cycle Motors aims the participants' performance evaluation in the determination of presented values, providing subsidies for the identification and solution of analytic problems and contributing to the harmonization of measurement results in the country, besides being a tool for data generation that can support new regulations.

Interlaboratory comparison is a quality tool for the identification of differences between laboratories, but the evaluation is punctual. An IC has the aim to compare measurement results of different participants, accomplished under similar conditions, and, thus, to obtain an evaluation of the technical skills of participants, providing them with an adequate mechanism to assess and to demonstrate reliability in their measurement results. Participants, in turn, have the opportunity to review their analysis procedures, as well as to implement improvements in their processes, as necessary.

This IC analyzed the emissions of the following parameters: CO, CO_2, HC, NO_x, Particulate Material e Average Specific Consumption in g/kWh and two comparison items were used, a Diesel motor offered by MWM Company and a Diesel motor offered by the Cummins Company. Participants were divided into two groups, group A (that analyzed MWM motor) and group B (that analyzed Cummins motor).

This report presents the result of the participants' performance, the methodology used in tests and the statistical analysis procedure.

This IC had as general objectives:
1) to compare laboratory results for the proposed tests;
2) to monitor laboratory results of Consumption analysis and regulated MAR I and P7 polluting;
3) to contribute to the confidence in laboratories measurement results that perform emissions dynamometer bench motor test;
4) to contribute to the continuous improvement of measurement techniques of regulated MAR I and P7 polluting and consumption of each laboratory.

2 Materials and Methods

2.1 Test Items

This IC used two comparisons items, a Diesel motor offered by MWM Company and a Diesel motor offered by Cummins Company. Although participants had to use the commercial fuel S10, motor provider laboratory performed a test with three types of diesel (Reference Diesel, Diesel without biodiesel and commercial Diesel) to determine possible dispersions among them. Due to the Diesel modifications since March/2018, participants that performed measurements after this date had to stock diesel for not having dispersions results.

Table 1- Comparison items characteristics.

Manufacturer	**MWM**	**Cummins**
Model	MAXX FORCE 7.2H	ISBe 6.7
Motor Number	Y1A031329	36533096
Fuel	Diesel – S10	Diesel – S10
Oil type	Ursa Premium TDX SAE 15W40	Premium Blue 15W40 – API CI4
Oil quantity	20,000 g	17.5 liters
Cooling Fluid	10 % Havoline XLI YF03	Etileno Glicol (50 %)
Diesel Oil Filter	478736	4989314
Carter Capacity	21438854	5262311

2.2 Metodology

Prescribed standards for participants to perform tests were ABNT NBR 15634:2012 and ISO 8178:2012. A performance curve was designed before emissions tests to evaluate the motor conditions. The instrumentation points and performance curve were available, according to assembly instruction, respecting, respectively, the characteristic of each motor.

Two distinct tests were performed, namely:

- Determination of Mean Specific Emission CO, CO_2, HC, NO_x, Particulate Material and Mean Specific Consumption in g/kWh, according to ABNT 15634:2012;
- Determination of Mean Specific Emission CO, CO_2, HC, NO_x, Particulate Material and Mean Specific Consumption in g/kWh, according to ISO 8178:2012.

Other parameters were measures by participants, but were not considered in the statistical evaluation for this IC. They will serve to assess possible discrepancies in the process of emission measurement by the participants themselves.

They are:

Rotation (rpm), Observed Torque (N.m), Observed Power (kW), Observed specific consumption (g/kWh), Debit (mg/str), Fuel Flow (kg/h), Intake air temperature – T1 (ºC), Intercooler input Temperature – T21 (ºC), Intercooler output Temperature – T22 (ºC), Exhaust manifold Temperature – T3 (ºC), Exhaust Temperature – T4 (ºC), Diesel Temperature (ºC), Lubricating oil temperature (ºC), Coolant Temperature (ºC), Air Intake Restriction Pressure - P1 (kPa), Intercooler inlet pressure – P21 (kPa), Intercooler outlet pressure – P22 (kPa), Exhaust manifold outlet pressure – P3 (kPa), Escape counter pressure – P4 (kPa), Barometric Pressure (kPa), Atmospheric Factor, Relative humidity (% UR), Air flow (kg/h), CO concentration (ppm), NO_x concentration (ppm), HC concentration (ppm), CO_2 concentration (ppm).

Participants were split into two distinct groups, A and B, the tables 2, 3, 4, 5, 6 and 7 show the boundary conditions and the reference values for the test in each group. A CETESB representative witnessed one of the five measurements of the IC, within each specific curve, in each participant site.

Table 2 - Characteristics for Group A test – P7 / MAR I.

Variable	Reference Value
Air filter restriction pressure	(5.0 ± 0.5) kPa
Intercooler Pressure Delta	(10 ± 2) kPa
Exhaust back pressure	(20 ± 2) kPa
Inlet air temperature	(20 ± 2) ºC
Air temperature at the intercooler outlet	(40 ± 2) ºC
Diesel temperature	(40 ± 2) ºC
Coolant temperature	85 ºC
Oil temperature	110 ºC
Relative humidity	50 % UR
Accelerator Pedal Linearization	0 % = 0.66 V and 100 % = 4.0 V

Table 3 - *Set Point* P7 - 13 points - Group A.

***Speed* [RPM]**	700	1399	1716	1716	1399	1399	1399	1716	1716	2032	2032	2032	2032
Torque [N·m]	0	740	369	553	370	555	185	738	184	706	176	530	353

Table 4 - *Set Point* MAR I - 8 points - Group A.

***Speed* [RPM]**	2200	2200	2200	2200	1300	1300	1300	700
Torque [N·m]	671	503	335	67	740	555	370	0

Table 5 - Characteristics for Group B test – P7 / MAR I.

Variable	Reference Value
Air filter restriction pressure	(3.7 ± 0.3) kPa
Intercooler Pressure Delta	(13.5 ± 0.5) kPa
Exhaust back pressure	(20.3 ± 0.5) kPa
Inlet air temperature	(21 ± 1) °C
Air temperature at the intercooler outlet	(49 ± 1) °C
Diesel temperature	(40 ± 1) °C
Coolant temperature (output)	(89 ± 2) °C
Oil temperature (Reference)	110 °C
Relative humidity	(50 ± 5)% UR
Accelerator Pedal Linearization	0 % = 1.45 V 50 % = 2.94 V 100 % = 4.38 V
Set Point – Rotation / Charge 13 points	2300 rpm with 100 % pedal (4.37 V)

Table 6 - *Set Point* P7 - 13 points - Group B.

***Speed* [RPM]**	700	1450	1768	1768	1450	1450	1768	1768	1768	2086	2086	2086	2086
Torque [N·m]	0	857	425	638	429	643	215	850	212	819	205	615	409

Table 7 - *Set Point* MAR I - 8 points - Group B.

***Speed* [RPM]**	2300	2300	2300	2300	1450	1450	1450	700
Torque [N·m]	770	577	385	77	857	643	429	0

3 Comparison Items Integrity

It was verified whether there is a statistically significant difference between the measurements CO, CO_2, HC, NO_x, PM and Corrected Consumption in g/kWh in the first analysis (X_1) and in the second analysis (X_2) for the 2 (two) tested Diesel motors, with p-values, with p-value less than 0.05. Thereby, it can be stated that, at a 95 % level of confidence, there is a statistically significant difference among averages and the sample data can be assumed as not coming from the same population. Thus, the 2 (two) tested Diesel Motors did not keep integrity during the Interlaboratory comparison. This situation did not prevent the tests to be done and that conclusions could be extracted regarding this activity.

Due to confidentiality of results, once MWM company and CUMMINS company are also IC participants, these results will not be presented.

4 Results evaluation

4.1 ANOVA and LSD

For the comparison among the average of all participants it was used the single-factor ANOVA comparison method for each parameter. This method uses a single test to determine if there are differences among participants averages instead of paired comparisons, the way is done with t test.

After ANOVA, if there is any participant that presented discrepant results it will be applied the procedure named "Least Significant Difference" (LSD) to identify which specific participant averages differ from others. This method calculates a difference, which is evaluated as the least difference that is significant. The difference between each pair of averages is then compared to the least significant difference to determine which averages are different.

For an equal number of replicas Ng for each participant, the least significant difference is calculated according to the equation below:

$$DMS = t \cdot \sqrt{\frac{2 \cdot MQE}{N_g}} \tag{1}$$

Where:

LSD = Least Siginficant Difference

t = t student

MQE = Mean Square Error

N_g = Replicates for each participant

4.2 Visualization of Results and Outliers Detection: Box-Plot

Box plot is a graphic used for visualization of the data set distribution. It consists of five measures: 1st quartile (Q1), 3rd quartile (Q3), median (Q2), minimum value (LI) and maximum value (LS). Besides, the box plot can be employed for outliers evaluation. This way, minimum and maximum values are calculated according to the equations below:

$$LI = Q_1 - 1.5 * (Q_3 - Q_1) \tag{2}$$

$$LS = Q_3 + 1.5 * (Q_3 - Q_1) \tag{3}$$

The diagnosis for detection of outliers is given by the following rule:

If the obtained value >LS or the obtained value <LI, the obtained value is considered an outlier;

If LI ≤ the obtained value ≤ LS, the obtained value is not considered an outlier;

Where the obtained value is the measurement result of each parameter for participant.

5 Results Presentation

5.1 Results Dispersion

In the presentation of the graphs for all tested parameters, a continuous gray line represents the average of the participants' results. The blue and red lines are, respectively, representations of Ref ± 1s and Ref ± 2s, where "Ref" is the average and "s" is the standard-deviation.

In this report, the last three characters of its identification code in tables, graphs and texts identify each participant.

5.1.1 Emissions Group A – MAR I

Figures 1 to 7 graphically present the average and standard-deviations of reported results for emission data by participants for each analyzed parameter.

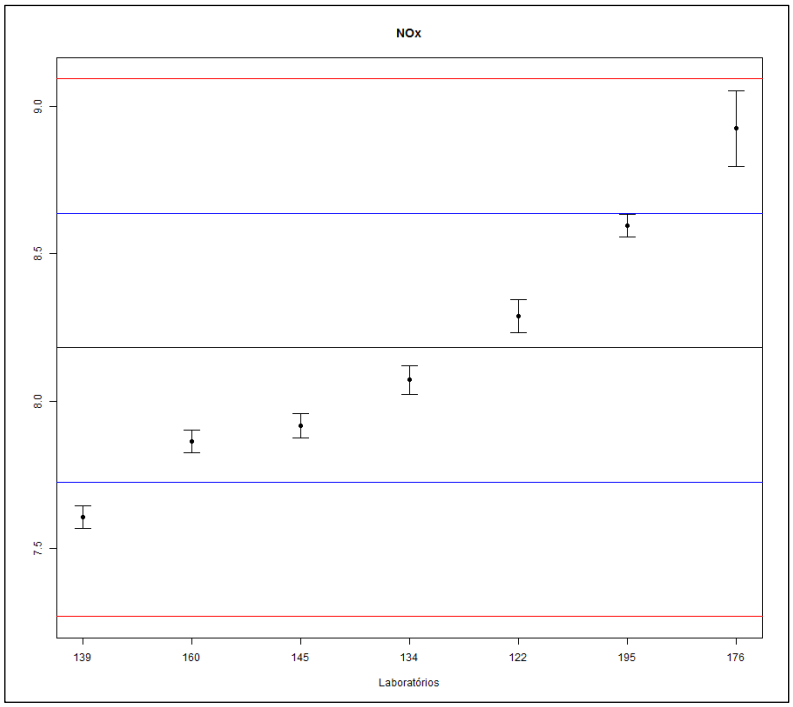

Figure 1 – Scatter plot of participants results for NO_x – Group A – MAR I.

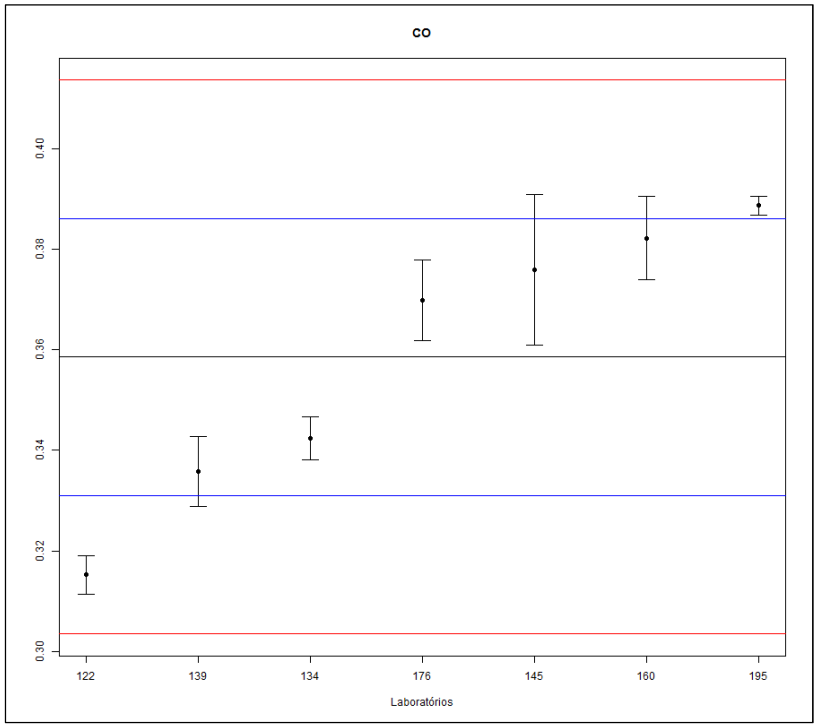

Figure 2 – Scatter plot of participants results for CO – Group A – MAR I.

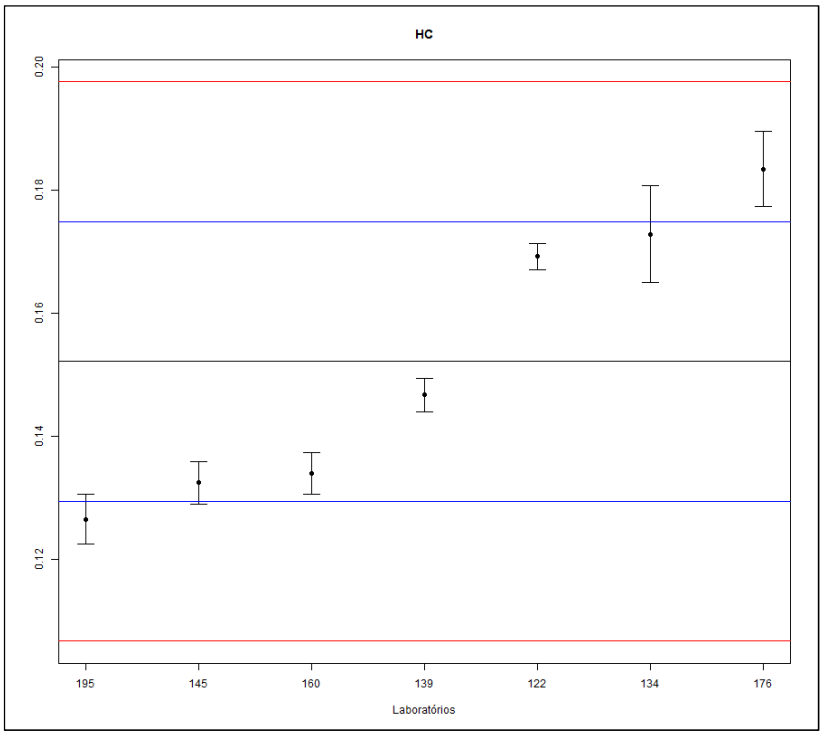

Figure 3 – Scatter plot of participants results for HC – Group A – MAR I.

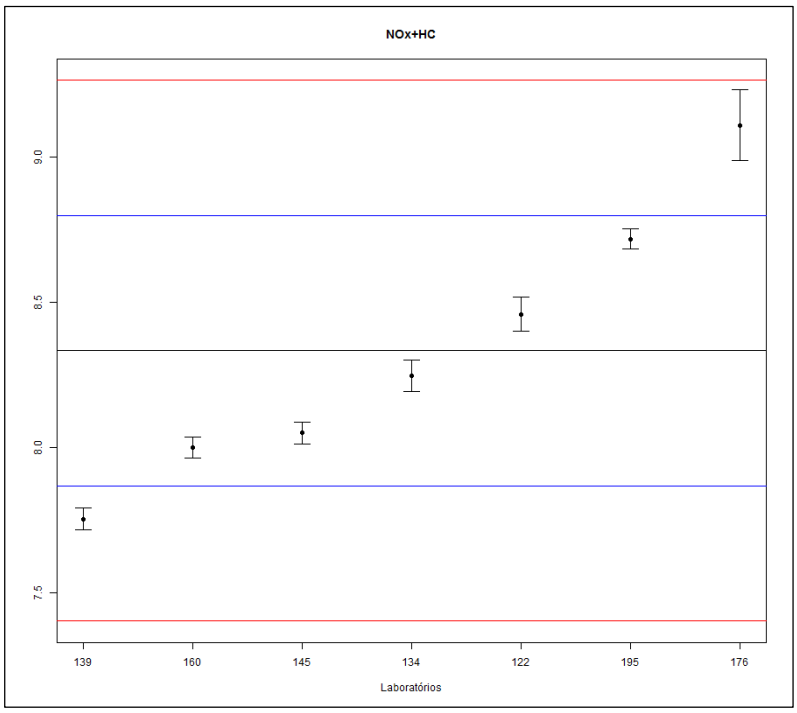

Figure 4 – Scatter plot of participants results for NO_x+HC – Group A – MAR I.

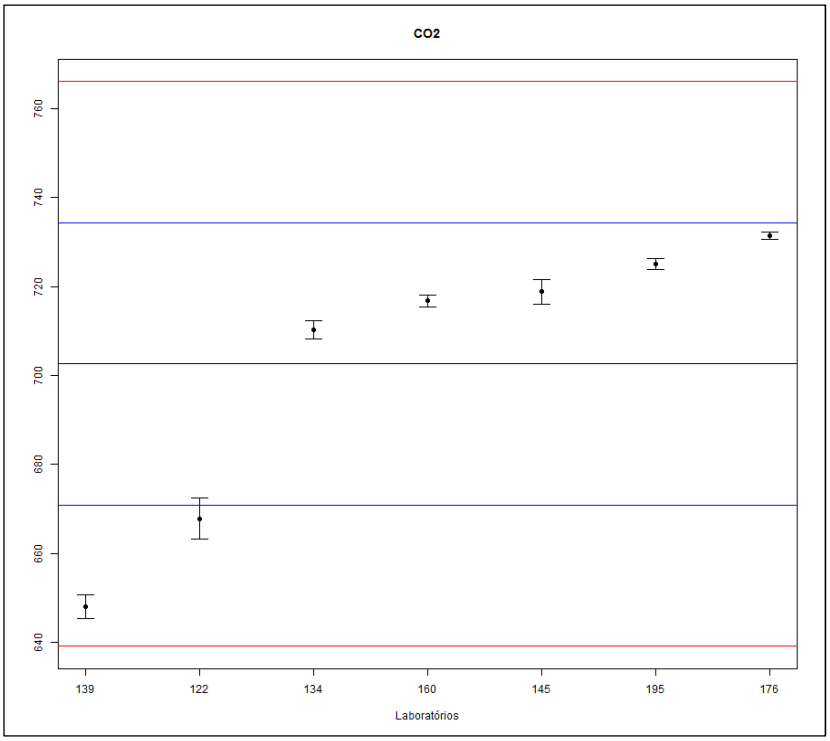

Figure 5 – Scatter plot of participants results for CO_2 – Group A – MAR I.

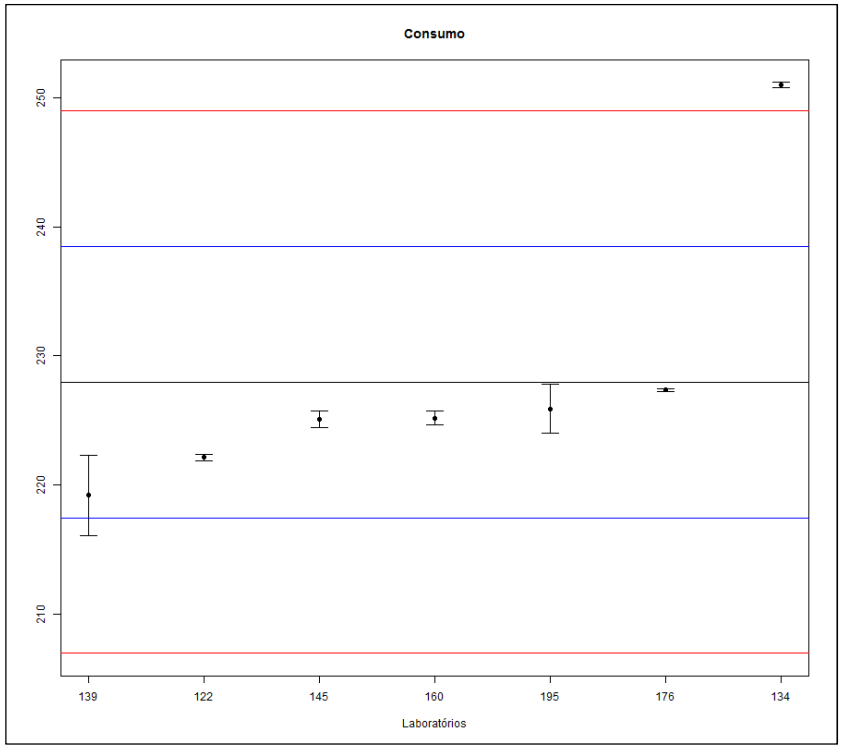

Figure 6 – Scatter plot of participants results for Consumption – Group A – MAR I.

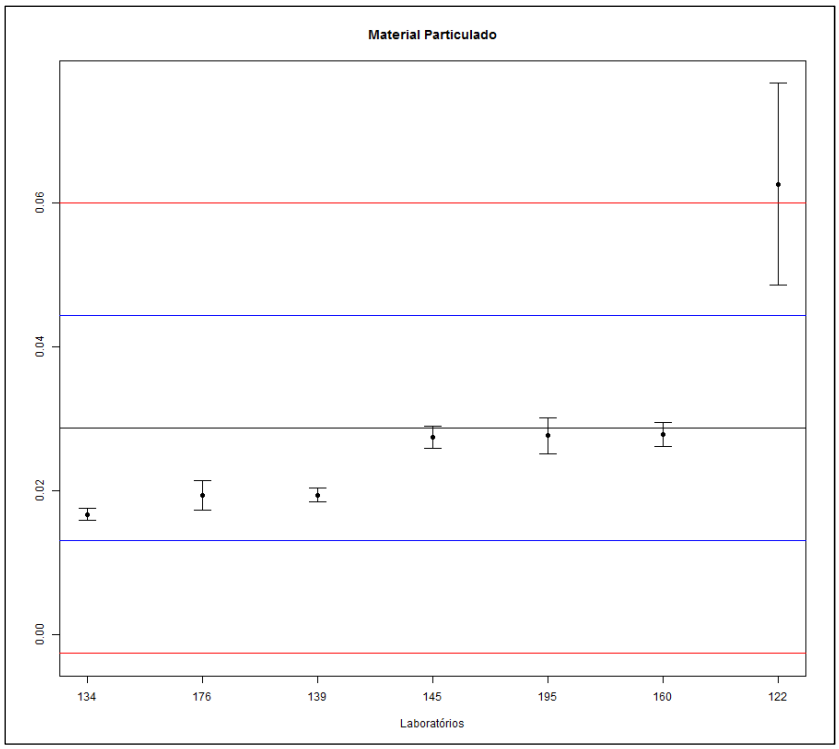

Figure 7 – Scatter plot of participants results for Particulate Material– Group A – MAR I.

Through the graphs, it can be seen that:

NO_x (g/kWh): all 7 participants presented results within the Ref ± 2s interval; participant 176 presented the greatest dispersion.

CO (g/kWh): all 7 participants presented results within the Ref ± 2s interval; participant 145 presented the greatest dispersion.

HC (g/kWh): all 7 participants presented results within the Ref ± 2s interval; participant 134 presented the greatest dispersion.

NO_x+HC (g/kWh): all 7 participants presented results within the Ref ± 2s interval; participant 176 presented the greatest dispersion.

CO_2 (g/kWh): 5 participants presented results within the Ref ± 1s interval and the remaining 2 participants within the Ref ± 2s interval; there was a low dispersion of results.

Consumption (g/kWh): 6 participants presented results within the Ref ± 1s interval; participant 134 presented questionable result.

Particulate Material: 6 participants presented results within the Ref ± 1s interval; participant 122 presented questionable result.

5.1.2 Emissions Group A – P7

Figures 8 to 14 graphically present the average and standard-deviations of reported results for emission data by participants for each analyzed parameter.

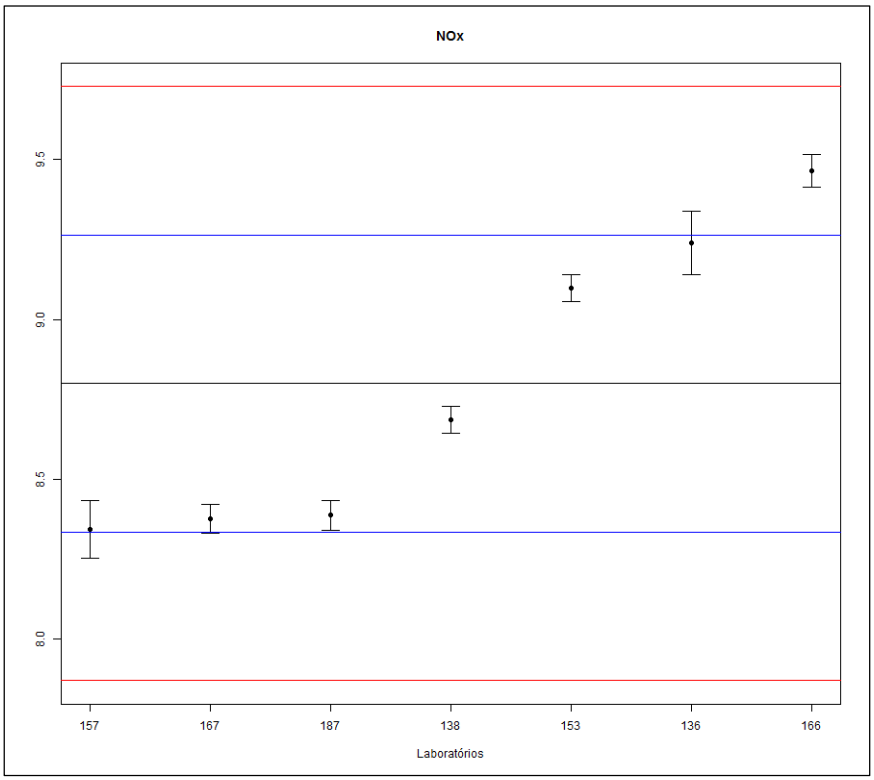

Figure 8 – Scatter plot of participants results for NO_x – Group A – P7.

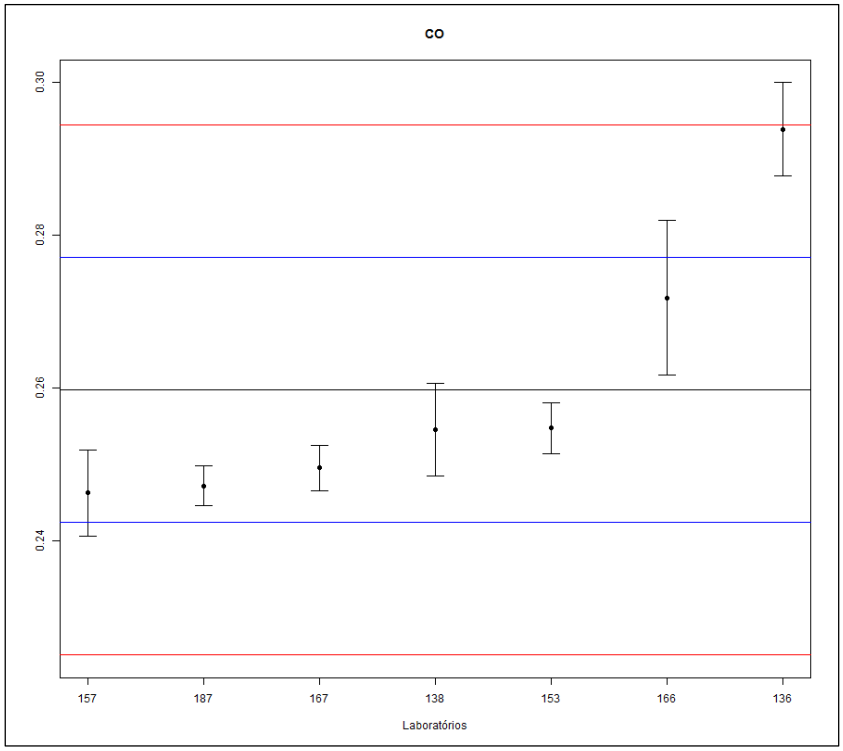

Figure 9 – Scatter plot of participants results for CO – Group A – P7.

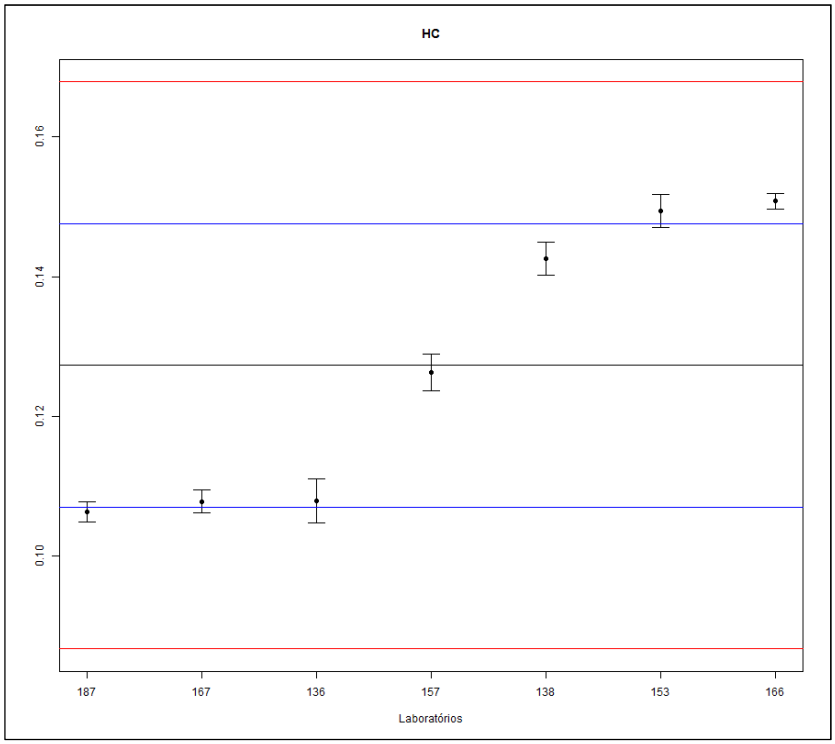

Figure 10 – Scatter plot of participants results for HC – Group A – P7.

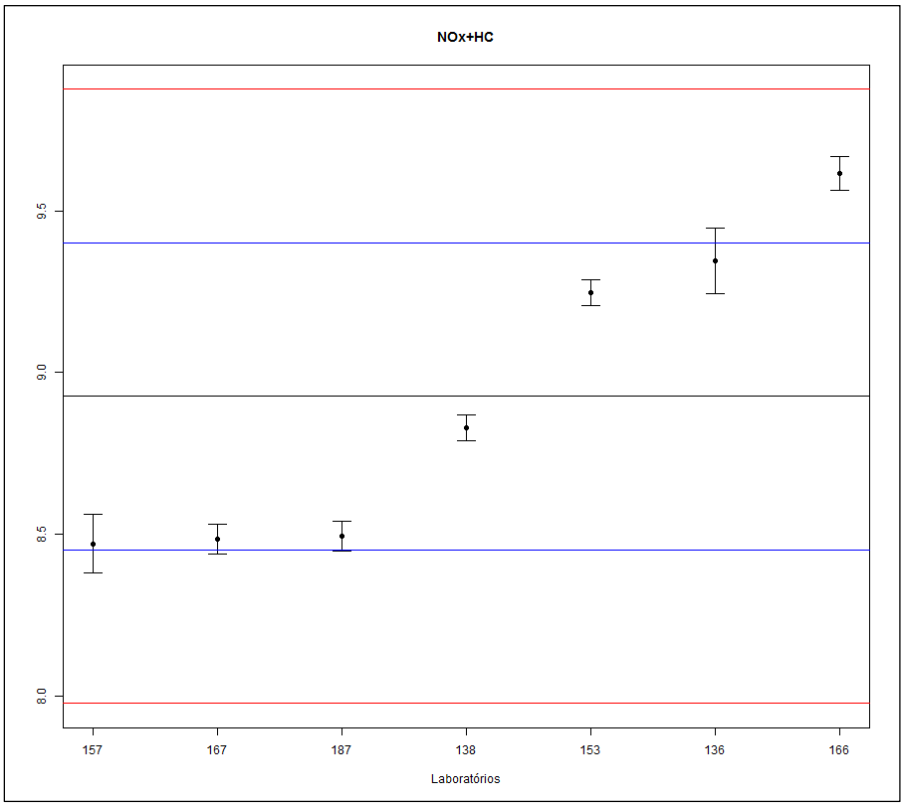

Figure 11 – Scatter plot of participants results for NO_x+HC – Group A – P7.

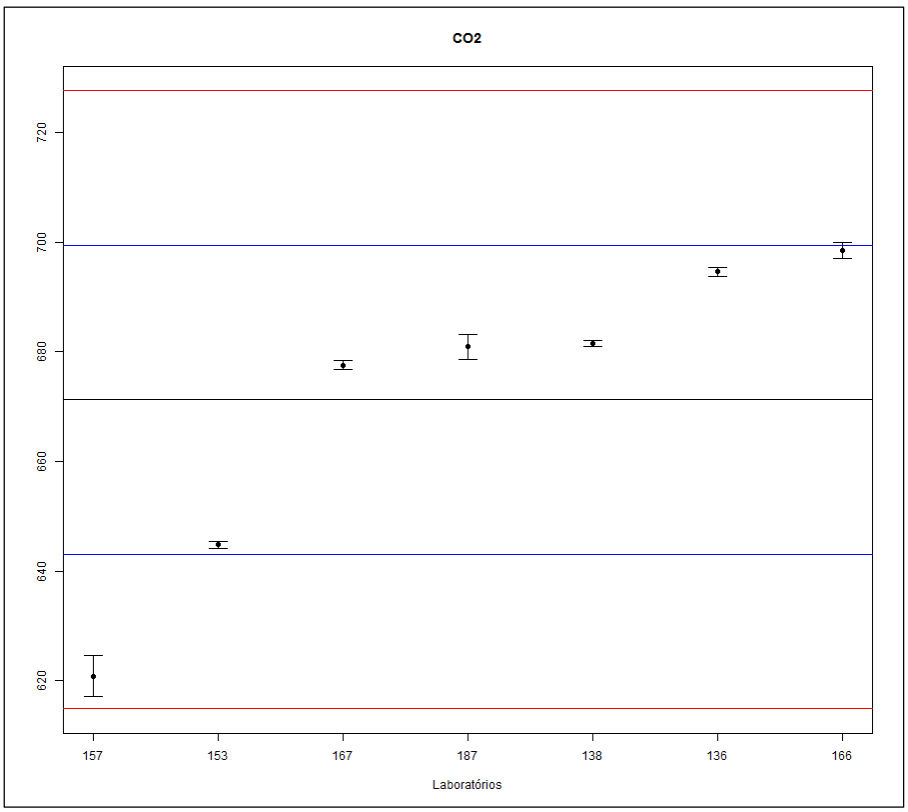

Figure 12 – Scatter plot of participants results for CO_2 – Group A – P7.

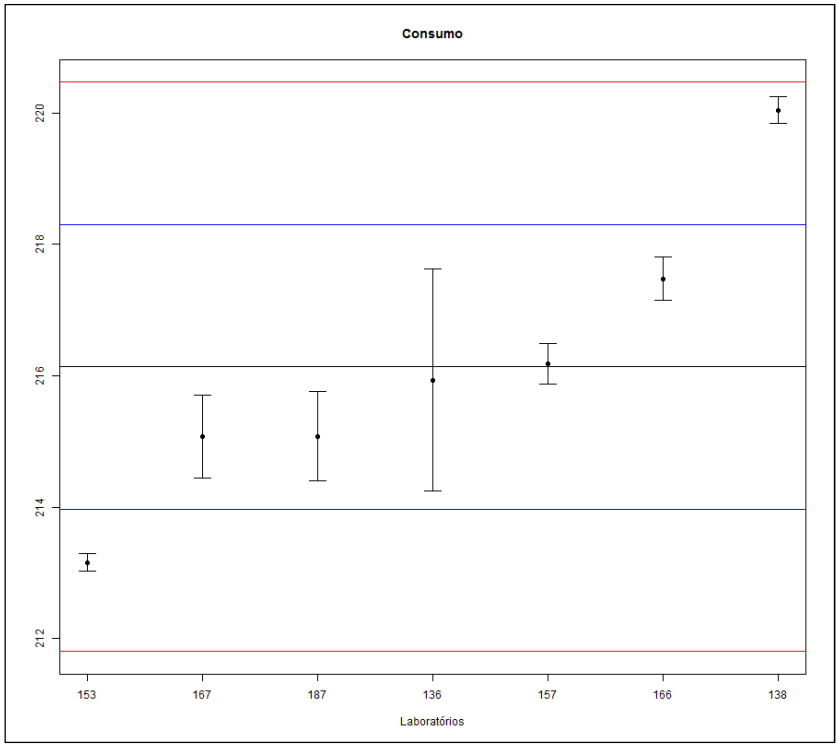

Figure 13 – Scatter plot of participants results for Consumption – Group A – P7.

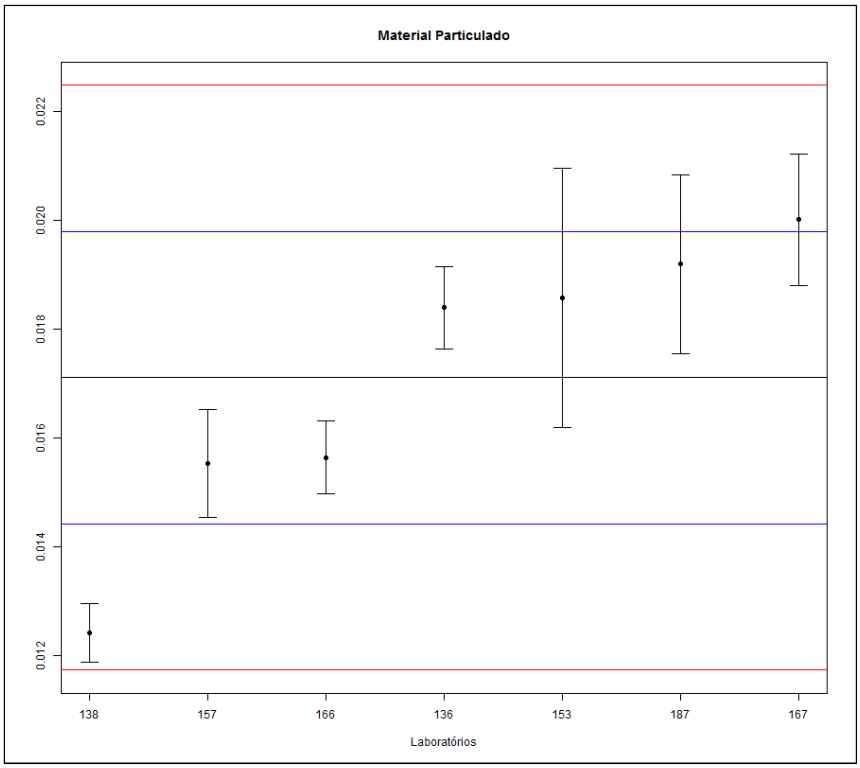

Figure 14 **–** Scatter plot of participants results for Particulate Material – Group A – P7.

Through the graphs, it can be seen that:

NO_x (g/km): 6 participants presented results between the Ref ± 1s interval and 1 participant within the Ref ± 2s interval; there was a low results dispersion.

CO (g/km): 6 participants presented results within the Ref ± 1s interval and 1 participant within the Ref ± 2s interval; participant 166 presented the greatest dispersion.

HC (g/km): 5 participants presented results within the Ref ± 1s interval and the remaining 2 participants' results are within the Ref ± 2s interval.

NO_x+HC (g/km): 6 participants presented results within the Ref ± 1s interval and 1 participant within the Ref ± 2s interval.

CO_2 (g/km): 6 participants presented results within the Ref ± 1s interval and 1 participant within the Ref ± 2s interval; there was a low results dispersion.

Consumption (g/kWh): 5 participants presented results within the Ref ± 1s and the remaining 2 participants' results are within the Ref ± 2s interval. Participant 136 presented de the greatest results dispersion.

Particulate Material: 5 participants presented results within the Ref ± 1s and the remaining 2 participants' results are within the Ref ± 2s interval. Participant 153 presented the greatest results dispersion, followed by participant 187 on a smaller scale.

5.1.3 Emissions Group B – MAR I

Figures 15 to 21 graphically present the average and standard-deviations of reported results for emission data by participants of Group B – MAR I for each analyzed parameter.

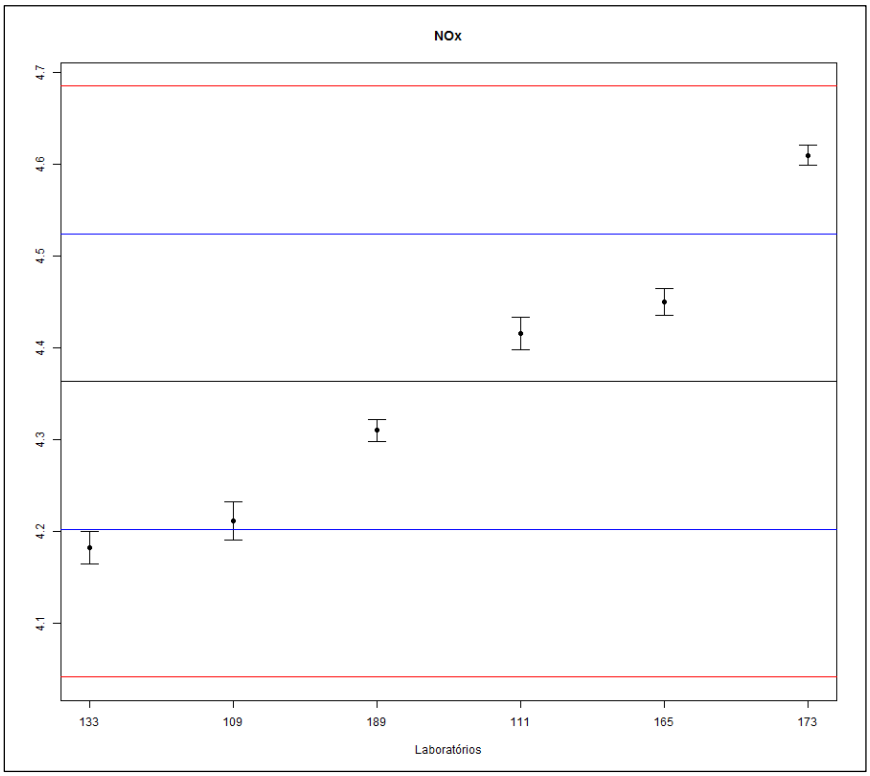

Figure 15 – Scatter plot of participants results for NO_x – Group B – MAR I.

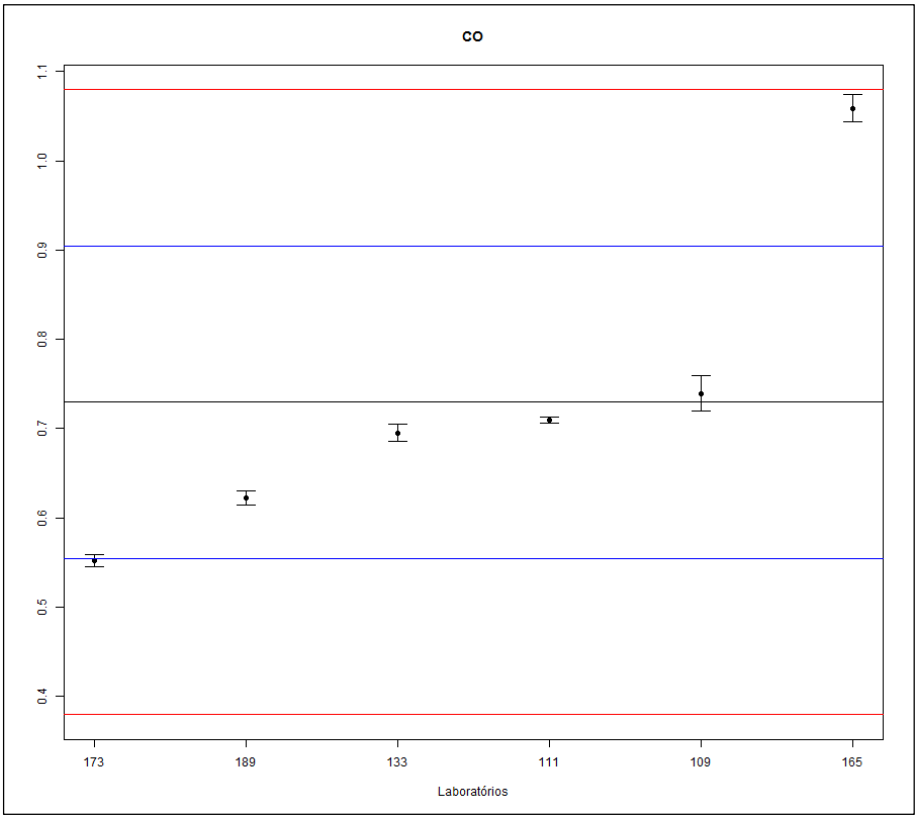

Figure 16 – Scatter plot of participants results for CO – Group B – MAR I.

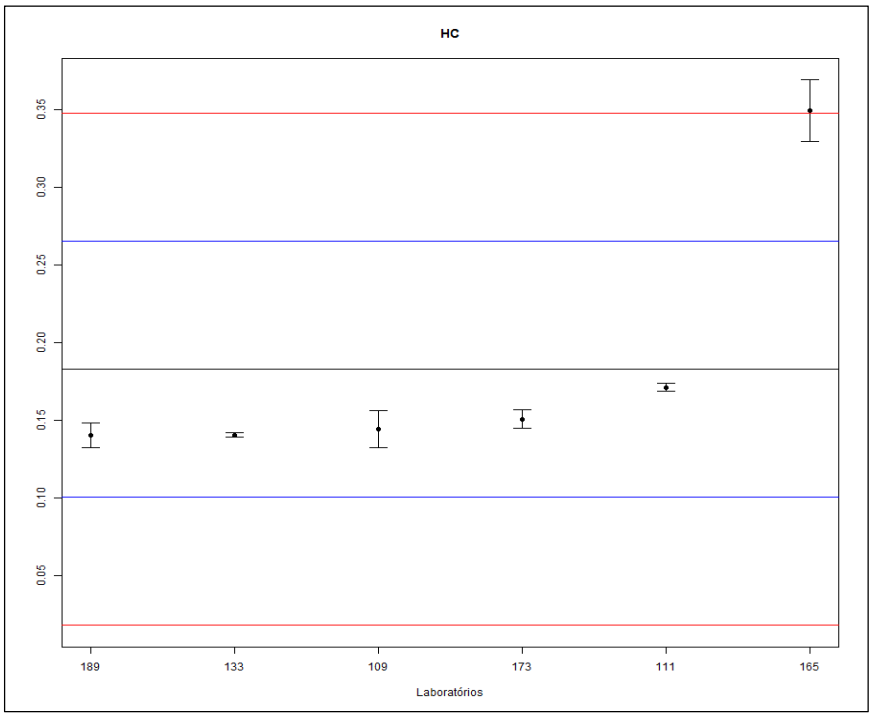

Figure 17 – Scatter plot of participants results for HC – Group B – MAR I.

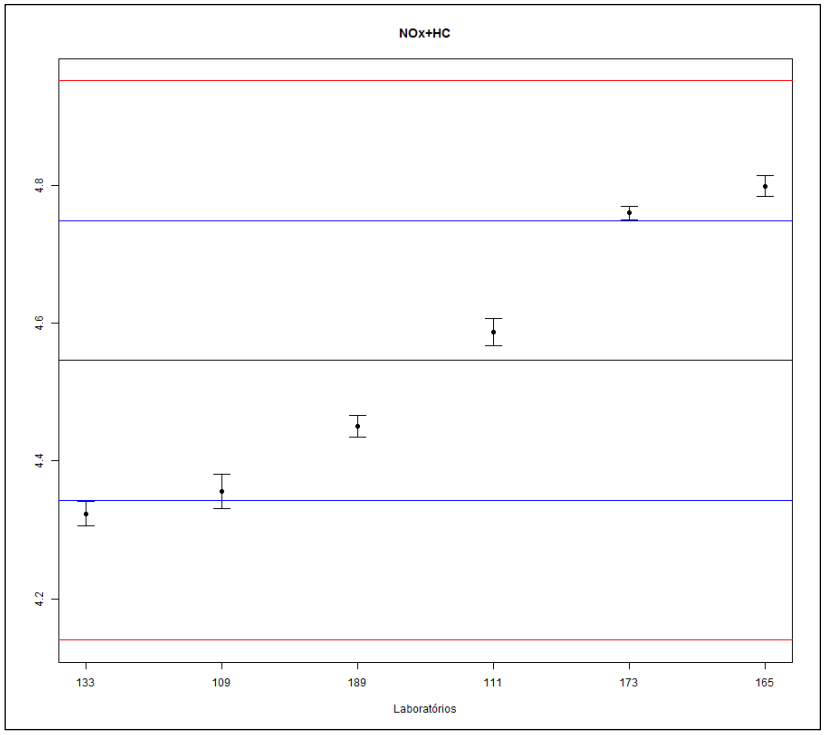

Figure 18 – Scatter plot of participants results for NO_x+HC – Group B – MAR I.

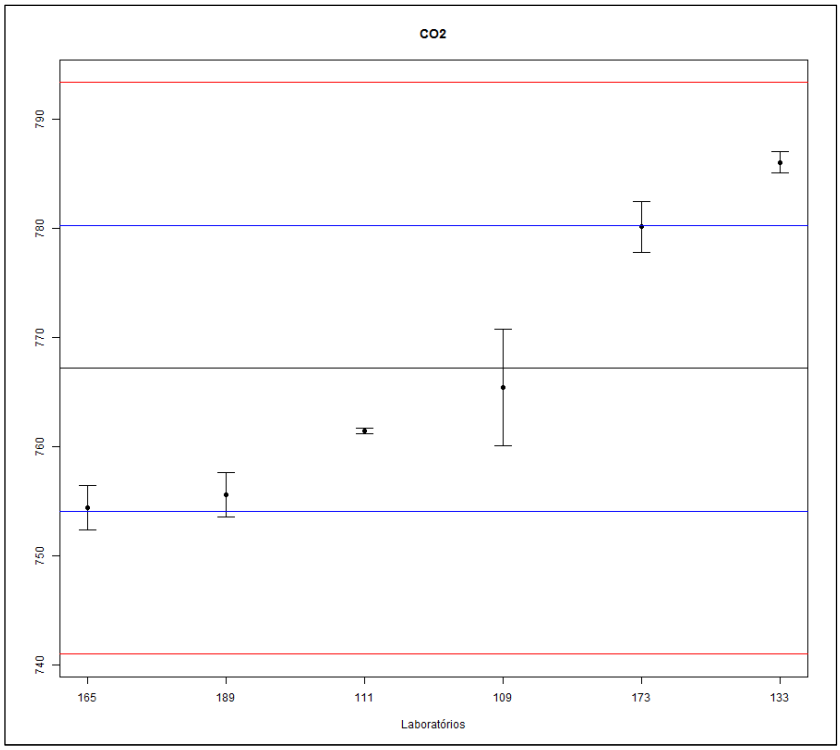

Figure 19 – Scatter plot of participants results for CO_2 – Group B – MAR I.

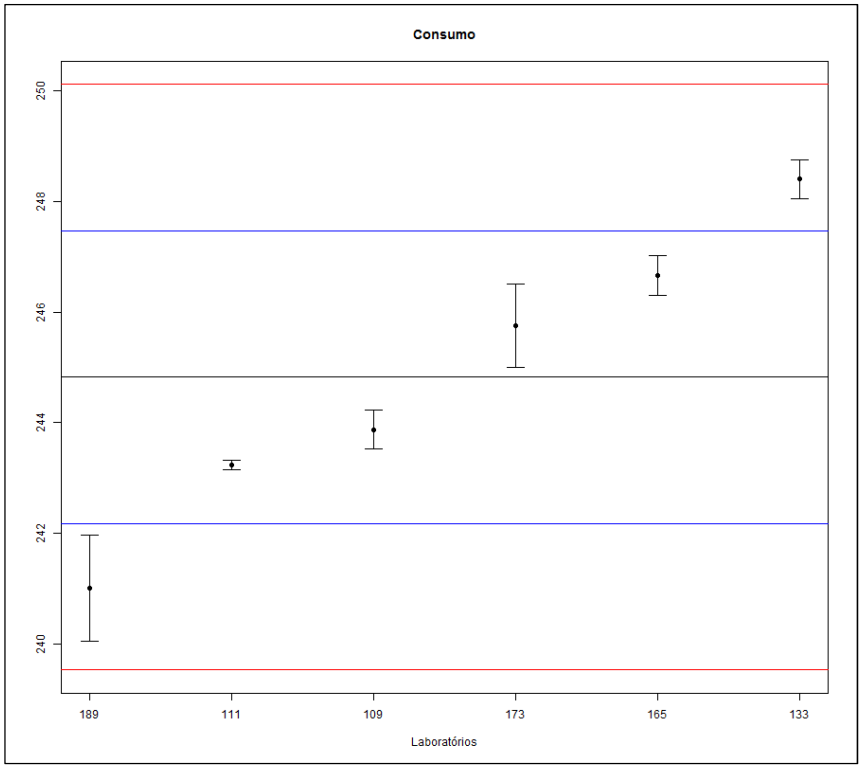

Figure 20 – Scatter plot of participants results for Consumption – Group B – MAR I.

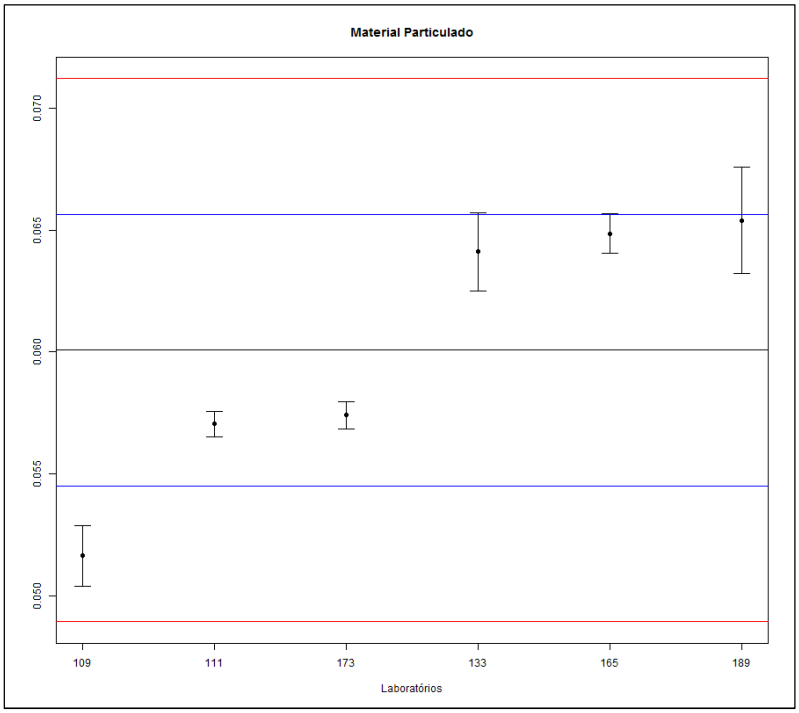

Figure 21 – Scatter plot of participants results for Particulate Material– Group B – MAR I.

Through the graphs, it can be seen that:

NO_x (g/km): 4 participants presented results within the Ref ± 1s and the remaining 2 participants' results are within the Ref ± 2s interval.

CO (g/km): 4 participants presented results within the Ref ± 1s interval and the remaining 2 participants' results are within the Ref ± 2s interval; there was a low results dispersion.

HC (g/km): 5 participants presented results within the Ref ± 1s interval and 1 participant presented a questionable result.

NO_x+HC (g/km): 3 participants presented results within the Ref ± 1s interval and the remaining 3 participants' results are within the Ref ± 2s interval.

CO_2 (g/km): 5 participants presented results within the Ref ± 1s interval and 1 participant within the Ref ± 2s interval; participant 109 presented the greatest results dispersion.

Consumption (g/kWh): 4 participants presented results within the Ref ± 1s interval and the remaining 2 participants' results are within the Ref ± 2s interval; participant 189 presented the greatest results dispersion.

Particulate Material: 5 participants presented results within the Ref ± 1s interval and 1 participant within the Ref ± 2s interval; participant 189 presented the greatest results dispersion.

5.1.4 Emissions Group B – P7

Figures 22 to 28 graphically present the average and standard-deviations of reported results for emission data by participants of Group B – P7 for each analyzed parameter.

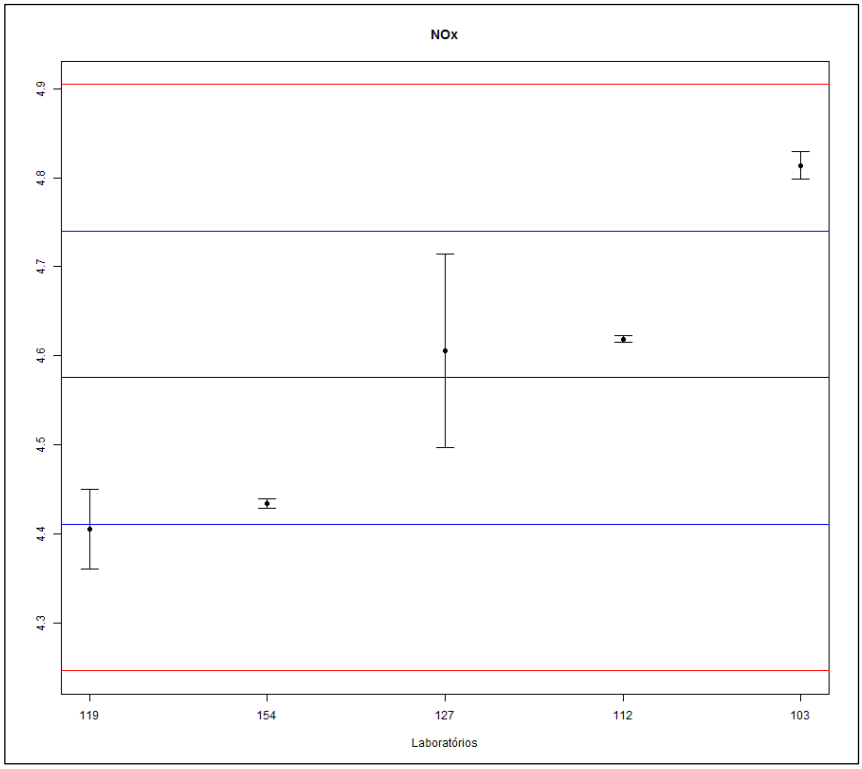

Figure 22 – Scatter plot of participants results for NO_x – Group B – P7.

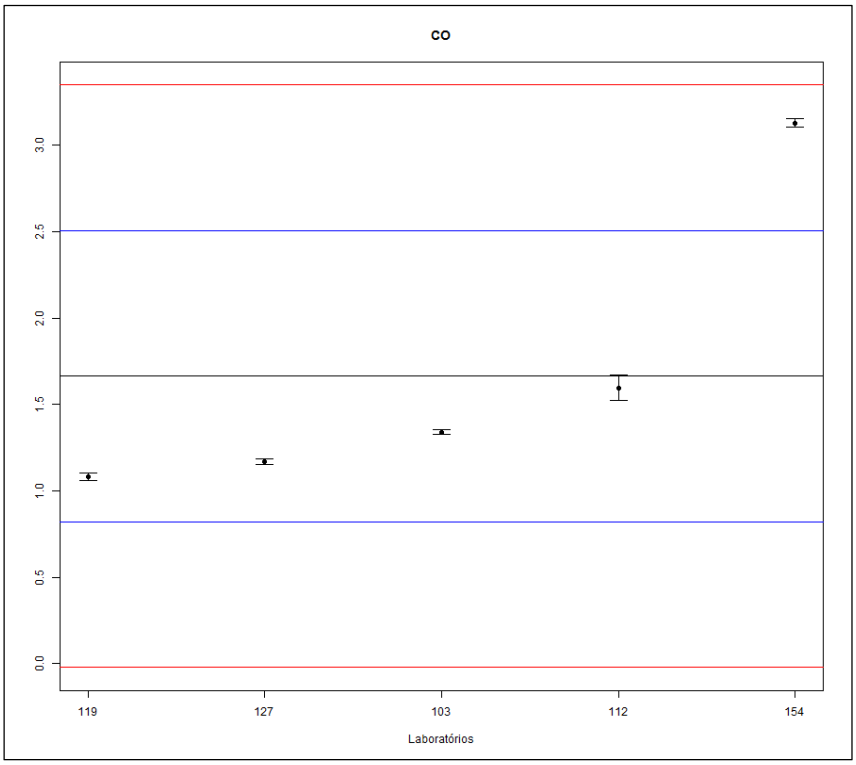

Figure 23 – Scatter plot of participants results for CO – Group B – P7.

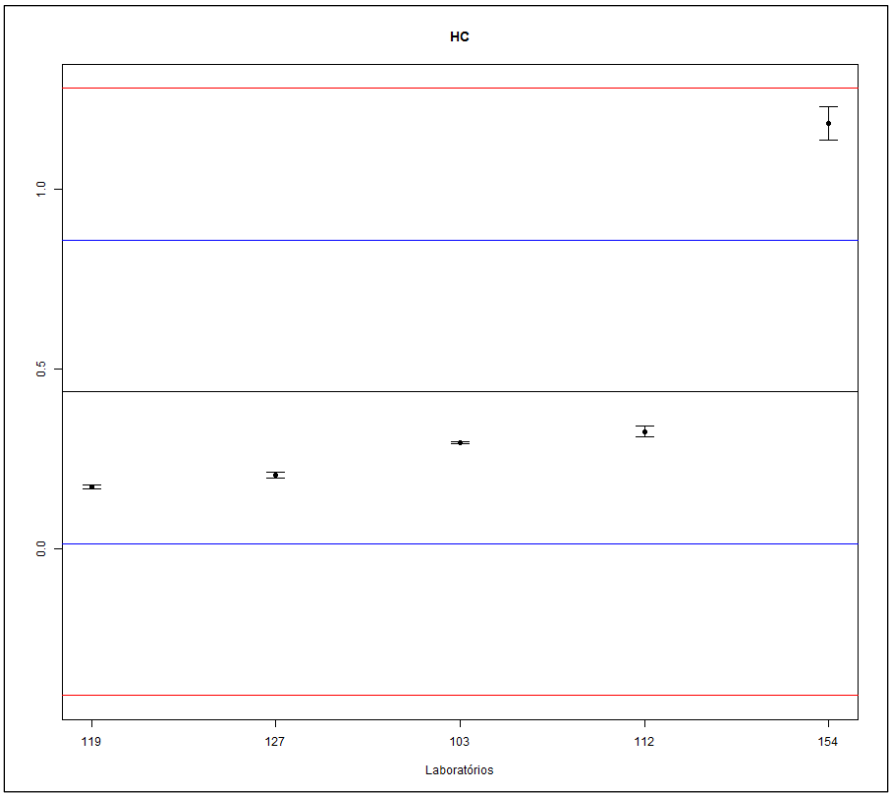

Figure 24 – Scatter plot of participants results for HC – Group B – P7.

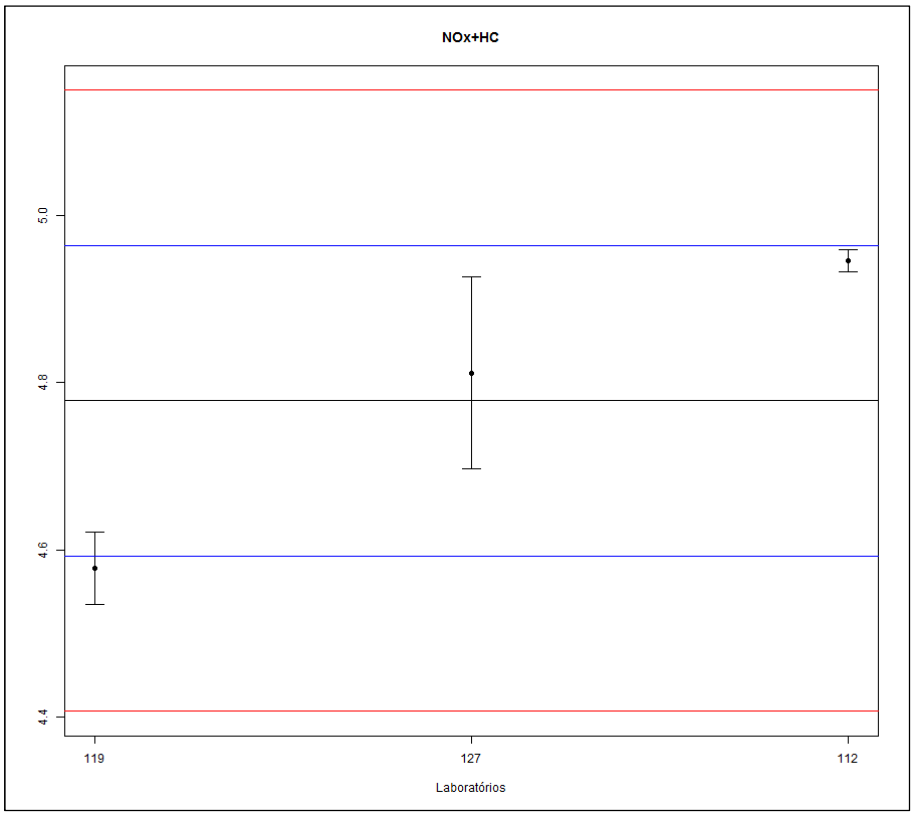

Figure 25 – Scatter plot of participants results for NO_x+HC – Group B – P7.

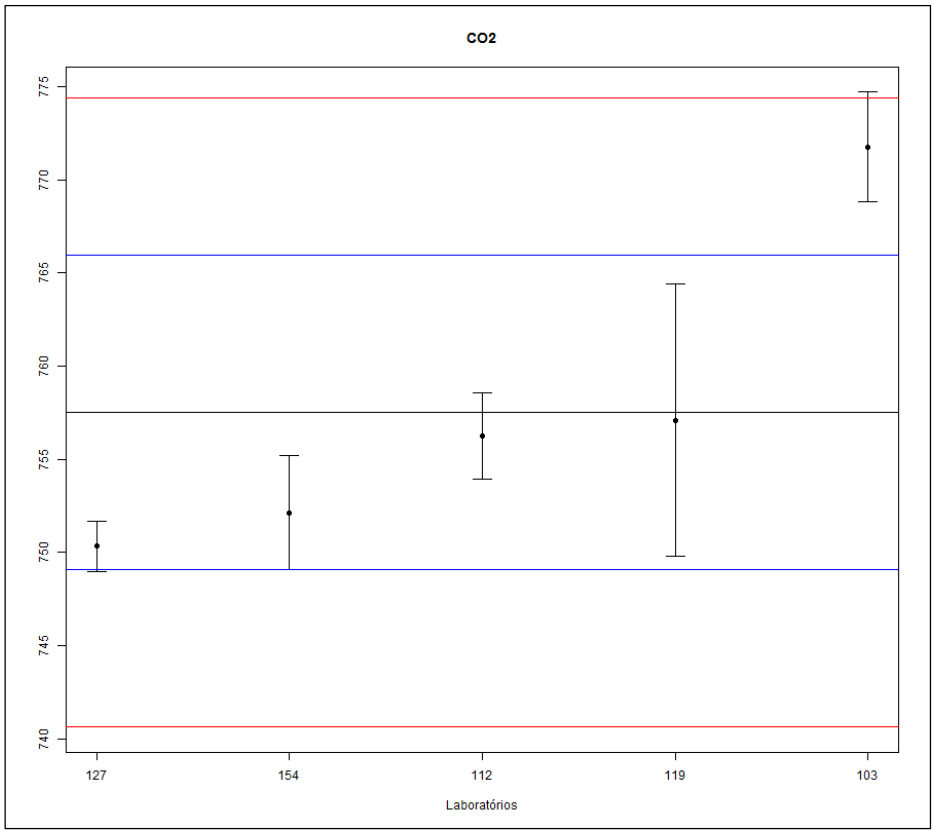

Figure 26 – Scatter plot of participants results for CO_2 – Group B – P7.

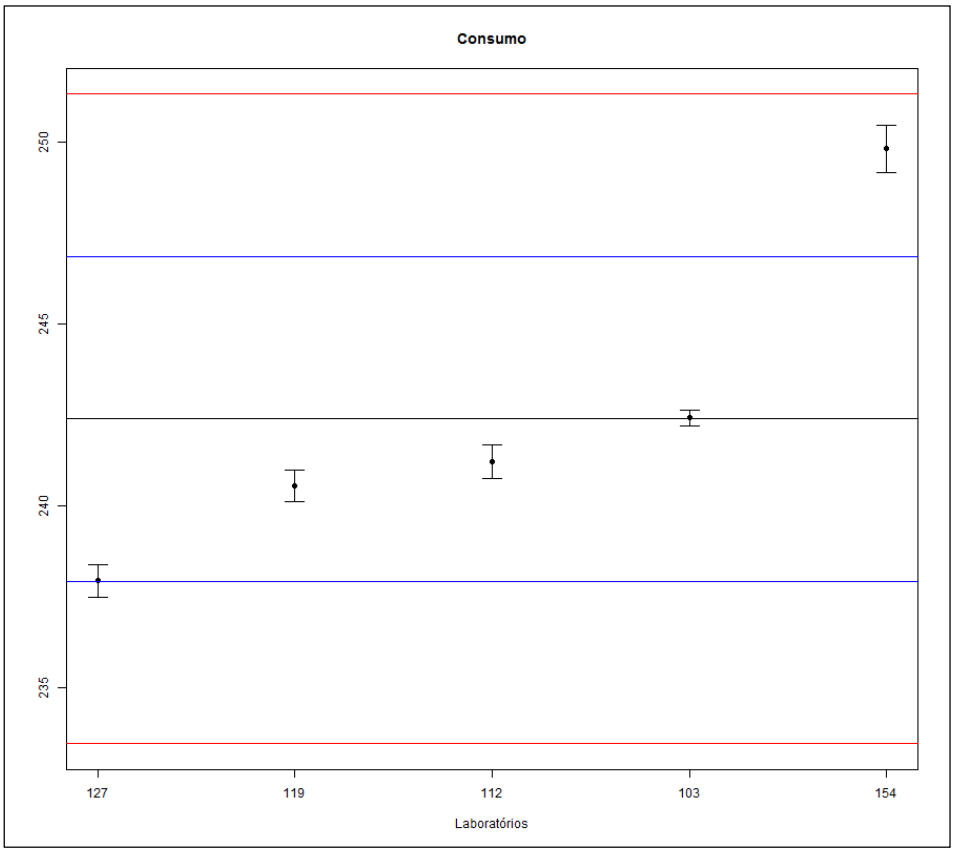

Figure 27 – Scatter plot of participants results for Consumption – Group B – P7.

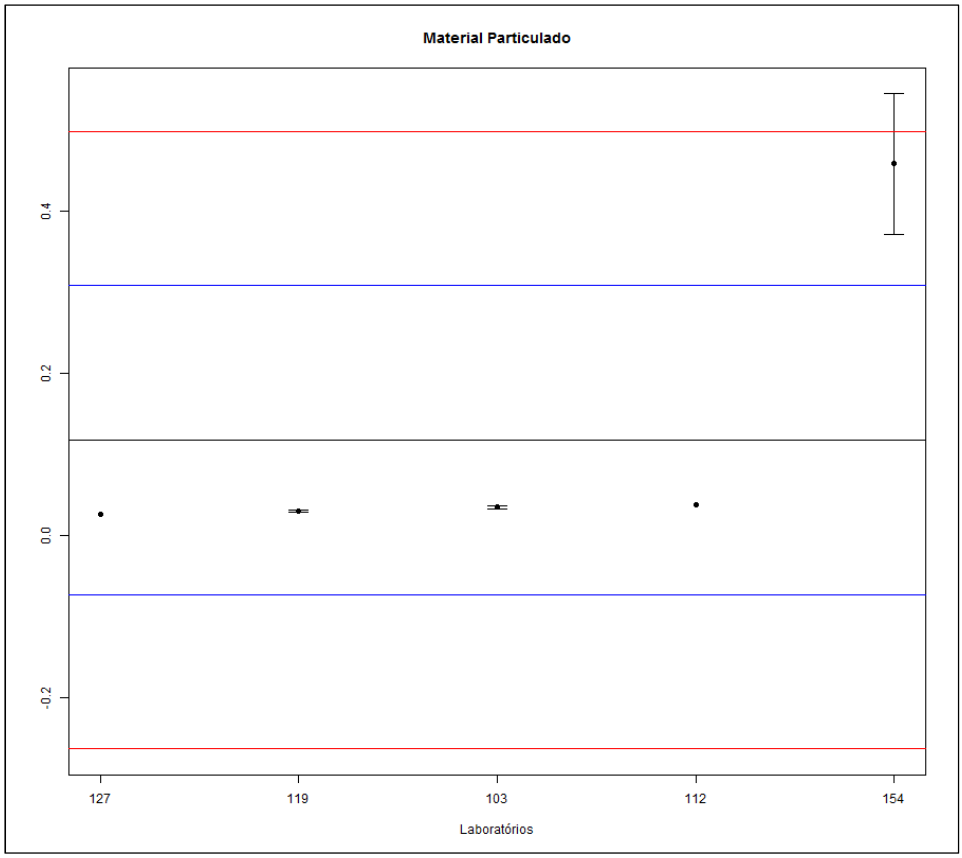

Figure 28 – Scatter plot of participants results for Particulate Material– Group B – P7.

Through the graphs, it can be seen that:

NO_x (g/km): 3 participants presented results within the Ref ± 1s interval and the remaining 2 participants' results are within the Ref ± 2s interval. Participant 127 presented the greatest results dispersion.

CO (g/km): 4 participants presented results within the Ref ± 1s interval and 1 participant within the Ref ± 2s interval.

HC (g/km): 4 participants presented results within de Ref ± 1s interval and 1 participant within de Ref ± 2s interval.

NO_x+HC (g/km): 2 participants presented results within the Ref ± 1s interval and 1 participant within the Ref ± 2s interval; participant 127 presented the greatest results dispersion.

CO_2 (g/km): 4 participants presented results within the Ref ± 1s and 1 participant within the Ref ± 2s interval; participant 119 presented the greatest results dispersion.

Consumption (g/kWh): 4 participants presented results within the Ref ± 1s interval and 1 participant within the Ref ± 2s interval.

Particulate Material: 4 participants presented results within the Ref ± 1s interval and 1 participant within the Ref ± 2s interval; participant 154 presented the greatest results dispersion.

5.2 IC Least Significant Difference – Group A – MAR I

Table 8 presents the least significant differences for group A – MAR I. The values in red color indicate where the pair of laboratories differ statistically.

Table 8 - IC Least Significant Difference – Group A – MAR I.

Participants	NO_x (g/kWh)	CO (g/kWh)	HC (g/kWh)	NO_x+HC (g/kWh)	CO_2 (g/kWh)	Consumption (g/kWh)	Particulate Material
122 - 134	**0**	**0.0001**	0.8841	**0**	**0**	**0**	**0**
122 - 139	**0**	**0.0018**	**0**	**0**	**0**	**0.0142**	**0**
122 - 145	**0**	**0**	**0**	**0**	**0**	**0.014**	**0**
122 - 160	**0**	**0**	**0**	**0**	**0**	**0.0121**	**0**
122 - 176	**0**	**0**	**0.0002**	**0**	**0**	**0**	**0**
122 - 195	**0**	**0**	**0**	**0**	**0**	**0.0015**	**0**
134 - 139	**0**	0.8393	**0**	**0**	**0**	**0**	1
134 - 145	**0.0022**	**0**	**0**	**0.0001**	**0**	**0**	**0.0399**
134 - 160	**0.0001**	**0**	**0**	**0**	**0.0014**	**0**	**0.0385**
134 - 176	**0**	**0.0001**	**0.0054**	**0**	**0**	**0**	1
134 - 195	**0**	**0**	**0**	**0**	**0**	**0**	**0.039**
139 - 145	**0**	**0**	**0.0002**	**0**	**0**	**0**	0.1498
139 - 160	**0**	**0**	**0.0008**	**0**	**0**	**0**	0.1498
139 - 176	**0**	**0**	**0**	**0**	**0**	**0**	1
139 - 195	**0**	**0**	**0**	**0**	**0**	**0**	0.1498
145 - 160	0.7238	0.8402	1	0.7255	0.7304	1	1
145 - 176	**0**	0.86	**0**	**0**	**0**	0.0856	0.1498
145 - 195	**0**	0.0812	0.2145	**0**	**0.0021**	1	1
160 - 176	**0**	0.09	**0**	**0**	**0**	0.0975	0.1498

Participants	NO_x (g/kWh)	CO (g/kWh)	HC (g/kWh)	NO_x+HC (g/kWh)	CO_2 (g/kWh)	Consumption (g/kWh)	Particulate Material
160 - 195	**0**	0.8402	0.075	**0**	**0.0001**	1	1
176 - 195	**0**	**0.0042**	**0**	**0**	**0.0019**	0.4972	0.1498

5.3 IC Least Significant Difference – Group A – P7

Table 9 presents the least significant differences for group A – P7. The values in red color indicate where de pair of laboratories differ statistically.

Table 9 - IC Least Significant Difference – Group A – P7.

Participants	NO_x (g/kWh)	CO (g/kWh)	HC (g/kWh)	NO_x+HC (g/kWh)	CO_2 (g/kWh)	Consumption (g/kWh)	Particulate Material
136 - 138	**0**	**0**	**0**	**0**	**0**	**0**	**0**
136 - 153	**0.0074**	**0**	**0**	0.0934	**0**	**0**	1
136 - 157	**0**	**0**	**0**	**0**	**0**	1	**0.0108**
136 - 166	**0**	**0**	**0**	**0**	**0.0092**	**0.017**	**0.014**
136 - 167	**0**	**0**	1	**0**	**0**	0.3347	0.3133
136 - 187	**0**	**0**	1	**0**	**0**	0.3347	1
138 - 153	**0**	1	**0.0002**	**0**	**0**	**0**	**0**
138 - 157	**0**	0.1828	**0**	**0**	**0**	**0**	**0.0063**
138 - 166	**0**	**0.0005**	**0**	**0**	**0**	**0.0001**	**0.0049**
138 - 167	**0**	0.819	**0**	**0**	**0.0088**	**0**	**0**
138 - 187	**0**	0.2704	**0**	**0**	1	**0**	**0**
153 - 157	**0**	0.1772	**0**	**0**	**0**	**0**	**0.0071**
153 - 166	**0**	**0.0005**	1	**0**	**0**	**0**	**0.0092**
153 - 167	**0**	0.7982	**0**	**0**	**0**	**0.0023**	0.4549
153 - 187	**0**	0.2608	**0**	**0**	**0**	**0.0023**	1
157 - 166	**0**	**0**	**0**	**0**	**0**	0.0563	1
157 - 167	1	1	**0**	1	**0**	0.1278	**0.0001**
157 - 187	1	1	**0**	1	**0**	0.1278	**0.0015**
166 - 167	**0**	**0**	**0**	**0**	**0**	**0.0002**	**0.0002**
166 - 187	**0**	**0**	**0**	**0**	**0**	**0.0002**	**0.0019**
167 - 187	1	1	1	1	**0.0307**	1	1

5.4 IC Least Significant Difference – Group B – MAR I

Table 10 presents the least significant differences for group B – MAR I. The values in red color indicate where the pair of laboratories differ statistically.

Table 10 - IC Least Significant Difference – Group B – MAR I.

Participants	NO_x (g/kWh)	CO (g/kWh)	HC (g/kWh)	NO_x+HC (g/kWh)	CO_2 (g/kWh)	Consumption (g/kWh)	Particulate Material
109 - 111	**0**	**0.0022**	**0.0027**	**0**	0.0987	0.2747	**0**
109 - 133	**0.0278**	**0**	1	**0.0265**	**0**	**0**	**0**
109 - 165	**0**	**0**	**0**	**0**	**0**	**0**	**0**
109 - 173	**0**	**0**	1	**0**	**0**	**0.0001**	**0**

Participants	NO_x (g/kWh)	CO (g/kWh)	HC (g/kWh)	NO_x+HC (g/kWh)	CO_2 (g/kWh)	Consumption (g/kWh)	Particulate Material
109 - 189	**0**	**0**	1	**0**	**0**	**0**	**0**
111 - 133	**0**	0.1861	**0.0007**	**0**	**0**	**0**	**0**
111 - 165	**0.0095**	**0**	**0**	**0**	**0.0017**	**0**	**0**
111 - 173	**0**	**0**	**0.0272**	**0**	**0**	**0**	1
111 - 189	**0**	**0**	**0.0007**	**0**	**0.0078**	**0**	**0**
133 - 165	**0**	**0**	**0**	**0**	**0**	**0.0002**	1
133 - 173	**0**	**0**	0.5927	**0**	**0.0078**	**0**	**0**
133 - 189	**0**	**0**	1	**0**	**0**	**0**	0.5493
165 - 173	**0**	**0**	**0**	**0.0077**	**0**	0.0597	**0**
165 - 189	**0**	**0**	**0**	**0**	1	**0**	1
173 - 189	**0**	**0**	0.5927	**0**	**0**	**0**	**0**

5.5 IC Least Significant Difference – Group B – P7

Table 11 presents the least significant differences for group B – P7. The values in red color indicate where the pair of laboratories differ statistically.

Table 11 - IC Least Significant Difference – Group B – P7.

Participants	NO_x (g/kWh)	CO (g/kWh)	HC (g/kWh)	NO_x+HC (g/kWh)	CO_2 (g/kWh)	Consumption (g/kWh)	Particulate Material
103 - 112	**0.0001**	**0**	0.1018	-	**0**	**0.002**	1
103 - 119	**0**	**0**	**0**	-	**0.0001**	**0**	1
103 - 127	**0**	**0**	**0**	-	**0**	**0**	1
103 - 154	**0**	**0**	**0**	-	**0**	**0**	**0**
112 - 119	**0**	**0**	**0**	**0**	1	0.0935	1
112 - 127	1	**0**	**0**	**0.0214**	0.1392	**0**	1
112 - 154	**0.0001**	**0**	**0**	-	0.4248	**0**	**0**
119 - 127	**0**	**0.0041**	0.0882	**0.0006**	0.0802	**0**	1
119 - 154	1	**0**	**0**	-	0.2553	**0**	**0**
127 - 154	**0.0002**	**0**	**0**	-	1	**0**	**0**

5.6 Average and Standard-deviation Results

Tables 12, 13, 14 e 15 presents the averages and standard-deviations for groups A and B – MAR I and P7.

Table 12 – IC Average and standard-deviation – Group A – MAR I.

Parameter	Average	Standard-deviation
NO_x (g/kWh)	8.181	0.456
CO (g/kWh)	0.359	0.028
HC (g/kWh)	0.152	0.023
NO_x + HC (g/kWh)	8.333	0.466
CO_2 (g/kWh)	702.62	31.73

Parameter	Average	Standard-deviation
Consumo (g/kWh)	227.98	10.51
Material Particulado	0.029	0.016

Table 13 - IC Average and standard-deviation – Group A – P7.

Parameter	Average	Standard-deviation
NO_x (g/kWh)	8.799	0.464
CO (g/kWh)	0.260	0.017
HC (g/kWh)	0.127	0.020
NO_x + HC (g/kWh)	8.927	0.475
CO_2 (g/kWh)	671.26	28.18
Consumo (g/kWh)	216.14	2.17
Material Particulado	0.017	0.003

Table 14 - IC Average and standard-deviation – Group B – MAR I.

Parameter	Average	Standard-deviation
NO_x (g/kWh)	4.363	0.161
CO (g/kWh)	0.730	0.175
HC (g/kWh)	0.183	0.082
NO_x + HC (g/kWh)	4.546	0.203
CO_2 (g/kWh)	767.17	13.11
Consumo (g/kWh)	244.82	2.65
Material Particulado	0.060	0.006

Table 15 - IC Average and standard-deviation – Group B – P7.

Parameter	Average	Standard-deviation
NO_x (g/kWh)	4.575	0.165
CO (g/kWh)	1.663	0.843
HC (g/kWh)	0.437	0.422
NO_x + HC (g/kWh)	4.779	0.186
CO_2 (g/kWh)	757.51	8.43
Consumo (g/kWh)	242.40	4.46
Material Particulado	0.118	0.190

5.7 Results Visualization and Outliers Detection: Box-Plot in Group A Emissions – MAR I.

Figures 29 to 35 graphically present the Box-Plot in Group A emissions – MAR I, for each analyzed parameter.

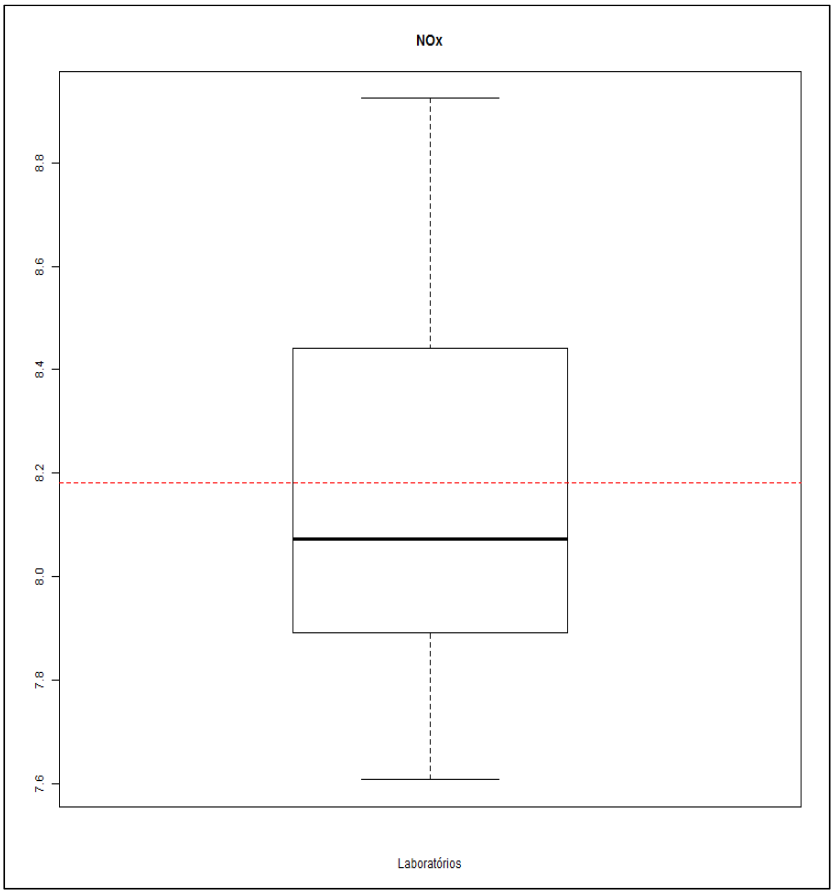

Figure 29 – Box-plot of results regarding NO_x measurement – Group A – MAR I.

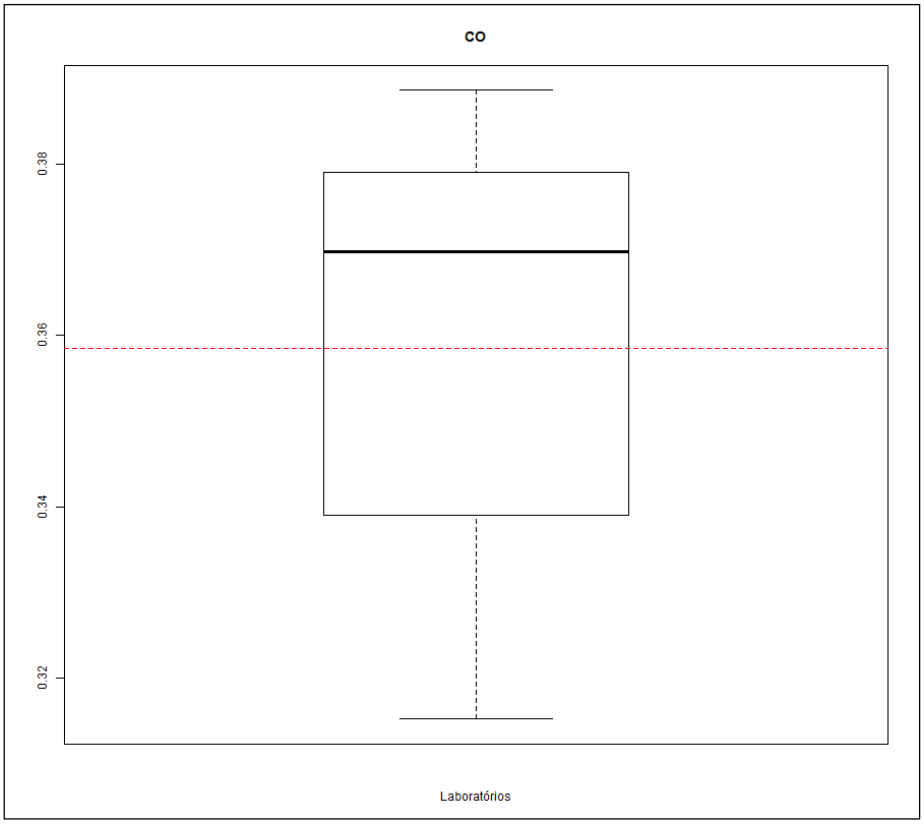

Figure 30 – Box-plot of results regarding CO measurement – Group A – MAR I.

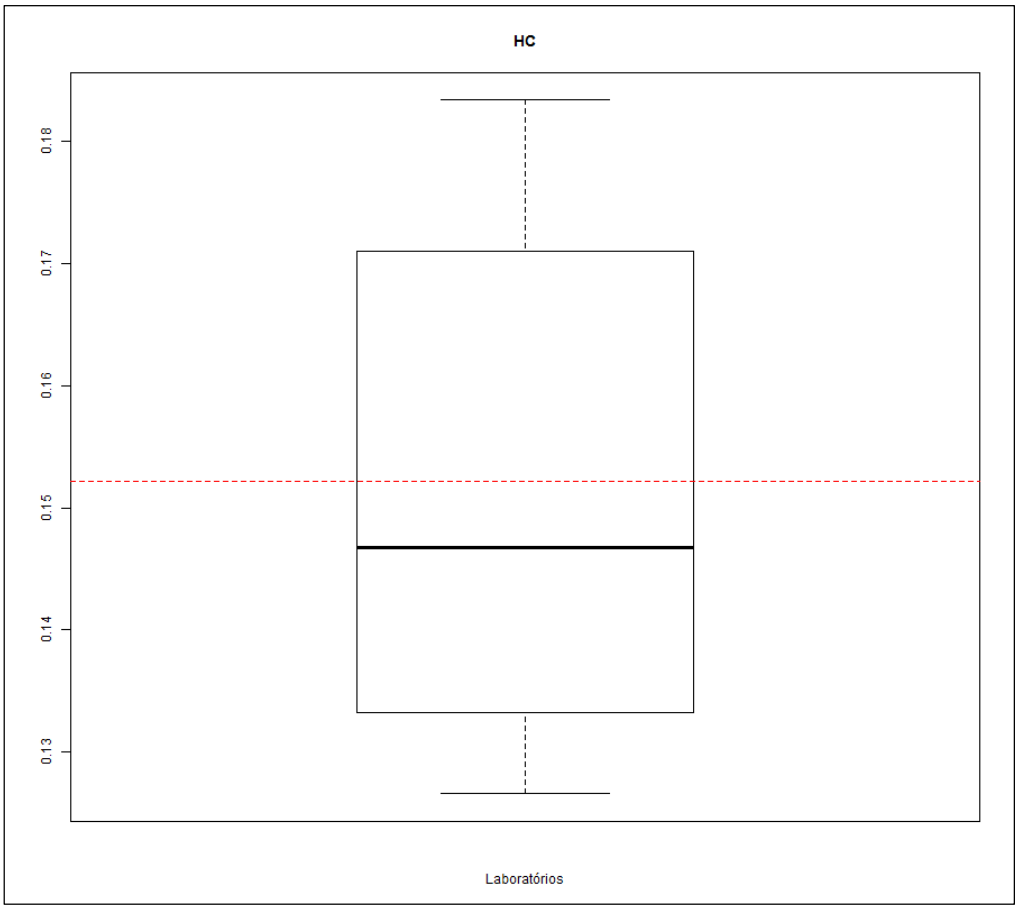

Figure 31 – Box-plot of results regarding HC measurement – Group A – MAR I.

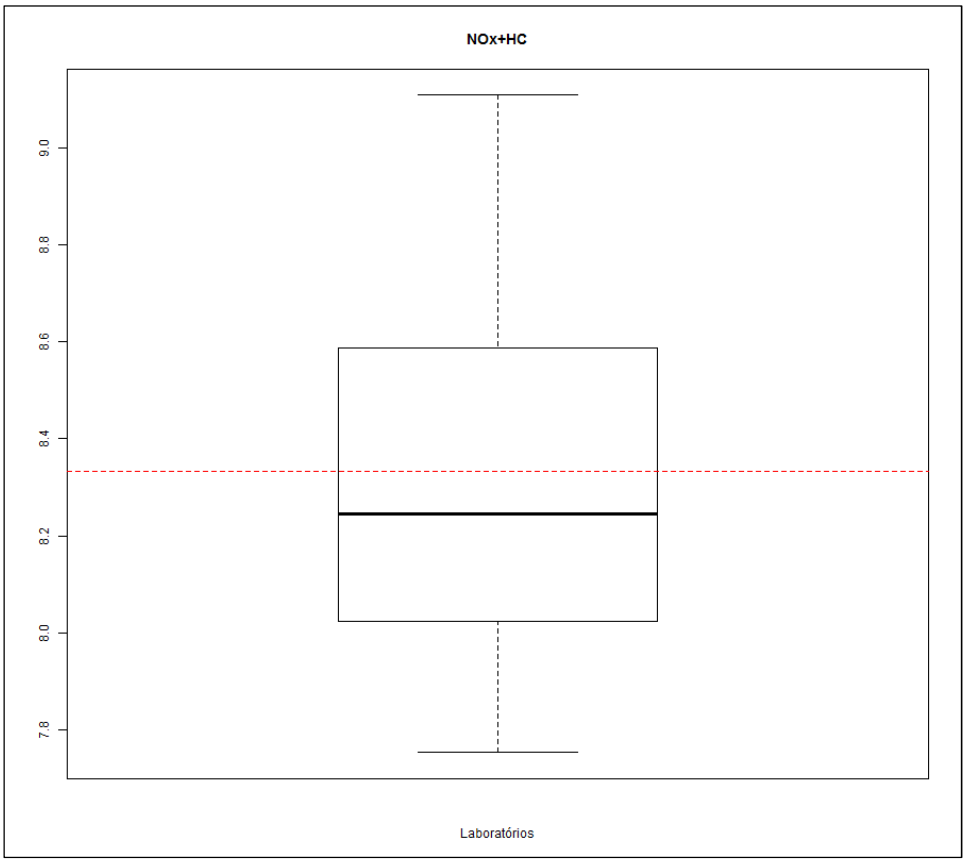

Figure 32 – Box-plot of results regarding NO_x+HC measurement – Group A – MAR I.

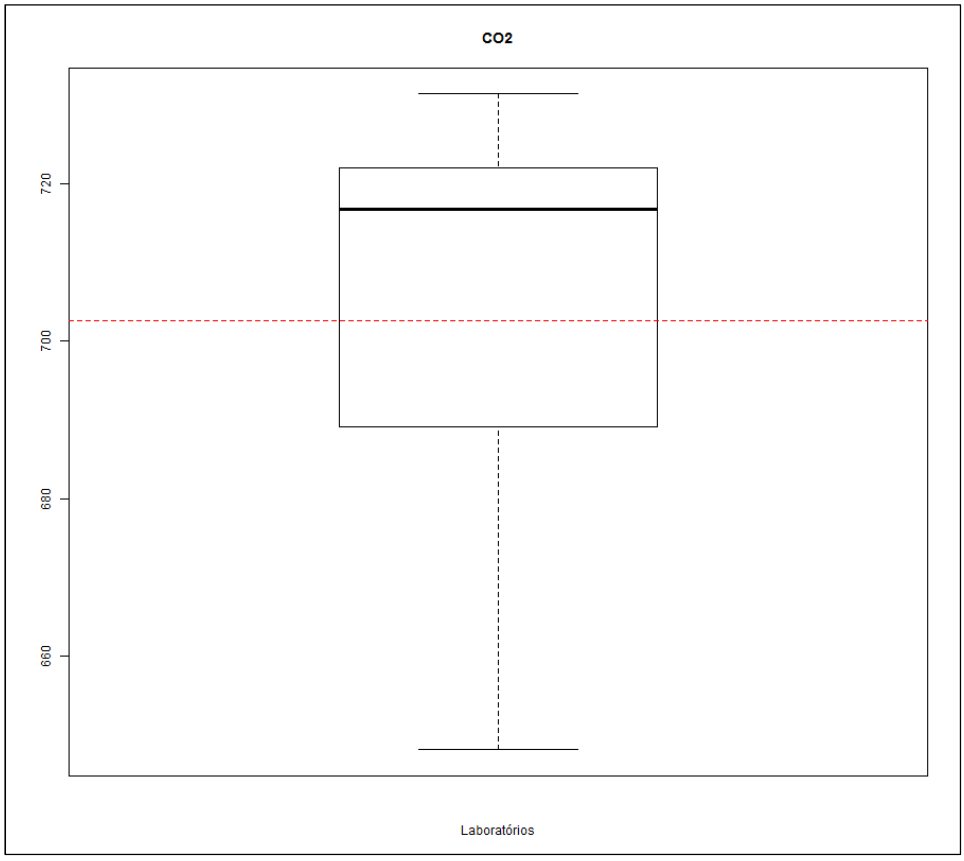

Figure 33 – Box-plot of results regarding CO_2 measurement – Group A – MAR I.

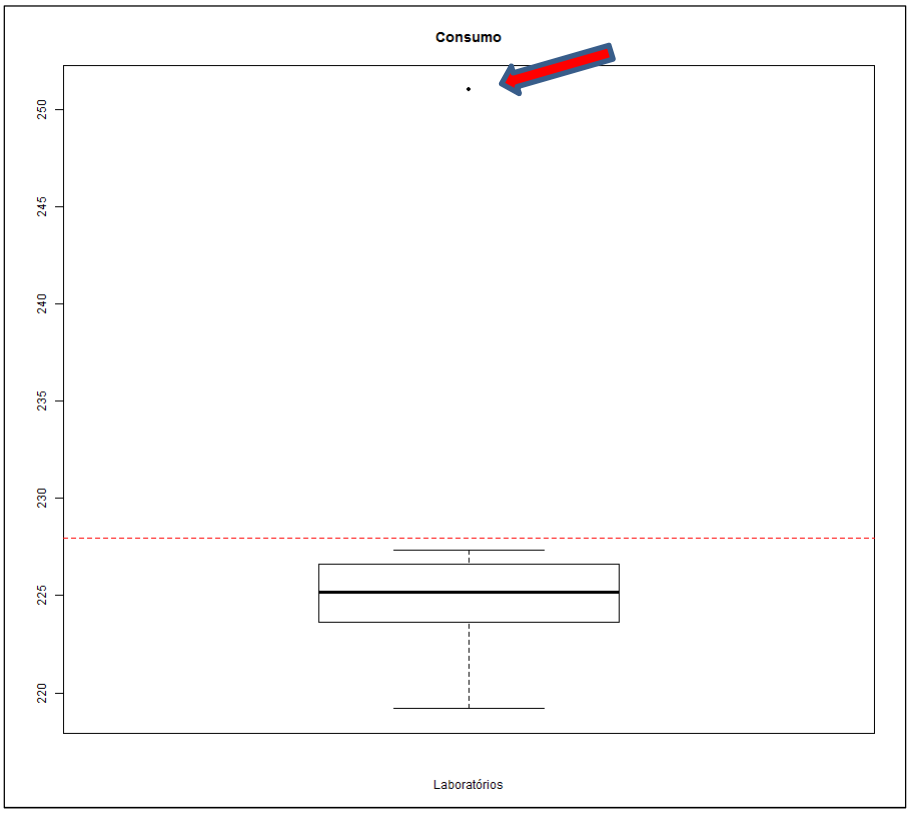

Figure 34 – Box-plot of results regarding Consumption measurement – Group A – MAR I.

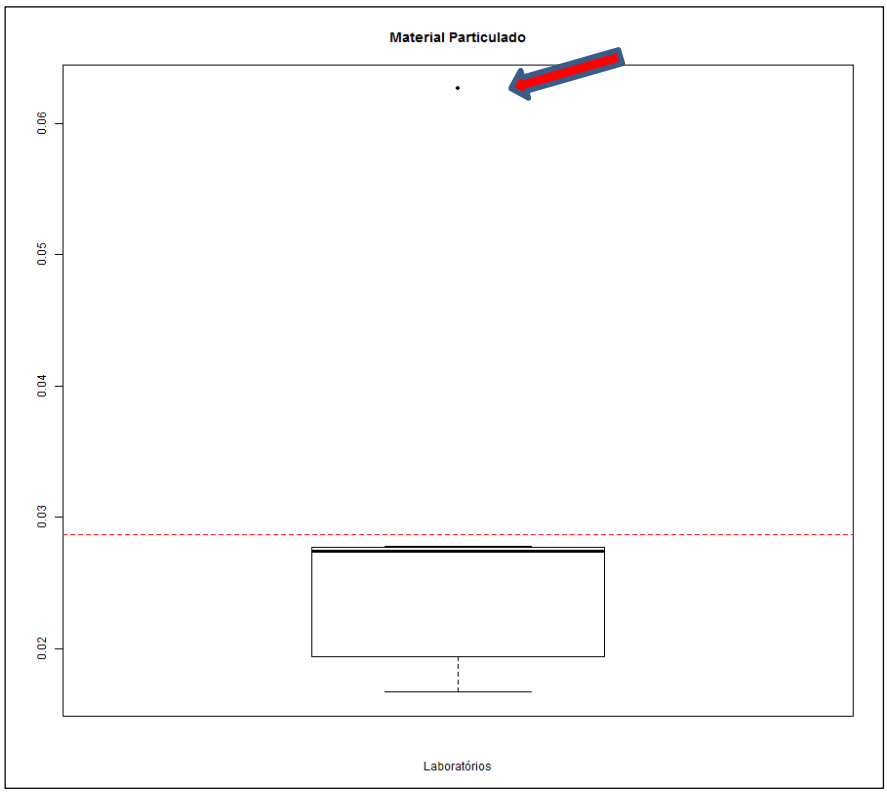

Figure 35 – Box-plot of results regarding Particulate Material measurement – Group A – MAR I.

The red arrow with blue contour presents outliers for Consumption (participant 134) and Particulate Material (participant 122) parameters.

5.8 Results Visualization and Outliers Detection: Box-Plot in Group A Emissions – P7.

Figures 36 to 42 graphically present the box-plot for Group A emissions – P7, for each analyzed parameter.

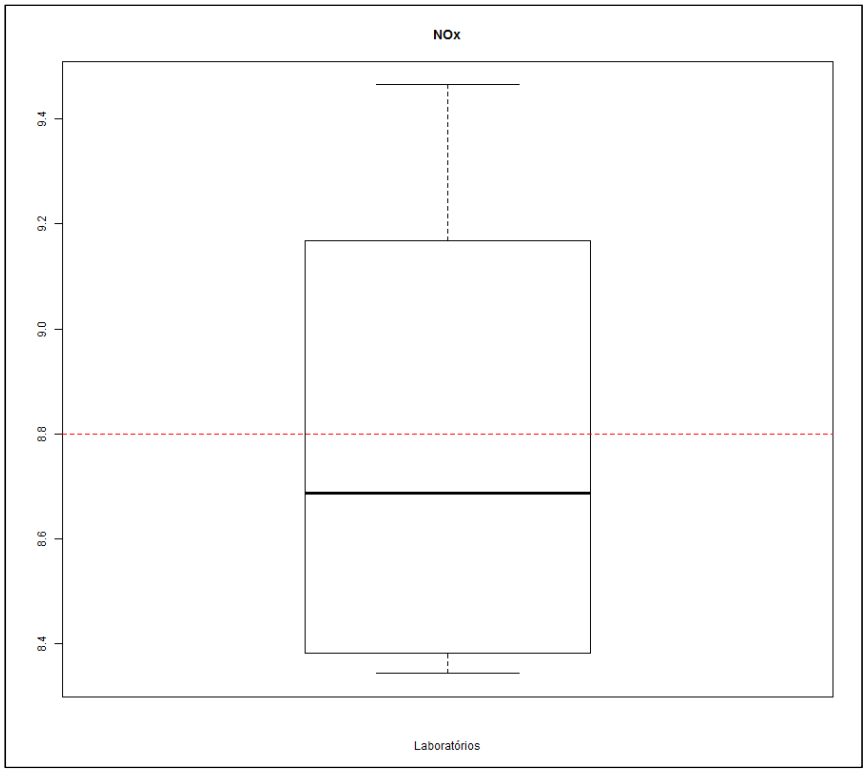

Figure 36 – Box-plot of results regarding NO_x measurement – Group A – P7.

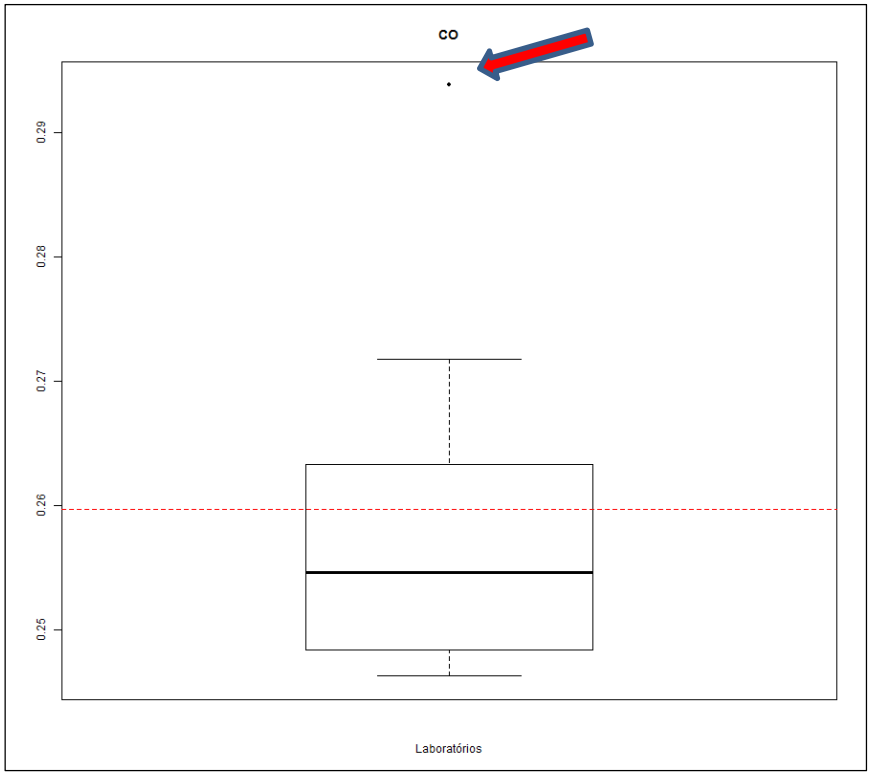

Figure 37 – Box-plot of results regarding CO measurement – Group A – P7.

The red arrow with blue contour presents outliers for CO (participant 136) parameter.

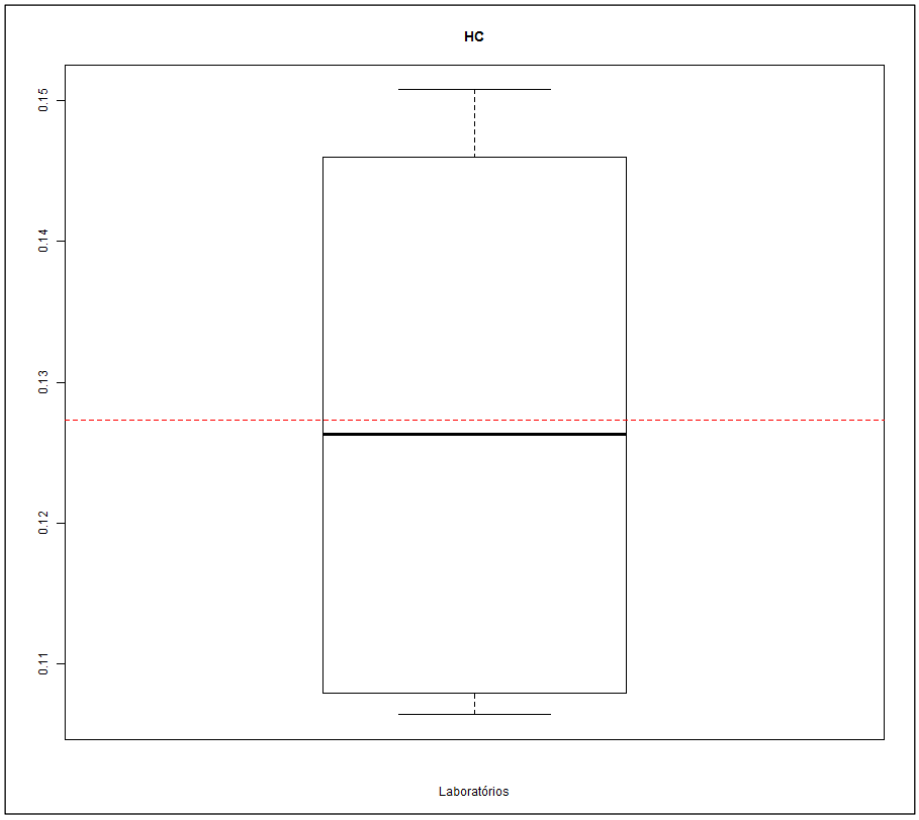

Figure 38 – Box-plot of results regarding HC measurement – Group A – P7.

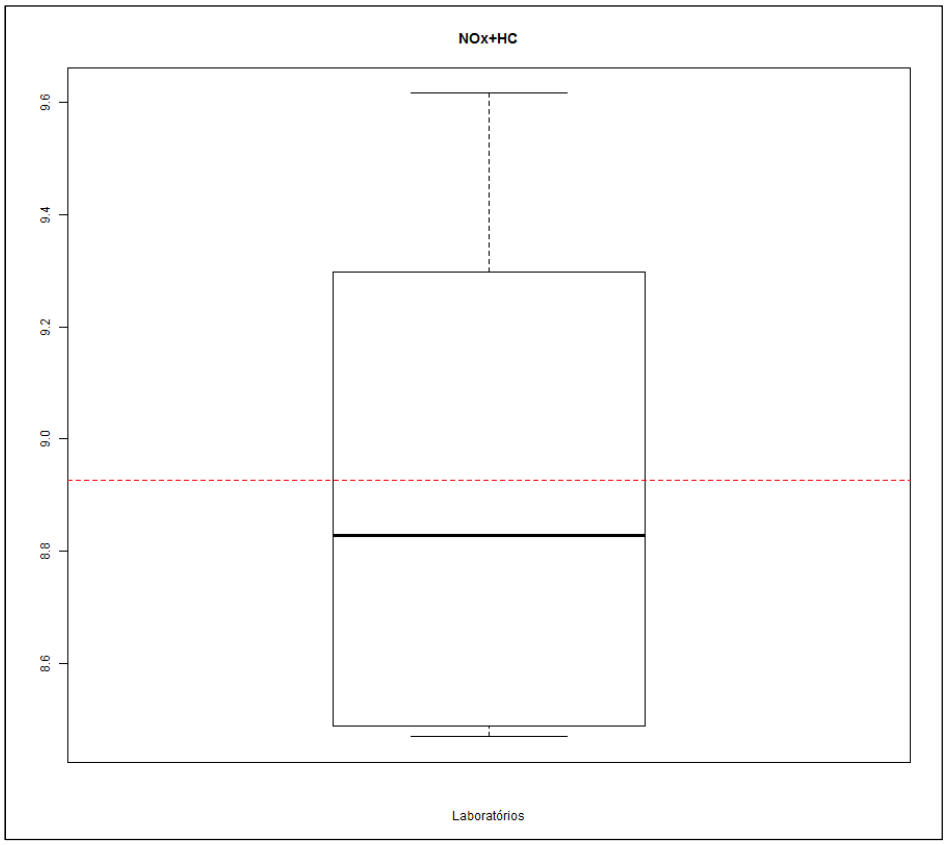

Figure 39 – Box-plot of results regarding NO_x+HC measurement – Group A – P7.

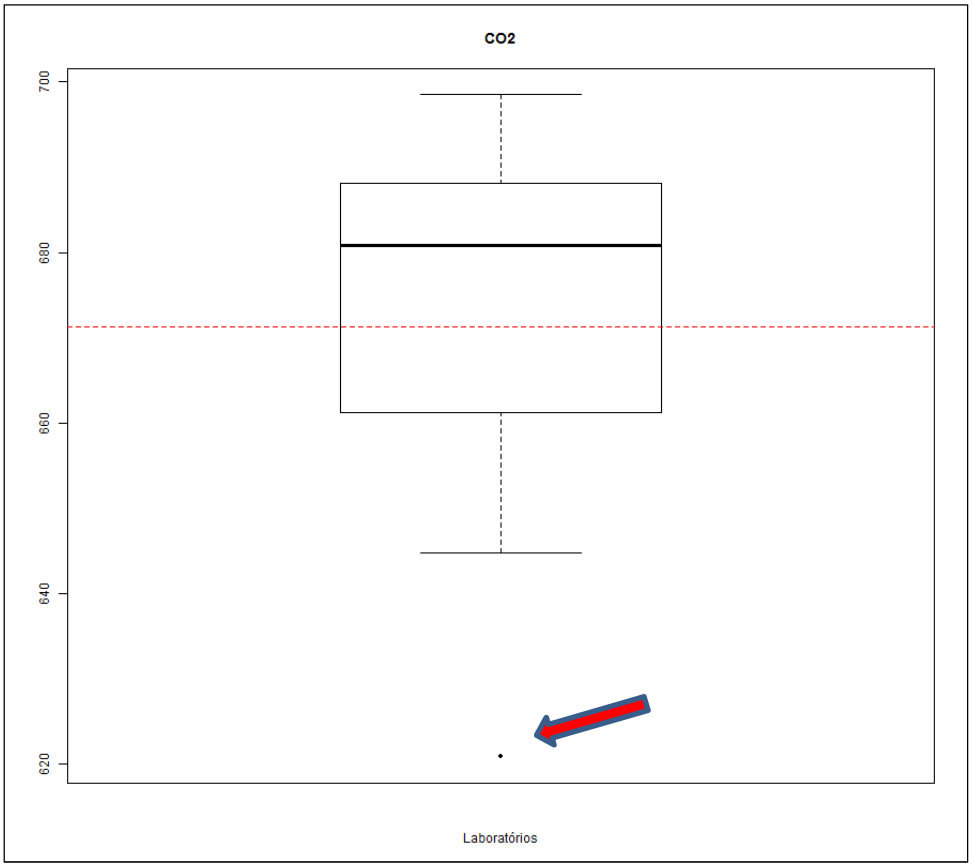

Figure 40 – Box-plot of results regarding CO_2 measurement – Group A – P7.

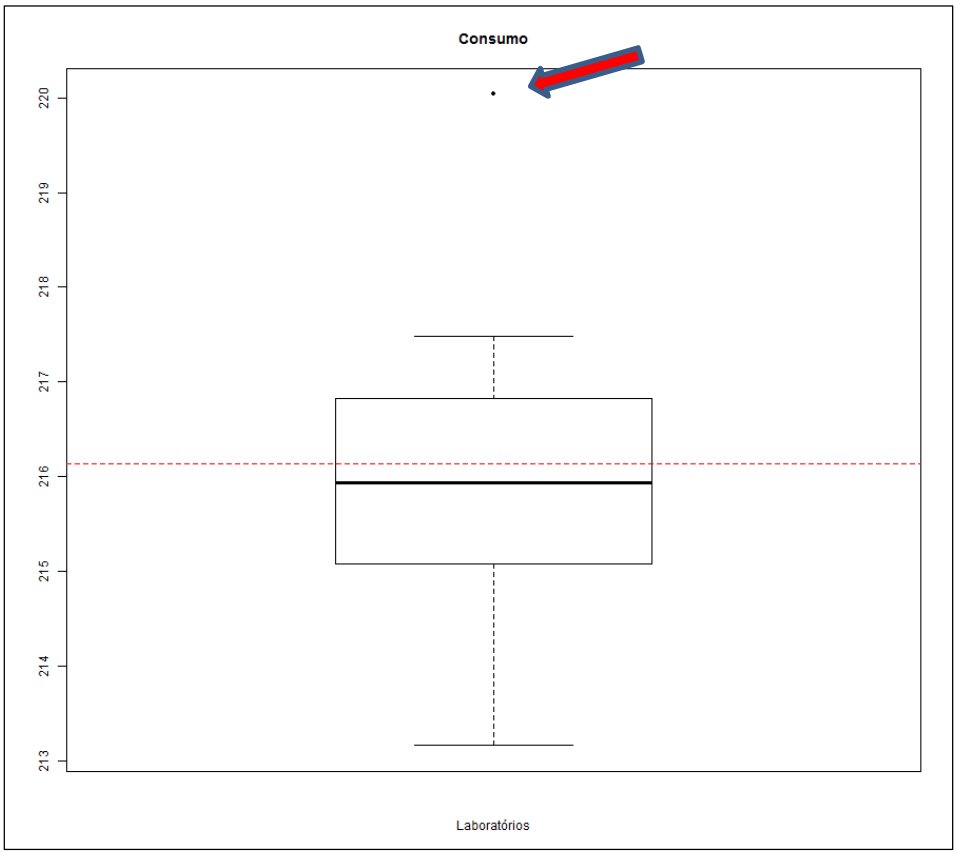

Figure 41 – Box-plot of results regarding Consumption measurement – Group A – P7.

The red arrow with blue contour presents outliers for CO_2 (participant 157) and Consumption (participant 138) parameters.

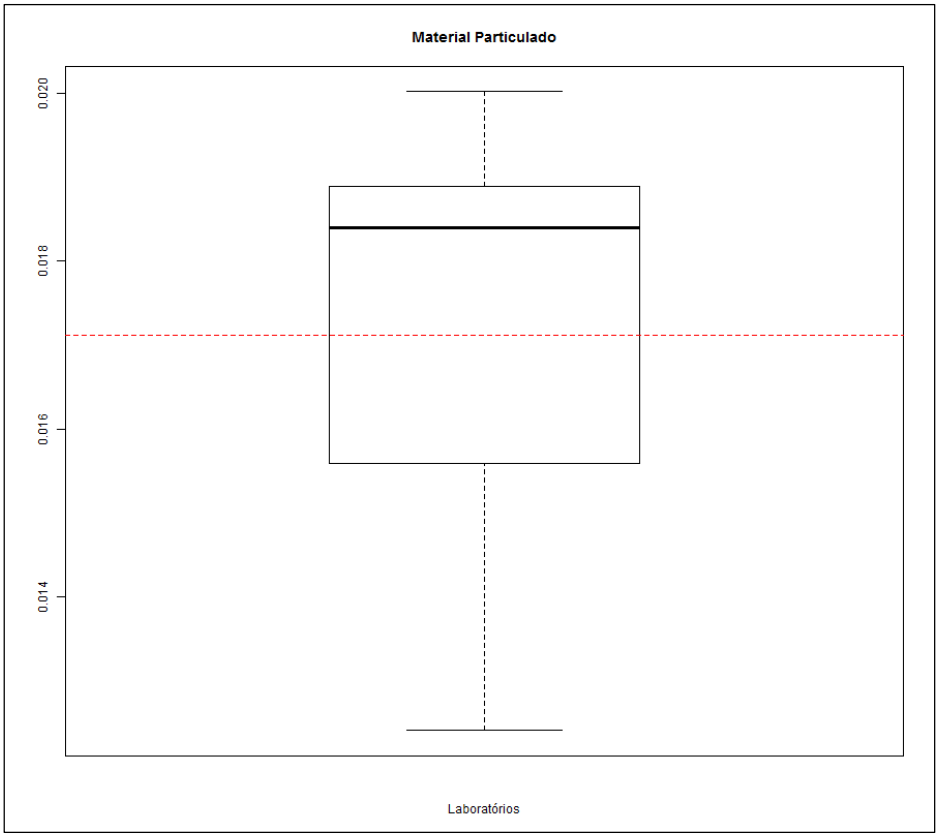

Figure 42 – Box-plot of results regarding Particulate Material measurement – Group A – P7.

5.9 Results Visualization and Outliers Detection: Box-Plot in Group B Emissions – MAR I.

Figures 43 to 49 graphically present the box plot for Group B emissions – MAR I, for each analyzed parameter.

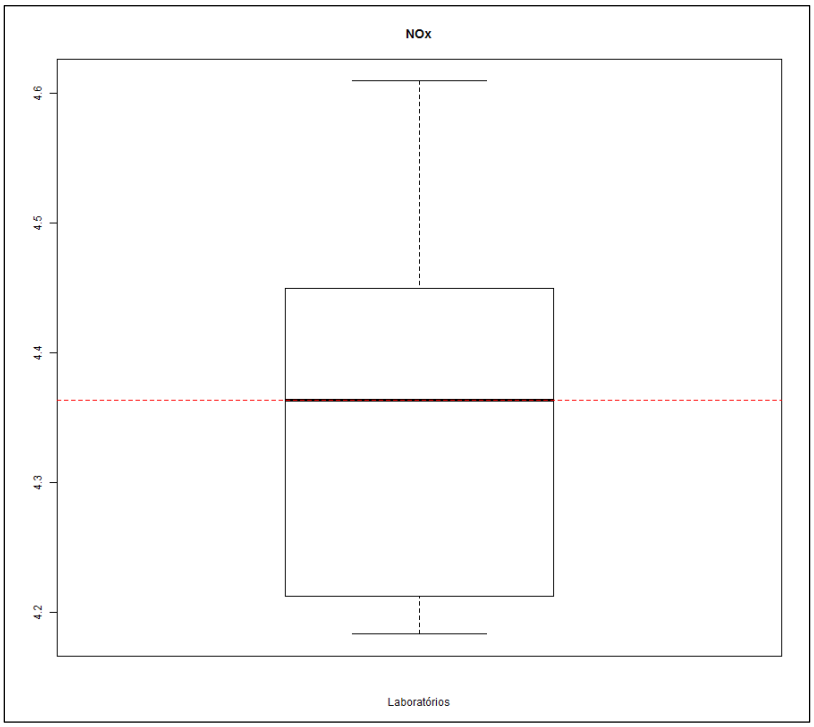

Figure 43 – Box-plot of results regarding NO_x measurement – Group B – MAR I.

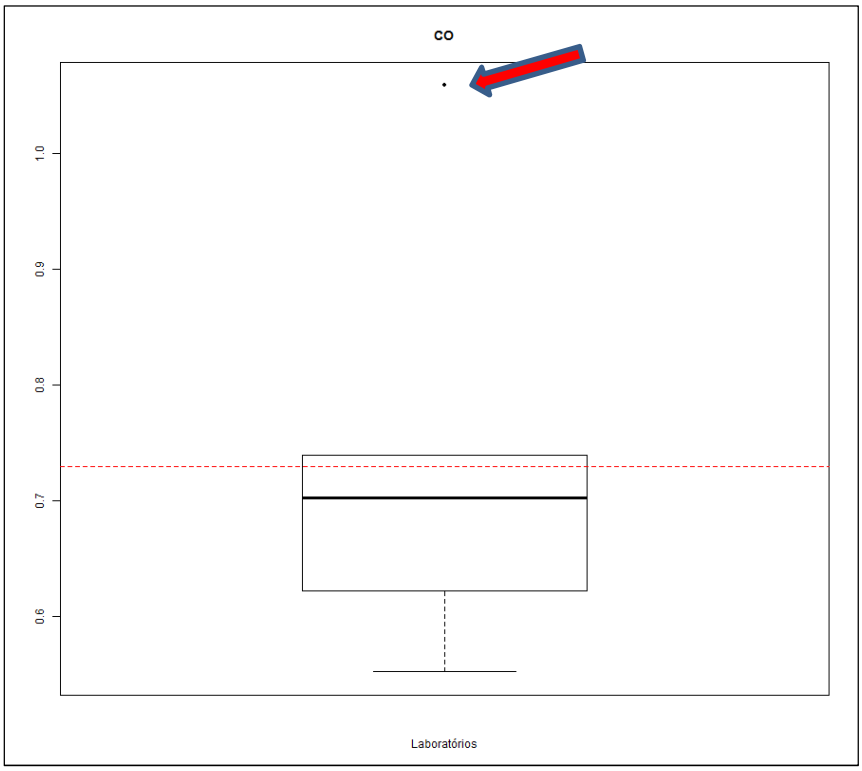

Figure 44 – Box-plot of results regarding CO measurement – Group B – MAR I.

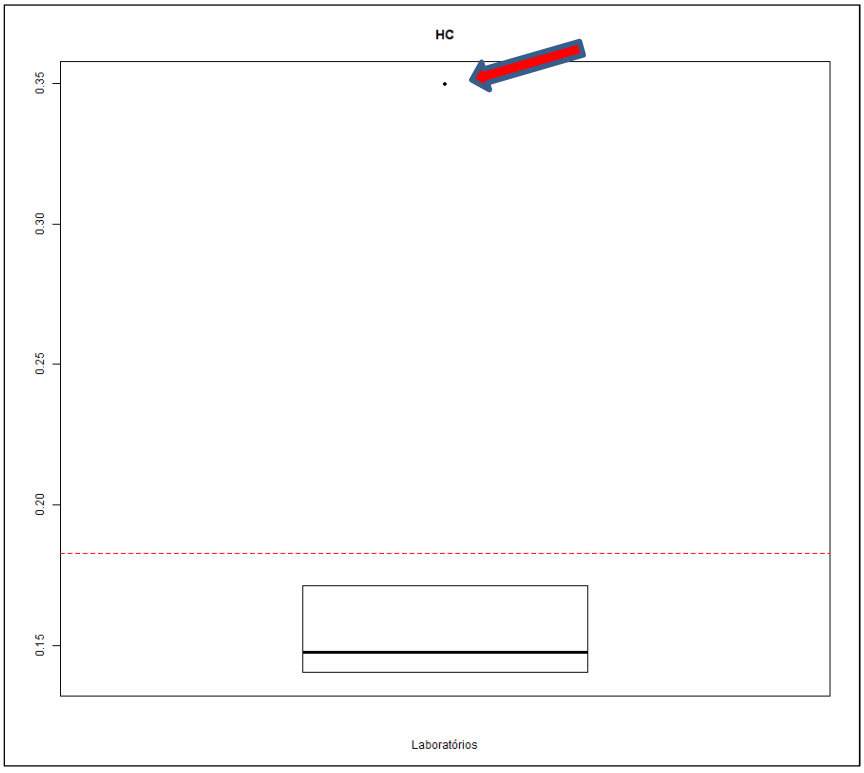

Figure 45 – Box-plot of results regarding HC measurement – Group B – MAR I.

The red arrow with blue contour presents outliers for CO (participant 165) and HC (participant 165) parameters.

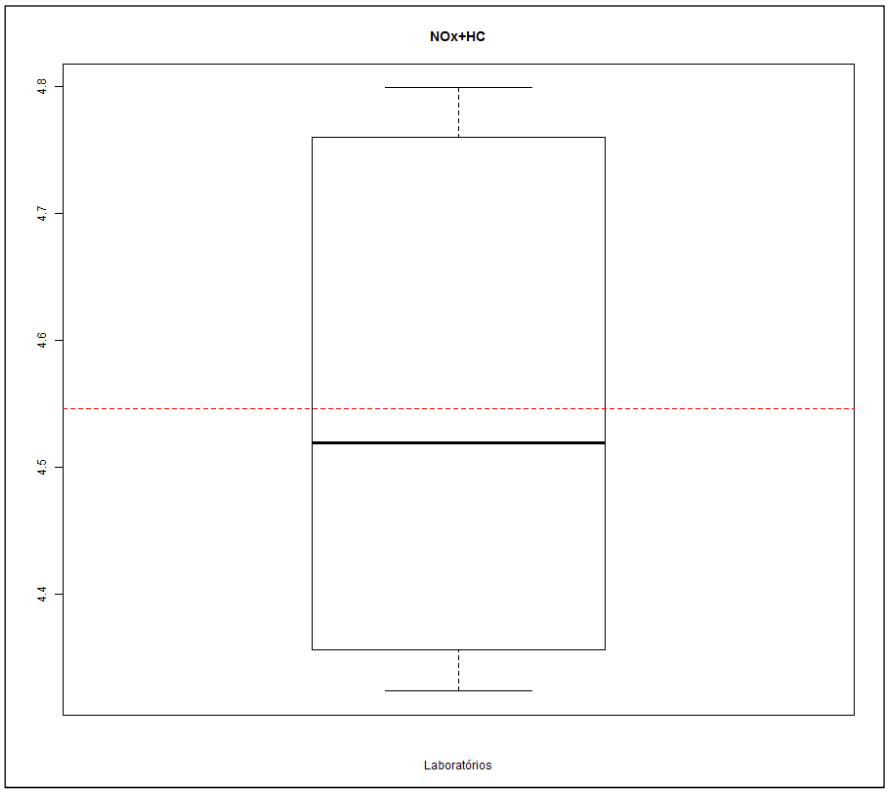

Figure 46 – Box-plot of results regarding NO_x+HC measurement – Group B – MAR I.

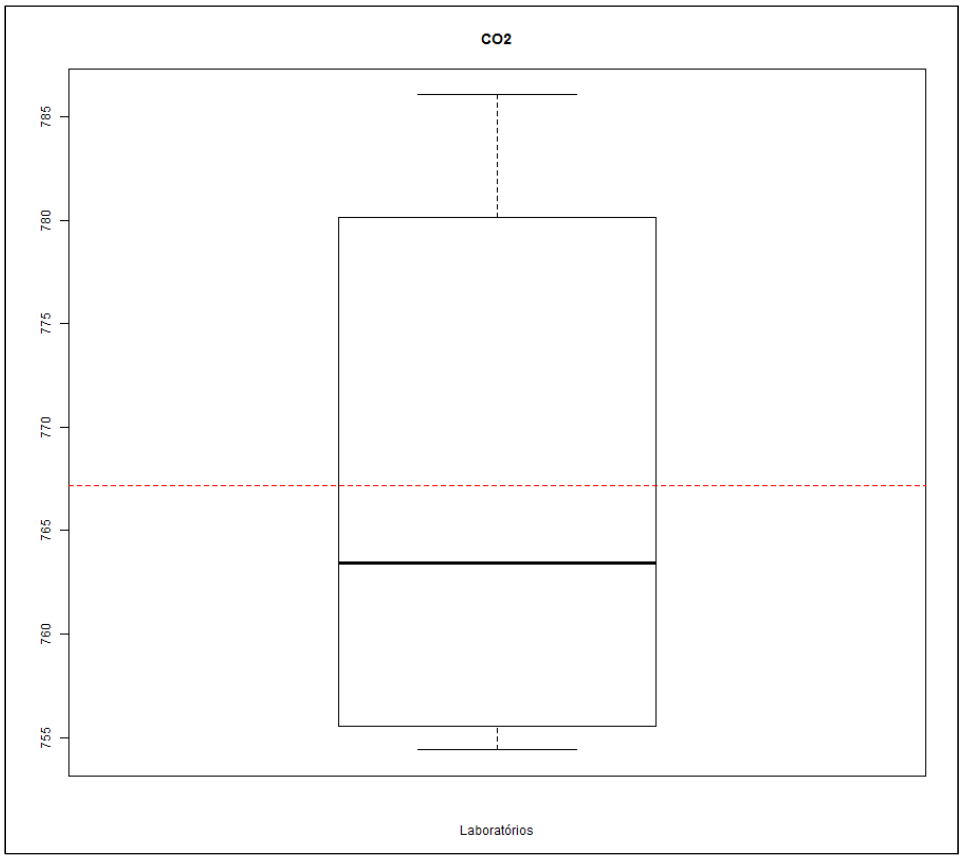

Figure 47 – Box-plot of results regarding CO_2 measurement – Group B – MAR I.

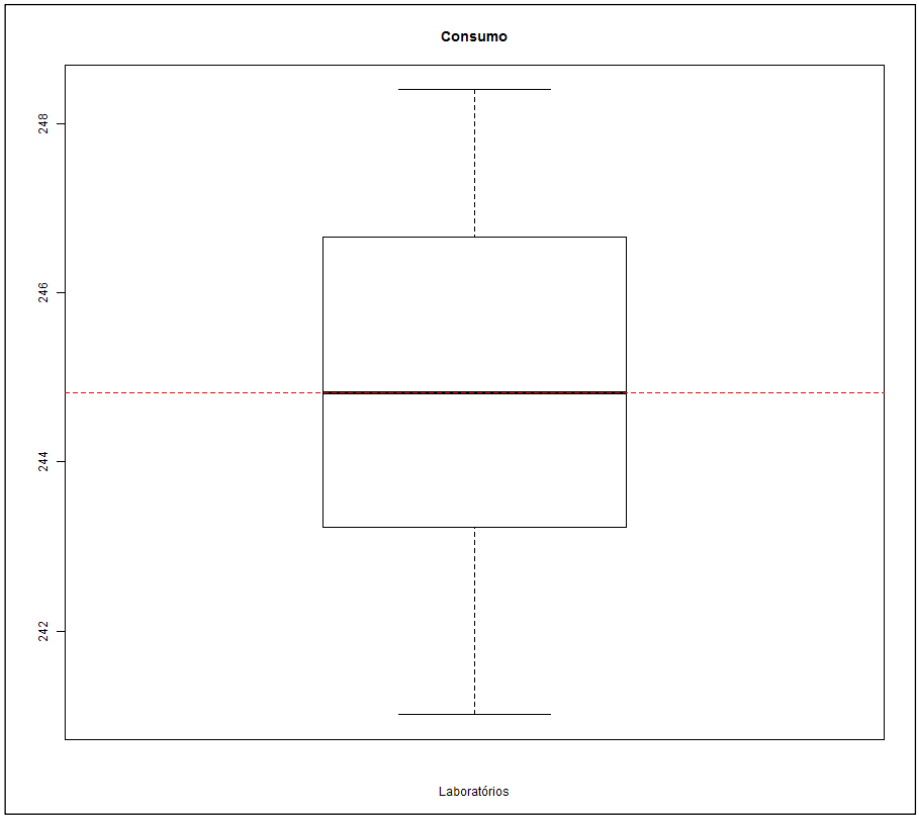

Figure 48 – Box-plot of results regarding Consumption measurement – Group B – MAR I.

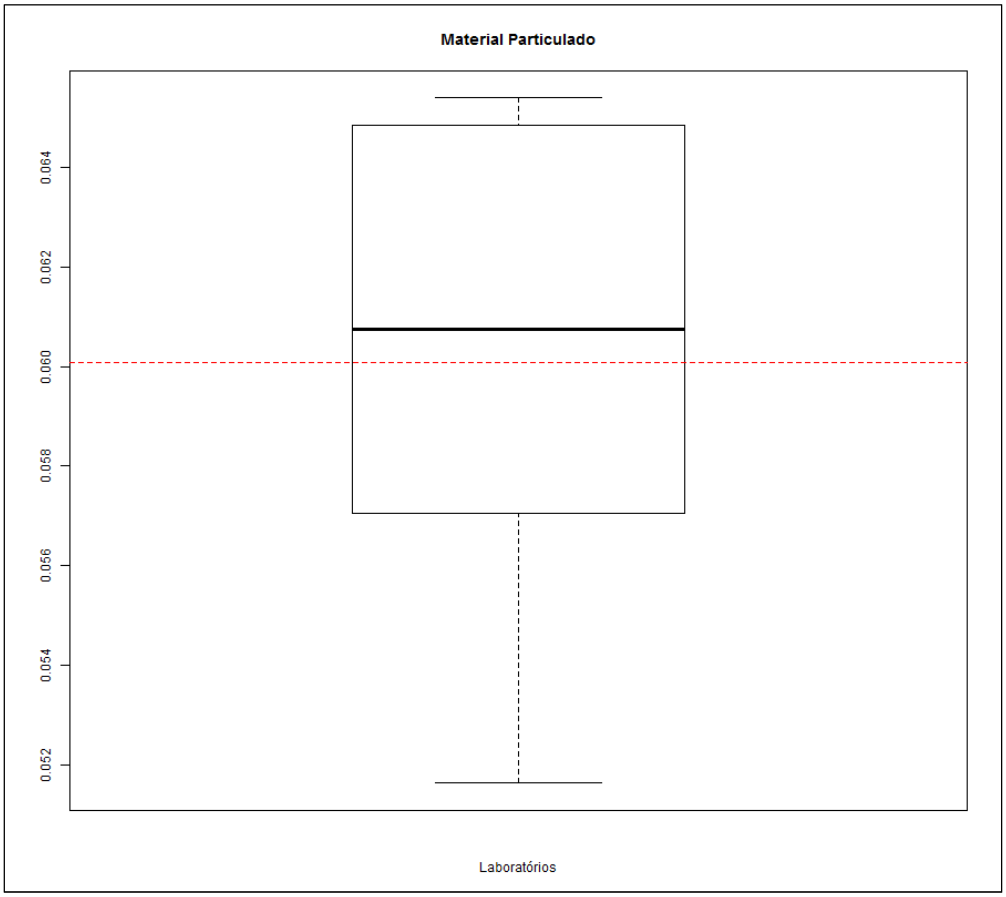

Figure 49 – Box-plot of results regarding Particulate Material measurement – Group B – MAR I.

5.10 Results Visualization and Outliers Detection: Box-Plot in Group B Emissions – P7.

Figures 50 to 56 graphically present the box plot for Group B emissions – P7, for each analyzed parameter.

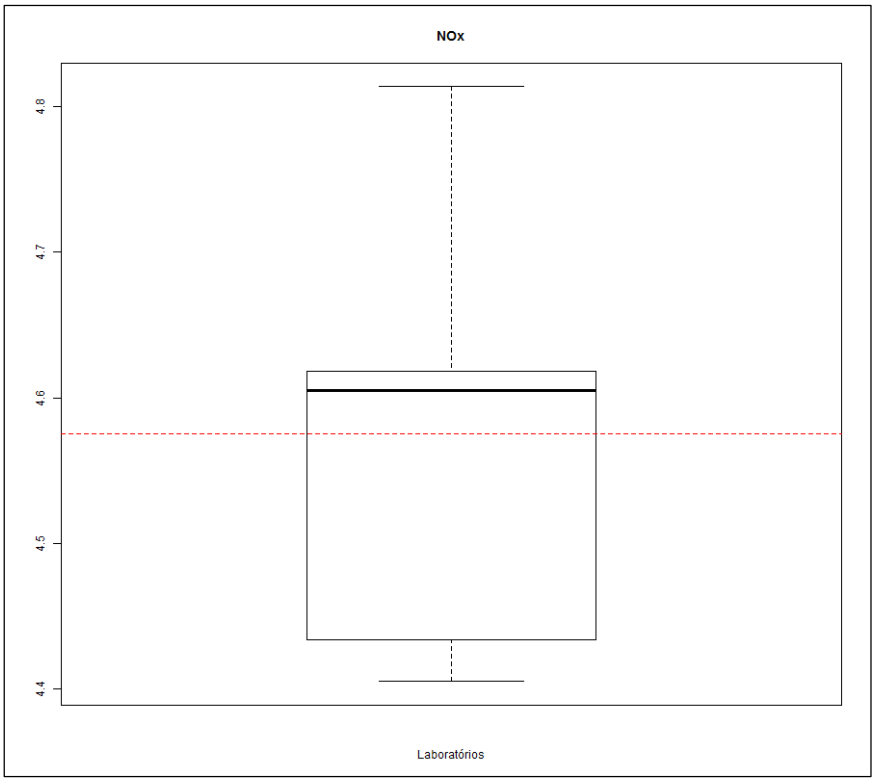

Figure 50 – Box-plot of results regarding NO_x measurement – Group B – P7.

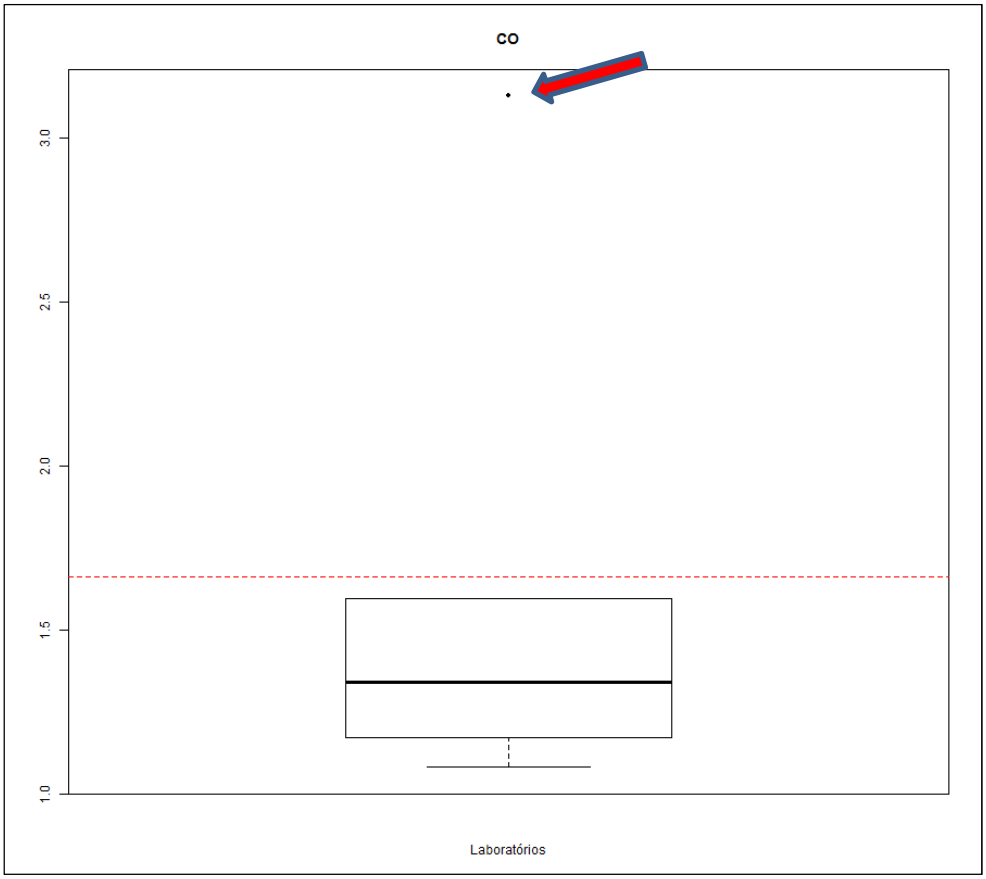

Figure 51 – Box-plot of results regarding CO measurement – Group B – P7.

The red arrow with blue contour presents outliers for CO (participant 154) parameter.

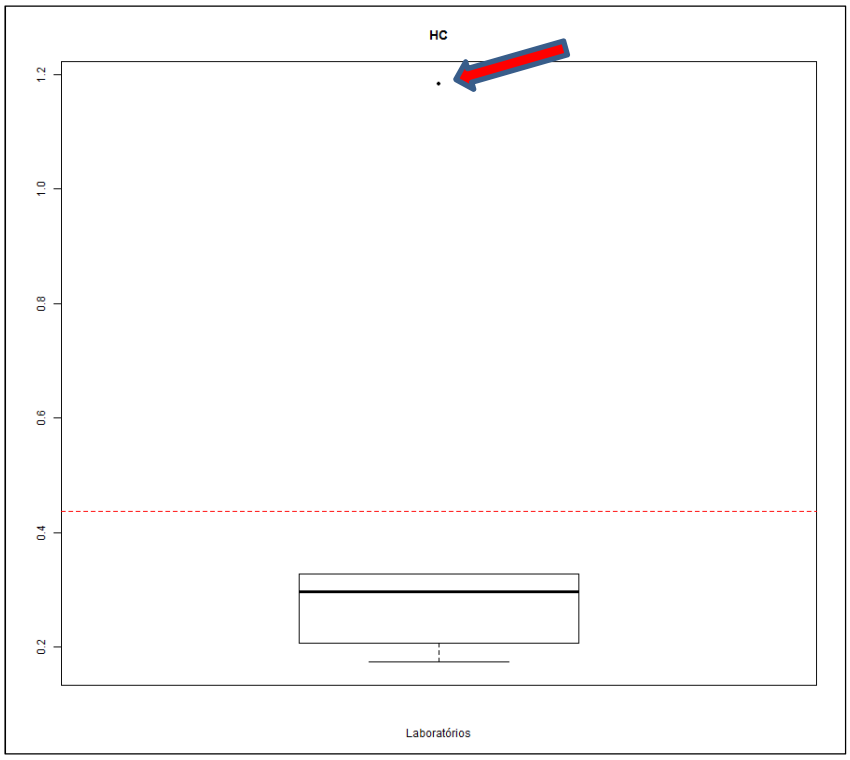

Figure 52 – Box-plot of results regarding HC measurement – Group B – P7.

The red arrow with blue contour presents outliers for HC (participant 154) parameter.

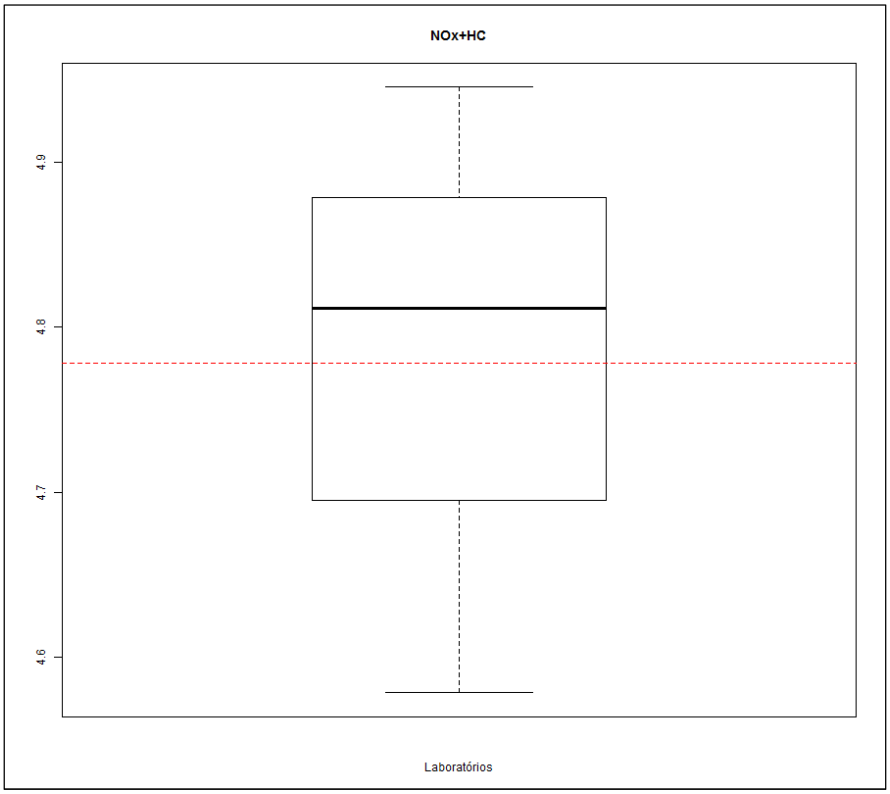

Figure 53 – Box-plot of results regarding NOx+HC measurement – Group B – P7.

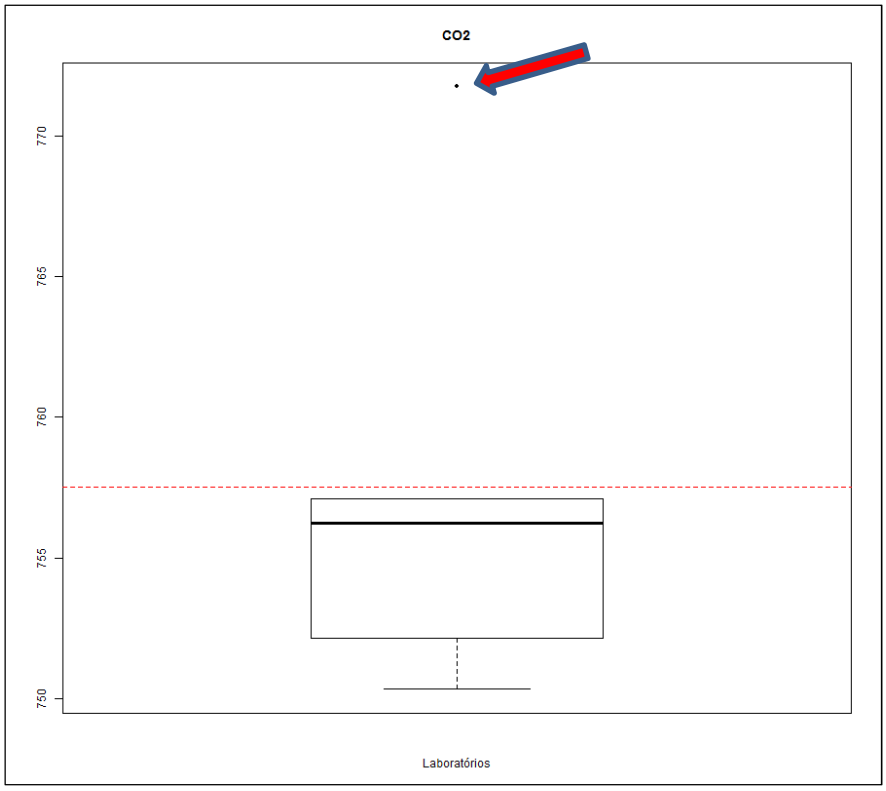

Figure 54 – Box-plot of results regarding CO_2 measurement – Group B – P7.

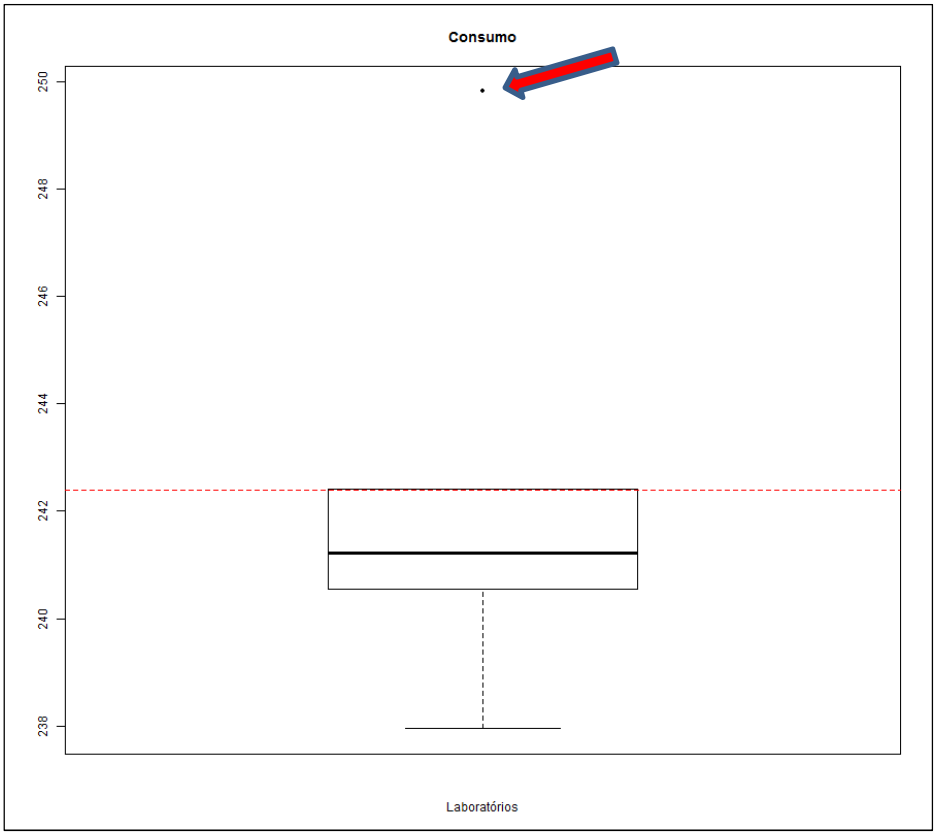

Figure 55 – Box-plot of results regarding Consumption measurement – Group B – P7.

The red arrow with blue contour presents outliers for CO_2 (participant 103) and Consumption (participant 154) parameters.

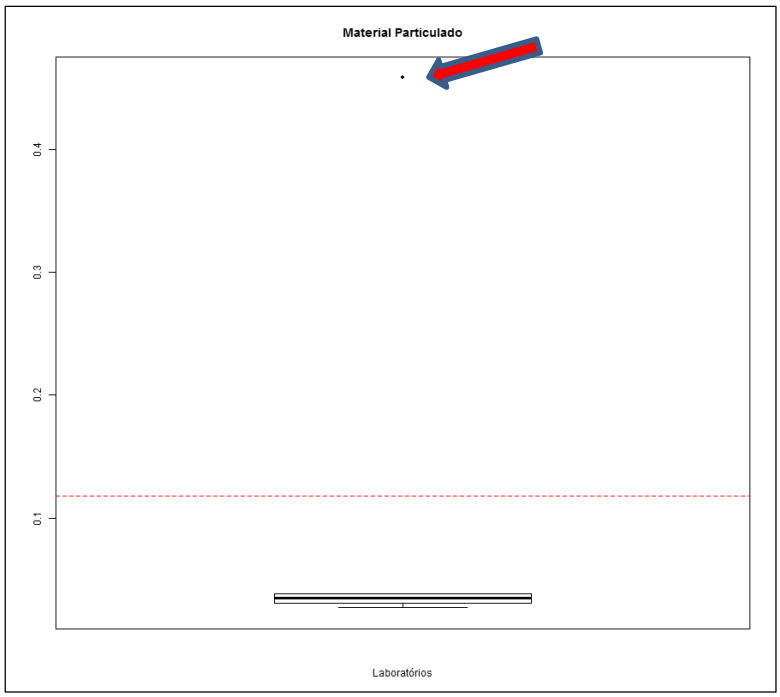

Figure 56 – Box-plot of results regarding Particulate Material measurement – Group B – P7.

The red arrow with blue contour presents outliers for Particulate Material (participant 154) parameter.

6 Participants' Results

6.1 Emissions Group A – MAR I

Tables 16 and 17 present the average and standard-deviation of each participant, where the result is the replicates mean value.

Note: All decimal places were considered for the calculation, but tables 16 and 17 the values are rounded to the same decimal places as it was requested in the results report form.

Table 16– Average and standard-deviation of participants for NO_x, CO, HC, NO_x+HC and CO_2 parameters - Group A – MAR I.

Code	NO_x (g/kWh)		CO (g/kWh)		HC (g/kWh)		NO_x+HC (g/kWh)		CO_2 (g/kWh)	
	Average	Standard-deviation	Average	Standard-deviation	Average	Standard-deviation	Average	Standard-deviation	Average	Standard-deviation
122	8.288	0.057	0.315	0.004	0.169	0.002	8.458	0.059	667.86	4.59
134	8.072	0.048	0.342	0.004	0.173	0.008	8.245	0.054	710.25	2.11
139	7.607	0.038	0.336	0.007	0.147	0.003	7.754	0.039	648.07	2.67
145	7.917	0.041	0.376	0.015	0.133	0.003	8.049	0.038	718.86	2.77
160	7.864	0.039	0.382	0.008	0.134	0.003	7.998	0.036	716.76	1.37
176	8.925	0.128	0.370	0.008	0.183	0.006	9.109	0.122	731.42	0.89
195	8.595	0.039	0.389	0.002	0.127	0.004	8.718	0.035	725.09	1.29

Table 17 – Average and standard-deviation of participants for Consumption and Particulate Material parameters - Group A – MAR I.

Code	Consumption (g/kWh)		Particulate Material	
	Average	Standard-deviation	Average	Standard-deviation
122	222.13	0.24	0.063	0.014
134	251.00	0.19	0.017	0.001
139	219.19	3.09	0.019	0.001
145	225.09	0.66	0.027	0.002
160	225.17	0.54	0.028	0.002
176	227.35	0.08	0.019	0.002
195	225.90	1.91	0.028	0.003

6.2 Emissions Group A – P7

Tables 18 and 19 present the averages and standard-deviations of each participant, where the result is the replicates mean value.

Note: All decimal places were considered for the calculation, but tables 18 and 19 the values are rounded to the same decimal places as it was requested in the results report form.

Table 18– Average and standard-deviation of participants for NO_x, CO, HC, NO_x+HC and CO_2 parameters - Group A – P7.

Code	NO_x (g/kWh)		CO (g/kWh)		HC (g/kWh)		NO_x+HC (g/kWh)		CO_2 (g/kWh)	
	Average	Standard-deviation	Average	Standard-deviation	Average	Standard-deviation	Average	Standard-deviation	Average	Standard-deviation
136	9.238	0.100	0.294	0.006	0.108	0.003	9.346	0.101	694.62	0.80
138	8.687	0.042	0.255	0.006	0.143	0.002	8.829	0.040	681.51	0.50
153	9.098	0.042	0.255	0.003	0.149	0.002	9.247	0.041	644.82	0.63
157	8.344	0.091	0.246	0.006	0.126	0.003	8.470	0.091	620.88	3.72
166	9.465	0.051	0.272	0.010	0.151	0.001	9.616	0.052	698.51	1.51
167	8.376	0.045	0.250	0.003	0.108	0.002	8.484	0.047	677.58	0.86
187	8.388	0.046	0.247	0.003	0.106	0.001	8.495	0.046	680.89	2.32

Table 19 – Average and standard-deviation of participants for Consumption and Particulate Material parameters - Group A – P7.

Code	Consumption (g/kWh)		Particulate Material	
	Average	Standard-deviation	Average	Standard-deviation
136	215.94	1.69	0.018	0.001
138	220.04	0.20	0.012	0.001
153	213.16	0.13	0.019	0.002
157	216.18	0.31	0.016	0.001
166	217.48	0.33	0.016	0.001
167	215.08	0.63	0.020	0.001
187	215.08	0.68	0.019	0.002

6.3 Emissions Group B – MAR I

Tables 20 and 21 present the averages and standard-deviations of each participant, where the result is the replicates mean value.

Note: All decimal places were considered for the calculation, but tables 20 and 21 the values are rounded to the same decimal places as it was requested in the results report form.

Table 20 – Average and standard-deviation of participants for NO_x, CO, HC, NO_x+HC and CO_2 parameters - Group B – MAR I.

Code	NO_x (g/kWh)		CO (g/kWh)		HC (g/kWh)		NO_x+HC (g/kWh)		CO_2 (g/kWh)	
	Average	Standard-deviation	Average	Standard-deviation	Average	Standard-deviation	Average	Standard-deviation	Average	Standard-deviation
109	4.212	0.020	0.739	0.020	0.144	0.012	4.356	0.025	765.42	5.34
111	4.416	0.018	0.710	0.003	0.171	0.003	4.587	0.020	761.44	0.27
133	4.183	0.018	0.695	0.010	0.141	0.001	4.323	0.018	786.07	0.95
165	4.450	0.015	1.059	0.015	0.350	0.020	4.799	0.015	754.40	2.05
173	4.610	0.011	0.552	0.007	0.151	0.006	4.760	0.010	780.15	2.34
189	4.310	0.012	0.622	0.008	0.140	0.008	4.451	0.016	755.56	2.05

Table 21 – Average and standard-deviation of participants for Consumption and Particulate Material parameters - Group B – MAR I.

Code	Consumption (g/kWh)		Particulate Material	
	Average	Standard-deviation	Average	Standard-deviation
109	243.87	0.35	0.052	0.001
111	243.23	0.09	0.057	0.001
133	248.40	0.34	0.064	0.002
165	246.66	0.35	0.065	0.001
173	245.75	0.75	0.057	0.001
189	241.01	0.96	0.065	0.002

6.4 Emissions Group B – P7

Tables 22 and 23 present the averages and standard-deviations of each participant, where the result is the replicates mean value.

Note: All decimal places were considered for the calculation, but tables 22 and 23 the values are rounded to the same decimal places as it was requested in the results report form.

Table 22 – Average and standard-deviation of participants for NO_X, CO, HC, NO_x+HC and CO_2 parameters - Group B – P7.

Code	NO_x (g/kWh)		CO (g/kWh)		HC (g/kWh)		NO_x+HC (g/kWh)		CO_2 (g/kWh)	
	Average	Standard-deviation	Average	Standard-deviation	Average	Standard-deviation	Average	Standard-deviation	Average	Standard-deviation
103	4.814	0.015	1.340	0.011	0.296	0.004	-	-	771.75	2.95
112	4.618	0.004	1.597	0.075	0.327	0.015	4.946	0.013	756.25	2.30
119	4.405	0.045	1.080	0.022	0.173	0.004	4.579	0.043	757.11	7.29
127	4.605	0.109	1.170	0.017	0.206	0.007	4.812	0.115	750.34	1.37

Code	NO_x (g/kWh)		CO (g/kWh)		HC (g/kWh)		NO_x+HC (g/kWh)		CO_2 (g/kWh)	
	Average	Standard-deviation	Average	Standard-deviation	Average	Standard-deviation	Average	Standard-deviation	Average	Standard-deviation
154	4.434	0.005	3.130	0.027	1.183	0.046	-	-	752.13	3.05

Table 23 – Average and standard-deviation of participants for Consumption and Particulate Material parameters - Group B – P7.

Code	Consumption (g/kWh)		Particulate Material	
	Average	Standard-deviation	Average	Standard-deviation
103	242.42	0.23	0.035	0.002
112	241.23	0.46	0.039	0.001
119	240.55	0.43	0.031	0.001
127	237.95	0.44	0.027	0.001
154	249.82	0.65	0.458	0.087

7 Analysis Witness

As established in the Interlaboratory Comparison protocol, a CETESB representative witnessed one of the IC five measurements, in its specific curves, at each laboratory participant and sent the results to the IC coordination. After finishing the tests, each participant sent their results to the coordination for statistical treatment.

7.1 Emissions Group A – MAR I

CETESB did not send the witnessed results related to 1 (one) participant of MAR I tests, even though it has been requested several times by the coordination of this IC. For confidentiality reasons, the participant identification code was not informed.

Participant 134 reported the Consumption value as 250.74 g/(kW.h) and the witnessed declared value for Consumption was 250.70 g/(kW.h).

7.2 Emissions Group A – P7

CETESB did not send the witnessed results related to 1 (one) participant of P7 tests, even though it has been requested several times by the coordination of this IC. For confidentiality reasons, the participant identification code was not informed.

7.3 Emissions Group B – MAR I

There was not disagreement between the results reported by participants and the results witnessed by CETESB that were sent by Group B – MAR I to the IC coordination.

7.4 Emissions Group B – P7

There was not disagreement between the results reported by participants and the results witnessed by CETESB that were sent by Group B – P7 to the IC coordination.

8 Confidentiality

Each participant was identified by an individual code which is only known by the participant and the IC coordination. As stated on the registration form, the identification of accredited laboratories and laboratories in stage of accreditation will be forwarded for information of the General Accreditation Coordination (Cgcre). The participant received, by email, his own identification code corresponding to the participation in this IC. This code was used to identify the participant in the results registration form. The results may be used in studies and publications by INMETRO respecting the confidentiality of each participant.

As established in section 4.10.4 of ABNT ISO/IEC 17043:2011, in exceptional circumstances, a regulatory authority may require the results and the identification of the participants to the PT provider. If this occurs, the provider will notify the IC participants about this action.

9 Conclusions

This was the first interlaboratorial comparison in Diesel-Cycle Motors emissions carried out within the Inmetro-AEA partnership. It should be clarified that this type of study is carried out only in Brazil and, considering its characteristics, it can be concluded that the results were quite satisfactory and its achievement has been of great importance to industry and society.

This first initiative of tests in diesel-cycle motors showed some inconsistences in the results regarding the stability of the test items, verified at the end of the IC. Concerning this situation, some questions need to be answered:

What are the reasons for the test items instability?
How the items stability can be guaranteed during all the IC period?

Is it necessary to make a previous study of test items to evaluate the stability before the beginning of the next IC?
Can possible variations of results also be attributed by the used test method?
To what extent do measurement instrumentation sites influence results?
Should we work on a standardization so that all participants can perform their tests as uniform as possible?

This IC used two comparison items and 2 (two) performance curves were designed per comparison item. The data were compared within their subgroups. This involved a large number of parameters and the follow-up of a regulatory body (CETESB).

Minimal discrepancies between the results reported during the CETESB testimony and those submitted to the coordination of this IC were noted. There were typing or rounding errors that did not influence the quality of the results. It is suggested that the procedure adopted by the testimony be reviewed to avoid occurrences of these types of errors.

Even with all these questions, the continuity of the study is of great importance for industry and society. Such studies will serve to solve the problems verified in this IC, to standardize the measurement methods and to consolidate the learning acquired in each comparison.

It is up to the participant of this interlaboratory comparison to perform a critical analysis of the results, and the whole process and laboratory experience should be considered. Therefore, participation in interlaboratory comparison on a continuous basis can guarantee the participant information about its measurement capacity and is of great importance for the monitoring of the validity of its results.

10 Participants

We received 15 (fifteen) registrations in the Interlaboratory Comparison in Diesel-Cycle Motors Emissions Tests and the participation of 13 (thirteen) laboratories, as two presented problems in the equipment and reported their withdrawal to the IC coordination. The list of participants who submitted the results to the IC coordination is shown in table 24. It is important to note that the numbering of the table is only indicative of the number of participants in the IC, and is not, in any way, associated with the identification of participants in the presentation results.

Table 24 – Participants.

	Institution
1.	AGCO do Brasil Soluções Agrícolas Ltda. AGCO Power Emission Test Lab.
2.	CAOA Montadora de Veículos Ltda. Centro de Pesquisa e Eficiência Energética (Cpee)
3.	CNH Industrial Brasil LTDA Betim Testing Center
4.	Cummins Brasil Ltda.
5.	Instituto de Pesquisas Tecnológicas do Estado de São Paulo S.A. IPT / IAV Laboratório de Motores
6.	Instituto de Tecnologia para o Desenvolvimento LEME - Laboratório de Emissões Veiculares
7.	International Indústria Automotiva da América do Sul Ltda. Centro Tecnológico MWM
8.	Mahle Metal Leve S.A. Laboratório de Motores
9.	Mercedes-Benz do Brasil Ltda.
10.	Robert Bosch Limitada. Tech Center Curitiba
11.	Scania Latin America Ltda.
12.	Umicore Brasil Ltda. Centro de Tecnologia em Emissões Veiculares (CTEV)
13	Volvo do Brasil Veiculos Ltda. Powertrain Engineering Laboratory - PEL

Total de participantes: 13.

11 References

- ABNT NBR ISO/IEC 17043:2011: Avaliação de Conformidade – Requisitos Gerais para ensaios de proficiência.
- Vocabulário Internacional de Metrologia: conceitos fundamentais e gerais e termos associados (VIM 2012). 1ª Edição Luso–Brasileira.
- Miller, J. C. and Miller, J. N. (1993). Statistics for analytical chemistry, 3rd Ed.; Ellis Horwood, Chichester, 1993.
- Freund, J.E.. Estatística aplicada economia, administração e contabilidade,11ª Ed., Editora Artmed, 2006.
- ABNT NBR 15634:2012, "Veículos rodoviários automotores — Análise e determinação do gás de exaustão segundo os ciclos ETC, ESC e ELR".

- ABNT NBR ISO 8178-1:2012 “Motores alternativos de combustão interna — Medição da emissão de gases de exaustão - Parte 1: Medição das emissões de gases e material particulado em banco de ensaio”.

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