Prediction of Gasoline Octane Rating Based on Ignition Delay Data from the Advanced Constant Volume Chamber Analyzer AFIDA

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ABSTRACT

This study investigates the application of ignition delay (ID) data in predicting the RON and MON octane ratings of gasolines type C, which are mandatory specification measurements conducted in a complex, costly, and time-consuming CFR engine. The ID measurements were obtained using the Advanced Fuel Ignition Delay Analyzer (AFIDA), a combustion analyzer that accurately measures this parameter under various pressure and temperature conditions, faster and cheaper, being able to simulate the combustion conditions of CFR engines. The research covered several gasolines formulated by refining streams and pure gasoline components, revealing significant correlations between octane rating and ID values, particularly for gasolines prepared from the same set of refinery streams, allowing for quick and economical optimizations in formulations. A data analysis approach was incorporated to enhance the accuracy of predictions, utilizing ID data, ethanol content and fuel density. The results emphasize the flexibility of AFIDA as a viable methodology for octane rating prediction, which can be applied in R&D, process and product optimization, as well as promoting discussions on alternatives for fuel certification.

INTRODUCTION

Knock resistance is a fundamental characteristic of gasolines, directly influencing the performance of internal combustion engines and the energy efficiency of vehicles [1,2]. Octane rating is the widely used measure for the anti-knock characterization of formulated gasolines and their components, expressing the ability of these products to resist detonation during the combustion cycle in spark-ignition engines. This phenomenon, known as "knocking", occurs when the air-fuel mixture auto-ignites before the ideal moment, resulting in irregular combustion that can cause engine damage and efficiency loss. The widely used tests for the anti-knock characterization of gasoline are the Research Octane Number (RON) and the Motor Octane Number (MON), measured according to the ASTM D2699 [3] and D2700 [4] test methods, respectively, using a standard CFR engine that allows for variation in the cylinder compression ratio to evaluate gasolines of different octane ratings. The two methods are complementary, as they are conducted under operational conditions of different severity. RON is determined under milder test conditions that simulate the operation of an engine under low load situations, while MON assesses the fuel performance under more severe conditions, such as high temperatures and pressures, which occur in engines operating at full load. The combination of these two parameters provides a comprehensive assessment of fuel quality, being essential for formulating gasolines that meet the performance requirements of modern engines and contribute to energy efficiency and the reduction of pollutant emissions [5]. These parameters are widely used in specifying gasoline production batches and evaluating product quality for various purposes [6-8].

Studies have demonstrated a significant correlation between knock resistance and the ignition delay (ID) of typical hydrocarbons of gasolines [9-13]. The ID comprises the interval between the start of compression and the start of auto-ignition of the air-fuel mixture, and its assessment can provide valuable insights into the behavior of the fuel under specific operating conditions. It is observed that hydrocarbons with higher detonation resistance are characterized by higher ID values and vice versa, suggesting that this parameter may be a useful indicator for predicting the octane rating of automotive gasolines and their components.

Traditional methods for evaluating ignition delay, such as shock tube – ST [14,15] and rapid compression machine – RCM [16,17], are widely used in academic settings for kinetic studies of gasoline combustion and its components, as they are methods that measure the ignition delay resulting solely from the chemical kinetics of air-hydrocarbon mixtures in the gas phase. However, these methods are not suitable as expedited alternatives for gasoline and its components analyses in industrial contexts. The complexity, high cost, and significant time required to conduct these tests limit their applicability in production environments or in quality control processes.

In this context, expedited methods for evaluating ignition delay data using constant volume chamber (CVC)

equipment have introduced innovative approaches for assessing combustion parameters of gasoline and their components [9-13,18]. CVC-type equipment can measure the ID time resulting from the combination of physical processes (vaporization) and the chemical kinetics of the mixture, thus requiring numerical models to utilize the results for validating combustion kinetic mechanisms or correlating with engine data.

The Advanced Fuel Ignition Delay Analyzer (AFIDA) is an example of constant volume chamber equipment that performs rapid and accurate measurements of ignition delay [12,18,19]. A version of this equipment dedicated to research and development activities is provided by the German company ASG Analytik-Service AG, which can operate under flexible conditions of temperature, pressure, and other operational parameters, allowing for the screening of conditions that may mimic combustion scenarios of different systems, including various types of spark-ignition engines. This method not only simplifies the analysis process but also enables a more agile assessment of gasoline ignition quality, making it a potential substitute for complex analyses conducted in CFR engines, for instance.

In this scenario, this study presents an experimental evaluation of the application of ignition delay (ID) data obtained in the AFIDA in predicting the RON and MON octane ratings of gasolines.

METHODOLOGY

SAMPLES – the work database was obtained with samples of gasolines prepared during the R&D activities, comprising 87 gasoline formulations, obtained by refining streams (cracked naphtha, reformate, alkylate, light naphthas) and pure components normally present in gasolines (*e.g.:* toluene, xylenes, heptane), used for property adjustments in specific projects.

All fuels were evaluated by compositional analysis (gas chromatography), as well as by density and ethanol content measurements, in order to compose a richer database, which could increase correlations in the data analysis phase. Fuel analyses were performed with standard test methods allowed by fuel specification[7]. Compositional analyses were performed by ASTM D6729 test method, densities were measured by ASTM D4052 test method and ethanol content was measured by NBR 13992 test method. Density and ethanol content tests were performed on samples within the following ranges (see attached fuel data):

- Density at 20°C: from 0.7224 to 0.8104 kg/L;
- Ethanol content: from 0 to 45 % volume.

ANTIKNOCKING CHARACTERISTICS – The evaluation of the knocking resistance of the gasolines was performed by the conventional RON test (ASTM D2699) and MON test (ASTM D2700). The octane number is determined using a CFR (Cooperative Fuel Research) engine that operates on a principle of comparing the knock characteristics of the test fuel against reference fuels with known octane ratings. During the test, the compression ratio of the single-cylinder engine gradually increased until a standardized knock intensity is detected by a specialized knock meter. For Research Octane Number (RON) determination using ASTM D2699, the engine operates at 600 rpm with an intake air temperature of 52°C, simulating mild driving conditions. For Motor Octane Number (MON) determination using ASTM D2700, more severe conditions are employed with the engine running at 900 rpm and an intake mixture temperature of 149°C, representing high-speed, high-load driving scenarios.

The actual testing procedure involves bracketing the test fuel between two reference fuel blends composed of iso-octane (2,2,4-trimethylpentane, assigned a value of 100) and n-heptane (assigned a value of 0). Once the knock intensity of the test fuel is established, its octane rating is calculated through interpolation between the reference fuels' values. This standardized methodology ensures consistent and reproducible results across different testing facilities worldwide, providing a reliable measure of a fuel's resistance to auto-ignition, which is crucial for preventing engine knock and ensuring optimal performance in spark-ignition engines.

The octane rating tests were performed with the following set of samples at the following ranges (see attached fuel data):

- RON: 87 gasolines with RON from 91.0 to 105.2;
- MON: 66 gasolines with MON from 80.2 to 89.0.

AUTOIGNITION DELAY DETERMINATION TEST – The Advanced Fuel Ignition Delay Analyzer – AFIDA (from ASG Analytik-Service AG) consists on a constant-volume combustion chamber (Fig. 1). This equipment was implemented at Petrobras Research Center, specifically for the evaluation of the knocking resistance of different gasolines and components, to provide information that can contribute to the identification of products of greater efficiency and performance, as well as to the development of fuels on a small scale.

The fundamental principle of AFIDA operation centers on a high-pressure, temperature-controlled combustion chamber. The testing process begins with the precise injection of a small, carefully measured fuel sample (typically around 20-50 microliters) into the preheated combustion chamber filled with compressed air at standardized conditions (typically 10-30 bar pressure and 500-550°C temperature). These conditions were selected after several screening tests, in order to achieve conditions that would allow greater data sensitivity and replicate the environment present in a CFR engine cylinder at the moment of fuel injection in the RON and MON conditions.

Once injected, the fuel undergoes atomization, evaporation, mixing with air and auto-ignition. The AFIDA system employs high-precision pressure transducers that continuously monitor the pressure rise within the combustion chamber. The ignition delay (ID), defined as the time interval between the start of injection and the onset of combustion

(detected as a specific pressure rise rate), is measured with millisecond accuracy.

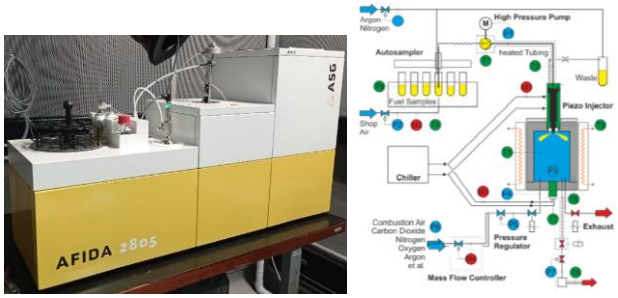

Figure 1. *AFIDA equipment and schematic of the injection system and the combustion chamber of the equipment.*

AFIDA tests were carried out with all 87 fuel samples under the following combinations of synthetic air pressures and temperatures in the combustion chamber: 10 bar and 20 bar at 500 °C, 20 bar and 30 bar at 550 °C. All tests were performed with 350 bar of injection pressure and stoichiometric air-fuel ratio (λ = 1.0).

DEVELOPMENT OF CORRELATION MODELS BETWEEN FUEL PROPERTIES AND AFIDA IGNITION DELAY RESULTS – Statistical preprocessing was made using the R statistical software environment. First, visualization techniques such as scatter plots were applied to examine relationships between ignition delay times and octane numbers, as well as correlation matrices to identify potential multicollinearity among physicochemical properties.

The model prescreening phase used LEAPS package in R, which implements an efficient branch-and-bound algorithm for subset selection in linear regression. This approach systematically evaluates different combinations of ignition delay at different temperatures (T) and pressures (P) to identify the most predictive variable sets. The best ignition delay condition (T and P) defined by adjusted R-squared was selected for further model improvement. This comprehensive evaluation helps researchers identify the optimal set of predictor variables that capture the underlying relationship between AFIDA ignition delay measurements and octane numbers.

Once the key predictor variables are identified, the nonlinear least squares modeling function (nlsLM) from the minpack.lm package was employed to determine the optimal coefficients for each parameter in the correlation model. This function implements the Levenberg-Marquardt algorithm, which combines the Gauss-Newton algorithm with gradient descent to provide robust convergence even with poor initial parameter estimates. The development process tested various functional forms to capture the complex, non-linear relationships between fuel composition, ignition behavior, and octane rating. Model validation was performed by assessing the root mean square error (RMSE) and coefficient of determination (R^2).

RESULTS AND DISCUSSION

RESEARCH OCTANE NUMBER (RON) CORRELATION – Based on the ignition delay (ID) determinations measured in AFIDA, it was previously verified that the experimental points obtained at 500°C, 10 bar of synthetic air, and an air-fuel ratio of 1.0 exhibited the best correlation with the Research Octane Number (RON), as illustrated in Figures 2 and 3.

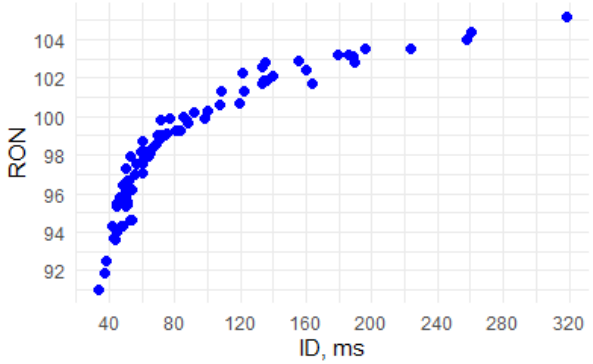

Figure 2. *RON vs. ID graph (500 °C, 10 bar of synthetic air, λ = 1.0).*

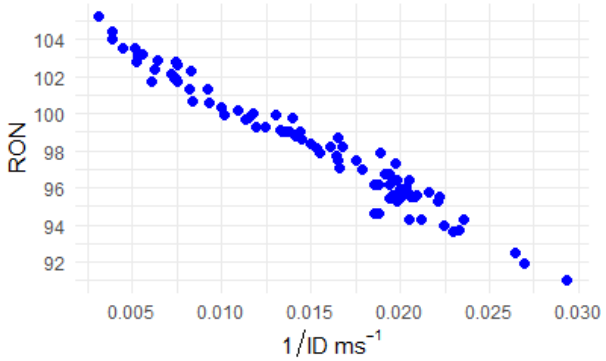

Figure 3. *RON vs. 1/ID graph (500 °C, 10 bar of synthetic air, l = 1.0).*

Based on ID vs RON behavior, two models were fitted to predict RON values: an inverse model, defined at figure 4 and a linear-exponential model, defined at figure 5.

The linear-exponential model is exceptionally well-suited for correlating the data pattern displayed in Figure 2. The scatter plot reveals a steep, nearly linear increase in RON at lower ignition delay values (below 100 milliseconds), followed by a gradually diminishing rate of increase at higher delay times, approaching an asymptotic plateau beyond 200 milliseconds. This characteristic curve aligns perfectly with the mathematical behavior of a linear-exponential function [RON = a x ID + b x exp(-c x ID) + d], where the linear component accounts for the baseline proportional relationship while the exponential term effectively models the diminishing returns at higher ignition delays. This modeling approach not only provides mathematical flexibility to accurately fit the observed data pattern but also reflects the underlying combustion chemistry principles where additional resistance to auto-ignition

(longer delays) translates to progressively smaller gains in octane rating, making it both statistically robust and physically meaningful.

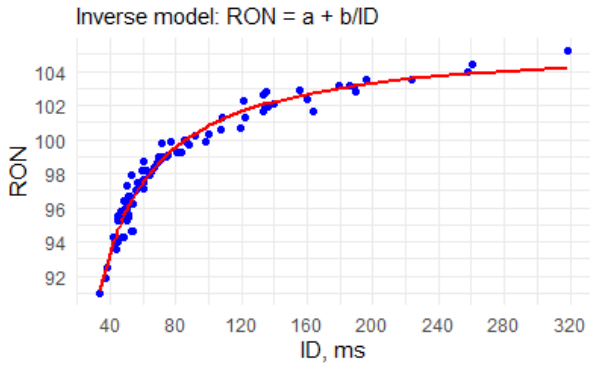

Figure 4. *Inverse RON model.*

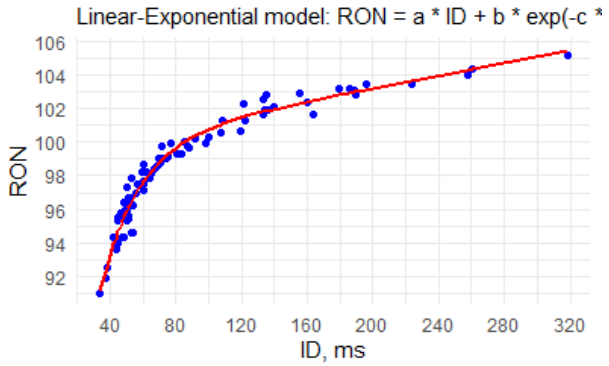

Figure 5. *Linear-exponential RON model.*

The residual plots presented in Figures 6 and 7 provide a comparative analysis of two different mathematical models correlating Research Octane Number (RON) with AFIDA ignition delay measurements: the Inverse model and the Linear-Exponential model. Both models demonstrate strong predictive capability as evidenced by their nearly identical coefficient of determination (R^2) values of 0.965 and 0.966, respectively.

The Inverse model residual plot (Figure 6) displays the difference between observed and predicted RON values across the octane range of approximately 91-105. The residuals appear generally randomly distributed around the zero line, which indicates good model fit. However, closer examination reveals several concerning patterns. There is a noticeable cluster of negative residuals around the 96 RON region, suggesting systematic underprediction in this range. Additionally, the spread of residuals appears to vary across the prediction range, with greater variability observed in the middle octane ranges (96-98) compared to the extremes. Some outliers with residuals approaching -2 units are visible around the 96 RON mark, indicating significant prediction errors for certain fuel samples.

The Linear-Exponential model residual plot (Figure 7) demonstrates a more consistent pattern of residuals across the entire RON prediction range. The distribution appears more uniform around the zero line, with fewer systematic patterns or trends. While there are still some outliers, the overall spread of residuals appears more homogeneous across the prediction range. This suggests better homoscedasticity, an important assumption for reliable statistical modeling. The Linear-Exponential model also seems to handle the full RON range more consistently, with no obvious regions of systematic over- or under-prediction.

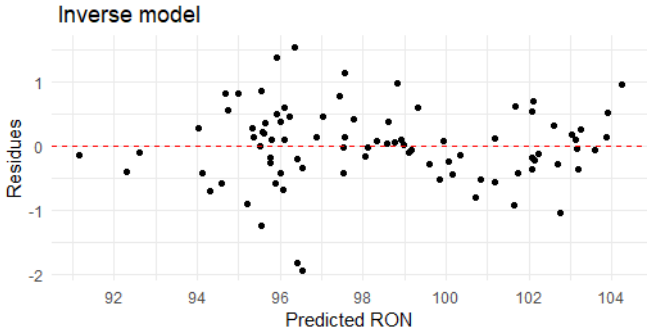

Figure 6. *Inverse RON model residues.*

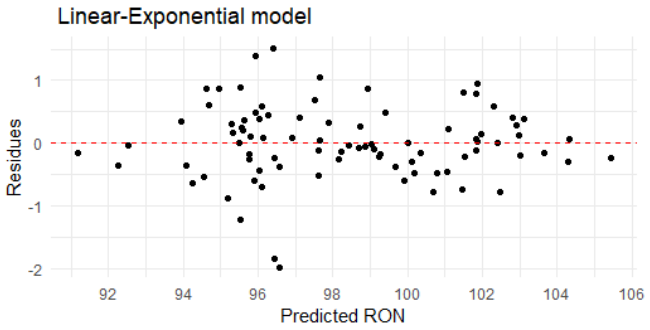

Figure 7. *Linear-exponential RON model residues.*

The parameters coefficients and regression metric for the RON models are presented on table I.

Table I. *Parameters coefficients and regression metrics for RON models*

Parameter	Inverse model	Linear-Exponential model
a	105.805	0.0189
b	-500.121	-37.265
c	-	0.0419
d	-	99.435
r^2	0.965	0.966
RMSE	0.598	0.586

Despite their nearly identical R^2 values, the residual plots suggest that the Linear-Exponential model offers subtle but important advantages over the Inverse model. The more random and uniform distribution of residuals in the Linear-Exponential model indicates better fulfillment of regression assumptions, particularly regarding constant error variance across the prediction range.

From a practical perspective, both models demonstrate excellent overall predictive capability with r^2 values exceeding 0.96, indicating that could serve as a reliable tool for estimating RON from AFIDA ignition delay

measurements. However, the slightly superior residual behavior of the Linear-Exponential model (r^2 = 0.966) suggests it may provide more consistent predictions across different fuel formulations and octane ranges. This marginal improvement could be particularly valuable when analyzing novel fuel blends or when precise octane predictions are desired at the boundaries of the calibration range.

In conclusion, while both models demonstrate strong statistical performance, the Linear-Exponential model appears to offer slightly better residual characteristics despite only a marginal improvement in R^2 value. This suggests that the mathematical form of the Linear-Exponential model more accurately captures the underlying relationship between ignition delay measurements and Research Octane Number across the full range of fuel samples tested.

MOTOR OCTANE NUMBER (MON) CORRELATION – Based on the ignition delay (ID) determinations measured in AFIDA, it was previously verified that the experimental points obtained at 500°C, 10 bar of synthetic air, and an air-fuel ratio of 1.0 exhibited the best correlation with the Motor Octane Number (MON), as illustrated in Figure 8 and 9.

The ID measured at 550°C and 30 bar also showed a strong correlation, especially when coupled with other properties as can be seen at Table II that provides a comprehensive comparison of different modeling approaches and their statistical performance. The progression of model complexity shows significant improvements in predictive capability. The basic Inverse and Linear-exponential models at 500°C and 10 bar conditions show modest performance (r^2 of 0.677 and 0.730 respectively). However, the incorporation of additional parameters, ethanol content (EtOH) and density, substantially enhances model performance. The best model, Linear-exponential + density + EtOH at 550°C and 30 bar conditions, achieves the highest coefficient of determination (r^2 = 0.797) and lowest RMSE (0.702).

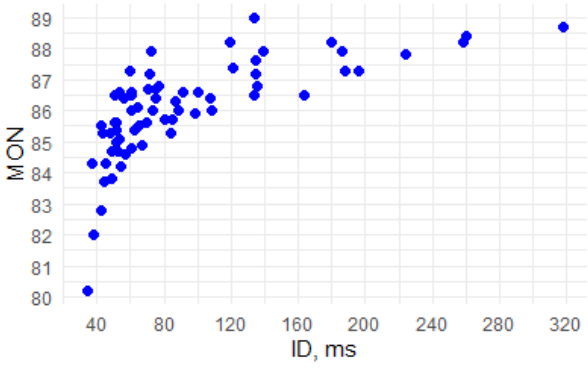

Figure 8. *MON vs. ID graph (500 °C, 10 bar of synthetic air, l = 1.0).*

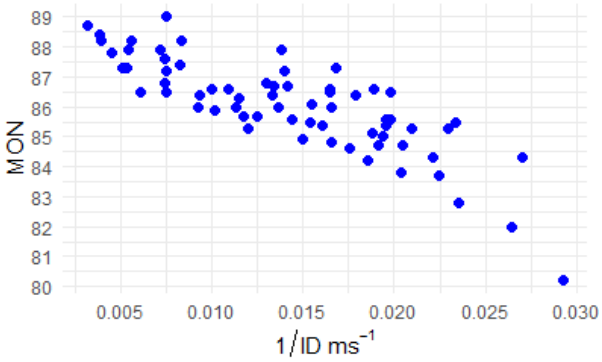

Figure 9. *MON vs. 1/ID graph (500 °C, 10 bars of synthetic air, l = 1.0).*

Table II. *Parameters coefficients and regression metrics for MON models*

Model (ID condition, °C|bar)	r^2	RMSE
Inverse (500|10)	0,677	0,886
Inverse (550|30)	0,663	0,905
Linear-exp (500|10)	0,730	0,809
Linear-exp (550|30)	0,680	0,882
Inverse + EtOH (500|10)	0,708	0,842
Inverse + EtOH (550|30)	0,772	0,744
Inverse + dens (500|10)	0,716	0,831
Inverse + dens (550|30)	0,710	0,840
Linear-exp + EtOH (500|10)	0,749	0,781
Linear-exp + EtOH (550|30)	**0,786**	**0,722**
Linear-exp + dens (500|10)	0,756	0,768
Linear-exp + dens (550|30)	0,721	0,824
Inverse + dens + EtOH (500|10)	0,724	0,818
Inverse + dens + EtOH (550|30)	**0,787**	**0,720**
Linear-exp + dens + EtOH (500|10)	0,759	0,766
Linear-exp + dens + EtOH (550|30)	**0,797**	**0,702**

The residual plots (Figures 10 to 12) provide insight into the quality of different model fits:

1. The Linear-Exponential + EtOH model (Figure 10) shows a relatively random distribution of residuals around zero, but with some pattern of increasing variance at higher predicted MON values.
2. The Inverse + density + EtOH model (Figure 11) demonstrates improved residual behavior, with points more evenly distributed across the prediction range, though there appears to be a slight upward trend in residuals at higher MON values.
3. The Linear-exponential + density + EtOH model (Figure 12) exhibits the most balanced residual distribution, with points scattered more randomly around the zero line across the entire prediction range, confirming its better statistical performance.

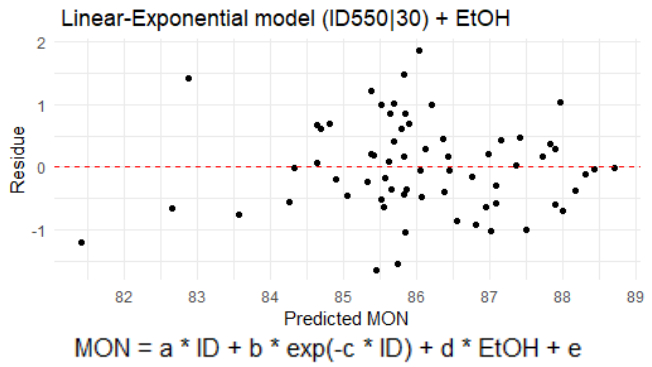

Figure 10. *Linear-exponential + EtOH MON model residues.*

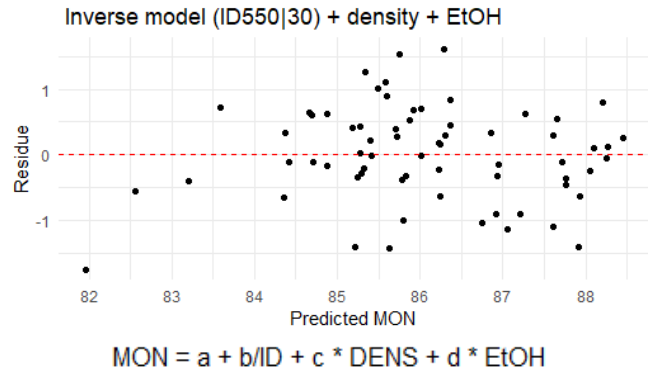

Figure 11. *Inverse model + density + EtOH MON model residues.*

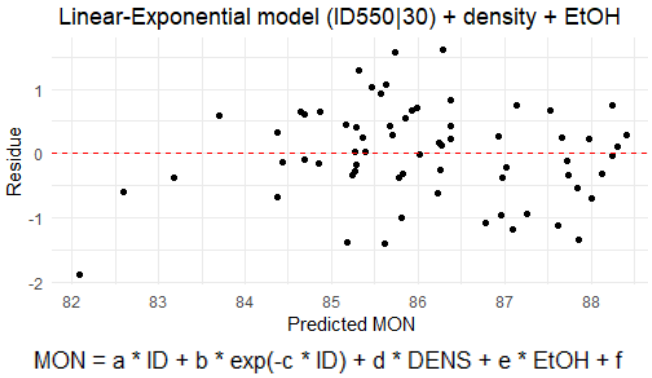

Figure 12. *Linear-exponential + density + EtOH MON residues.*

The parameters coefficients and regression metric for the MON models are presented on table III. In conclusion, the analysis demonstrates that while there is a fundamental correlation between MON and ignition delay measurements from the AFIDA instrument, achieving high predictive accuracy requires more sophisticated modeling approaches that incorporate additional fuel properties. The Linear-exponential model incorporating both density and ethanol content parameters at 550°C and 30 bar test conditions provides the most robust correlation, explaining nearly 80% of the variance in MON values with the lowest prediction error among all tested models.

Table III. *Parameters coefficients and regression metrics for MON models.*

Parameter	Linear-exp + EtOH (550|30)	Inverse + density + EtOH (550|30)	Linear-exp + density + EtOH (550|30)
a	0.322	100.06	3.461
b	-9337	-93.066	-60.127
c	0.909	-10.487	-0.032
d	0.058	0.052	-9.79
e	80.68	-	0.053
f	-	-	138.19
r^2	0,786	0,787	0,797
RMSE	0,722	0,720	0,702

CONCLUSIONS

This paper presents the results of a work whose main objective was to investigate the correlation between AFIDA ignition delay determination and octane rating (RON and MON) for experimental gasoline formulations. A matrix of 87 experimental formulations for RON and 66 for MON was used to develop successful correlations with AFIDA ignition delay determination.

The creation of robust correlation models between traditional fuel quality metrics (RON and MON) and AFIDA ignition delay measurements represents a significant advancement in fuel characterization methodology. Those predictive models can translate AFIDA results into octane parameters, potentially offering a faster and more resource-efficient alternative for process control and blend optimization at refineries.

The results showed that ignition delay is a reliable parameter for predicting RON results. However, for MON prediction, ignition delay alone did not provide a strong correlation, but by incorporating additional fuel properties (density and ethanol content), the model could be improved.

The main goal was to explore models that predict octane ratings mainly based on ID data. For more advanced modeling approaches, we aimed to use simple properties that are easy to measure and are required during routine activities (*e.g.* certification or quality control). This makes it easier to implement the equipment and the related information. More complex models could be developed using compositional data, but they require more analysis and sophistication, which may hinder their use in routine tasks.

The results of this work contribute to a better understanding of combustion behavior, antiknocking, and their relationship with gasoline properties.

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ANNEX – FUEL DATA

Id	Density 20°C (ASTM D4052)	EtOH %vol (NBR 13992)	Research Octane Number (RON)	Motor Octane Number (MON)	AFIDA ID 500°C 10 bar	AFIDA ID 550°C 30 bar
1	0,7502	28	96,7	85,0	51,5	11,1
2	0,7224	26	93,7	85,5	42,9	10,4
3	0,7380	23	96,4	86,5	50,5	11,6
4	0,7416	28	98,2	87,3	59,6	11,7
5	0,7478	36	100,7	88,2	119,7	16,0
6	0,7504	42	102,6	89,0	133,6	15,1
7	0,7392	22	97,9	86,6	52,9	11,5
8	0,7504	22	99,8	87,2	71,7	13,4
9	0,7502	22	97,7	86,6	60,7	12,6
10	0,7544	22	98,1	85,5	65,1	12,5
11	0,7349	22	98,8	86,7	70,9	12,4
12	0,7352	22	96,4	85,6	51,1	11,5
13	0,7267	26	93,6	85,3	43,5	10,2
14	0,7481	26	95,6	85,4	51,1	11,4
15	0,7318	26	94,0	83,7	44,6	9,9
16	0,7519	27	99,8	86,3	86,9	14,6
17	0,7462	26	96,2	84,2	54,0	11,7
18	0,7291	26	97,0	86,4	55,9	11,8
19	0,7496	26	97,5	86,0	60,4	11,9
20	0,7297	26	95,8	84,7	48,9	10,5
21	0,7518	27	99,9	85,9	98,2	14,3
22	0,7376	26	99,1	86,4	75,3	12,5
23	0,7499	26	99,0	86,0	73,4	12,4
24	0,7328	26	99,0	85,6	69,5	12,4
25	0,7492	26	100,0	85,7	85,2	13,7
26	0,7321	26	102,8	87,6	134,8	15,5
27	0,7499	26	102,3	87,4	121,3	16,1
28	0,7338	26	101,7	86,5	133,6	15,2
29	0,7495	26	101,7	86,5	163,8	16,5
30	0,7314	26	91,9	84,3	37,0	9,2
31	0,7523	26	95,8	83,8	49,1	11,2
32	0,7587	26	99,9	86,8	77,0	13,1
33	0,7353	26	95,6	85,3	47,8	10,3
34	0,7298	26	95,3	84,3	45,2	10,0
35	0,7375	26	98,7	86,5	60,7	11,5
36	0,7517	26	97,3	85,6	50,6	11,2
37	0,7328	26	97,9	86,1	64,6	11,6
38	0,7572	26	100,2	86,6	91,6	14,2
39	0,7547	22	98,2	85,4	62,3	12,4
40	0,7344	22	99,0	87,9	72,5	12,9
41	0,7344	23	96,2	85,1	53,2	11,3
42	0,7548	22	97,1	84,8	60,4	12,4
43	0,7604	26	94,6	N.D.	54,0	12,0
44	0,7580	27	94,6	N.D.	53,3	12,0
45	0,7379	27	94,3	N.D.	47,2	10,7
46	0,7433	27	95,5	N.D.	48,6	10,8
47	0,7521	26	96,0	N.D.	49,2	11,7
48	0,7468	26	95,6	N.D.	49,9	10,7
49	0,7420	27	95,5	N.D.	49,8	11,0
50	0,7485	27	95,9	N.D.	50,0	11,0
51	0,7414	26	95,3	N.D.	50,5	10,6
52	0,7626	27	96,2	N.D.	51,6	11,6
53	0,7474	27	94,3	N.D.	48,7	10,8
54	0,7427	26	95,5	N.D.	47,9	10,6
55	0,7427	26	95,4	N.D.	51,4	10,7
56	0,7305	27	95,5	N.D.	45,0	10,1
57	0,7395	26	95,8	N.D.	46,2	10,8
58	0,7344	25	96,4	N.D.	48,7	11,3
59	0,7659	24	98,6	N.D.	69,1	13,2
60	0,7575	24	101,3	N.D.	122,3	17,3
61	0,7568	24	102,4	N.D.	159,8	17,3
62	0,7557	24	102,8	N.D.	189,9	18,7
63	0,7523	24	102,9	N.D.	155,3	17,0
64	0,7589	0	91,0	80,2	34,1	9,2
65	0,7685	0	92,5	82,0	37,9	9,9
66	0,7779	0	94,3	82,8	42,5	10,7
67	0,7915	0	96,7	84,7	52,3	12,6
68	0,8104	0	99,0	86,7	74,7	15,6
69	0,7652	20	97,5	84,6	57,0	11,1
70	0,7678	27	99,3	85,3	83,8	11,5
71	0,7696	35	101,3	86,0	108,2	13,5
72	0,7729	45	103,1	87,3	188,2	14,7
73	0,7726	20	98,4	84,9	66,8	12,0
74	0,7735	27	99,7	86,0	88,3	13,1
75	0,7756	35	101,9	86,8	135,9	13,7
76	0,7779	45	103,5	87,3	196,0	14,4
77	0,7794	20	99,3	85,7	80,4	12,2
78	0,7806	27	100,6	86,4	107,7	13,2
79	0,7833	45	103,5	87,8	223,8	15,2
80	0,7905	20	100,3	86,6	100,5	14,3
81	0,7908	27	101,9	87,2	134,3	14,8
82	0,7909	35	103,2	87,9	185,7	15,6
83	0,7909	45	104,4	88,4	260,2	16,0
84	0,8059	20	102,1	87,9	139,4	17,3
85	0,8048	27	103,2	88,2	179,4	17,4
86	0,8036	35	104,0	88,2	257,9	17,4
87	0,8018	45	105,2	88,7	318,3	16,8

N.D.: Not determined.